XXVIII.—*On the Geology of Norfolk as illustrating the Laws of the Distribution of Soils.* By Joshua Trimmer, F.G.S.

It is impossible to enter on an inquiry in which geology is connected with agriculture, without being reminded that we are indebted to the son of an Oxfordshire yeoman for those discoveries which laid the foundation of all our geological knowledge. It was William Smith who ascertained for the English strata down to the coal measures, that they have a regular and invariable order of succession and a general dip towards the east; so that in traversing the island from east to west, we cross the edges of beds which emerge successively from beneath each other, and form bands of various sandstones, clays, and limestones, ranging from S.W. to N.E. He also ascertained the important fact that each group of strata is characterised by a peculiar group of organic remains, by which it may be identified under doubtful circumstances: as, when the rocks above it and below it are concealed, or when the ordinary mineral characters have changed. He was also the first to point out the distinction between those regular strata, each of which must have been, in succession and for ages, the bed of the sea, inhabited by animals whose remains are deposited on the spots where they lived, and that loose covering of sand, gravel, and clay, often containing large boulders derived from far distant rocks, which is so generally distributed over the surface, and which, long called diluvium, is now regarded by a large and increasing number of geologists as having originated in the action of ice, partly terrestrial, but chiefly marine. These discoveries he prosecuted, under great difficulties, with the sturdy, indomitable spirit of an English yeoman. He completed his great work, the map of the strata of England and Wales, alone, almost unknown, through a great part of his career, with little assistance from private patronage, and no public support. To accomplish it, he exhausted his slender patrimony and the profits of a successful professional career. He paid that penalty, as Professor Sedgwick has said, which many men of genius have paid before him: he suffered, in his peace and in his fortune, from having outstripped the men of his own time in the progress of discovery. It was from foreign philosophers that he received the first acknowledgment of his merits. At home, to compensate for the long neglect which he had experienced there, honours were lavished upon him in his old age; geologists acknowledged him, with one consent, as the father of English geology; the Geological Society of London awarded to him the first medal, struck from the proceeds of a fund bequeathed to them by Dr. Wollaston for the encouragement of original discoveries; the University of Dublin conferred on him the honorary degree of

Doctor of Laws; and to solace the poverty to which he reduced himself, by the individual performance of that which ought to have been a national work, the Government conferred on him, at the request of the British Association for the Advancement of Science, an annual pension of one hundred pounds.

The phenomena of the stratified rocks, and of their organic contents, have attracted a large share of the attention of naturalists and philosophers, for the wonderful views which they disclose of the ancient natural history of the earth, the revolutions through which it has passed, and the various races of plants and animals by which it has successively been peopled. It was for their practical utility that his discoveries were chiefly valued by Smith: and, as an engineer engaged in planning and executing canals, draining land, laying out water-meadows, and superintending mining operations, he derived no small assistance from his acquaintance with the structure of the earth and the laws of stratification. His knowledge of the alternation of porous with retentive strata, and of the phenomena of springs dependent on this structure, enabled him to select the best lines for his canals, so as to economise the supply of water and to save expense in the construction of them; it caused him to be consulted on the means of overcoming difficulties by which the first engineers of the day had been baffled, simply because they were ignorant of those despised facts which he had so successfully observed and generalised; it enabled him to drain the Prisley bog, in which Elkington had failed, though he had received from Parliament a reward of one thousand pounds for the discovery of a mode of draining adapted to certain descriptions of wet soil, but not of general application; it enabled him to restore the supply of water to the hot wells at Bath, when it had escaped into a new channel; and to economise at Scarborough the scanty resources which the locality afforded of water fit for domestic purposes, so as to secure an adequate supply to its increasing population.

His habits of observing the action of the sea upon the coast taught him, by copying nature, to devise a simple, cheap, and efficacious method of stopping the breaches, more than a mile in length, in the sand hills, constituting the only barrier by which the sea is excluded from the valleys of eastern Norfolk; and to preserve more than forty thousand acres of valuable land, to which the ocean was again asserting its claim, after having abandoned it for nearly a thousand years.

The valuable South Hetton Colliery was opened in consequence of his urgent and persevering advice to Colonel Braddyll, to sink for coal through the magnesian limestone, in opposition to the "practical" opinions of the most eminent coal viewers of the North, who were guided only by their own limited experience of

a limited district, unaided by those general principles, deduced from more extended observation, which he brought to the solution of the question.

The relations existing between the geological structure of a district and the system of agriculture pursued in it constituted a favourite point of view from which the father of English geology loved to contemplate the science which he had created; and so intimately is the natural vegetation which a soil supports connected with its chemical composition, and this again with that of the rocks from which it is derived, that by these means alone he was not unfrequently enabled to define on his maps the limits of strata when not too much obscured by the detrital deposits. An eminent agriculturist and land-agent, having heard him explain the structure of the Wiltshire hills and vales, their relation to the neighbouring districts, and the influence of this structure on the system of culture pursued on them, exclaimed, "That is the only way to learn the true nature of soils." "Even such sympathy," says Professor Phillips, the nephew and biographer of Smith, "was highly prized by the modest father of geology, who in later years, when that science had obtained a high degree of public favour, frequently recounted, among many mortifying instances of disregard, this apparently slight and solitary case of encouragement."

Fifty years have elapsed since this remark on the value of geological knowledge to practical men was uttered by a practical man; and how little progress has been made during that period in the work which Smith commenced, and which he had so much at heart—the application of geology to the improvement of the soil! This has arisen, not from the inability of geologists to afford assistance, but from the little encouragement they have received from agriculturists to pursue this course of investigation. We are now, however, at the commencement of a new era, when the economic value of science is beginning to be better appreciated. The number is increased of those, like Mr. Davis, who declared the road to the true knowledge of soils to lie through the paths of geology; like Mr. Bevan, who requested of Smith a sight of his maps and sections, when he was folding them up, disheartened at the little attention which they received at an agricultural meeting; or like Sir John Johnston, the friend and patron of Smith's declining years, who engaged his services as land-steward to the Hackness estates. Still there are many who, if they dare not now openly denounce geology as a visionary speculation, are yet in their hearts incredulous as to its practical utility. Some there are who a few years ago would have been among the scorners, but who now, when science is rising in public estimation, are willing enough to partake the triumph, and with

little knowledge of either agriculture, chemistry, or geology, are putting themselves forward as their expounders, and are expounding them in a manner not very likely to bring science into repute with practical men.

The laws which regulate the distribution of soils constitute a more complicated problem than is usually supposed. In the agricultural application of geology, we must remember the existence of the loose covering of detrital matter as well as the regular alternations of the stratified beds and irregular intrusive masses of unstratified rocks; and we must not fall into the error of exaggerating the agricultural influence of the two latter, because the former is excluded from our geological maps, which only exhibit the solid rock nearest to the surface. The detrital deposits, from their superficial position and their almost universal distribution, are of the most importance to the farmer. They not unfrequently attain a depth of several hundred feet, producing a class of soils in which the agricultural influence of the subjacent solid rocks is reduced to its minimum; and when, on the other hand, they do not exceed a depth of two feet, and that influence approaches its maximum, they include not only the soil turned over by the plough, but the subsoil, in the strictly agricultural sense of the term. In those cases in which they are the thinnest they always modify considerably the characters of the soil derived from the subjacent solid strata, and in those cases in which the detrital deposits attain their greatest development, the solid strata still exercise some influence, partly by the intermixture of their fragments in the surface soil with others transported from a distance, and partly by the beds of clay, marl, &c., derived from their ruins, and buried at greater but still accessible depths, where they furnish, to those who will seek for and use them, the means of correcting chemical and mechanical defects in the composition of the soil and subsoil. No agricultural maps, therefore, such as those appended to the Reports of the Board of Agriculture, which only exhibit, and that imperfectly and on a very small scale, the variations of the surface, and neglect those of the substrata contained in the detrital deposits and in the still deeper solid strata, nor geological maps from which those detrital deposits, except in a few extraordinary cases, are excluded, can exhibit the true agricultural relations either of an extensive district or a single estate.

Norfolk affords a striking illustration of these truths. Well defined by natural boundaries, the Ocean, the Waveney, the little Ouze, and the Nen, it forms only part of a large geological district, in which the superficial deposits, from their extensive development, assume an important agricultural character. With some interruptions from the alluvial tracts of the Humber, the

Wash, and the Yare, this district extends from the coast of Holderness, in Yorkshire, to the banks of the Thames, if not further to the south. On the western side of the watershed of England we have again similar superficial accumulations, extending from the mountains of Cumberland down both sides of the Cambrian Chain, fringing the western coast of England and Wales, and the eastern coast of Ireland, running up the hollows into the interior, and covering the central plain of the new red sandstone in the counties of Lancashire, Cheshire, Shropshire, Worcestershire, and Warwickshire, with thick beds of sand, gravel, loam, and clay, containing fragments of marine shells of existing species, and large blocks derived from far distant rocks.

Although the superficial deposits are of so much economic importance, and from their position are those which might have been expected to have first attracted attention, and although their history, if deciphered, would be so interesting, interposed as they are between that condition of nature with which man is contemporary and those long epochs represented by the great series of fossiliferous strata which preceded the existence of our race, they are those with which geologists have the least acquaintance, because they are those which they have studied the least. For a long time they were regarded, on the authority of the Huttonians, as the effect of atmospheric action and fluviatile erosion, during a long lapse of ages, on the surface of existing continents. At a later period they, as well as the tertiary strata, more recent than those of the Paris basin, were attributed by Cuvier, Smith, and others, to the Noachian deluge. "We saw," says Professor Sedgwick, in renouncing this hypothesis which he had long advocated, "we saw the clearest evidence of diluvial action, and we had in our Sacred Histories the record of a general deluge. On this double testimony we gave unity to a vast succession of phenomena, not one of which we perfectly comprehended, and under the name of diluvium classed them all together." *

While the supporters of the diluvial hypothesis were successively abandoning it as the newer tertiary strata became better known, fragments of marine shells of existing species began to be discovered in these superficial deposits, the greatest height at which they have been observed at present being nearly 1392 feet; and immediately a geological party arose who regarded them as ordinary examples of tertiary marine strata, or as the raised beaches of an era still more recent, and shut their eyes to those characters which distinguish them from the strata of any other epoch. Some dismissed them with the summary conclu-

* Sedgwick's Anniversary Address, 'Proceedings of the Geological Society,' vol. i., p. 313.

sion that they were formed not during one epoch, but many; that they had been shot off the flanks of mountain chains during successive movements of elevation, and that it was impossible to distinguish the detritus of different periods thus blended together. In this spirit of hasty generalisation, it has been too much the custom with those who have undertaken the investigation of the superficial deposits to think that they have accomplished the task by bestowing on them a new name. Hence, besides those of Detrital Deposits, Diluvium, Post-tertiary Strata, and Loose Covering of the Earth, their many synonyms of Northern Drift, Erratic Block Group, Boulder Formation, Terrains de Transport, Mud Cliffs, Tertiary Strata, Post-Pliocene Strata, Moraines, and Glacial Formation. The glacial theory of Agassiz has again attracted attention to them, and whenever they shall be studied with the same diligence and patience which have been bestowed upon other departments of geology, there can be no doubt that they will be studied with equal success, and that a rich harvest will be reaped as valuable for its economic results as for the important chapter which will be opened in the history of the earth.

