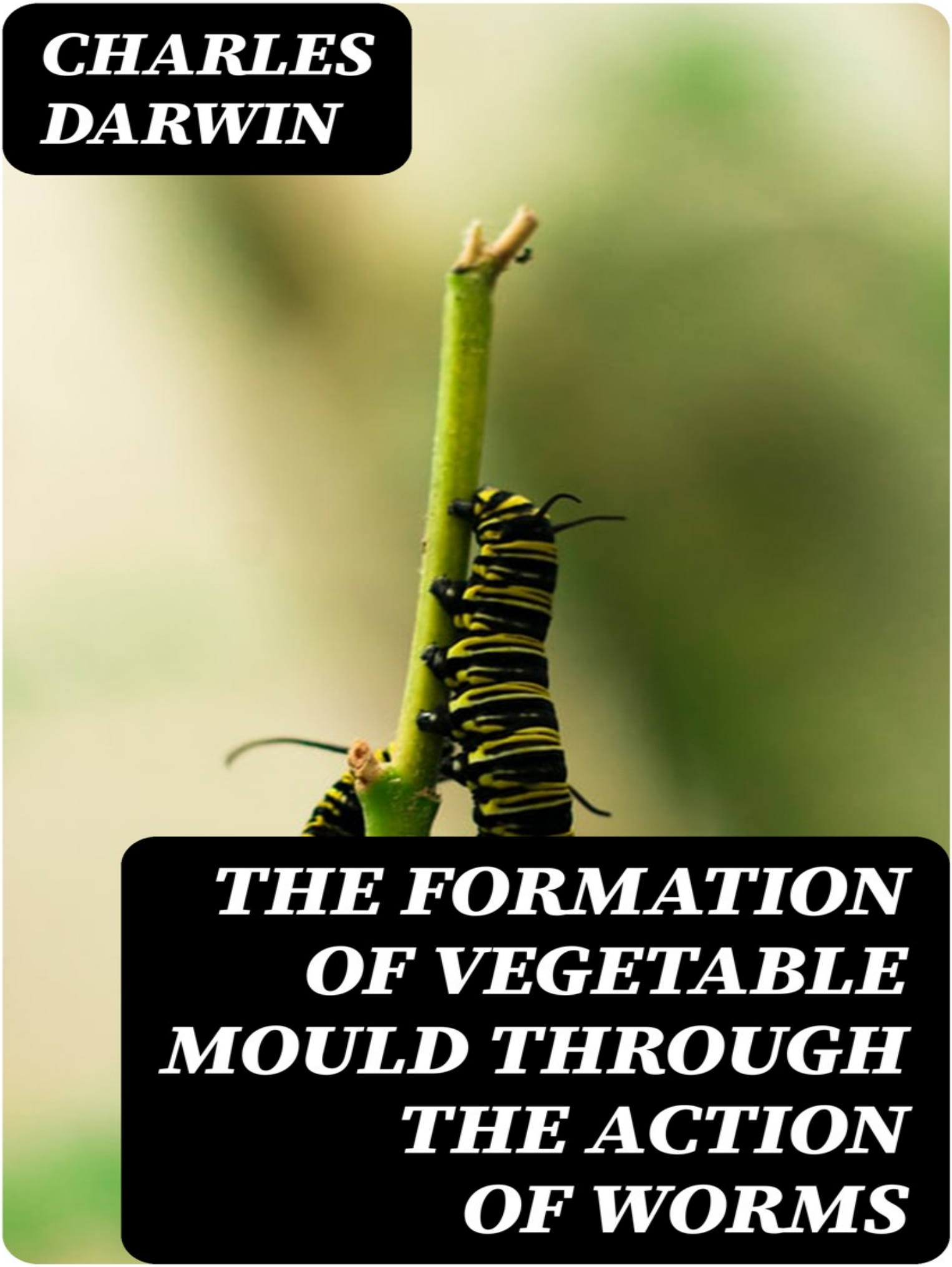
CHARLES DARWIN



THE FORMATION OF VEGETABLE MOULD THROUGH THE ACTION OF WORMS

Charles Darwin

The Formation of Vegetable Mould Through the Action of Worms

With Observations on Their Habits

EAN 8596547252986

DigiCat, 2022
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INTRODUCTION.

