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THE FORMATION OF VEGETABLE MOULD THROUGH THE ACTION OF WORMS, WITH OBSERVATIONS ON THEIR HABITS. By Charles Darwin, LL.D., F.R.S. With Illustrations. London: John Murray. 1881.

Not only is Mr Darwin's new volume a work of absorbing interest and of the highest scientific value—this was to be expected; it has the further great merit of being perfectly intelligible to the general reader, as if it had been specially written for popular circulation. The extraordinary importance of the Conqueror worm is immensely enhanced. His hostile and hateful action is left on one side; he is represented as a great operator in the economy of nature, and a laborious benefactor of man. Every one has observed the surface of a garden, field, walk, or road, pierced of a morning with the innumerable holes of worms, the viscid earth being piled around the hole, and not unfrequently leaves, straws, threads, bits of paper, rags of cloth, and such like, half-drawn down after the worms into their holes. But it is not everyone whose mind has followed up this common and suggestive circumstance by accurate and prolonged investigation and scientific generalisation. Nearly half a century has passed since Mr Darwin turned his attention to the action of worms. In 1837, he showed "that small fragments of burnt marl, cinders, &c., which had been strewed over the surface of several meadows were found after a few years lying at the depth of some inches beneath the turf, but still forming a layer"—an apparent sinking of superficial bodies which is due, "as was first suggested to him by Mr Wedgwood of Maer Hall in Staffordshire, to the large quantity of fine earth continually brought up to the surface by worms in the form of castings." The incredulity with which some of his conclusions were received only served to strengthen his determination to investigate the matter fully. Remarking on the objection that, "considering their weakness and size, the work they are represented to have accomplished is enormous," he pronounces this "an instance of that inability to sum up the effects of a continually recurrent cause, which has often retarded the progress of science, as formerly in the case of geology, and more recently in that of the principle of evolution." He has now attacked the problem on another side, namely, by weighing all the castings thrown up within a given time in a measured space. As a result, he now affirms his belief that the whole layer of vegetable mould covering the face of the land in every moderately humid country, "has passed, and will again pass, every few years, through the bodies of worms."

Mr Darwin devotes two chapters of very considerable length to a preliminary inquiry into the habits of those kinds of worms that bring up earth to the surface in the form of castings—the only kinds that he concerns himself with on the present occasion. A layer, though a thin one, of fine earth, which probably long retains some moisture, is, as Mr Darwin thinks, necessary to their existence; and the mere compression of the soil appears to be in some degree favourable to them, considering how often they abound in old gravel walks and in footpaths across fields. Though not present on very bare and rocky mountains, where there is no depth of soil to prevent the worms from being frozen, castings have been found at a height of 1500 feet on Schiehallion, at nearly double that height at Turin, and at a great altitude on the Nilgiri and Himalaya Mountains. Though terrestrial animals, worms can live a long time under water. In the great heat of summer and cold of winter, they bore deep down and cease to work. Ordinarily, during the day, they remain in their burrows; in the night watches, they come to the air and perambulate, though not adventurously, being usually tethered by the insertion of their tails in their burrows. Frequently, however, and especially after wet weather succeeding severe drought or frost, they quit their burrows on a voyage of discovery, by and by finding new sites to inhabit; but, for the most part, a worm travelling at large in the day time is probably an invalid. Worms often lie for hours almost motionless close beneath the mouths of their burrows, most probably for the sake of warmth, a providential arrangement for the hungry thrushes and blackbirds that keep watch for their palatable bodies. After describing the structure of worms, Mr Darwin records the interesting experiments he applied in order to determine the development of their senses. Though without eyes, worms can just distinguish between light and darkness, light affecting their cerebral ganglia (and no part of the lower regions of their bodies), through their skin, by its intensity and its duration. Here is a most important consideration in view of evolution. Worms are stone deaf; they regarded the notes of a metal whistle, the shouts of human lungs, and the tones of Mr Darwin's piano, with impartial and absolute indifference. Their sense of smell is limited and feeble; they pay no attention to the scent of tobacco juice, millefleurs perfume, or paraffin, but they are not so very long in discovering bits of cabbage, onion, and raw meat, buried in the pots that contain them. They have a sensitive touch, however, by which, among other things, they are probably enabled to gain a general notion of the form of an object. They also show preferences of taste; liking red cabbage leaves better than green, celery better than either, and carrots better than celery. On the mental side, there is little to record. They are timid creatures, with some appreciation of certain corporeal pleasures; but disciples of ancient Izaak will be glad to doubt, on the highest authority, whether the amount of their wriggling is the measure of their suffering. They swallow rose thorns and small splinters of glass, and make no difficulty about it. They perhaps have a trace of social feeling. "It is surprising that they should exhibit some skill in lining their burrows with their castings, and with leaves, and in the case of some species in piling up their castings into tower-like constructions. But it is far more surprising that they should apparently exhibit some degree of intelligence instead of a mere blind instinctive impulse in their manner of plugging up the mouths of their burrows"—an achievement that has surprised Mr Darwin more than anything else in regard to worms. The following is the conclusion he reaches after a full consideration of the facts:—

