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EARTH-WORMS AND THEIR WONDERFUL WORKS.*

By W. H. LARRABEE.

THE subject of Mr. Darwin's latest volume is the share which worms have taken in the formation of the layer of vegetable mold that covers the surface of the land in every moderately humid country. It is a real surprise to learn, from the observations which Mr. Darwin has so patiently made for nearly half a century, and which he records in this work, how important a part these unconsidered creatures have played in giving to the surface of the land its generally fine consistency and fertile properties, and how essentially and vastly they have contributed to the comfort and prosperity of mankind. Ever since his first paper on vegetable mold was read before the Geological Society of London, in 1837, Mr. Darwin has kept on with his investigations, in flower-pots in his room, in his garden, and in the field, and has detected the work of the worms wherever anything will grow—in meadows and table-lands, in cultivated places and in woods, on mountains fifteen hundred feet high in Scotland, nearly twice as high at Turin, seven thousand feet above the sea on the Nilgiri Hills of Southern India, and on the slopes of the Himalayas—effecting the transformation of the hard, cold earth, and the raw leaves into fine, fruitful soil. It is easy to say, as some have done, that the creatures are too insignificant to accomplish so extensive a work; but the facts adduced by Mr. Darwin convey a striking lesson in the principle that nothing is so minute that it can be despised.

We may first consider the agent apparently so insignificant that has done so much to transform and clothe the surface of the earth.

* The Formation of Vegetable Mold through the Action of Worms, with Observations on their Habits. By Charles Darwin, LL. D., F. R. S. With Illustrations. Published by D. Appleton & Co., New York.

Lumbricus is the name of the best-known genus, of which the species have not been accurately distinguished and numbered; but only a part of them bring up earth in the form of castings, and are engaged in making tillable soil. They appear to be found wherever there is moist earth containing vegetable matter, but seem to abound most where the ground is loose and well charged with humus. Dryness is unfavorable and even fatal to them; but, although they are terrestrial animals, they have been found by M. Perrier to be capable of living for a considerable time under water. During the summer, when the ground is dry, and during the winter, when it is frozen, they penetrate to a considerable depth in the earth and cease to work. They are nocturnal in their habits, and may be often seen at night crawling over the ground, more often moving their heads and bodies around while their tails are still inserted in their burrows. Only sickly worms, such as are afflicted by the parasitic larva of a fly, as a rule travel in the day-time; and those which are seen dead on the ground after heavy rains are supposed to have been creatures afflicted in some way that have died of weakness rather than by drowning. They often lie quite still close beneath the mouths of their burrows, where their heads may be seen on looking for them, and, in this position, offer a tempting bait to birds.

FIG. 1.—DIAGRAM OF THE ALIMENTARY CANAL OF AN EARTH-WORM (*Lumbricus*), (copied from Ray Lankester in "Quarterly Journal of Microscopical Society," vol. xv, new series, pl. vii).

The body of a large worm consists of one or two hundred almost cylindrical rings or segments, each furnished with minute bristles, and is endowed with a well-developed muscular system. The mouth is provided with a little projection or lip, capable of taking hold of things, and of sucking. Internally, a strong pharynx, corresponding, according to Perrier, with the protrusile trunk or proboscis of other annelids, and which is pushed forward when the animal eats, is situated behind the mouth. The pharynx leads into the œsophagus, on each side of the lower part of which are three pairs of large glands, which secrete a surprising amount of carbonate of lime. They are unlike anything that is known in any other animal, and their use is largely a matter of speculation. Mr. Darwin thinks they are partly excretions of the excess of lime contained in the leaves which the animal eats, and that they otherwise aid digestion by affording a neutralizing agent against the acids of its food. In most of the species the œsophagus is enlarged into a cup in front of

the gizzard. The latter organ is lined with a smooth, thick, chitinous membrane, and is surrounded by weak longitudinal but powerful transverse muscles. Grains of sand and small stones, from one twentieth to a little more than one tenth of an inch in diameter, may be found in the gizzard and intestines, and are supposed to serve, like millstones, to triturate the food. The gizzard opens into the intestine, which presents a peculiar remarkable longitudinal involution of the walls, by which an extensive absorbent surface is gained. The circulatory system is well developed. Breathing is done by the skin, without special respiratory organs. The nervous system is fairly developed, with two almost confluent cerebral ganglia situated near the anterior end.

Worms have no eyes, and are measurably indifferent to light ; yet they can distinguish night from day, and are quickly affected by a strong light, and after some time by a moderate light shining continuously upon them. They do not much mind a moderate radiant heat, but are sensitive to cold. They have no sense of hearing, but are extremely sensitive to vibrations in any solid object. Worms in pots, which had paid no attention to the sound of a piano, when placed on the piano instantly drew into their holes when the notes were struck. Their whole body is sensitive to contact, as of a puff of air. Their sense of smell is feeble, but responds fairly well to the odor of the cabbage and onion or whatever they like, as was shown to Mr. Darwin by some very interesting experiments. They are omnivorous, and swallow enormous quantities of earth, out of which they extract any digestible matter which it may contain, consume decayed and fresh leaves and vegetable matter, and raw, roasted, and decayed meat, but like raw fat best.