The base of these deposits in Norfolk consists of a great sheet of chalk with an undulating and waterworn surface which dips under the sea to the southward of east, and rising towards the interior, attains its greatest elevation along a line which ranges from Lopham Ford, between the sources of the Waveney and the little Ouze, by Swaffham to Brancaster, and constitutes the watershed of the county, known as the Downs of Norfolk. On the eastern side of the watershed the surface consists of deposits of the erratic block group, varying in depth from less than three to more than three hundred feet. Within this area is a tract in which the Norwich, or mammalian, crag is interposed between the chalk and the erratic deposits. It is bounded on the north, the east, and the south, by the Ocean and the marshes of the Yarmouth estuary, south of which it reappears in Suffolk. Its western boundary is an irregular, and not very well ascertained line, which may be described, in general terms, as ranging from Weybourne to some point between Bungay* and Diss, ramifying among the hollows in the chalk, which appears to have broken with islands and promontories the continuity of the sea in which the crag was deposited. Beneath the greater portion of the larger area east of the

* In the map accompanying Woodward's 'Geology of Norfolk,' Bungay is made the western boundary of the crag on the south. That is the furthest point in which shells have been observed in it. It is there seen covered by the till of the erratic block group. I have traced the same kind of sands, holding the same relative position to the till, but without fossils, considerably to the westward of Harlestone. They are also seen in the upper part of the valley of the Wensum, near Swanton Morley.

watershed, the upper or soft chalk forms the base of the crag and detrital deposits. The out-crop of the strata brings to the surface along the western edge of the watershed the lower beds of hard chalk, provincially called corlk, which contains much disseminated siliceous matter, and is sufficiently hard to be used as a building stone.

From beneath this, the gault, and the representatives of the green sand—the red chalk and the carstone—successively emerge, and are succeeded by the Kimmeridge clay, which forms the base of the alluvial deposits of the Wash, and is not separated as in the south of England, by the coralline oolite from the Oxford clay, neither has it the Portland oolite above it. As the drift approaches the watershed, it gradually thins off, and loses much of that regularity of deposit which is observable in the Cromer and Gorlston coast sections, and in those of the valleys of the Waveney, the Wensum, and the Yare. It is found on the summit of the watershed, with still less regularity of stratification, and, on the steep slopes of its western escarpment, has been much more broken by denuding action.

Those who will take the trouble to compare the agricultural districts into which Young has divided Norfolk, in his map appended to the Reports of the Board of Agriculture, with those of which Marshall and Kent have described the boundaries, will find but little accordance existing between them; and it will be still more difficult to trace a connexion between any of these agricultural districts and the geological districts of any geological map extant. Neither is there any work or map descriptive of the geology of Norfolk which does not require correction in some material point. The county map of William Smith is the best. The diligence of local observers has been able to make few alterations in his boundaries of the chalk and the strata below it; and those have been occasioned by the scrupulous accuracy which induced him to map only what he had actually seen, and caused him to represent the gault in discontinuous patches, which has since been traced by Mr. Rose, as a narrow continuous band. His map of Norfolk is likewise the best agricultural map extant, dividing the county into the light and strong soiled districts which represent, with as much accuracy as possible on so small a scale, the general outline of the areas occupied by different members of the drift; by an error, however, very excusable at the time his map was published, when the tertiary strata more recent than those of the Paris and London basins were little known, he has mistaken their place in the geological scale, and has referred the drift to the London and Plastic clay series, placing the crag below the latter. To this map I shall again have occasion to refer when describing the districts into which I divide the county. Its

merits and defects will be better understood after the succession of deposits above the chalk shall have been described.

We have seen, that in the person of William Smith, geology was of agricultural origin, and was at an early period of his discoveries applied to the business of agriculture. In Marshall, one of the earliest writers on the agriculture of Norfolk, we have another proof of the intimate connexion between geology and agriculture, since he, who merely undertook to describe the practical details of the Norfolk system of husbandry, was insensibly led into the description of geological phenomena, at a time when that science only revelled in crude speculation and soared above the observation of facts.

Justice to so early an observer requires, in this paper, some notice of his geological investigations.

Marshall resided in Norfolk from 1780 to 1782, during which time he had the management of the Suffield estates. He divides the country into three agricultural districts, those of East, West, and South Norfolk. His description of the Norfolk practice is confined principally to East Norfolk, in which he resided, his knowledge of the others being acquired by occasional rides through them. The surface of East Norfolk he describes as an almost uniform flat, except in a border towards the sea-coast, which is broken, and in many places bold and picturesque; and except in the more southern hundreds, which abound in marshes and fens, or lakes and broads, some of them of considerable size. With these exceptions, he pronounces the soil as scarcely containing an acre which may not be called sandy-loam; its quality, however, differing widely, both in texture and productiveness, in general shallow, five or six inches being the maximum of depth, the northern part abounding with barren heaths and unfertile inclosures, the southern hundreds principally covered with a richer, deeper, and highly productive soil. Young, in speaking of this district, appears quite at a loss for epithets to express his admiration of those parts not occupied by broads and marshes: "The arable land is," he says, "a fine, deep, putrid, sandy loam, adhesive enough to fear no drought, and friable enough to throw off superfluous moisture, so that all seasons suit it; from texture free to work, and from chemical qualities sure to produce in luxuriance whatever the industry of man may commit to its fertile bosom." Kent calls it a fine sandy loam, equal in value to the best parts of the Austrian Netherlands, so fruitful and pleasant to work that the occupier is seldom put out of his rotation. This is almost the only district of the county respecting the boundaries of which these writers are agreed; though they differ widely in their estimates of the merits of the husbandry pursued in it.

In treating of the substrata of East Norfolk, Marshall de-

scribes the most prevalent as an "unfathomable ocean of sand," while in some places an absorbent brick earth is the immediate subsoil, marl rising occasionally near to the surface, but seldom so high as the "pan." He adverts to the existence of "scalds" in this district, as more pernicious than springy patches in cold-soiled countries, with this additional evil, that he looks upon the former as incurable, while partial retentiveness may be more easily removed. These "scalds," or spots of burning soil, he attributes to a more absorbent subsoil being interposed in patches through one less absorbent, and by "heads," or prominent parts of the substratum of sand, rising up through the stratum of brick earth in the manner that "heads of marl" shoot up towards the surface.

He notices the hard crust, provincially called the "pan," immediately under the cultivated soil, the breaking of which was then, as it is even now, in a minor degree, looked to with so much dread by the farmers of Norfolk. He regards it as a production, not of nature but of art,

"Or, to speak more correctly, a consequence of the Norfolk culture carried on from time immemorial with the Norfolk plough, whose broad flat share, being held invariably in a horizontal position, and unless in fallowing, invariably at the same depth, the surface of the subsoil becomes formed, by the action of the share, the pressure and sliding of the heel of the plough, and the trampling of the horse, into a firm and even floor upon which the soil is turned and returned, as it would be if spread on a floor of stone or other hard material."

The fossil manures of Norfolk he describes as—

1. The chalk marl of Thorpe Market, in the Hundred of South Erpingham.
2. The clay marl of Hemsby, in the Hundred of East Flegg.
3. The soft chalk of Thorpe by Norwich.
4. The hard chalk of Swaffham.

"The grand fossil manure of Norfolk is," he says, "*Marl*, through whose fertilising quality, judiciously applied, lands, which seem to have been intended by nature as a maintenance for sheep and rabbits, have been rendered capable of fattening bullocks of the largest size, and finishing them in the highest manner."

He mentions two sorts of this marl, whose geological relations I shall hereafter describe, distinct in their appearance, though similar in their fertilising qualities.

"The central and northern parts of the district abound," he says, "universally with a whitish coloured chalk marl, while the Flegg Hundreds and the sea-coast are equally fortunate in a grey coloured clay-marl."

He infers that the former had been in use for centuries, from the size of oak-trees growing in old marl-pits, while the use of clay-marl as manure seemed to be of much later date, "many

farmers being still blind to its merits, because it is not *marl*, but *clay*, by which name," he says, "it is universally known."

"The name, however, would be of little importance, were it not indiscriminately applied to unctuous earths in general, whether or not they contain any portion of calcareous matter. Nothing is marl which is not white, for notwithstanding that the county has been so long and so largely indebted to its fertilising qualities, her husbandmen, even in this enlightened age, remain totally ignorant of its fertilising properties; through which want of information much labour and expense are thrown away. One man, seeing the good effect of the Flegg clay, concludes that all clays are fertilising, and finding a bed of strong brick-earth on his farm, falls to work at a great expense claying, while another, observing this man's miscarriage, concludes that all clays are unprofitable, and in consequence is at a great expense, equally misapplied, in fetching marl from a great distance, while he has perhaps, on his own farm, if judiciously sought, an earth of a quality equally fertilising with that which he is throwing away money and time in fetching. This is a strong evidence of the utility of chemical knowledge in the investigation of fossil manures."

In describing the chalk marl of Thorpe Market, he notices the singularity of its position:—

"It does not lie in strata, as fossils do in general, nor in a continuation of rocks like chalk and limestone, but in distinct masses of different figures and magnitudes, rising with irregular heads towards the surface, and sinking to a depth of perhaps 10 and 20 feet, and sometimes to a depth unfathomed. If the abyss of sand, in which they lie buried, could be rendered transparent, these clouds of marl would, I apprehend, be seen scattered under the surface of this country in resemblance of the clouds of vapour which we frequently see in summer suspended in the atmosphere."

He then notices the variations in the composition of these masses, from an intermixture of other than calcareous matter, and adverts to the lumps of chalk and the flints which they contain, similar to those found in the chalk pits of other districts.

We here recognise geological facts correctly observed, though the fathomless ocean of sand, and the clouds of marl rising like vapour through it, are exaggerated and fanciful descriptions, and savour somewhat of the cosmological speculations of the day.

At a later period, in his 'Agriculture of the Southern Counties,' published in 1797, we find Marshall using the word *geology*,*

* Having but little acquaintance with the obsolete literature of geology, I supposed this to be the first instance of the use of the term. With the Wernerians the science was "geognosy," with Smith "mineralogy," and he styled himself a "mineral surveyor." On referring the question to those geologists the most likely to possess information on this point, I found them unable to call to mind an instance of the use of the word in any treatise older than 1799. The earliest period to which I have succeeded in tracing it is 1755. In the first edition of 'Johnson's Dictionary' of that year, geology is defined to be "the doctrine of the earth," without

and proposing the formation of a geological map for agricultural purposes, in the following words:—

"A geological map of England, shaded somewhat agreeably to the sketch I have given of Yorkshire, showing, not only its mountain upland and vale districts, but giving an adequate idea of their elevation and casts of surface, would, on the instant, be a valuable acquisition to science; and whenever the Government of the country shall turn their attention to the country itself, such a map, or maps, pointing out at sight the elevations, the casts of surface, the waters, the soils, and the substrata, as they relate to agriculture, will be found to be an acquirement of considerable value."

In the same work on the 'Southern Counties' he gives a very correct description of the physical features of the Weald of Kent and Sussex dependent on geological structure, noticing the steep escarpments of the chalk opposed to each other, the "declination" of the surface of the North and South Downs in opposite directions, and the escape of the waters of the Weald through lateral gorges in the chalk. In treating of the vale of Maidstone, he describes, under their local names, the agricultural characters of the different members of the greensand which occur there, in such manner, however, as to render it evident that he was not aware of their subterposition to the chalk, nor of the laws of stratification in general, which, by this time, Smith had worked out. His analysis, too, of the marl and chalk of Norfolk, however rude and imperfect, is an early instance of an attempt to bring chemistry to the aid of agriculture. He appears, however, to have considered the efficacy of these manures to be almost entirely due to the calcareous matter contained in them, and to have overlooked their mechanical effects in imparting adhesiveness to the soil.

In my examination of the geology of Norfolk with reference to its agriculture, I determined to confine myself to the superficial deposits, adopting from previous observers, unless when any obvious error should appear, the boundaries of the regular strata, which had been investigated by them with more minuteness than I could hope to be able to bestow upon them. To the superficial deposits belong the best and the worst land in the county. The deep rich loams of the Happing and Flegg hundreds, spoken of in such glowing terms by Marshall, Kent, and Young, which lately produced eleven quarters of wheat to the acre, and which not unfrequently yield seven or eight quarters, as well as the thin soils, which, at the time those authors wrote, were employed as

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any authority being cited. The term appears, therefore, to have been revived after having fallen into disuse. It is clearly older than the Wernerian controversy, Werner having been appointed Professor of Mineralogy at Freyberg in 1775.

sheep-walks and rabbit-warrens, declared by one of them to be the best purpose to which they could be applied, are alike members of the drift.