> To sum up, as chance does not determine the manner in which objects are drawn into the burrows, and as the existence of specialised instincts for each particular case cannot be admitted, the first and most natural supposition is that worms try all methods until they at last succeed; but many appearances are opposed to such a supposition. One alternative alone is left, namely, that worms, although standing low in the scale of organisation, possess some degree of intelligence. This will strike everyone as very improbable; but it may be doubted whether we know enough about the nervous system of the lower animals to justify our natural distrust of such a conclusion. With respect to the small size of the cerebral ganglia, we should remember what a mass of inherited knowledge, with some power of adapting means to an end, is crowded into the minute brain of a workerant.

Regarding the food and digestion of worms Mr Darwin has much to record. They are omnivorous, with a preference for raw fat beyond all other substances offered them. He gives special attention to the question how far they swallow earth as food, concluding that they extract from it numerous organisms, together with some cellulose from any leaves and roots not utterly decayed. A particularly interesting part is Mr Darwin's investigation into the functions of the remarkable calciferous glands, "nothing like which is known in any other animal." There is much instructive matter, also, on the construction of the burrows and the ejection of the castings.

Mr Darwin then proceeds to the more immediate object of the volume, and investigates the amount of fine earth brought up by worms to the surface, and afterwards spread out more or less completely by the rain and wind. "The amount can be judged of by two methods—(1) by the rate at which objects left on the surface are buried, and (2) more accurately by weighing the quantity brought up within a given time." Both methods are illustrated by examples in detail. We quote an example of the first method:—

> Near Maer Hall, in Staffordshire, quicklime had been spread about the year 1827 thickly over a field of good pasture land, which had not since been ploughed. Some square holes were dug in this field in the beginning of October, 1837, and the sections showed a layer of turf, formed by the matted roots of the grasses, 1 inch in thickness, beneath which, at a depth of 2½ inches (or 3 inches from the surface), a layer of the lime in powder or in small lumps could be distinctly seen running all round the vertical sides of the holes. The soil beneath the layer of lime was either gravelly or of a coarse sandy nature, and differed considerably in appearance from the overlying dark-coloured fine mould. Coal-cinders had been spread over a part of this same field either in the year 1833 or 1834; and when the above holes were dug, that is after an interval of 3 or 4 years, the cinders formed a line of black spots round the holes, at a depth of 1 inch beneath the surface, parallel to and above the white layer of lime. Over another part of this field cinders had been strewed only about half a year before, and these either still lay on the surface or were entangled in the roots of the grasses; and I here saw the commencement of the burying process, for worm-castings had been heaped on several of the smaller fragments. After an interval of 42 years this field was re-examined, and now the two layers of lime and cinders were found almost everywhere at a greater depth than before by nearly 1 inch, or we will say ¾ of an inch. Therefore mould to an average thickness of 22 of an inch had been annually brought up by the worms, and had been spread over the surface of this field.

The principle is shown to hold good on the most various qualities of land. Mr Darwin goes on to show how not only small objects, but also great stones (if not so huge as to keep the earth dry beneath them) are slowly undermined by worms, and gradually sink into the ground. "The straightness and regularity of the lines formed by the embedded objects, and their parallelism with the surface of the land, are the most striking features of the case; for this parallelism shows how equably the worms must have worked; the result being, however, partly the effect of the washing down of the fresh castings by rain." But the specific gravity of objects does not affect their rate of sinking, nor does the weight of the huge stones, although considerable, appear sensibly to aid their downward progress.