Mr. Darwin discovered in worms evidences of a degree of intelligence. They line their burrows with leaves as a protection, it is supposed, against the cold of the clammy ground, and plug the entrances to them with leaves and leaf-stalks. It requires some manipulation to get these leaves in right, but the worms know how to perform it, and can discriminate between the easiest way to draw the leaf in and other ways. Commonly, seventy or eighty per cent of the leaves are drawn in by the tips, that being the direction in which they go in most easily and fold most nicely. Some leaves, however, may be drawn in nearly as easily by the sides or the bases as by the tips, and a larger proportion of these are drawn in in those ways. The worm likes to gnaw the base of the petiole of the ash-leaf, and this leaf is drawn in by the base. Pine-leaves, which grow in pairs attached to a single base, must be drawn in by the base or not at all, and the worm rarely makes a mistake in the matter. Mr. Darwin suggests here, however, that we must not suppose the worm to know too much, and that some other quality than mechanical convenience may guide it to the selection of the base of the pine-leaf. Sometimes, when the worm begins to plug

its hole, it drags leaf-stalks in by the base so as to fill it faster; but as soon as it comes to close quarters, it turns and drags the rest of the stalks in by the tips. Triangles of paper were given worms instead of leaves, and they likewise drew them in in the easiest way, apparently at the first trial. When worms can not obtain leaves, petioles, sticks, etc., with which to plug up the mouths of their burrows, they often protect them by little heaps of stones; and such heaps of smooth, rounded pebbles may frequently be seen in gravel-walks. A lady interested in this study removed the little heaps of stones from the mouths of several burrows, and cleared the surface of the ground for some inches all around. She went out on the following night with a lantern, and saw the worms, with their tails fixed in their burrows, dragging the stones inward by the aid of their mouths. After two nights some of the holes had eight or nine small stones over them; after four nights one burrow had about thirty and another thirty-four stones, and one of the stones weighed two ounces. The strength of worms is also shown by their often displacing stones in a well-trodden gravel-walk, a task that sometimes demands considerable effort.

Worms excavate their burrows in two ways: by pushing away the earth on all sides where the ground is loose or only moderately compact, and where they are able to disappear from sight with surprising agility; and by swallowing the dirt, where the ground is hard, and ejecting the swallowed earth afterward in the form of the "castings" which are found at the mouths of their burrows. Worms also swallow earth to extract the nutritous matter which may be contained in it, and in larger quantity than for making their burrows; and the residue of this, after the nutriment is extracted, is also cast out. The deposition of castings, then, is no insignificant part of the labor that they perform, and leaves very perceptible traces upon the surface. The castings may be seen by any one who will take the pains to look for them, and often in garden-walks without looking for them, piled up in the shape of towers of greater or less height around the burrows. The towers formed by a naturalized East Indian worm, at Nice, France, which are sometimes distributed as thickly as five or six to a square foot, are built to a height of from two and a half to three inches. The tower of a *perichæta* in the Botanic Garden at Calcutta, of which Fig. 2 is an exact representation, measured three and a half inches high and 1·35 inch in diameter. One tower from Calcutta was five inches high and two and a half inches in diameter; and the average weight of twenty-two castings sent Mr. Darwin from Calcutta was an ounce and a quarter. The largest castings mentioned came from the Nilgiri Hills in South India, seven thousand feet above the sea, and afforded one specimen that weighed a quarter of a pound, the largest convolutions of which were about an inch in diameter. The manner of forming the casting is described by Mr. Darwin: "A worm after swallowing earth, whether for making its

burrow or for food, soon comes to the surface to empty its body. The ejected earth is thoroughly mingled with the intestinal secretions, and is thus rendered viscid. After being dried it sets hard. I have watched worms during the act of ejection, and when the earth was in a very liquid state it was ejected in little spurts, and when not so liquid by a slow, peristaltic movement. It is not cast indifferently on any side, but with some care, first on one and then on another side, the tail being used almost like a trowel. As soon as a little heap is formed the worm apparently avoids, for the sake of safety, protruding its tail, and the earthy matter is forced up through the previously deposited soft mass." Some of the towers, as the figure shows, exhibit a considerable degree of skill in their construction. The castings are not always ejected on the surface of the ground, but are often lodged in any cavity that may be met in burrowing. The burrows run down, sometimes perpendicularly, generally a little obliquely, to a depth of three, six, and even eight feet, and are usually lined with a thin layer or plaster of fine, dark-colored earth which the animals have voided, in addition to which a lining is made, near the mouths, of leaves, also plastered. Bits of stones and seeds are also sometimes found in the bottom of the burrows, having been taken down apparently with a purpose.