The questions, therefore, of which I proposed to myself the solution were the following :—

1. The laws which regulate the distribution of soils under the combined influence of the solid strata and the drift.

2. The geological relations of the marl and clay which have effected so great a revolution in the cultivation of Norfolk, whether they are peculiar to that county, or whether the landowners of other parts of England may expect to find on their estates similar means of improvement.

3. Whether the structure and composition of the soil and substrata of Norfolk would suggest any improvement in the established practice of that district.

4. The attempt to solve these practical problems could not fail to throw some light on that part of geology which is at present the most obscure, namely, the history of the deposits which immediately preceded the present condition of the earth, and the agencies which impressed upon them their peculiar characters.

In all these inquiries I trust I have accomplished something; but in this paper I shall confine myself to the two former. The third will be made the subject of a future communication. The last would be out of place in the pages of this Journal, and will be only adverted to so far as is necessary for the elucidation of the laws regulating the distribution of soils.

These laws may be thus stated :—

1. The deposits of the erratic block group indicate, in England, a long period occupied in their formation upon a terrestrial surface gradually submerged, and in their denudation during gradual re-elevation; the whole period being characterised by peculiar agencies which distinguish it from the long series of the secondary and tertiary groups which preceded, and from the modern or alluvial deposits which succeeded and are still in progress.

2. The variations of soil, in districts thickly overspread with drift, depend upon the amount of this denudation, which has in some instances caused the lower beds of the erratic block group, of different composition from the upper beds, to be the strata nearest to the surface.

3. The effects resulting from this cause have been modified by a deposit hitherto little noticed, which closed the erratic block period, and which has been spread unconformably over the denuded surface of the earlier members of that group.

4. This latest deposit, which shades off into the alluvial de-

posits, varies in depth from less than six inches to more than five feet; and its depth is dependent on the contour of the surface, which is itself a result of denudation.

5. It is frequently found resting upon rocks of all ages, without the intervention of any other member of the drift.

6. Its depth in such cases is equally dependent on contours which are the result of the denudation of those older formations effected in part during the submergence of the erratic block period, and in part during antecedent geological epochs.

In order to generalise the phenomena of the variations of soil, I knew that it was necessary to lay down those variations on a map exhibiting accurately, and on a large scale, the physical features of the district. Stimulated, therefore, by the importance of the problems, both in pure and applied geology, of which Norfolk appeared to offer the key, I did not hesitate to expend the fifty pounds, which was the utmost the Journal Committee felt justified in allotting to these objects, in traversing the county for the purpose of laying down the variations of soil upon the Ordnance map; although it was expressly stipulated, on the part of the Royal Agricultural Society, that they would not engage in a survey, and although Young has stated of the agricultural map appended to his Report of Norfolk, that he had been obliged to travel many hundreds of miles to give it as much accuracy as such a sketch was susceptible of, short of that which would have required years rather than months for its completion.

On commencing this work in the vicinity of Norwich, I found the variations of soil so sudden, so frequent, and apparently so arbitrary, that I almost despaired of reducing them to any law. I therefore repaired to the cliffs of Cromer for the purpose of studying the order of succession there exhibited, and the sequence of events indicated by it. Up to this period I had been impressed with the belief that there was little or no regularity in the deposits of the erratic block period; that they had either been formed by the violent and transient action of the sea, bursting in waves over the surface of the land, or that, if formed on a permanently submerged surface, the boulder clay had been dropped at random, in detached masses, from floating icebergs, among sand and gravel. I found, by the aid of the coast and river sections, that the upper and lower strata of the drift are distinct formations, differing in their characters, and continuous over areas as extensive as many of those occupied by the tertiary strata; possessing, in common with them, appearances which could only have resulted from gradual accumulation; while those by which they are distinguished from all other sea-born strata appear capable of a satisfactory explanation by the prevalence, during the epoch of

the drift, of an arctic climate in the temperate latitudes, of whic so much evidence has recently been collected.

No sooner had I adopted the theory of gradual submergence and gradual denudation, than all the variations of soil which had previously perplexed me were seen to be a necessary consequence of it. Each fell into its appropriate place; and in little more than a week I was able, from the contour of the surface, and even from the representation of it on the Ordnance map, to anticipate the nature of the soil which I should find in a given locality in the district lying to the north-east of Norwich. As I advanced into South Norfolk I was again at fault. Clay occurred where I expected to find sand, and sand where I looked for clay. Again I repaired to the coast sections at Gorlston, and the river sections of the valley of the Waveney, and found that these apparent exceptions were likewise a consequence of the law, and proved its truth. In East Norfolk, for instance, the denudation in the deepest valleys had scarcely cut through the sand and gravel of the upper drift down to the clay of the lower drift. In South Norfolk it had exposed large areas of this clay, leaving only outlying patches of the upper drift, and in some places had even cut through the lower drift down to the sand of the still lower crag, or through that to the chalk.

Having proceeded in this manner over the eastern half of the county, I had done enough to lay the basis of a safe induction, and much more than my agreement with the Royal Agricultural Society required, and I now passed more rapidly over the remainder, making wider traverses, and ceasing to map the surface variations. The scale of the Ordnance map is the smallest on which these variations can be shown; they vanish when we attempt to reduce it. I shall therefore illustrate them by means of sections instead of maps.

The order of succession prevailing among the supracretaceous deposits of Eastern Norfolk is shown in Sections I. and II., which also show their relations to the chalk and the lower strata which emerge from beneath it in West Norfolk.

The existence of freshwater beds and of a forest, interposed between the crag and the northern drift, which had been described by Taylor,* in his work on the 'Geology of Norfolk,' in 1827, was denied by Mr. Lyell† in 1829, who regarded the freshwater beds as a deposit in a depression of the drift, and the subterranean forest at Happisburgh, &c., as beds of lignite in the crag, between which and the drift he declared himself unable to draw a line of demarcation. At that time it was not known that the

* 'Geology of East Norfolk,' by R. C. Taylor, 1827.
† 'Principles of Geology.'

crag of Norfolk was a more recent deposit than that of Suffolk. This fact was established by Mr. Charlesworth* in 1836, and in 1837 the Rev. W. Clarke† insisted on the distinction between the Norwich crag and the detrital deposits which he still called diluvium.

On a re-examination of the Cromer cliffs in 1839, Mr. Lyell, who had adopted Mr. Charlesworth's classification of the crag of Norfolk and Suffolk, recognised the distinction between the Norwich crag and the northern drift, admitted the correctness of the order of succession established by Taylor and Woodward,‡ and the existence of freshwater beds and a forest between the crag and the drift. I have deemed it necessary to notice these facts, because the error of this eminent geologist, promulgated in that popular work, 'The Principles of Geology,' appears to have been more attractive than his correction of it in the pages of the 'Philosophical Magazine;'§ since there are still many who might be supposed to be cognisant of the latter who are still incredulous respecting the correctness of Mr. Taylor's sections.

I shall now proceed to a particular description of each of the deposits above the chalk.

1. *The Crag.*

The lowest of these is the Norwich or mammalian crag. It consists of a marine or fluvio-marine deposit, of very irregular thickness, containing the bones of elephantine and other mammals of extinct species, accompanied by marine shells (mixed in some places with freshwater shells), a very large proportion of which belong to existing species. Its most constant member consists of a collection of large chalk flints 2 or 3 feet thick, imbedded in a base of ferruginous gravel and sand, resting on the chalk and mixed with marine shells. It is in this part of the deposit that the bones and teeth of elephants, and other mammalian remains found in the crag, principally occur. In other parts it consists of beds of sand and gravel, varying in depth to more than 20 feet. I have never seen shells in it at a greater height above the chalk than 10 feet. Over extensive areas it is entirely free from them. Its boundaries in Norfolk, as far as they can be ascertained in consequence of the depth of covering, have been already stated.

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* 'Magazine of Natural History for 1836,' and 'Report of the British Association for the Advancement of Science for 1836.'

† Transactions of the Geological Society, New Series, vol. v., p. 360, 'On the Geological Structure of the County of Suffolk, and its Physical Relations with Norfolk and Essex.'

‡ 'Woodward's Outlines of the Geology of Norfolk,' 1833.

§ 'On the Boulder Formation, or Drift associated with Fresh-water Deposits in the Mud-cliffs of Eastern Norfolk.' 'London and Edinburgh Philosophical Magazine,' Series III., vol. xvi., No. 104. May, 1840.

In its prolongation into Suffolk it is seen to rest on the red or Suffolk crag, containing a different assemblage of fossils, which in its turn rests on the coralline crag, and that again on the London clay.

Being so extensively covered by the drift, it is only exposed in sea and river-cliffs and chalk-pits, and its beds of shells being less extensively developed than those of the Suffolk crag, are rarely used like them as a fossil manure. For this purpose those of Suffolk are largely employed, with great benefit to the light soils of that county; though the term marl applied to them increases the confusion in which the nomenclature of agriculture is involved. On the whole, the Norwich mammalian crag is of little agricultural importance.

2. *The Freshwater Beds.*

The crag is succeeded in the ascending order by ferruginous sand and gravel, and greenish blue clay, abounding with sulphate of iron and vegetable remains, freshwater shells, bones, teeth and scales of freshwater fishes, together with remains of elephantine and other large mammals. The depth of the deposit inferred from numerous sections is usually somewhat less than 10 feet. It is seen in the base of cliffs between Weybourne and Happisburgh, on the shore between high and low water. Its greatest development is at Runton and Mundesley. At the latter place the peaty deposit attains a thickness of nearly 20 feet, and with the freshwater shells which accompany it, is partly below, partly interlaced with the lowest members of the drift. I have seen patches of clay of a greenish blue colour, and containing freshwater shells and vegetable remains, at the base of the cliffs between Gorleston and Lowestoffe.

The concurrent testimony of the collectors of the mammalian remains places them in these freshwater deposits, and not in the drift. I have myself extracted three specimens from their matrix. These were, 1, a rib of *Elephas primigenius*, from ferruginous sand and gravel at the very base of the cliff near Cromer, in which some stumps of trees were rooted, and within a few yards of them; 2, a rib which I supposed to be that of *Cervus megaceros* (*Megaceros Hibernicus* of Owen), but which was lost on its way to London for identification. It was imbedded in pyritous sand and gravel, containing flattened wood, in the cliff, a little south of Mundesley, several feet above high-water mark.

Besides these I have found a large palmated deer's horn, resembling that of the *Megaceros*, the fragments of which are now under examination. Its site was a greenish blue clay and silt, resembling that of the freshwater deposits, but containing marine shells, and associated with yellow sand, also containing the usual

crag species, which is seen at low water about half a mile west of Cromer.

By the wasting of the coast considerable quantities of the freshwater deposits are annually washed into the sea. The peaty beds, and the clay impregnated with sulphate of iron, have, in some instances, been applied to the land, and always with beneficial effect.

3. *The Subterranean Forest.*

At various points on the coast stumps of fir-trees occur rooted in the sand, gravel, and clay, of the above deposit. In fresh sections of the cliffs these rooted trees are clearly seen to be covered by the mass of the drift. The forest is only visible between high and low water in certain states of the wind and tides, when the sand and shingle which usually cover it are removed. Its subterposition to the drift of the cliffs, which can only be seen where their base is free from debris, is still questioned by some geologists even since it has been admitted by Mr. Lyell. The authorities for the fact, as eye-witnesses of it, have hitherto been Taylor, Woodward, and Mr. Symons of Cromer. During my recent examination of the geology of Norfolk I have had several opportunities, from personal observation, of confirming their reports.

4. *Marine Bed between the Freshwater Strata and the Drift.*

On each side of the gap at Runton I have observed immediately above the freshwater beds the rare phenomenon, in connexion with the English drift, of a regular marine bed of shells, evidently on the spot which their inhabitants had frequented while living. On the east side of the gap the deposit contains two or three species grouped together; on the west side the bed consists of numerous individuals of a single species of a large gaping bivalve, with the two valves united. The existence of these beds is doubted by some geologists, because they did not themselves see them during a rapid tour along the coast. They are only visible, like the subterranean forest, when the base of the cliffs is clear of debris.