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THE share which worms have taken in the formation of the layer of vegetable mould, which covers the whole surface of the land in every moderately humid country, is the subject of the present volume. This mould is generally of a blackish colour and a few inches in thickness. In different districts it differs but little in appearance, although it may rest on various subsoils. The uniform fineness of the particles of which it is composed is one of its chief characteristic features; and this may be well observed in any gravelly country, where a recently-ploughed field immediately adjoins one which has long remained undisturbed for pasture, and where the vegetable mould is exposed on the sides of a ditch or hole. The subject may appear an insignificant one, but we shall see that it possesses some interest; and the maxim “de minimis non curat lex,” does not apply to science. Even Élie de Beaumont, who generally undervalues small agencies and their accumulated effects, remarks: [2] “La couche très-mince de la terre végétale est un monument d’une haute antiquité, et, par le fait de sa permanence, un objet digne d’occuper le géologue, et capable de lui fournir des remarques intéressantes.” Although the superficial layer of vegetable mould as a whole no doubt is of the highest antiquity, yet in regard to its permanence, we shall hereafter see reason to believe that its component particles are in most cases removed at not a very slow rate, and are replaced by others due to the disintegration of the underlying materials.

As I was led to keep in my study during many months worms in pots filled with earth, I became interested in them, and wished to learn how far they acted consciously, and how much mental power they displayed. I was the more desirous to learn something on this head, as few observations of this kind have been made, as far as I know, on animals so low in the scale of organization and so poorly provided with sense-organs, as are earth-worms.

In the year 1837, a short paper was read by me before the Geological Society of London, [3] “On the Formation of Mould,” in which it was shown that small fragments of burnt marl, cinders, &c., which had been thickly 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. This apparent sinking of superficial bodies is due, as was first suggested to me 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. These castings are sooner or later spread out and cover up any object left on the surface. I was thus led to conclude that all the vegetable mould over the whole country has passed many times through, and will again pass many times through, the intestinal canals of worms. Hence the term “animal mould” would be in some respects more appropriate than that commonly used of “vegetable mould.”

Ten years after the publication of my paper, M. D’Archiac, evidently influenced by the doctrines of Élie de Beaumont, wrote about my “singulière théorie,” and objected that it could apply only to “les prairies basses et humides;” and that “les terres labourées, les bois, les prairies élevées,

n’apportent aucune preuve à l’appui de cette manière de voir.” [4a] But M. D’Archiac must have thus argued from inner consciousness and not from observation, for worms abound to an extraordinary degree in kitchen gardens where the soil is continually worked, though in such loose soil they generally deposit their castings in any open cavities or within their old burrows instead of on the surface. Hensen estimates that there are about twice as many worms in gardens as in corn-fields. [4b] With respect to “prairies élevées,” I do not know how it may be in France, but nowhere in England have I seen the ground so thickly covered with castings as on commons, at a height of several hundred feet above the sea. In woods again, if the loose leaves in autumn are removed, the whole surface will be found strewed with castings. Dr. King, the superintendent of the Botanic Garden in Calcutta, to whose kindness I am indebted for many observations on earth-worms, informs me that he found, near Nancy in France, the bottom of the State forests covered over many acres with a spongy layer, composed of dead leaves and innumerable worm-castings. He there heard the Professor of “Aménagement des Forêts” lecturing to his pupils, and pointing out this case as a “beautiful example of the natural cultivation of the soil; for year after year the thrown-up castings cover the dead leaves; the result being a rich humus of great thickness.”

In the year 1869, Mr. Fish [5] rejected my conclusions with respect to the part which worms have played in the formation of vegetable mould, merely on account of their assumed incapacity to do so much work. He remarks that “considering their weakness and their size, the work they

are represented to have accomplished is stupendous." Here we have 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.