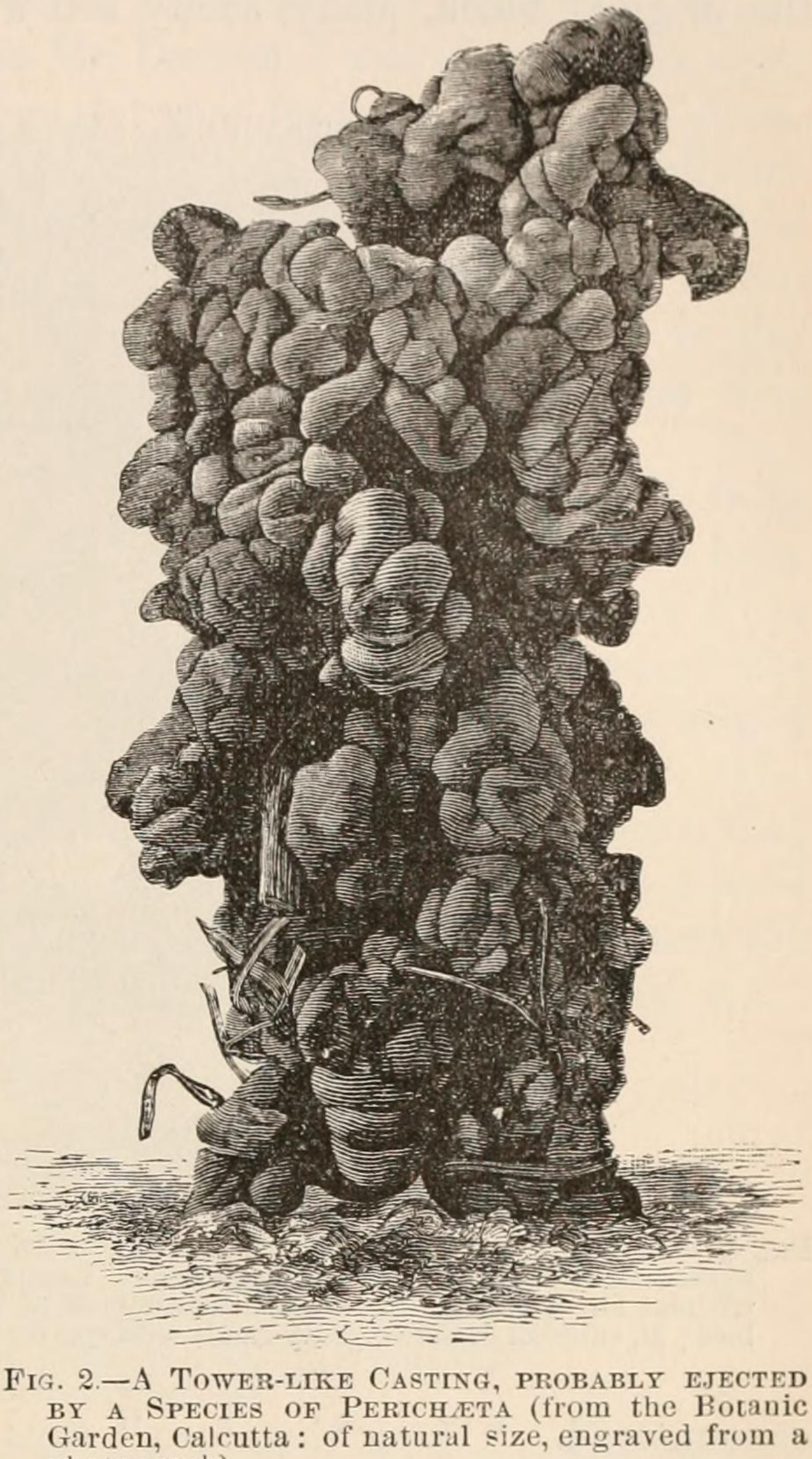

FIG. 2.—A TOWER-LIKE CASTING, PROBABLY EJECTED BY A SPECIES OF PERICHÆTA (from the Botanic Garden, Calcutta: of natural size, engraved from a photograph).

The amount of earth brought up by worms from beneath the surface has been carefully estimated by observing the rate at which stones and other scattered objects on top of the ground are buried. A piece of waste, swampy land, which was inclosed, drained, plowed, harrowed, and thickly covered with burned marl and cinders, and sowed with grass, in 1822, fifteen years afterward, presented the appearance, where holes were dug into it, shown by Fig. 3, the scale of which is half that of nature. Beneath a sod an inch and a half thick was a layer of vegetable mold, free from fragments of every kind, two and a half inches thick. Under this was another layer of mold, an inch and a half thick,

full of fragments of burned marl, conspicuous from their red color, fragments of coal-cinders, and a few white-quartz pebbles. Beneath this layer, and at a depth of four and a half inches from the surface, the original black, peaty, sandy soil with a few quartz pebbles was