Three times after their discovery I visited the place at intervals of several months, for the purpose of procuring specimens, and found the beds covered. Mr. Symons, to whom I pointed out the spots where I had discovered them, and whose constant residence in the neighbourhood enables him to seize the favourable moment for observation, has since seen them several times, and has undertaken to collect a suite of specimens for examination by some competent naturalist, that it may be ascertained whether there are among them any of the extinct species of the Norwich crag. There was no intermixture of the marine and freshwater shells; they were arranged in separate beds.

5. *The Lower Drift—Till or Boulder Clay.*

Above this marine deposit occurs the till or boulder clay, the lowest member of the northern drift. It is proved to be a marine deposit by the marine shells which it contains; but they occur wherever I have observed it, in England, Wales, and Ireland, in a very different condition from those of the Norwich crag, or of the marine bed last mentioned, consisting rarely of anything but fragments, distributed with the utmost irregularity through the mass—species of different habits, the inhabitants of sandy and of muddy bottoms, of deep and shallow water, being mixed confusedly together and associated with fragments of various rocks, often little waterworn, but much scratched, derived from a number of distant localities intermixed largely with local detritus. The base through which these fragments of shells and rocks are distributed is often not very dissimilar in other respects from the London clay. The foreign detritus consists of blocks and pebbles of granite, gneiss, mica-slate, clay-slate, greenstone, porphyry, and other rocks which occur no nearer than Scotland or Norway.

They constitute the tail of a stream of detritus, traceable over a large portion of the north of Germany, the blocks diminishing in size and quantity with their distance from the Scandinavian peninsula. Besides these fragments, those of Kimmeridge clay and lias are met with, containing their characteristic fossils. Those of the London clay and carboniferous strata are more rare. The most abundant detritus consists of fragmentary chalk and chalk-flints. These are found under a variety of conditions: 1, as detached masses of chalk enveloped in the clay;* 2, as masses of fragmentary chalk collected together with little or no intermixture of other matter, and free from attrition by aqueous action; 3, as fragments sometimes quite angular, sometimes more or less waterworn, dispersed irregularly through the clayey matrix, in juxtaposition with the detritus derived from greater distances. On the flanks of those masses of chalk which have been brought together without attrition and unmixed with other matter, their materials have been rearranged by marine action after being finely comminuted and intimately combined with clay, thus producing proper marls, of various shades of white, grey, blue, and yellow. The insulated masses of chalk and transported chalk rubble are most abundant in the cliffs of Cromer, between Trimingham and Weybourne. Towards the termination of the cliffs near Happisburgh the thickness of the clay diminishes. Its upper surface sinks to below the level of the sea, and disappears be-

* One of these transported masses of solid chalk at Old Hythe Point is nearly 80 feet high.

neath the sand-hills and the alluvium of the Yare. Detached portions of the clay are, however, met with in the "hards" or "holms" which rise like islands from among the alluvial deposits. In composition this clay is somewhat different from that of the Cromer cliffs, consisting of a mixture of blue clay, such as it occurs in these cliffs, with yellow clay and sand. In this form it is the grey clay-marl of East Flegg described by Marshall. South of the Yarmouth estuary it is again visible in the cliffs between Gorlston and Lowestoffe, occupying their upper part, with a large development of crag-sand below it, and a thin covering of the sands and gravels of the upper drift above it.

Following it up the valley of the Waveney, we find it still holding the same relative position to these two sandy deposits, except where, by the denudation of the upper sand, the clay has been exposed over extensive areas in the southern hundreds of Norfolk, and over a still more extensive portion of the north of Suffolk. Oolitic detritus increases in quantity as the till is traced towards the west, in the river sections, and in the clay-pits which have been so abundantly opened throughout the district. This detritus consists of fragments of the Kimmeridge clay and other oolitic rocks, with their characteristic fossils; among which, vertebræ of saurians and the septaria of the Oxford clay, known by the name of turtle-stones, abound. Mr. Rose of Swaffham possesses an extensive collection of these bouldered fossils, and Woodward's 'Geology of Norfolk' contains a catalogue of them, with the strata from which they have been derived. The oolitic sandstones frequently occur as large unabraded blocks. The Kimmeridge clay is seen sometimes under the form of accumulated masses of its unmixed fragments, sometimes in small pieces dispersed, with fragmentary chalk, through yellow clay mixed with sand.

In the northern parts of central Norfolk, and in the ramifications of the till among the chalk, the chalk detritus increases in quantity till it constitutes the largest portion of the mass, which then is scarcely distinguishable from the transported and reconstructed chalk to be mentioned presently, as enveloped in the upper drift of East Norfolk as well as in the till. This form of till abounds in the neighbourhood of Wells, constituting the "clay" which has been so extensively and profitably used on the Holkham estates. The least chalky varieties have been found the best. In the drift of the Cromer cliffs the chalk detritus has been chiefly derived from the soft upper beds; in that of southern and central Norfolk, fragments of the lower or hard chalk prevail. The masses of transported Kimmeridge clay and chalk, associated with irregular accumulations of sand and gravel, which occur in hollows on the summit of the watershed, may be consi-

dered as belonging rather to the upper drift than to the till. On the slope of the western escarpment portions of deep beds of till again occur at the heads of some of the valleys, but from the steepness of the slope it has been more denuded than in the more level districts on the east; and the greater portion of the western valleys have been swept clean of the detrital deposits, the chalk having only a thin covering of sand. In the lower parts of these valleys the till is covered by the alluvial deposits.

The upper surface of the till is very irregular in the Cromer cliffs, as shown in Section III., its depth varying from less than 10 to 70 or 80 feet.

In the river sections of the southern and central parts of the county, and in the pits where the till rests on the sand of the crag, it is seldom that more than 10 feet of it are exposed, but large portions of its upper part have evidently been removed by denudation. Where it is deep it has not been sunk through. In the section of strata penetrated in sinking a well at Diss, as recorded by Mr. John Taylor,* its depth appears to have been about 50 feet.

6. *The Upper Drift.*

The till is generally said to be unstratified, but improperly as regards that of Norfolk, because in the least stratified portions alternations of deposits are marked by irregular seams of fragmentary chalk. These are best seen either in fresh sections, or when masses of the clay have been exposed to the wash of the sea. The face of the cliff is in general covered by a crust brought down by the rain, which conceals the stratification. In the upper drift, however, stratification is much more decided, consisting of alternating beds of sand, gravel, loam, and coarse shingle. The till passes upwards into laminated blue clay and silt, which again pass into the yellow sands of the upper drift, containing large masses of fragmentary chalk.

The till occurs but once, and that at the commencement of the period of the drift; after which, the peculiar causes, whatever they were which produced it, ceased. In the upper drift there are several alternations of the fragmentary and reconstructed chalk. These, in East Norfolk, constitute a large portion of the "marl" which has been so extensively used for the improvement of its light soils. It is found in some cases mixed with a variable proportion of blue and yellow clay and sand, in others it is sufficiently pure to be burned for lime. Among the numerous instances of lime-kilns situated on these beds of transported and

* Lond. and Ed. Phil. Mag., vol. v. p. 295; and Proc. Geol. Soc. vol. ii. p. 93.

reconstructed chalk, the lime-works near the town of Cromer and at Thorpe Market may be mentioned. Near Saxthorpe is a bed in which the transported chalk intimately combined with a bluish clay yields an hydraulic lime.

The singular contortions into which the strata of the upper drift have been thrown, particularly between Sidestrand and Old Hythe Point, have attracted much attention, and various explanations of them have been offered, none of which can be considered satisfactory. The contorted strata cover others which are perfectly horizontal, so that they could not have been caused by a force acting from below, nor by lateral pressure during movements of upheaval. I have suggested subsidence occasioned by the melting of masses of ice among which these contorted strata were formed, as more accordant with the conditions to be explained, than the hypothesis of icebergs ploughing up the bed of a shallow sea in which they stranded. Woodward, in his 'Geology of Norfolk,' has given sections of the whole line from Happisburgh to Weybourne, as they existed when he wrote; but from the waste of the coast the details are in a constant state of change. In these sections he has exhibited the contorted strata as well as they can be shown on so small a scale. I have copied from his work a representation of one of them in Section III.

Let us here pause to consider the events indicated by the succession of deposits above described; for those events have had an important influence on the agriculture of Norfolk. To geologists they will be sufficiently obvious; but in preparing this paper I labour under the double disadvantage of writing for the information of those who must be presumed to be unacquainted with geology, and of drawing conclusions of practical importance, partly from facts with which geologists are familiar, and partly from facts which are now for the first time publicly announced.

1. We have in the crag a deposit gradually formed beneath the sea by ordinary marine action, as is proved by the shells which it contains, and by the condition in which they are found.

2. The freshwater beds and the rooted stools of trees show this marine bed to have been at a subsequent period sufficiently elevated above the sea to have been covered in some parts with the deposits of rivers and lagoons, and in others to have supported a forest. The size of some of the trees proves that the surface continued in this state for a considerable period.

3. This terrestrial surface was again submerged and covered by a marine deposit. This, at its commencement (the marine bed at Runton), resembled the crag, but as the submergence proceeded, it assumed characters (the till) very different from those of any former or subsequent marine formation. The ques-

tion of the agencies which produced this difference I shall not discuss in these pages.

4. The marine deposit thus formed was again laid dry. During its elevation valleys were excavated in it, and over large areas the upper drift was stripped off with the exception of some detached masses. The change in the relative level of the land and sea during these operations must in Norfolk have exceeded 600 feet, for the forest on the Cromer coast is partly below, very little above the sea, and the highest parts of the watershed are covered with the upper drift.*

5. *Warp of the Drift.*

Over the denuded surface of the upper drift and of the lower drift, when the denudation has extended so low, another deposit has been thrown down, which has hitherto been little noticed, or has been passed over in the descriptions of geological sections under the name of vegetable mould. It appears to have been a deposit from turbid waters returning to a state of tranquillity. I have named it provisionally the warp of the drift, a name which is, however, not altogether appropriate, because, though in low situations, and on level surfaces, it resembles the warp or sediment left by the tidal waters of muddy estuaries, and is scarcely distinguishable from modern alluvial deposits; yet in other situations, far above the reach of existing streams, stones of considerable size (in Norfolk chiefly flints) are contained in it, and in the vicinity of mountain-chains, the large blocks or boulders which either strew the surface or are enveloped in this deposit appear to have been dispersed at the period of its formation. Its history is yet to be discovered. For some time after it had attracted my attention I regarded it as the deposit left by the waters under which the drift was formed, as they gradually retired during the upheaval and desiccation of the land; but in the course of my observations in Norfolk, I have met with indications of the denuded surface of the drift having become dry land before this warp was spread over it.

The point, however, which most concerns our present inquiry is, that the varieties of soil depend principally on the depth and composition of this deposit, while these again depend on the form

* Captain Robe, in reply to inquiries made by Mr. Rose, gave these as a rude estimate of the heights of the following points:—Docking, 600 to 650 feet; Swaffham, 450; Great Massingham, 600; adding that the triangulation of Norfolk was performed with instruments too small to be depended upon for the vertical angles; and that without accurate instruments it would be impossible to class the ranges according to their relative altitudes, those altitudes differing so little among themselves. See Mr. Rose's paper in the Phil. Mag.

of the surface. But for this warp the Happing hundred would have consisted of as barren sand as any in the county. It is there often 4 or 5* feet deep, while on the higher portions of Norfolk its depth is less than 6 inches. Soils of the latter description, whether loam or clay, are called by the farmer thin-skinned.

This warp differs more or less from the subsoil on which it rests. On sands it contains a greater mixture of argillaceous matter producing a sandy loam of different degrees of adhesiveness, on clay it contains an intermixture of sand producing a clay loam, or at any rate, clays less adhesive than those of the subsoil.