Although these several objections seemed to me to have no weight, yet I resolved to make more observations of the same kind as those published, and to attack the problem on another side; namely, to weigh all the castings thrown up within a given time in a measured space, instead of ascertaining the rate at which objects left on the surface were buried by worms. But some of my observations have been rendered almost superfluous by an admirable paper by Hensen, already alluded to, which appeared in 1877. [6] Before entering on details with respect to the castings, it will be advisable to give some account of the habits of worms from my own observations and from those of other naturalists.

[First Edition,
October 10*th*, 1881.]

CHAPTER I.
HABITS OF WORMS.

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Nature of the sites inhabited—Can live long under water—Nocturnal—Wander about at night—Often lie close to the mouths of their burrows, and are thus destroyed in large numbers by birds—Structure—Do not possess eyes, but can distinguish between light and darkness—Retreat rapidly when brightly illuminated, not by a reflex action—Power of attention—Sensitive to heat and cold—Completely deaf—Sensitive to vibrations and to touch—Feeble power of smell—Taste—Mental qualities—Nature of food—Omnivorous—Digestion—Leaves before being swallowed, moistened with a fluid of the nature of the pancreatic secretion—Extra-stomachal digestion—Calciferous glands, structure of—Calcareous concretions formed in the anterior pair of glands—The calcareous matter primarily an excretion, but secondarily serves to neutralise the acids generated during the digestive process.

EARTH-WORMS are distributed throughout the world under the form of a few genera, which externally are closely similar to one another. The British species of Lumbricus have never been carefully monographed; but we may judge of their probable number from those inhabiting neighbouring countries. In Scandinavia there are eight species, according to Eisen; [8a] but two of these rarely burrow in the ground, and one inhabits very wet places or even lives under the water. We are here concerned only with the kinds which bring up earth to the surface in the form of

castings. Hoffmeister says that the species in Germany are not well known, but gives the same number as Eisen, together with some strongly marked varieties. [8b]

Earth-worms abound in England in many different stations. Their castings may be seen in extraordinary numbers on commons and chalk-downs, so as almost to cover the whole surface, where the soil is poor and the grass short and thin. But they are almost or quite as numerous in some of the London parks, where the grass grows well and the soil appears rich. Even on the same field worms are much more frequent in some places than in others, without any visible difference in the nature of the soil. They abound in paved court-yards close to houses; and an instance will be given in which they had burrowed through the floor of a very damp cellar. I have seen worms in black peat in a boggy field; but they are extremely rare, or quite absent in the drier, brown, fibrous peat, which is so much valued by gardeners. On dry, sandy or gravelly tracks, where heath with some gorse, ferns, coarse grass, moss and lichens alone grow, hardly any worms can be found. But in many parts of England, wherever a path crosses a heath, its surface becomes covered with a fine short sward. Whether this change of vegetation is due to the taller plants being killed by the occasional trampling of man and animals, or to the soil being occasionally manured by the droppings from animals, I do not know. [9b] On such grassy paths worm-castings may often be seen. On a heath in Surrey, which was carefully examined, there were only a few castings on these paths, where they were much inclined; but on the more level parts, where a bed of fine earth had been

washed down from the steeper parts and had accumulated to a thickness of a few inches, worm-castings abounded. These spots seemed to be overstocked with worms, so that they had been compelled to spread to a distance of a few feet from the grassy paths, and here their castings had been thrown up among the heath; but beyond this limit, not a single casting could be found. A layer, though a thin one, of fine earth, which probably long retains some moisture, is in all cases, as I believe, necessary for their existence; and the mere compression of the soil appears to be in some degree favourable to them, for they often abound in old gravel walks, and in foot-paths across fields.

Beneath large trees few castings can be found during certain seasons of the year, and this is apparently due to the moisture having been sucked out of the ground by the innumerable roots of the trees; for such places may be seen covered with castings after the heavy autumnal rains. Although most coppices and woods support many worms, yet in a forest of tall and ancient beech-trees in Knole Park, where the ground beneath was bare of all vegetation, not a single casting could be found over wide spaces, even during the autumn. Nevertheless, castings were abundant on some grass-covered glades and indentations which penetrated this forest. On the mountains of North Wales and on the Alps, worms, as I have been informed, are in most places rare; and this may perhaps be due to the close proximity of the subjacent rocks, into which worms cannot burrow during the winter so as to escape being frozen. Dr. McIntosh, however, found worm-castings at a height of 1500 feet on Schiehallion in Scotland. They are numerous on some hills

near Turin at from 2000 to 3000 feet above the sea, and at a great altitude on the Nilgiri Mountains in South India and on the Himalaya.