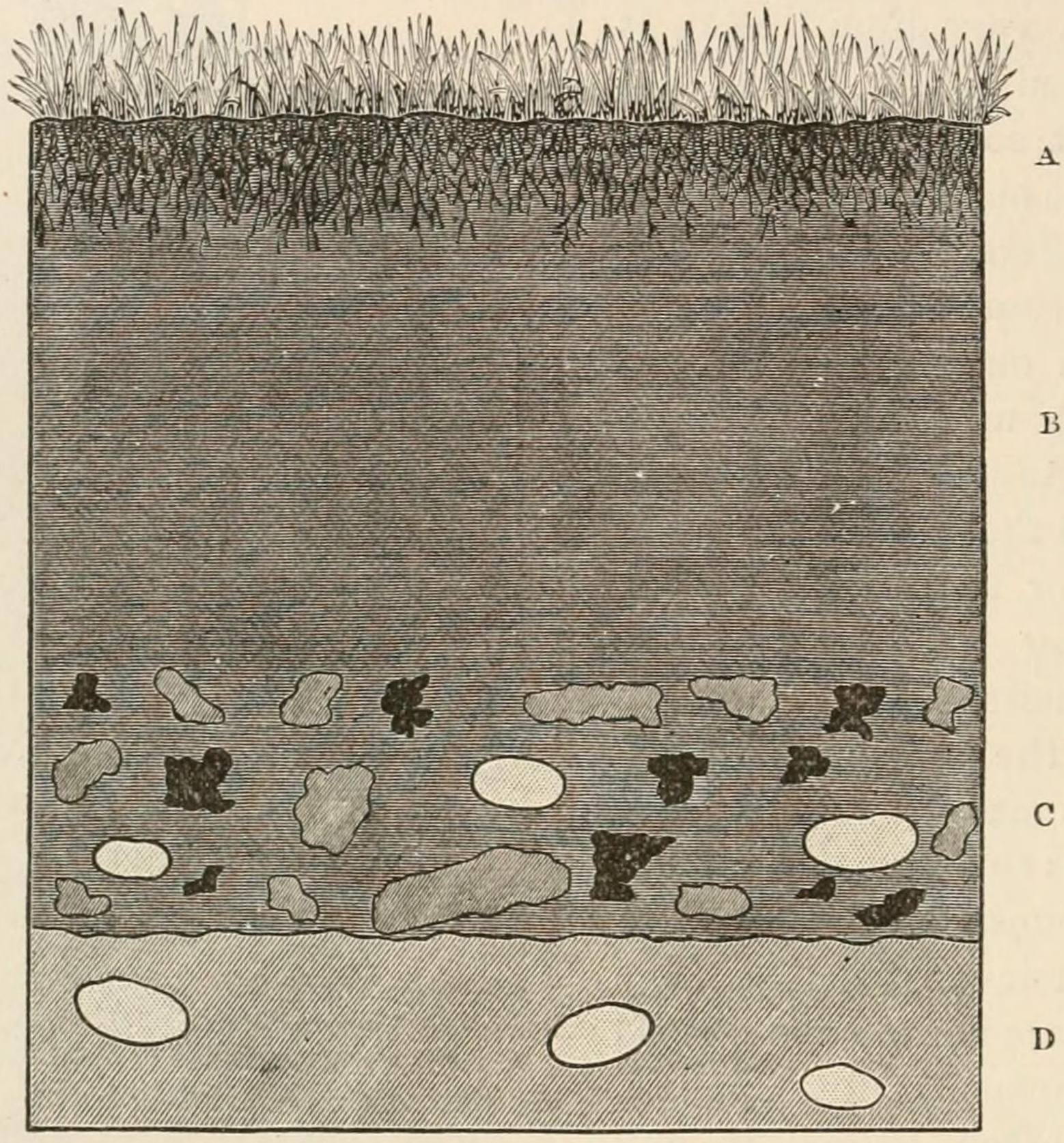

FIG. 3.—SECTION, REDUCED TO HALF THE NATURAL SCALE, OF THE VEGETABLE MOLD IN A FIELD, DRAINED AND RECLAIMED FIFTEEN YEARS PREVIOUSLY. A, turf; B, vegetable mold without any stones; C, mold with fragments of burned marl, coal-cinders, and quartz-pebbles; D, sub-soil of black, peaty sand, with quartz-pebbles.

encountered. "Here, therefore," says Mr. Darwin, "the fragments of burned marl and cinders had been covered in the course of fifteen years by a layer of vegetable mold, only two and a half inches in thickness, excluding the turf." Six and a half years afterward this field was re-examined, and the fragments were found at from four to five inches beneath the surface, having been covered in that time with an inch and a half more of mold. The average annual increase of thickness for the whole period was ·19 of an inch. This was less than the average increase of thickness in some other fields similarly observed, in which the accumulation amounted to ·21 and ·22 of an inch annually.

Another field, lying upon the chalk, and sloping rather steeply in one part, which was turned into pasture-land in 1841, was for several years so thickly covered with small and large flints that Mr. Darwin's sons always called it "the stony field." When they ran down the slope the stones clattered together; and Mr. Darwin remembers doubting whether he should live to see the larger flints covered with vegetable

mold and turf. But the smaller stones disappeared before many years had elapsed, as did every one of the larger ones after a time; so that after thirty years, or in 1871, a horse could gallop over the compact turf from one end of the field to the other, and not strike a single stone with his shoes. This, says Mr. Darwin, "was certainly the work of the worms, for, though castings were not frequent for several years, yet some were thrown up month after month, and these gradually increased in numbers as the pasture improved." The accumulation of mold was, however, of the slowest, measuring only .083 of an inch a year. A flagged path in Mr. Darwin's garden disappeared in the course of years, it might be said under his very eyes, the worms covering it with an inch of mold.

A stone, sixty-four inches long, seventeen inches broad, and from nine to ten inches thick, part of the ruins of a lime-kiln that had been torn down thirty-five years before, lay in a field, its base sunk from one to two inches below the general level, while the surface of the field for about nine inches around it sloped up toward it to the height of four inches above the surrounding ground close to the stone. The stone could not have sunk by its weight, and there was evidence that one of its pointed ends, the upper surface of which was now on a level with the surrounding turf, must have stood clear of the ground for several inches. The situation of the stone is represented in Fig. 4.