The greatest height to which this deposit extends has yet to be determined. In Norfolk it has been spread, however thinly, over the highest parts of the county. The situations in which it is wanting are those which, from the form of the surface, would have been swept by currents instead of the water being allowed to stagnate over them, and to deposit its sediment. On steep escarpments it is almost wholly wanting, and in such situations the subjacent strata, whether gravel, sand, or clay, of the drift, or any member of the regular strata, exert their full influence on the characters of the soil. The following sections will illustrate the varying depths of this deposit dependent on the form of the ground.

No. IV. represents the head of a valley about a quarter of a mile wide, excavated in the drift. The intensity of the surface-line denotes the varying depth of the warp or surface-soil.

The warp is less than a foot deep on the summit of the plateau, wanting on the steep sides, and from a foot to 18 inches deep in the bottom of the valley.

No. V. represents the valley when its width has increased to half a mile, and its sides, instead of being steep, have a gradual slope.

In such cases there is a gradual increase in the depth of the warp from the summit of the plateau to the bottom of the valley, where it is from 18 inches to 2 feet deep.

As the valley expands in the lower part of its course, Section VI., a warp is found in its bottom, varying in depth from 2 to 4 or 5 feet, and gradually thinning off up the sloping sides.

Even on the summit of the hills which bound the lower part

* The analysis by Dr. Playfair, published in a recent number of this Journal, of the soil of a field near Sutton, which produced eleven quarters of wheat to the acre in 1844, contains nothing to indicate any extraordinary fertility. Soils, however, which yield to analysis only a small proportion of those ingredients essential to the growth of our cultivated plants, become highly productive when of great depth; and this is the case not only with that under consideration, but with most of the very fertile land of the Happing hundred.

of a valley, if they are surrounded by still higher hills, the warp is deeper than in the bottom of a valley near its head.

In winding valleys a gradual slope and a deep warp are found on one of its sides, Section VII., and steep escarpments with little or no warp upon the other, and these change reciprocally from side to side of the valley.

This has evidently been caused by the action of currents of water, of which the valleys were the channels during the deposition of the warp, and which have flowed at higher levels than the existing streams, and even through valleys now perfectly dry. The phenomena are analogous to those of river erosion, in which the current is deflected from side to side, and thus produces alternately bluff banks and low alluvial tracts; wearing away the banks at the points where it strikes them, and depositing the materials on the opposite side. The extent to which the denudation has been carried further modifies the quality of the soil. When, as in Section IV., the valley through its whole course is excavated entirely on the sands and gravels of the upper drift, we have a sandy loam on an absorbent subsoil, the depth of the soil increasing as we descend the valley.

When the denuding action has been carried further so as to reach the clay of the lower drift, as shown in Sections VI. and VII., we have stronger loams upon a retentive base; soils which in their natural state are often cold and wet, but become highly productive when drained. Where the upper drift has been wholly swept off large areas, we have a warp of clay-loam, varying in depth with the form of the surface, on a subsoil of clay. Outlying patches of the upper drift, remaining on a partially denuded surface, are covered with loamy warps, varying in depth with the form of the ground, and in strength with the extent of surface of the lower drift exposed in their vicinity, while the subsoil varies from absorbent to retentive, with the depth of the outlying patches of upper drift.

These variations will be better understood from the section which I have given across Norfolk, from Sidestrand on the north to the Waveney on the south, Section II., than from any map, unless constructed on a scale much too large to accompany this paper.

Poringland Heath shown in that section, and Strumpshaw Hill, which is off the line of it, but is shown in Section I., are, in Smith's county map and sections, erroneously laid down as patches of London clay. The gravel of the upper drift, about 30 feet deep, which caps them, was evidently mistaken by him for the upper marine of the Paris basin, of which the Bagshot sands are considered the English equivalent: the blue till for the London clay, the brown and yellow varieties, with much

disseminated chalk rubble, for the plastic clay below it, and the crag for the sand and gravel which abound in the lower part of that formation. This error, as regards the outliers of Poringland and Strumpshaw, has been partially continued in the map which accompanies Woodward's 'Geology of Norfolk,' in which they are represented as detached masses of clay, instead of as detached masses of gravel upon a continuous bed of clay. Professor Phillips, in his Geological Map of the British Islands, following the authority of his illustrious relative, has extended the plastic clay over the whole district occupied by the strong soils of Smith's County Map, adding in a note, that it is difficult to ascertain the boundaries of that formation in Norfolk. After very diligent search I have been unable to find a single outlier of the London or plastic clay within the area indicated. Even their bouldered fossils are by no means abundant, and the small quantity met with occur chiefly near the borders of Suffolk.

The phenomena presented by the junction of the soil and subsoil are very remarkable. The surface of the subsoil is indented with furrows and pierced with conical and cylindrical cavities similar to those which are common on the surface of the chalk, whether covered by the tertiary strata of all ages, from the plastic clay to the Norwich Crag inclusive, or by the more recent strata of the drift, which may be called the erratic tertiaries.

Almost every excavation opened throughout the district shows this furrowed surface of the subsoil, the depth of the cavities, except in some extreme cases, varying from 2 to 4 feet. It is most striking when the subsoil consists of a bed of transported chalk or of till, but is not confined to them. The furrows abound in subsoils of sand and gravel, as well as of transported chalk and till: the cylindrical and conical cavities are best developed in the two latter, but I have seen them in sand.

Section VIII. is a sketch of the junction of the soil and subsoil over a pit of the most chalky variety of till near Langham. In this case the greatest depth of indentation is 3 feet, and the depth of warp or surface soil varies in the space of a few yards from less than 6 inches to 3 feet.

Section IX. is a sketch of the junction of the soil with a subsoil of more clayey till than the last, near Hardingham. In this case the depth of the furrows and pipes varies from 3 to 6 feet, and one of the pipes extends to the depth of 9 feet. If all the projecting points of till were removed to a level with the dotted line A B, it would give a soil with a regular depth of 3 feet.

This furrowing of the surface of the subsoil is a fact of considerable importance in pure geology, with reference to the agencies concerned in the formation of the surface soil or warp of the drift; it is of no less importance in its bearing on practical

questions in agriculture connected with drainage and evaporation, 'scalds,' deep and shallow ploughing, and subsoiling.

Brick-earth of the Nar.

I have deferred till this place the consideration of the brick-earth, or rather clay, of the valley of the Nar, and the fresh-water deposits of Gaytonthorpe, both of which appear to have preceded the formation of the warp, because it was necessary that the reader should be made acquainted with that hitherto undescribed member of the erratic block period, in order to understand its relations to these beds.

Throughout the whole depth of the upper and lower drift, the thickness of which, in some of the Cromer sections, exceeds 300 feet, no regular bed has yet been discovered containing shells of marine animals that had lived upon the spot. I have mentioned a deposit of this kind interposed at Runton, between the till and the fresh-water beds at the commencement of the submergence. The brick-earth of the valley of the Nar appears to have been formed towards the termination of the subsequent period of elevation, and to be covered only by the warp of the drift, which closed the erratic block epoch. This deposit is mentioned by Young in his report to the Board of Agriculture, under the name of oyster-shells and marine mud, used as a dressing for turnips, and of great efficacy on land that has been worn out with corn. Its fossil contents, and the area occupied by it, have been described by Mr. Rose in an interesting paper 'On the Geology of West Norfolk' in the 'Philosophical Magazine.'*

He has traced it in brickfields, clay-pits, and wells for 9 miles up the valley of the Nar, with an average breadth of half a mile; the most eastern point at which it has been observed being between Narford and Westacre. It has been named, not very appropriately, brick-earth, by which loam is usually understood, whereas it is in reality a blue clay, used in the manufacture of tiles and white kiln-burnt bricks. From the marine shells which it contains, their state of preservation, and the manner in which the species are grouped, it appears to have been an estuary deposit. The greatest height of the undisturbed clay in the valley, even near its eastern extremity, does not, according to Mr. Rose's estimate, exceed 30 feet above the level of the sea; but at a greater elevation by about 60 feet, there is in Walton Field a considerable accumulation of shells in sand and gravel, which from their broken state and the high angle at which the beds are inclined, appears to have constituted the beach of that inlet of which the clay was the deep water deposit.

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* 'London and Edinburgh Philosophical Magazine' for 1836, vol. vii.

Mr. Rose still maintains the opinion advanced in his paper, that the Nar clay is not any where covered by deposits containing blocks transported from a distance. When, however, I was explaining to him my views of a threefold division of the erratic block group into lower and upper drift and warp of the drift, he informed me that since his paper was published, he had found several sections in which the Nar clay was covered by what, perhaps, might be the warp, though, for reasons which I have already stated, he objected to the term as inappropriate. I visited most of the sections indicated by him, and found them, as far as I could judge in the unfavourable state of the pits at that season of the year, to be as he described them. They are, 1, the brickfield at East Winch, where the Nar clay with fossils is covered by 7 feet of red gravel and gravelly clay, containing large unabraded flints; 2, Pentney Warren and Narford, where the angular fragments of flint are smaller; 3, a spot near Bilney Church, where 4 or 5 feet of a deposit to which he admits the term warp to be applicable, cover peat, which lies immediately upon the Nar clay with its characteristic marine shells.

The fresh-water deposit at Gaytonthorpe I shall show presently not only to be covered by the warp of the drift, but to have suffered partial denudation from it.

The shells found in the Nar clay are all of existing species now inhabiting the British seas, though they differ from those found in the marine silt of the adjoining marshes, which are the group still living in the existing estuary. They are accompanied, in some of the pits, by broken bones and teeth of the horse, elephant, and rhinoceros. If these were not washed out of some older deposits, and if the place in the erratic block series which I assign to the Nar clay be correct, it would appear that in England the rhinoceros and elephant were not entirely destroyed by the submergence which produced the till and upper drift. Mr. Lyell has shown that in America the mastodon flourished after the erratic block period. The great fossil deer of Ireland appears to have inhabited the British Isles both before and after that epoch. The auroch, or bison (*Bison priscus* of Owen), which was contemporary with the extinct mastodon, entombed in the Norwich crag and other tertiary beds of older date, has survived all these revolutions, and is still living in Lithuania, where it is preserved in one of the Royal or Imperial forests like our wild cattle of Chillingham Park.*

The Nar clay, though it has been penetrated to the depth of 40 feet, has not been sunk through. The proof of its super-

* See Murchison's 'Geology of Russia,' and Owen's 'British Fossil Mammalia.'

position to the till is therefore incomplete. It may, however, be inferred from the fact that till has been found underlying the alluvial deposits in deep excavations in the marshes.

Freshwater Deposits of Gaytonthorpe.

About 2 miles north of the ancient estuary of the Nar there is a small parallel valley, also opening to the Wash. In this valley, and a quarter of a mile north of Gaytonthorpe, a blue clay, containing lumps of waterworn chalk, and abounding with small crystals of sulphate of lime, is worked for brick-making. No shells have yet been found in it, and in their absence it is doubtful whether it is a form of till or an estuary deposit like that of the Nar. About half a mile east of this brick-field clay has been formerly dug for agricultural purposes on the farm of Gaytonthorpe Hall, on the north side of the road, but the pit is now full of water. On the south side of the road is another pit at a higher level, still worked. In this pit several beds of clay and calcareous sand rest upon an irregular surface of a bed resembling in composition the more chalky varieties of till. The surface soil consists of a loamy warp, containing in some parts accumulations of flints of considerable size, and filling furrows and pipes deeply excavated in the calcareous sand and associated clay. The depth and extent of the several beds will be understood from the accompanying section (Section X.), which is constructed on the same vertical and horizontal scale, namely, 20 feet to 1 inch. From the spot where "bones" is written on the section, Mr. Rose has obtained a nearly complete set of the teeth of the lower jaw of a species of *bos*.