Earth-worms must be considered as terrestrial animals, though they are still in one sense semi-aquatic, like the other members of the great class of annelids to which they belong. M. Perrier found that their exposure to the dry air of a room for only a single night was fatal to them. On the other hand he kept several large worms alive for nearly four months, completely submerged in water. [11] During the summer when the ground is dry, they penetrate to a considerable depth and cease to work, as they do during the winter when the ground is frozen. Worms are nocturnal in their habits, and at night may be seen crawling about in large numbers, but usually with their tails still inserted in their burrows. By the expansion of this part of their bodies, and with the help of the short, slightly reflexed bristles, with which their bodies are armed, they hold so fast that they can seldom be dragged out of the ground without being torn into pieces. [12] During the day they remain in their burrows, except at the pairing season, when those which inhabit adjoining burrows expose the greater part of their bodies for an hour or two in the early morning. Sick individuals, which are generally affected by the parasitic larvæ of a fly, must also be excepted, as they wander about during the day and die on the surface. After heavy rain succeeding dry weather, an astonishing number of dead worms may sometimes be seen lying on the ground. Mr. Galton informs me that on one such occasion (March, 1881), the dead worms averaged one for every two and a half

paces in length on a walk in Hyde Park, four paces in width. He counted no less than 45 dead worms in one place in a length of sixteen paces. From the facts above given, it is not probable that these worms could have been drowned, and if they had been drowned they would have perished in their burrows. I believe that they were already sick, and that their deaths were merely hastened by the ground being flooded.

It has often been said that under ordinary circumstances healthy worms never, or very rarely, completely leave their burrows at night; but this is an error, as White of Selborne long ago knew. In the morning, after there has been heavy rain, the film of mud or of very fine sand over gravel-walks is often plainly marked with their tracks. I have noticed this from August to May, both months included, and it probably occurs during the two remaining months of the year when they are wet. On these occasions, very few dead worms could anywhere be seen. On January 31, 1881, after a long-continued and unusually severe frost with much snow, as soon as a thaw set in, the walks were marked with innumerable tracks. On one occasion, five tracks were counted crossing a space of only an inch square. They could sometimes be traced either to or from the mouths of the burrows in the gravel-walks, for distances between 2 or 3 up to 15 yards. I have never seen two tracks leading to the same burrow; nor is it likely, from what we shall presently see of their sense-organs, that a worm could find its way back to its burrow after having once left it. They apparently leave their burrows on a voyage of discovery, and thus they find new sites to inhabit.

Morren states [14] that worms often lie for hours almost motionless close beneath the mouths of their burrows. I have occasionally noticed the same fact with worms kept in pots in the house; so that by looking down into their burrows, their heads could just be seen. If the ejected earth or rubbish over the burrows be suddenly removed, the end of the worm's body may very often be seen rapidly retreating. This habit of lying near the surface leads to their destruction to an immense extent. Every morning during certain seasons of the year, the thrushes and blackbirds on all the lawns throughout the country draw out of their holes an astonishing number of worms, and this they could not do, unless they lay close to the surface. It is not probable that worms behave in this manner for the sake of breathing fresh air, for we have seen that they can live for a long time under water. I believe that they lie near the surface for the sake of warmth, especially in the morning; and we shall hereafter find that they often coat the mouths of their burrows with leaves, apparently to prevent their bodies from coming into close contact with the cold damp earth. It is said that they completely close their burrows during the winter.