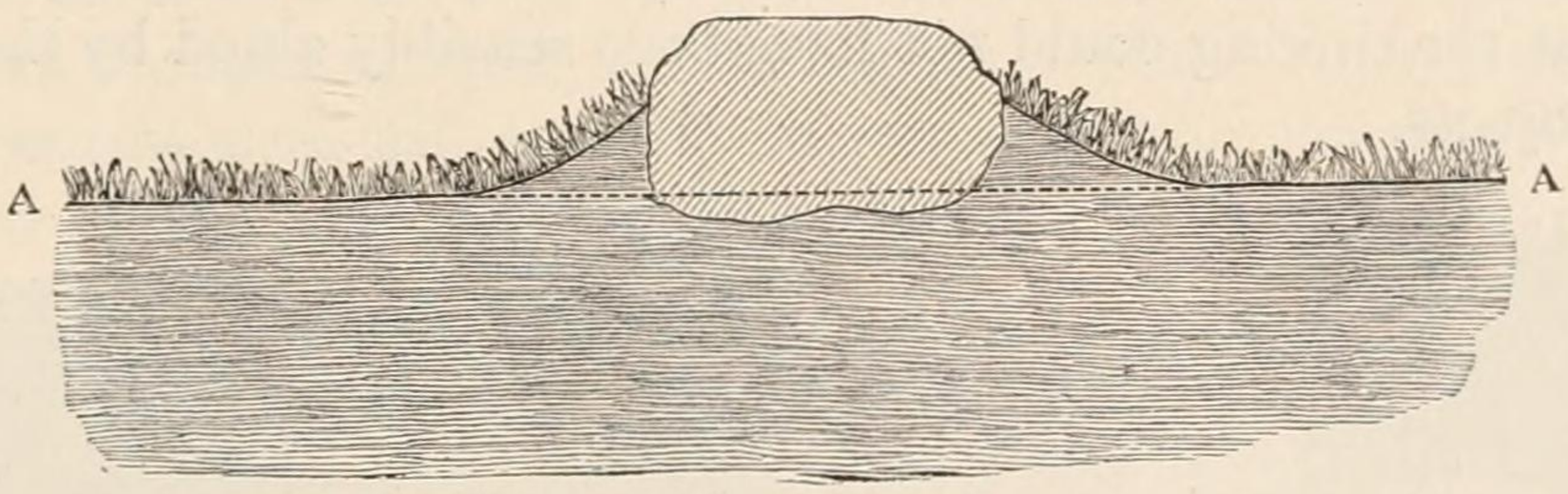

FIG. 4.—TRANSVERSE SECTION ACROSS A LARGE STONE WHICH HAD LAIN ON A GRASS-FIELD FOR THIRTY-FIVE YEARS. A A, general level of the field. The underlying brick rubbish has not been represented. Scale one half inch to one foot.

When the stone was removed, an exact cast of its lower side, forming a shallow crateriform hollow, was left, the inner surface of which, except where the base had been in contact with brick rubbish, consisted of fine black mold. The turf-covered border, which sloped up to the stone, consisted of fine vegetable mold, in one part seven inches thick, and was evidently derived from worm-castings, several of which had been recently ejected. This stone would have sunk to the level of the field in two hundred and forty-seven years if none of the castings were washed away by rains.

Some of the fallen stones at Stonehenge have become buried to a moderate depth in the ground, and are surrounded by sloping borders of turf, on which recent castings were seen. In the case of the stone represented in the cut (Fig. 5), which is by no means the most marked specimen, the turf-covered border sloped on one side to the height of

four inches, and on the other side of two and a half inches, above the general level.

Thus, evidence is gathered that small objects left on the surface of the land where worms abound soon get buried, and that large stones

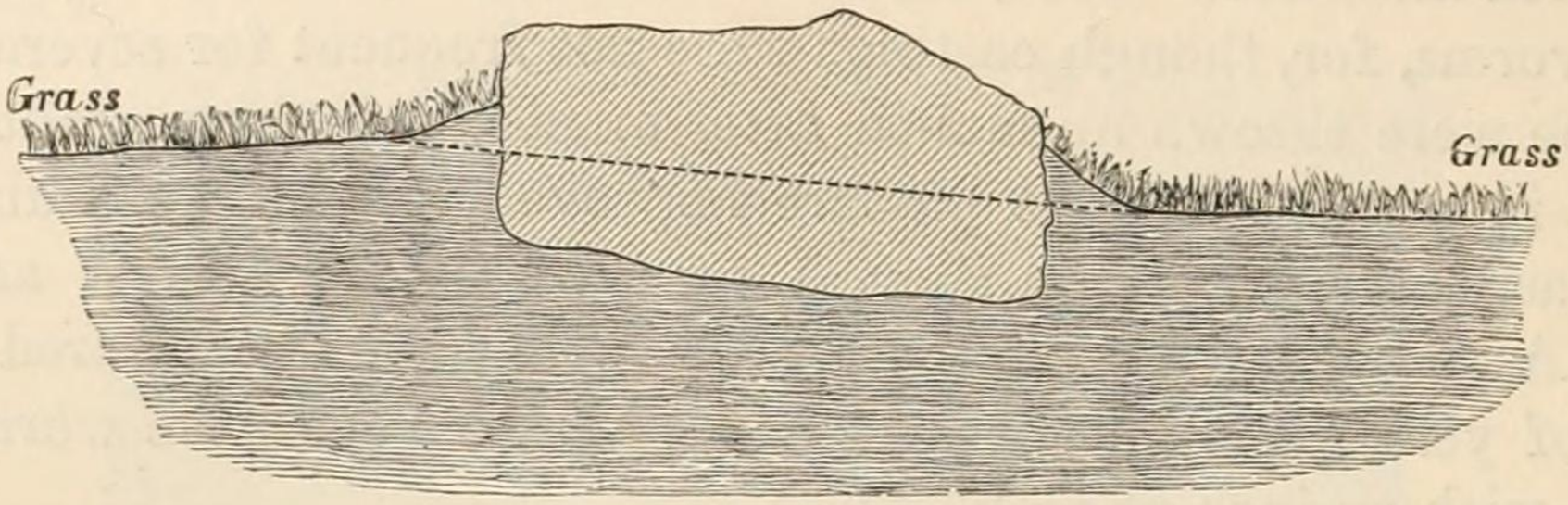

FIG. 5.—SECTION THROUGH ONE OF THE FALLEN DRUIDICAL STONES AT STONEHENGE, SHOWING HOW MUCH IT HAD SUNK INTO THE GROUND. Scale one half inch to one foot.