From the numerous fragments of a very thin univalve in the calcareous sand, accompanied by horny *opercula*, resembling those of a small *paludina*, and from part of a *unio* occurring in one of the beds of clay, I was satisfied that they were freshwater deposits. The specimens which I procured were too imperfect to enable me to obtain an opinion on them from an eminent naturalist; but Mr. Rose, who conducted me to the pit, and who was at first reluctant to believe them fluviatile, has recently set the question at rest by the discovery of several entire specimens of *cyclas* and one *planorbis*. Though the *species* are not yet determined, there can be no mistake about the presence of these freshwater *genera*. We may, therefore, conclude, that whatever were the causes which produced the warp, they were not in operation until the latter portion of the period of elevation, when the marine strata which had accumulated upon a terrestrial surface submerged to the extent of 600 feet at least, had been again laid dry, and had continued a terrestrial surface for a sufficient time to permit a considerable accumulation of freshwater strata near the head of a valley which was filled perhaps in its lower part with an estuary

like that of the Nar, receiving in its upper part the drainage of the high grounds on the east. The warp also was not deposited until after the cessation of those agencies, whatever they were, which were so unfavourable to animal life as to have caused the absence of regular deposits of shells through a series of marine strata more than 300 feet thick.

About a quarter of a mile higher up the valley, a gravel pit has been opened in a superficial deposit of angular flints which appears to be of the date of the warp.

The elevation of the Gaytonthorpe valley is probably somewhat greater than that of the valley of the Nar; but the obscurity still hanging over these interesting deposits will not be wholly removed till a section shall have been obtained exhibiting the base on which the Nar clay rests, and till the heights of these valleys above the sea shall have been accurately determined.

The elevation above the sea of the different points in Sections I. and II. is in a great measure conjectural (see Note, p. 465), and the proportion between the vertical and horizontal scales greatly exaggerated, in order to render the different deposits distinct. Were those sections constructed on a true scale, the vertical scale in Section I., which is the most exaggerated, should not have been greater than at present, on a base line 26 feet long.

Agricultural Districts.

The agricultural districts dependent on varieties of soil into which I divide Norfolk are the following:—

I. The alluvial district of East Norfolk.
II. The district of the deep upper drift.
III. The district of the lower drift.
IV. The district of the thin upper drift.
V. The alluvial district of West Norfolk.

Each of these consists of minor divisions. In describing the boundaries of the districts and sub-districts I shall refer to Smith's County Geological Map.

I. Alluvial District of East Norfolk.

This comprehends three sub-divisions: those of—1. Alluvial Sand; 2. Alluvial Clay; 3. Peat.

The alluvial sand consists of the Yarmouth Denes and the hills of blown sand which stretch along the coast from Eccles to Hemsby, with an average breadth of less than a quarter of a mile. Though of little agricultural value, either from the extent or quality of their surface, they are indirectly of great importance, as on the maintenance of them in their integrity depends the exclusion of the sea from the valuable portions of the alluvial district of East Norfolk.

We have already mentioned the closing of the breaches in the sand-hills by means of sand and shingle as one of the triumphs of applied geology in the hands of Smith. For three years he laboured in vain to prevail on the Commissioners of these marshes to substitute such simple means for the piles of masonry and the forests of timber which they were employing in vain. At length he induced some of them to accompany him to the shore, where he pointed out the mode in which nature had formed the barrier, and by which he proposed to aid nature in sustaining it. He showed them how a shallow sea agitated by violent storms tore up the materials of its bottom, and impelled them on the shore, projecting a portion beyond the reach of the retiring wave. He pointed out how the ordinary action of the tide during intervals of tranquillity arranged the materials thus thrown up in a gradual slope, in rolling up which the waves spent their force and found a barrier of their own formation more efficacious in withstanding their fury than solid constructions which opposed to them an abrupt resistance. The arguments thus supported were irresistible, and the astonished Commissioners exclaimed—"Oh, that none of us should have thought of this before!" Smith, now allowed full scope to follow his own plans, employed a number of carts to draw the blown sand from the highest part of the neighbouring sand-hills, arranging it in a slope of one to twelve on the side of the sea, and one to three or four on the side of the land, sealing down the sand, as he proceeded, by a covering of the heaviest shingle which he could procure near the spot, and which he had observed to remain unmoved during the most violent gales. In less than a year the breach, more than a mile in length, was stopped, and the ordinary operations commenced of drawing off the surface-water by machinery—for these marshes lie below the ordinary level of high water, and have a very limited fall at low water. The measures which Smith proposed for their further improvement have not been followed up; but his unresisting slopes have withstood the heaviest storms of the German Ocean for more than forty years; and on the practice or neglect of the lessons which he taught the Commissioners in this department of agricultural engineering depends the existence not only of the rich alluvial tract of the Yare and the Waveney, in Norfolk and Suffolk, but ultimately the question whether Yarmouth itself, the site of which was a sandbank separated from the mainland before A.D. 900, shall, in the course of those changes now in progress, of which Geology takes cognisance, remain a flourishing town, or return to the state of a sandbank again.*

* Such is the account of the operations given by Professor Phillips, in the 'Memoirs of William Smith,' from the voluminous notes of his

2. *Alluvial Clay.*

This occupies a triangular space, the base of which is a line drawn from the canal joining the Yare and the Waveney along the course of the latter river and the Bredon Water, and thence along part of the North Denes to East Caistor. The other sides of the triangle are formed by lines extending, the one from East Caistor, about a quarter of a mile south of West Caistor and Runham to Stokesby—the other from Stokesby, passing about half a mile west of Halvergate, to the point where the canal before mentioned enters the Waveney.

3. *The Peat.*

The western edge of the alluvial clay is bordered with a peaty margin, about half a mile broad, which unites the peat districts of the Waveney and the Yare with those of the Bure and its tributaries, the Ant and the Hundred Stream.

That portion of the peat of the Waveney which is in Norfolk extends, with a very irregular breadth, varying from less than a quarter of a mile to nearly a mile, from Burgh St. Peter's to the bog in which that river rises at Lopham Ford. The peat of the Yare borders both sides of the river, with an average breadth of about a mile and a half, from the Yare and Waveney Canal to Sirlingham; above which, to Trowse near Norwich, it contracts to half a mile. The widest part of the peat of the Bure is below the confluence of the Ant and the Hundred Stream with that river, the breadth varying from three miles at its northern and southern extremities, to about a mile and a half in the centre. Along the separate course of these streams the breadth of the peat varies from half a mile to a mile on the banks of the Bure from its junction with the Ant to Wroxham—on the banks of the Ant from the junction before-mentioned to Stalham Broad—and on the banks of the Hundred Stream to Hickling and Horsey Broads. The upper parts of the Yare and Wensum above Norwich, and of the Bure and Ant above Wroxham and Stalham, as well as their tributary streams, are, in many places, fringed with peaty meadows, varying from one-eighth to one-fourth of a mile in breadth.

II. District of the deep upper Drift.

This occupies all that portion of Smith's map, tinted with the colour used by him to denote light soils, which lies to the east of

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uncle. One of the Commissioners, who remembered the proceedings, informed me that Smith laid down faggots in the first instance to aid the retention of the sand.

his strong land district. It may be divided into two sub-districts —those of the thick and the thin warp—though each of these, in point of fact, consists of many districts, separated from each other by soils of a different quality.

1. *The Sub-District of the deep Warp.*

A line drawn from Trimingham to Loddon, and another from Loddon to East Caistor, will, with a few trifling exceptions, include between them and the sea-coast all the best loams of East Norfolk, interspersed among much of a lighter and thinner staple and some sand, and among the peat which borders the rivers and broads. The areas occupied by these different varieties of soil are extremely irregular, the deep and strong loams being found in the bottoms of valleys and other low situations not covered by peat, the thinner and lighter loams occurring on the summits and upper slopes of the high ground, and the sand on steep escarpments, in the manner already explained.

2. *The Sub-district of the thin Warp.*

In the tract east of a line drawn from Trimingham to Loddon the better descriptions of loam prevail. In the other part of the eastern light land district of Smith's map there are small areas of the same description of soil in the valleys, but they form the exception, the greater portion of the district being occupied by a thin warp on the summits, or by the sand and gravel of the upper drift and crag exposed by denudation on the steep escarpments bounding the valleys of the principal streams.

III. District of the lower Drift.

This comprises the space in southern and central Norfolk marked in Smith's map with the tint denoting strong land. That map represents, with as much accuracy as is possible on so small a scale, the area throughout which the clay of the lower drift has been exposed more or less by denudation. Irregular as the boundaries are, as shown on that map, the ramifications are found to be far more irregular where we follow the denudation into its details. This district of Smith's map is divided into two by the Wensum, the smallest lying to the north of that river. The separation is caused by the denuding action having extended along that great line of drainage through the till down to the sand and gravel of the crag, a large extent of which has been exposed on the steep sides of the valley. Within each of his strong land districts there is likewise every variety of soil, arising in some cases from denudation to a similar depth, though on a

smaller scale, but more frequently from outlying portions of the upper drift, covered by a deep or thin warp, remaining on the surface of the till.

Sub-Districts.

If we divide Smith's largest district of strong soil by a line drawn from Wymondham to Attleborough, wheat and bean land, consisting of the denuded surface of the till covered by a warp of clay loam, will be found to prevail over the southern portion—the outlying patches of upper drift constituting exceptional cases—while in its northern part, and in the small district lying north of the Wensum, the proportions are reversed, the loams of the upper drift covering the greater portion, and the till being only exposed, except in artificial excavations, in the bottoms of the valleys which intersect it. In the portion of the district south of Wymondham the Suffolk plough and the Suffolk course of husbandry prevail.

IV. District of the thin upper Drift.

This comprehends the whole of Smith's light land district lying on the west of his district of strong soil. It occupies the summit level of the county, on which a thinner deposit of the upper drift appears to have been thrown down, originally, than in the eastern side. It covers also with a thin coating the greater part of those areas which, following the usual course adopted in geological maps, he has represented as occupied by the rock nearest the surface. On the summit of the watershed the drift varies in depth, from less than three feet to more than thirty. Between the chalk and the warp there are generally interposed two or three feet of rubbly chalk, mixed with patches of sand and yellow clay. This is covered, in some cases, by merely a thin sandy warp; in others by thirty or forty feet of sand, gravel, and coarse shingle, with little regularity of stratification, and having masses of transported chalk and Kimmeridge clay enveloped in them. The thin upper drift of the watershed is covered in general by a more sandy warp than is found on the lower summits; there is, however, in different parts considerable variation in the quantity of argillaceous matter contained in it. This increase takes place here, as in other districts, in hollows and situations where during the submergence water would have stagnated and deposited the finely divided matter held in suspension, while sharp sand and gravel are exposed in situations which, from the contour of the surface, would have been swept by brisker currents. These prevail in the southern portion of the district,

on the borders of Suffolk, of which it is said that a gentleman, being asked in which county his property was situated, replied, "Sometimes in the one, sometimes in the other; it blows backwards and forwards."

In the district of thin upper drift we may include the western escarpment, in which the chalk and other rocks are covered only by a warp, or by a warp upon a thin crust of gravel and sand. There, however, the thinness of the covering must be considered not as an original condition of deposit, but as the result of denudation during the period of elevation, since there is reason to believe, from the patches of till remaining at the heads of some of the valleys—till being also known to lie under the alluvium of the marshes—that this western side of the watershed was covered during the period of submergence with as deep accumulations of upper and lower drift as the eastern side; that they have been more denuded during their elevation, owing to the greater acclivity of the base on which they rested, and that the gravel and sand now in contact with the chalk were deposited after their removal, but before the formation of the Gaytonthorpe beds, and of the Nar clay, and the warp.

Towards the bottom of the valleys, and as they approach the alluvial district, they are covered by a deeper warp, which produces some small tracts of strong or deep loams, sometimes upon an absorbent, sometimes upon a retentive base, ramifying, with the contour of the surface, among tracts of lighter and stronger soil, under conditions very similar to those which have been described on the eastern side of the county.

V. Western Alluvial District.

This valuable, improved, and still improving tract is divisible, like the alluvium of East Norfolk, into two sub-districts, that of the clay or loam, and that of the peat, the former the nearest to the sea, the latter at the inland extremity of the alluvial district; but as I have merely passed rapidly across it I do not undertake to define their limits.