In exemplification of the second method, Mr Darwin presents the results of a very extensive and careful investigation of the weight of the castings accumulated at the mouth of single burrows, these being collected partly in England, partly at Nice, and partly in Lower Bengal and on the Nilgiri Mountains. They "generally exceeded an ounce in weight after being dried, and sometimes nearly equalled a quarter of a pound" (one Nilgiri casting even exceeding this weight). The following observation, among others, may be commended to farmers:—

> The largest castings in England were found on extremely poor pasture land; and these, as far as I have seen, are generally larger than those on land producing a rich vegetation. It would appear that worms have to swallow a greater amount of earth on poor than on rich land in order to obtain sufficient nutriment.

Taking an average of cases actually observed within given spaces, under very different conditions, the castings ejected were calculated to yield annually per acre as much as 15 tons—a remarkable testimony to the activity and importance of worms. Comparing the results of the two methods, the amount of earth brought to the surface during ten years is found to be somewhat greater than that calculated from the castings actually weighed. The excess, however, is readily accounted for, by obvious enough considerations. Hensen estimates that 53,767 worms exist in an acre of garden land, and about half as many in cornfields. This would give 20 ounces as the weight of earth ejected by a single full-sized worm during a year. But a single casting often exceeds one ounce, as we have seen; and it is probable that worms eject more than 20 such full-sized castings in a year. If they eject more, the inference is that there are fewer worms per acre. Whatever the precise numbers and quantities, Mr Darwin's investigation produces a deep conviction of the important part played by worms in the economy of nature.

In his fourth chapter Mr Darwin examines the action of worms in the burial of the remains of ancient buildings. For this purpose he refers in some detail to the Roman villa unearthed at Abinger, in Surrey, in 1876; to the buried pavement of Beaulieu Abbey, in Hampshire; to the Roman villas discovered at Chedworth, in Gloucestershire, in 1866, and at Brading, in the Isle of Wight, last year; to the ruins of the small Roman town of Silchester, in Hampshire; and to the old Roman city of Wroxeter (Uriconium), in Shropshire. The elegant and tesselated pavements left by the Romans, as well as the coins, gold ornaments, stone implements, iron arrow heads, and such like

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drops on the surface of the ground before and since, have been hidden and preserved by burial under the castings of worms. No doubt the washing down of neighbouring soil and the deposition of dust have aided in the work of concealment; while the settling of the ground has had something to do with the subsidence of the walls. But after all allowances are freely made, the results are to be set down chiefly to the activity of worms.

The final subject of consideration is the action of worms in the disintegration and denudation of the soil. Worms are constantly forming new burrows, and old burrows are constantly collapsing, so that the mould is ever in slow movement, and the particles are ever rubbing together. Thus fresh surfaces are being continually exposed to the action of the carbonic acid in the soil, and to the humus acids which are such powerful agents in the decomposition of rocks. The acids generated in the alimentary canal of worms during the digestive process are probably nearly of the same nature as those in ordinary humus. It is through the vast quantity of leaves they draw into their burrows, partially digest, and commingle with earth, that worms communicate to vegetable mould its uniform dark tint. By these various means the amount of the soil will constantly tend largely to increase. But not only do worms aid directly in the chemical disintegration of rocks, but the particles of the softer rocks suffer some amount of mechanical trituration in their muscular gizzards, wherein small stones, beads of glass, fragments of bricks, &c., serve the purpose of mill stones. This is an important fact in a geological point of view, and Mr Darwin has given much study to it. If a weight of more than ten tons of earth (to take a safe average) annually pass through the bodies of worms on each suitable acre of land, then "the results for a country like Great Britain, within a period not very long in a geological sense, such as a million of years, cannot be insignificant." The product is estimated at 320 million million tons of earth!