sink slowly downward by the same means. Every step of the process could be followed. Among the most striking features of the case are the straightness and regularity of the lines formed by the imbedded objects in cases where they have covered a considerable surface, and their parallelism with the surface of the land, for this parallelism shows how equally the worms must have worked. The specific gravity of the objects does not affect their rate of sinking, as could be seen by porous cinders, burned marl, chalk, and quartz pebbles having all sunk to the same depth within the same time; and many considerations seem to show that the sinking could not have been sensibly aided by the weight of the objects.

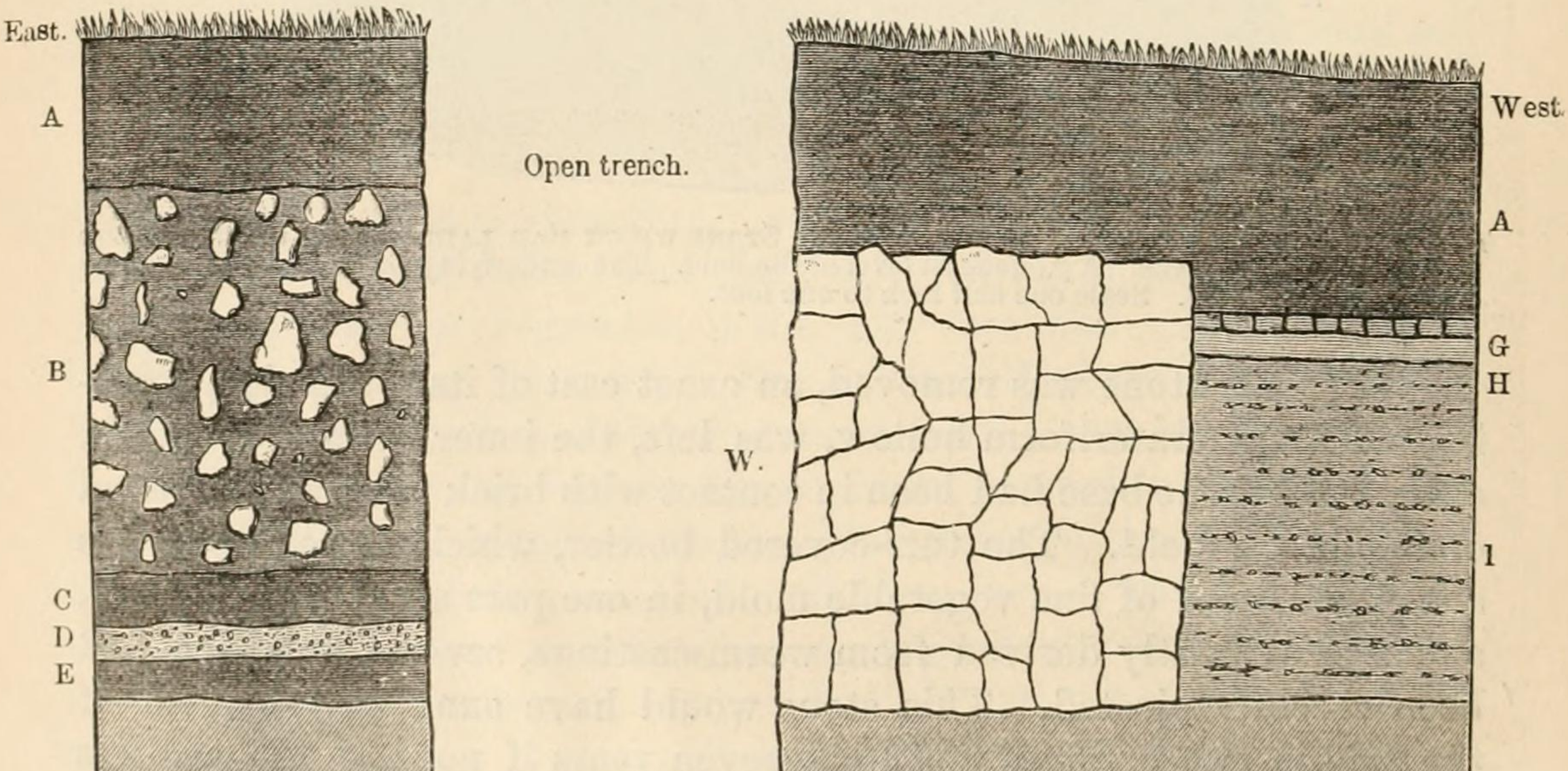

FIG. 6.—SECTION THROUGH THE FOUNDATIONS OF A BURIED ROMAN VILLA AT ABINGER. A A, vegetable mold; B, dark earth full of stones, thirteen inches in thickness; C, black mold; D, broken mortar; E, black mold; F F, undisturbed sub-soil; G, tesseræ; H, concrete; I, nature unknown; W, buried wall.

The estimates of the amount of mold brought up by the worms, based on actual weighings and measurements of the castings at particular spots, give results ranging from 7·56 to 18·12 tons per acre in one year, and a volume sufficient to make when spread out a layer of soil of from one to more than two inches thick in ten years.