Sections of the alluvium are only laid open in occasional excavations. These, as recorded by local observers, are such as to indicate the gradual silting up of an estuary until the salt water was excluded and a peaty morass formed, liable to inundations of fresh water. When arrived at this state its further desiccation was effected by the embanking of tracts lying nearer to the sea.

Mr. Rose has given the following as the succession of deposits laid open in the excavation of the Eau Brink Canal, near Lynn:—

	FT.	IN.
1. Surface soil, brown clay, with sand . . .	4	0
2. Blue clay, fresh-water shells	3	0
3. Peat, containing bones of ruminants . . .	2	2½
4. Blue clay, like No. 2	8	0
5. Peat, with alder and hazel bushes, the lower portions clay, containing roots of marsh plants .	3	0
6. Dark blue clay, not cut through, a marine silt.		
	20	2½

The marine shells in No. 6. are a different group from that of the Nar clay, and are of species identical with those now inhabiting the estuary.

In a well in the town of Lynn a similar succession of deposits was found to rest on till (blue clay with nodules of chalk) twenty to thirty feet deep.

The reclaiming of this tract was commenced by the Romans. After their departure the embankments were neglected and the fens were again submerged and covered by the beds No. 2. In this state they remained till the time of Charles I., when these operations of draining and embanking were resumed, which have been prosecuted with such well-known energy and success during the last half century, and which form a striking contrast to the neglect which the alluvial district of East Norfolk has experienced. The series of deposits exhibited in the preceding section appears to indicate a condition of surface, such as may be supposed to have prevailed at Mundesley and Runton during the formation of the fresh-water deposits and the growth of the forest, before that submergence which has there left as its monument the strata of lower and upper drift more than three hundred feet thick.

The large quantity of fine sediment held in suspension by the waters of the Wash, and its effects in depositing soil in favourable situations, are strikingly exemplified by a fact observed by Smith, that the surface is the lowest on the part first reclaimed, that is, within the area embanked by the Romans, while its height increases on the outside of each subsequent embankment, the highest ground of all being a space beyond the sea wall, still overflowed by the tide.

Fossil Manures of Norfolk.

From the distribution of the soils in Norfolk under the combined influence of the solid strata and the drift, I proceed to the geological relations of its fossil manures, and to the question whether the clay and marl, which have been so largely and beneficially employed in that county, are peculiar to it, or may reasonably be expected in the substrata of other districts. In

describing the deposits above the chalk, I have mentioned those which have been used for the improvement of the soil—that is, nearly all of them. A recapitulation here may not be amiss. Taking them in the ascending order, we have—

1. The peat and clay of the fresh-water deposit below the till rarely employed, but always beneficially.

2. The till. A variety composed of the mixture of the blue and yellow till is the clay of East Flegg—the grey clay-marl of Marshall. The same, with a larger mixture of detritus derived from the hard chalk and the oolites, is extensively employed not only upon light soils, but upon the clay-loams, the wheat and bean lands of South Norfolk, and the adjoining parts of Suffolk. The blue till of Cromer cliffs, of which, on a moderate computation, sufficient to fertilize 20,000 acres is annually washed into the sea, though little used, has when used been invariably found beneficial. The farmers in the neighbourhood of North and South Repps, who have the transported chalk close at hand, cart this blue clay from Trimingham, a distance of three and four miles, paying 6*d.* the load for it on the shore, or 1*s.* at the summit of the cliff.

In a hollow in the chalk near Castleacre is a blue clay containing lumps of chalk, which appears to belong to this part of the series. Mr. Hudson has used it on a loam, by no means very light, with great benefit, particularly visible in the subsequent crops of clover. On a field at Trunch, consisting of a still better loam, Mr. Amis, now of Frettenham, spread a quantity of blue clay, the same as that of the Cromer cliffs, which a gentleman in the neighbourhood requested him to remove from some excavation which he had made. The result was, in the first instance, a splendid crop of oats, followed by a great improvement in the subsequent crops, which is undiminished after the lapse of more than ten years.

3. The most chalky varieties of till constitute the "clay" of the neighbourhood of Holkham, which is scarcely distinguishable from No. 4; the least pure varieties of the transported chalk or "marl" of East Norfolk.

4. I have already stated that some of this transported chalk is pure enough to be burned for lime, that other varieties consist of fragments of chalk mixed with a variable proportion of yellow sand and clay. "At Wighton," says Young, "I saw an extraordinary fine white marl not as commonly in globules, but more resembling the equal consistence or texture of white butter." Wighton is near Wells. I have seen similar varieties in some of the marl pits of East Norfolk; in the coast sections they are found to proceed from the flanks of masses of transported chalk, the materials of which, finely comminuted and re-arranged by aqueous action, have been mixed with a portion of clay. The globules, spoken of by Young as of ordinary occurrence, are lumps of chalk.

5. *Sand of the upper drift.*—Sand spread in a thick coat on the coarse turf is one of the first steps used in Norfolk for the improvement of peaty meadows; a department of husbandry, however, in which that county does not shine. In a few instances I have seen a ferruginous sand employed on arable land—the soil a very light and thin loam—applied to the young clover. Whether any benefit had been found to result, or whether custom had so established the use of underground manures, that sand was resorted to where clay and marl were not to be had, I know not. In the former case an analysis of the sand would be very desirable.

6. The clay of the Nar with its beds of fossil oysters and other shells.

7. The fresh-water clay and calcareous sand of Gaytonthorpe employed on Mr. Sooly's farm.

If to the substances above enumerated, we add the hard and the soft chalk, raised from the solid strata, and also the London clay, and the shelly beds of the red crag—the two latter largely employed in Suffolk — we have no less than eleven mineral manures, besides varieties of some of them, used in Norfolk and the adjoining county for the improvement of the soil, ten of them bearing the names of clay and marl.

The marl from which the light lands of East Norfolk have derived so much benefit is CHALK—either chalk alone or mixed with a slight proportion of sand and clay—raised from the undisturbed strata of chalk, or from its transported detritus imbedded in the upper and lower drift. To those parts of the district which do not possess chalk, in one or other of these forms, on the spot, and at accessible depths, it is conveyed from the chalk pits of Thorpe, Whitlingham, and Horsted, burthened in some cases with the cost of thirty or forty miles of expensive inland navigation, to which again is not unfrequently added a land carriage, from the wharf at which it is landed, of four or five miles. The rotten and weathered chalk near the surface, and on the sides of the large pipes or cavities, which is partially mixed with "uncallow," is sold to the farmers under the name of marl, not because it is better for the land than the pure chalk, but because it is unfit for burning into lime. Farmers who possess chalk pits on their land have informed me that the deeper they went the more they found the quality improve.

Wherever, then, along the range of the chalk through England sandy and light loamy soils are found, they are capable of improvements like those which have so much raised the value of similar soils in Norfolk. The different beds of chalk vary considerably in the proportion of sand, clay, and phosphate of lime which is mixed with their carbonate of lime; and it may, in some cases, be found more economical to convey chalk from a distance,

than to use that raised on the spot. An analysis of the chalk of different localities, and at different depths, is therefore highly desirable. That given by Dr. Playfair in a recent number of this Journal, of a specimen which I sent from Frettenham Common may be considered as representing the composition of the soft upper chalk of Norfolk. It contains, it will be remembered, a portion of phosphate of lime, though not in a sufficient quantity to produce the effects attributed to it in retarding for a time the action of bones, which must be due to some other cause.

Practice has not yet settled the relative merits of marl—that is to say, of pure chalk—and of clay—that is to say, of a natural mixture of fragmentary chalk with sand and clay. On this point as much contrariety of opinion prevails, at the present time, as when Young made his Report to the Board of Agriculture. Much of the marl of East Norfolk consists of a slight mixture of sand and clay in a mass composed principally of chalk; and the clay of East Flegg consists of a base of clay rendered more or less calcareous by a mixture of fragmentary chalk, the proportion of which increases westward and northward, until in the north-west of the county it differs but little from much of the transported chalk called marl in East Norfolk. There are few portions of the chalk range of England which have not been acted upon in some degree or other by the operations which produced the drift, and where deposits similar to some of those of Norfolk may not be expected. Where these natural mixtures of chalk and clay are wanting, large portions of the range are contiguous either to the tertiary clays of the London and Hampshire basins, or to the clays of the Gault, Kimmeridge, and Oxford beds. The ruins of the latter have contributed largely to the mass of the till of Norfolk; and those of the London clay enter extensively into the composition of the till of Suffolk. In those cases where mixtures of these with chalk have not been effected by nature they may be produced artificially, chalk and clay being both accessible either as regards depth or distance. Experiments, therefore, in the application of the tertiary and oolitic clays alone, or mixed with chalk in different proportions, or with lime where chalk is too remote, are well worth the trial. In speaking of its accessibility, it must be borne in mind that a Norfolk farmer does not hesitate to remove "uncallow," that is sand and gravel, from three to five yards deep, to raise an equal depth of chalk, transported chalk, or till, as the case may be; and in the pits at Thorpe-by-Norwich 20 yards of "uncallow" are removed to obtain very little more than 20 yards of chalk. The work is performed in a manner the least advantageous, small portions only being cleared at a time, the "uncallow" removed to a considerable distance in wheelbarrows, the water at a certain level kept down by hand, and the fossil

manure drawn up a steep ascent by horses in cumbrous carts. Were the operations conducted on a large scale, aided by the steam-engine and other mechanical appliances which excavators by profession have learned from the science of engineers, there can be no doubt that the same substances might be raised from depths and conveyed to distances which would now be deemed prohibitory, even in Norfolk, and that land might be improved, under such circumstances, with chalk, or clay, or a mixture of the two, at a cheaper rate than that at which most farms have been clayed or marled in that county. Nor is it only the light lands in the vicinity of chalk which would be benefited by its application. On the wheat and bean lands of the southern portion of the district of the lower drift of Norfolk heavier dressings of till are applied than on the light soils of the thick and thin upper drift in the northern, eastern, and western parts of the county; and by the testimony of all with whom I have conversed, this application of clay to clay is beneficial. This clay, however, contains a large proportion of hard chalk, and it is very probable that this is the beneficial ingredient, and that the hard chalk alone, were it accessible, would answer a better purpose.

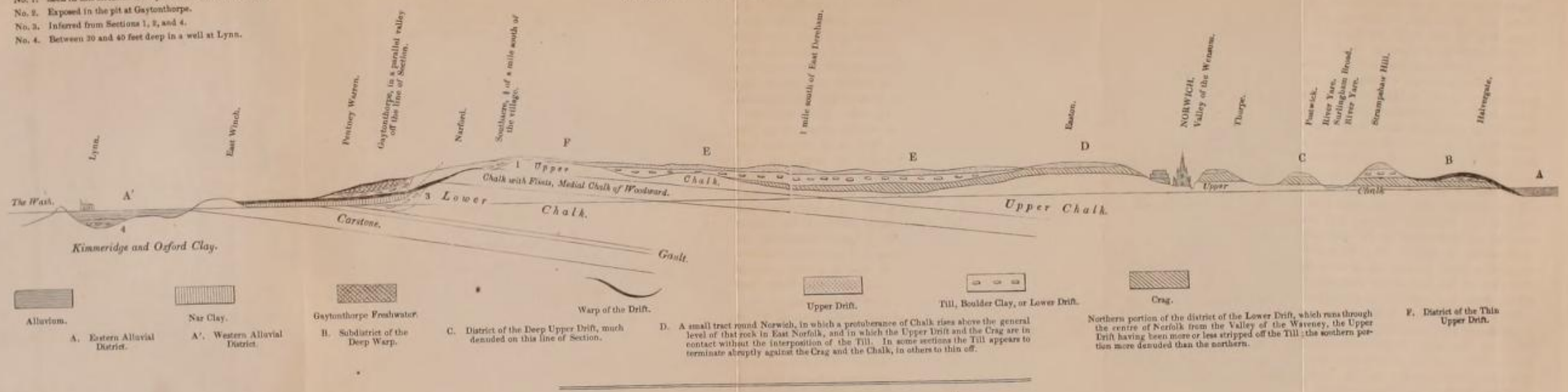
Neither is it only in the vicinity of the chalk that these improvements are practicable. On the western side of the central ridge of England, large accumulations of the deposits of the erratic block period, as already stated, occur. The lower portion of these consists, as in Norfolk, of boulder clay derived from the grinding down of the Silurian slates, from the ruins of the lias (of which large outliers, near Whitchurch in Shropshire, attest the former extent), or from the wreck of the clays of the new and old red sandstone formations. This boulder clay is in many places highly calcareous, partly from the fragments of shells present in it, partly from the detritus of limestone rocks. On the coast sections of the long point of Caernarvonshire, fragments of the carboniferous limestone are so abundant in this clay, at some points, that they are collected for lime-burning; and even the distant chalk of the county of Antrim has contributed its calcareous matter to the mass. In the same vicinity there are sandy surfaces which would benefit largely by the application of this clay, in conjunction with the cultivation of turnips, to which they are at present utter strangers. In Cheshire also, and the adjoining counties, and, in short, wherever the upper drift extends, there are soils of sand and gravel capable of improvement by means of the accompanying clay of the lower drift, or by the clays of the stratified rocks.