Structure.—A few remarks must be made on this subject. The body of a large worm consists of from 100 to 200 almost cylindrical rings or segments, each furnished with minute bristles. The muscular system is well developed. Worms can crawl backwards as well as forwards, and by the aid of their affixed tails can retreat with extraordinary rapidity into their burrows. The mouth is situated at the anterior end of the body, and is provided with a little

projection (lobe or lip, as it has been variously called) which is used for prehension. Internally, behind the mouth, there is a strong pharynx, shown in the accompanying diagram (Fig. 1) which is pushed forwards when the animal eats, and this part corresponds, according to Perrier, with the protrudable trunk or proboscis of other annelids. The pharynx leads into the œsophagus, on each side of which in the lower part there are three pairs of large glands, which secrete a surprising amount of carbonate of lime. These calciferous glands are highly remarkable, for nothing like them is known in any other animal. Their use will be discussed when we treat of the digestive process. In most of the species, the œsophagus is enlarged into a crop in front of the gizzard. This latter organ is lined with a smooth thick chitinous membrane, and is surrounded by weak longitudinal, but powerful transverse muscles. Perrier saw these muscles in energetic action; and, as he remarks, the trituration of the food must be chiefly effected by this organ, for worms possess no jaws or teeth of any kind. Grains of sand and small stones, from the 1/20 to a little more than the 1/10 inch in diameter, may generally be found in their gizzards and intestines. As it is certain that worms swallow many little stones, independently of those swallowed while excavating their burrows, it is probable that they serve, like mill-stones, to triturate their food. The gizzard opens into the intestine, which runs in a straight course to the vent at the posterior end of the body. The intestine presents a remarkable structure, the typhlosolis, or, as the old anatomists called it, an intestine within an intestine; and Claparède [17] has shown that this consists of a deep

longitudinal involution of the walls of the intestine, by which means an extensive absorbent surface is gained.

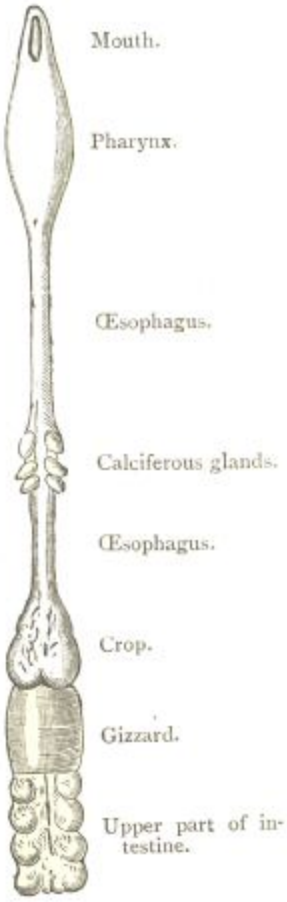

FIG. 1.—Diagram of the alimentary canal of an earth-worm (Lumbricus), copied from Ray Lankester in 'Quart. Journ. of Microscop. Soc.' vol. xv. N.S. pl. vii.

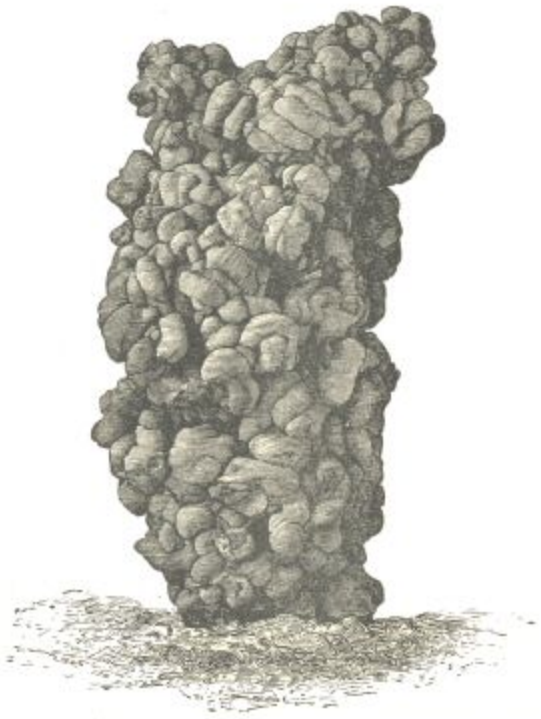

FIG. 2.—Tower-like casting from near Nice, constructed of earth, voided probably by a species of Perichæta: of natural size, copied from a photograph.