"Archæologists," says Mr. Darwin, "are probably not aware how much they owe to worms for the preservation of many ancient objects. Coins, gold ornaments, stone implements, etc., if dropped on the surface of the ground, will infallibly be buried by the castings of worms in a few years, and will thus be safely preserved until the land at some future time is turned up." The remains of ancient buildings seem also to have been buried effectively, in large part, through the action of worms. An example of this kind is furnished at Abinger, Surrey, where the remains of an ancient Roman villa were discovered in 1877. The cut (Fig. 6) represents the appearance presented by the buried wall and the ground around it at a point where one of the trenches was dug. The mold here was from eleven to sixteen inches thick over the tesselated floor, G, and from thirteen to fifteen inches thick over the broken summit of the wall, W. No signs of worms appeared on the trodden-down earth over the *tesseræ* when they were first cleared, but many signs of fresh worm-action were seen on the next day, and for the next seven weeks these signs were very abundant. Numerous burrows were also found in the course of the digging, and worms were brought up from a considerable depth. Three years afterward the worms were still at work, burrowing in the concrete floor and the mortar of the walls, as they had probably been doing ever since

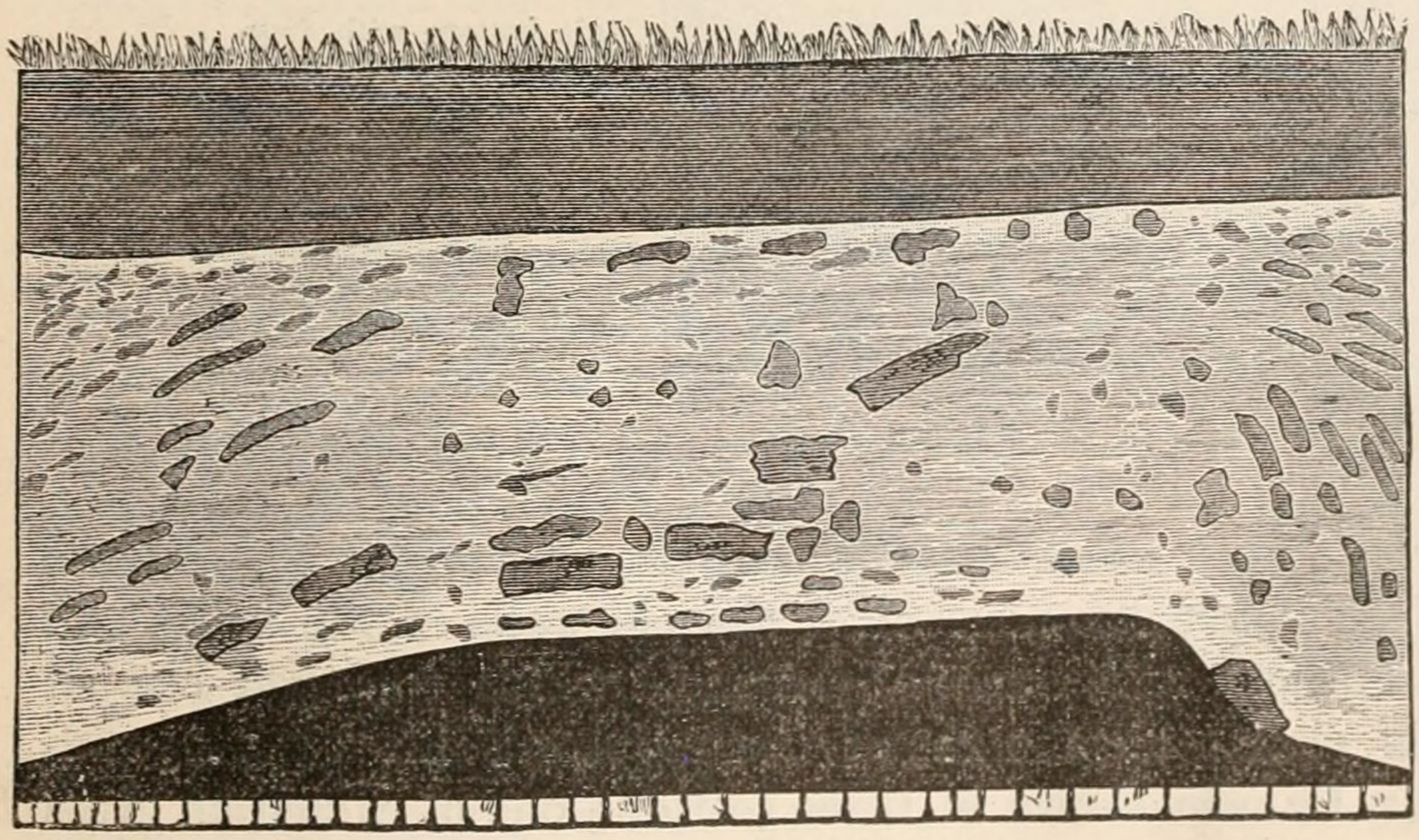

FIG. 7.—SECTION WITHIN A ROOM IN THE BASILICA AT SILCHESTER. Scale $\frac{1}{18}$.

the concrete had become decayed enough to allow them to penetrate it; and even before that period they probably lived under the floor, making burrows which, collapsing from time to time, helped make the walls and floor sink.