I cannot close this paper without acknowledging my obligations to Mr. Rose for the information and assistance which I received from him in his own geological domain of West Norfolk.

SECTIONS OF THE TILL OF WEST NORFOLK

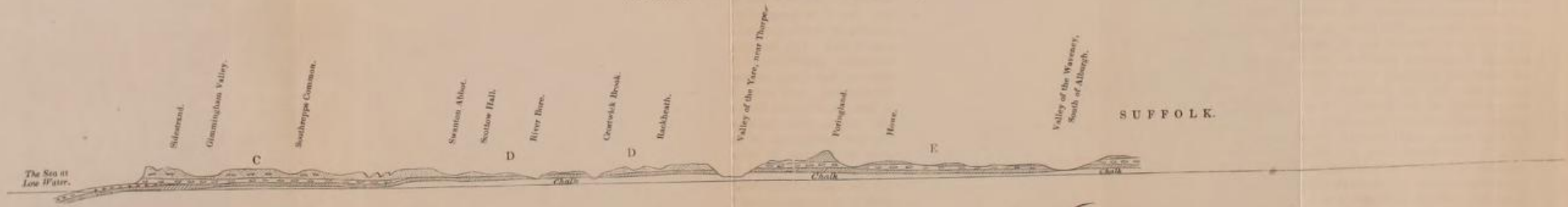
No. 1. Seen in this situation on a parallel Section at Harpley.
No. 2. Exposed in the pit at Gaytonthorpe.
No. 3. Inferred from Sections 1, 2, and 4.
No. 4. Between 30 and 40 feet deep in a well at Lynn.

Section I.—*East and West Section across Norfolk.*



Alluvium.
A. Eastern Alluvial District.
Nar Clay.
A'. Western Alluvial District.
Gaytonthorpe Freshwater.
B. Subdistrict of the Deep Warp.
C. District of the Deep Upper Drift, much denuded on this line of Section.
Warp of the Drift.
Upper Drift.
D. A small tract round Norwich, in which a protuberance of Chalk rises above the general level of that rock in East Norfolk, and in which the Upper Drift and the Crag are in contact without the interposition of the Till. In some sections the Till appears to terminate abruptly against the Crag and the Chalk, in others to thin off.
Till, Boulder Clay, or Lower Drift.
Crag.
Northern portion of the district of the Lower Drift, which runs through the centre of Norfolk from the Valley of the Waveney, the Upper Drift having been more or less stripped off the Till; the southern portion more denuded than the northern.
F. District of the Thin Upper Drift.

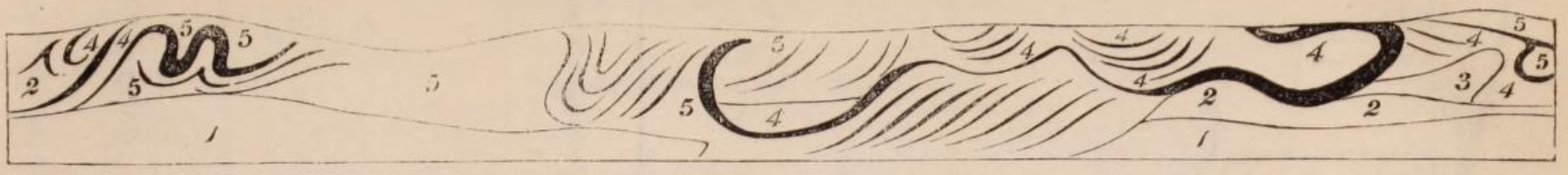
Section II.—*North and South Section across Norfolk.*



Crag.
Subterranean Forest.
C. District of the Deep Upper Drift.
Till, Boulder Clay, or Lower Drift.
D. The Till appears not to have extended over this tract.
Gravel and Sand of Upper Drift.
Beds of transported Chalk in the Upper Drift.
E. Southern or most denuded portion of the District of the Lower Drift, which extends through Suffolk, until cut off by the Chalk about six miles north of Ipswich.
Warp of the Drift.

[To face p. 482.

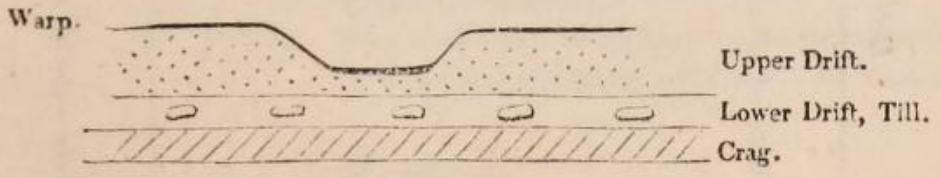
SECTION III.—*Contorted Strata of Drift.*



1. Till. 2. Laminated Blue Clay. 3. A mass of transported Chalk. 4. Chalk detritus, finely comminuted and mixed with Clay. 5. Sand.

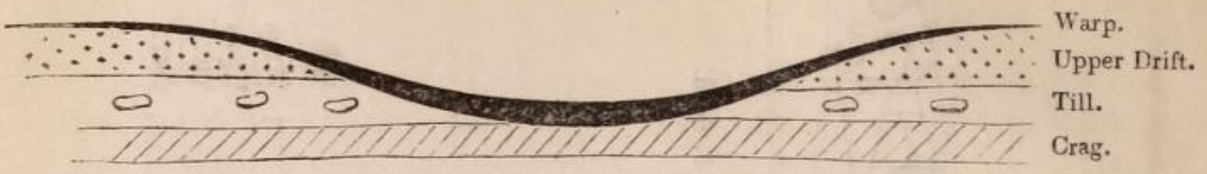
The strong black lines represent contorted beds of Gravel and Loam in the Sand.

SECTION IV.



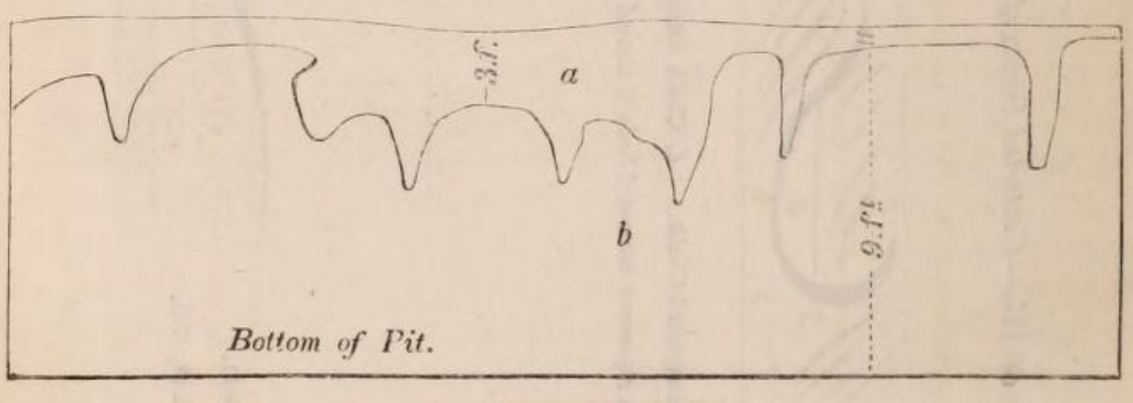
SECTION V.

SECTION VI.



SECTION VII.

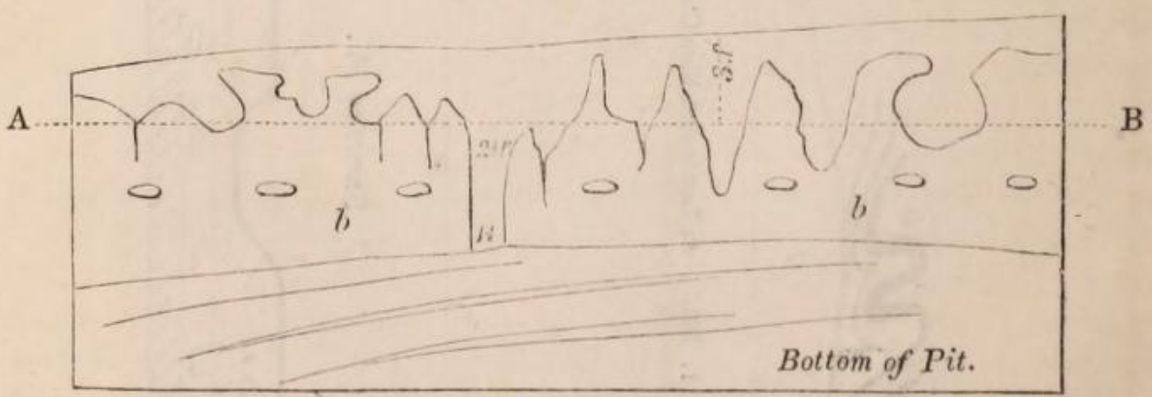
SECTION VIII.



a. Loamy Warp.

b. Flints and rolled fragments of Chalk in a base of finely comminuted Chalk and Clay.

SECTION IX.

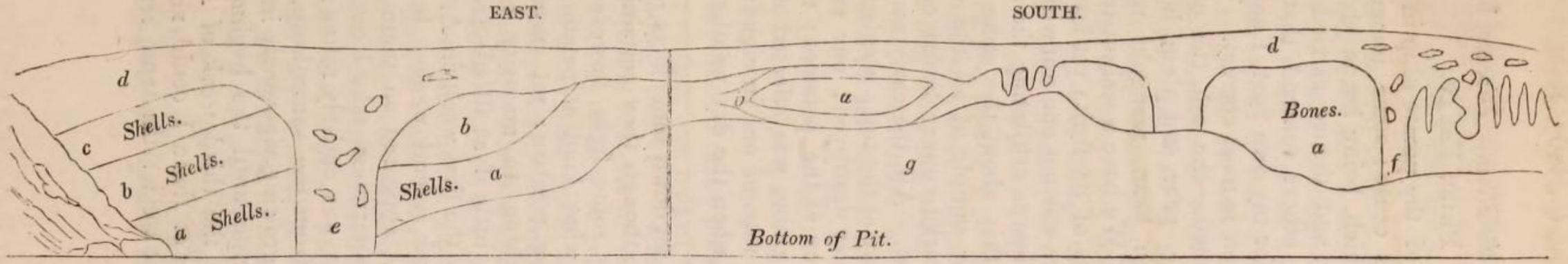


a. Loamy Warp. *b*. Till.

c. The same materials as the Till, namely Chalk and Clay, but containing irregular seams of Sand and Gravel.

SECTION X.—*Section of the Pit at Gaytonthorpe.*

Vertical and Horizontal Scale—20 feet to 1 inch.



a. Grey Clay.

b. Grey and Yellow Silt
c. White Calcareous Sand } Freshwater Beds.

d. Warp of the Drift, Sandy Loam containing unabraded Flints. some of them of large size, as at *e* and *f*

. Drift like the most chalky varieties of Till; fragments of Chalk with Flints, and fragments of Kimmeridge Clay and other Oolitic Rocks.