[*To face p.* 16.

The circulatory system is well developed. Worms breathe by their skin, as they do not possess any special respiratory organs. The two sexes are united in the same individual, but two individuals pair together. The nervous system is fairly well developed; and the two almost confluent cerebral ganglia are situated very near to the anterior end of the body.

Senses.—Worms are destitute of eyes, and at first I thought that they were quite insensible to light; for those kept in confinement were repeatedly observed by the aid of a candle, and others out of doors by the aid of a lantern, yet they were rarely alarmed, although extremely timid animals. Other persons have found no difficulty in observing worms at night by the same means. [18a]

Hoffmeister, however, states [18b] that worms, with the exception of a few individuals, are extremely sensitive to light; but he admits that in most cases a certain time is requisite for its action. These statements led me to watch on many successive nights worms kept in pots, which were protected from currents of air by means of glass plates. The pots were approached very gently, in order that no vibration of the floor should be caused. When under these circumstances worms were illuminated by a bull's-eye lantern having slides of dark red and blue glass, which intercepted so much light that they could be seen only with some difficulty, they were not at all affected by this amount of light, however long they were exposed to it. The light, as far as I could judge, was brighter than that from the full moon. Its colour apparently made no difference in the result. When they were illuminated by a candle, or even by a bright paraffin lamp, they were not usually affected at first. Nor were they when the light was alternately admitted and shut off. Sometimes, however, they behaved very differently, for as soon as the light fell on them, they withdrew into their burrows with almost instantaneous rapidity. This occurred perhaps once out of a dozen times. When they did not withdraw instantly, they often raised the anterior tapering

ends of their bodies from the ground, as if their attention was aroused or as if surprise was felt; or they moved their bodies from side to side as if feeling for some object. They appeared distressed by the light; but I doubt whether this was really the case, for on two occasions after withdrawing slowly, they remained for a long time with their anterior extremities protruding a little from the mouths of their burrows, in which position they were ready for instant and complete withdrawal.

When the light from a candle was concentrated by means of a large lens on the anterior extremity, they generally withdrew instantly; but this concentrated light failed to act perhaps once out of half a dozen trials. The light was on one occasion concentrated on a worm lying beneath water in a saucer, and it instantly withdrew into its burrow. In all cases the duration of the light, unless extremely feeble, made a great difference in the result; for worms left exposed before a paraffin lamp or a candle invariably retreated into their burrows within from five to fifteen minutes; and if in the evening the pots were illuminated before the worms had come out of their burrows, they failed to appear.

From the foregoing facts it is evident that light affects worms by its intensity and by its duration. It is only the anterior extremity of the body, where the cerebral ganglia lie, which is affected by light, as Hoffmeister asserts, and as I observed on many occasions. If this part is shaded, other parts of the body may be fully illuminated, and no effect will be produced. As these animals have no eyes, we must suppose that the light passes through their skins, and in

some manner excites their cerebral ganglia. It appeared at first probable that the different manner in which they were affected on different occasions might be explained, either by the degree of extension of their skin and its consequent transparency, or by some particular incident of the light; but I could discover no such relation. One thing was manifest, namely, that when worms were employed in dragging leaves into their burrows or in eating them, and even during the short intervals whilst they rested from their work, they either did not perceive the light or were regardless of it; and this occurred even when the light was concentrated on them through a large lens. So, again, whilst they are paired, they will remain for an hour or two out of their burrows, fully exposed to the morning light; but it appears from what Hoffmeister says that a light will occasionally cause paired individuals to separate.