Castings, which are viscid and soft on ejection, are rendered still softer during rain, at which time worms apparently prefer to eject them; and, if on an inclined surface, naturally flow more or less down the slope, the finest particles being washed farthest down. During dry weather castings often crumble into small rounded pellets, which from their mere weight tend to roll down any slope. Even on level ground, and in a humid climate, the castings are blown to leeward by a strong wind. Thus the superficial mould does not accumulate to a great thickness, which would in many ways check the disintegration of the underlying rocks. The ultimate consequences of this removal of worm castings are sufficiently startling:—

It was found by measurements and calculations that on a surface with a mean inclination of 9° 32′, 2·4 cubic inches of earth which had been ejected by worms crossed, in the course of a year, a horizontal line one yard in length; so that 240 inches would cross a line a hundred yards in length. This latter amount in a damp state would weigh 11½ pounds. Thus a considerable weight of earth is continually moving down each side of every valley, and will in time reach its bed. Finally, this earth will be transported by the streams flowing in the valleys into the ocean, the great receptacle of all matter denuded from the land. It is known, from the amount of sediment annually delivered into the sea by the Mississippi, that its enormous drainage-area must on an average be lowered ·0263 of an inch each year, and this would suffice in four and a half million years to lower the whole drainage area to the level of the sea-shore. So that, if a small fraction of the layer of fine earth, ·2 of an inch in thickness, which is annually brought to the surface by worms, is carried away, a great result cannot fail to be produced within a period which no geologist considers extremely long.

Worms are thus seen to co-operate with the farmer and gardener in preparing the ground to receive fibrous-rooted plants and seedlings of all kinds. They plough almost unceasingly. They labour to expose the mould to the air, to sift and to triturate it, to enrich it by mixture of partially digested leaves, bones of dead animals, the harder parts of insects, and other fertilising matters, and to fit it to retain moisture to absorb all soluble substances. They drain the surface water through their burrows, which often penetrate the ground almost perpendicularly to a depth of five or six feet; and similarly they facilitate the downward passage of plant roots. They frequently cover with their castings seeds that might not otherwise be able to

[illegible] to some degree, though only to a small degree, they actually increase the soil; "but their chief work is to sift the finer from the coarser particles, to mingle the whole with vegetable *debris*, and to saturate it with their intestinal secretions." Comprehensively regarded, they are universal cultivators and fertilisers of the soil, while they plane down the elevated slopes into the alluvial valleys below. It is only the trained intellect of the scientific student that is able to appreciate, in its full significance, the influence thus exerted by worms through geological tracts of time. "It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly organised creatures."

It is of special local interest to observe that Mr Darwin acknowledges on many pages his indebtedness to our distinguished townsman, Dr King, superintendent of the Botanic Garden in Calcutta. All the observations at Nice, and many of those in India, were made by Dr King.

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LITERATURE.

On the Origin of Species by Means of Natural Selection, or, the Preservation of Favoured Races in the Struggle for Life. By CHARLES DARWIN, M.A. London: Murray. 1859.

An inquiry as to the origin of an hypothesis might be almost as interesting a psychological problem as that of the species of animal and vegetable beings. Mr. Darwin has favoured the philosophical world with a new hypothesis on the origin of species. This hypothesis bears such a striking resemblance to that of the author of the "Vestiges of the Natural History of Creation," that we can but regard one as the development of the other. The author of the "Vestiges" meets with scant justice at the hands of Mr. Darwin. The theory of the former has done much to clear away the ground for that of the latter. Both have so many features in common, that we are certainly surprised to find the "Vestiges" only once alluded to in Mr. Darwin's work, and that only in these terms. "The author of the 'Vestiges of Creation' would, I presume, say that after a certain unknown number of generations, some bird had given birth to a woodpecker, and some plant to the mistletoe, and that these had been produced perfect as we now see them; but this assumption seems to me to be no explanation, for it leaves the case of the adaptations of organic beings to each other, and to their physical conditions of life, untouched and unexplained." This is a most unfair representation of the hypothesis of the author of the "Vestiges"—one which we are sure any person perusing his work with ordinary care would feel satisfied he would repudiate—one which gives a most imperfect and distorted view of his hypothesis. As Mr. Darwin's work is written professedly to supply this supposed deficiency in the scheme of the "Vestiges" plan of creation, it may be as well to review both hypotheses in their mutual relations to each other.

The vulgar, that is the ordinary view taken by most scientific naturalists, is, that each distinct species of animal owes its origin to a distinct and separate act of divine creation. These distinct and separate acts of creation are regarded both in the "Vestiges" and by Mr. Darwin as so many miracles or deviations from the law of nature. The object of both writers is to diminish the number of these. The "Vestiges" reduces all to one act of creation—that act of creation being the one which gave to the particles of created matter those laws by means of, or according to, which all combinations, whether as organic or inorganic bodies, are formed, and without which they could not be made. These laws are immutable, and admit of no exceptions. Mr. Darwin does not go so far as this. "I believe," he says, "that animals have descended from at most only four or five progenitors, and plants from an equal or lesser number." This is his creed. All the animals and vegetables which have ever lived on our globe owe their origin to ten distinct acts of creation at the most. The miracles of creation are ten in number; they may be less. This far he believes he can reduce the acts of creation by direct logical proof. Analogy, he admits, would lead him one step further—namely, to the belief that all animals and plants have descended from some one prototype. But analogy he considers a deceitful guide. Being [illegible]tial, he thinks it therefore only probable that "all the organic beings which have ever lived on this earth have descended from some one primordial form, into which life was first breathed."

The author of the "Vestiges" claims nothing more than probability for his hypothesis. With respect, then, to the origin of all species of living beings by the operation of one law, both the "Vestiges" and Mr. Darwin are in accord. In this they differ. The author of the "Vestiges" takes a step further back. He does not admit the miracle of breathing life into one primordial form. His primordial forms owe their existence to no new creative act. They have been evolved from dead matter simply by the ordinary laws of matter, and are simply products of certain [illegible] of matter. Make precisely [illegible], and life appears as the result.

[illegible] series to pass through all the grades [illegible] animated nature up to the same climax of [illegible] as Mr. Darwin's one *primordial form*. The great object of both writers is to sweep away the vulgar idea of miracles from the book of nature. One goes a little in advance of the other. Mr. Darwin has not yet reached the rationalism of his master. Both scout the idea of irreverence. Both believe they are doing service to the God of nature. Both repudiate atheism. Both think the honour of God diminished by the belief that any deviations from the first laws of creation are necessary.

This may perhaps be made clearer by a reference to the arguments of the author of the "Vestiges." The objection of Hume to miracles is known to every one. The laws of nature are invariable. It is contrary to our experience that they should be suspended. A miracle is the suspension of the laws of nature. It is not contrary to our experience that human testimony should be false, therefore no amount of human testimony can render the fact of a miracle credible. This objection has been answered in many ways. Mr. Babbage, in his ninth or supplementary "Bridgewater Treatise," gave an exemplification of what appeared to him its fallacy. According to Mr. Babbage a miracle is only an apparent, not a real suspension of the laws of nature. I can, he says, construct a calculating machine. I can so arrange it, according to a particular law, that it shall, by a handle being turned, produce a certain series of numbers, the law of the succession of those numbers being determined by the mechanical arrangements I have made for the motion of the machine. A person ignorant of this law and its consequences sees that this machine produces the natural numbers 1, 2, 3, 4, &c., in a regular and unbroken series, from one up to a hundred million. By all ordinary laws of induction, surely a person who has observed this has the right to anticipate that the next number will be one hundred million and one. The odds, calculated according to the mathematical theory of probabilities, are a hundred million to one that it will be so. The handle is turned, and the next number that actually appears is greater by 10,000, and the next greater by 30,000, than we should have predicted from the successive occurrences of one hundred million events. The machine has not deviated from the law of its constructor; the apparent suspension is only a proof that no amount of observation of successive facts will necessarily lead us to a knowledge of the law which regulates their occurrence. No knowledge, therefore, that we can obtain by experience of the laws of nature, even though that experience be the cumulative experience of the whole human race, can enable us to assume that an event which we may call miraculous cannot take place. This event, though contrary to our experience, may only be a consequence of the law which has regulated all the other events from which our experience is derived.

This illustration of Mr. Babbage the author of the "Vestiges" takes as the key-note for his hypothesis. He supposes the Creator, on the creation of the world—or even further back than that, at the creation of the starry host of heaven—to have impressed certain laws on matter. By the evolution of these laws stars are created out of nebulæ. These stars or suns, when cooling, throw off their planets, and these planets their satellites. These all move according to the laws originally impressed upon them. Thus day and night and seasons are produced for planets and satellites. Then, not by any special act of creation—not by any breathing of life into a primordial form, but according to laws strictly impressed on matter at its creation, matter gives birth to living beings. This origin of life may have often occurred, or it may only have happened once on this earth during the aons of years it has, according to the "Vestiges," revolved round its central luminary. Then from simple germs of life, like has produced its like, till, strictly in accord with its primordially impressed law, it gives birth to another—unlike itself. This proceeds in regular

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