When a worm is suddenly illuminated and dashes like a rabbit into its burrow—to use the expression employed by a friend—we are at first led to look at the action as a reflex one. The irritation of the cerebral ganglia appears to cause certain muscles to contract in an inevitable manner, independently of the will or consciousness of the animal, as if it were an automaton. But the different effect which a light produced on different occasions, and especially the fact that a worm when in any way employed and in the intervals of such employment, whatever set of muscles and ganglia may then have been brought into play, is often regardless of light, are opposed to the view of the sudden withdrawal being a simple reflex action. With the higher animals, when close attention to some object leads to the disregard of the

impressions which other objects must be producing on them, we attribute this to their attention being then absorbed; and attention implies the presence of a mind. Every sportsman knows that he can approach animals whilst they are grazing, fighting or courting, much more easily than at other times. The state, also, of the nervous system of the higher animals differs much at different times, for instance, a horse is much more readily startled at one time than at another. The comparison here implied between the actions of one of the higher animals and of one so low in the scale as an earth-worm, may appear far-fetched; for we thus attribute to the worm attention and some mental power, nevertheless I can see no reason to doubt the justice of the comparison.

Although worms cannot be said to possess the power of vision, their sensitiveness to light enables them to distinguish between day and night; and they thus escape extreme danger from the many diurnal animals which prey on them. Their withdrawal into their burrows during the day appears, however, to have become an habitual action; for worms kept in pots covered by glass plates, over which sheets of black paper were spread, and placed before a north-east window, remained during the day-time in their burrows and came out every night; and they continued thus to act for a week. No doubt a little light may have entered between the sheets of glass and the blackened paper; but we know from the trials with coloured glass, that worms are indifferent to a small amount of light.

Worms appear to be less sensitive to moderate radiant heat than to a bright light. I judge of this from having held

at different times a poker heated to dull redness near some worms, at a distance which caused a very sensible degree of warmth in my hand. One of them took no notice; a second withdrew into its burrow, but not quickly; the third and fourth much more quickly, and the fifth as quickly as possible. The light from a candle, concentrated by a lens and passing through a sheet of glass which would intercept most of the heat-rays, generally caused a much more rapid retreat than did the heated poker. Worms are sensitive to a low temperature, as may be inferred from their not coming out of their burrows during a frost.

Worms do not possess any sense of hearing. They took not the least notice of the shrill notes from a metal whistle, which was repeatedly sounded near them; nor did they of the deepest and loudest tones of a bassoon. They were indifferent to shouts, if care was taken that the breath did not strike them. When placed on a table close to the keys of a piano, which was played as loudly as possible, they remained perfectly quiet.

Although they are indifferent to undulations in the air audible by us, they are extremely sensitive to vibrations in any solid object. When the pots containing two worms which had remained quite indifferent to the sound of the piano, were placed on this instrument, and the note C in the bass clef was struck, both instantly retreated into their burrows. After a time they emerged, and when G above the line in the treble clef was struck they again retreated. Under similar circumstances on another night one worm dashed into its burrow on a very high note being struck only once, and the other worm when C in the treble clef was struck. On

these occasions the worms were not touching the sides of the pots, which stood in saucers; so that the vibrations, before reaching their bodies, had to pass from the sounding board of the piano, through the saucer, the bottom of the pot and the damp, not very compact earth on which they lay with their tails in their burrows. They often showed their sensitiveness when the pot in which they lived, or the table on which the pot stood, was accidentally and lightly struck; but they appeared less sensitive to such jars than to the vibrations of the piano; and their sensitiveness to jars varied much at different times.

It has often been said that if the ground is beaten or otherwise made to tremble, worms believe that they are pursued by a mole and leave their burrows. From one account that I have received, I have no doubt that this is often the case; but a gentleman informs me that he lately saw eight or ten worms leave their burrows and crawl about the grass on some boggy land on which two men had just trampled while setting a trap; and this occurred in a part of Ireland where there were no moles. I have been assured by a Volunteer that he has often seen many large earth-worms crawling quickly about the grass, a few minutes after his company had fired a volley with blank cartridges. The Peewit (*Tringa vanellus*, Linn.) seems to know instinctively that worms will emerge if the ground is made to tremble; for Bishop Stanley states (as I hear from Mr. Moorhouse) that a young peewit kept in confinement used to stand on one leg and beat the turf with the other leg until the worms crawled out of their burrows, when they were instantly devoured. Nevertheless, worms do not invariably leave their burrows