Other striking examples of the action of worms are found in the ruins of the old Roman town of Silchester, of which Figs. 7 and 8 show the extent to which the basilica has been covered. In Fig. 7, the concrete floor, still covered here and there with *tesseræ*, is found at three feet below the surface, and on it are piles of charred wood, represented by the black. Fig. 8 does not reach to the natural soil. Worm-castings were observed on the floors of several of the rooms, in one of which the tesselation was unusually perfect. One or

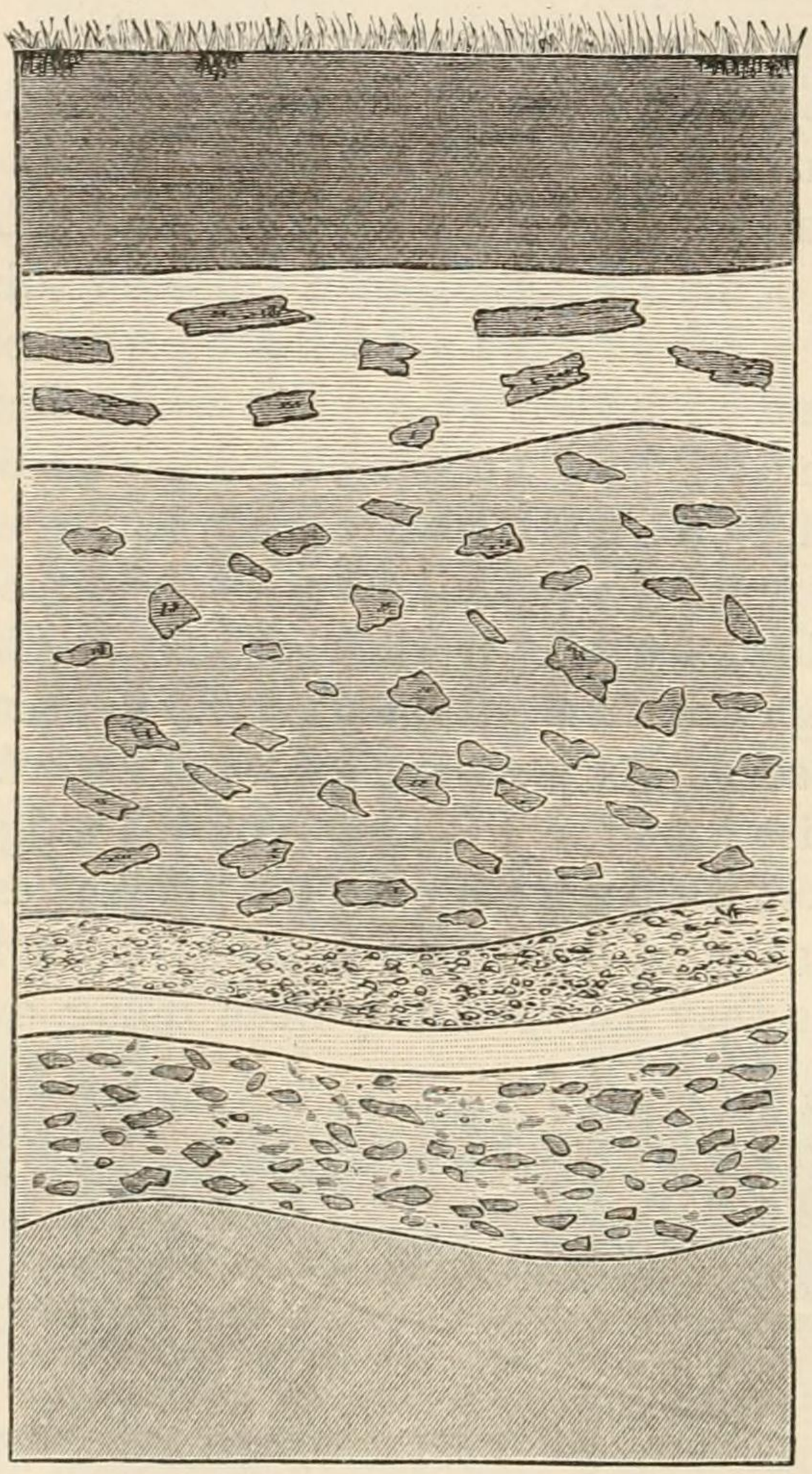

FIG. 8.—SECTION IN THE CENTER OF THE BASILICA AT SILCHESTER.

occasionally two open worm-burrows were found beneath all the loose *tesseræ*. Worms have also penetrated the old walls of the ruins, and were found in them, with traces of the mold which they had carried to them. In almost all the rooms the pavement has sunk considerably, as Mr. Darwin shows in three sections, one of which he gives (Fig. 9). Dust blown by the wind and earth washed from the hills may have partly aided in covering up these buildings, but the chief share of the work is attributable to worms.

Worms also contribute to the disintegration of the rocks and the denudation of the land, by generating humus acids which act on the carbonates, by grinding up in their crops the stones they swallow, and

by bringing earth to the surface in their castings, to be blown away by the winds and washed away by the rains into the valleys. They are extraordinarily numerous. Hensen says there are 53,767 of them in an acre of garden-soil, and Mr. Darwin is willing to allow half that number, or 26,886, to the acre in corn-fields and pasture-lands; and as in many parts of England a weight of more than ten tons of dry earth annually passes through their bodies and is brought to the surface on each acre, the whole superficial bed of vegetable mold must pass through them every few years. By triturating this earth, by subjecting its minerals to the action of the humus acids, and by periodically exposing the mold to the air, they prepare the ground in an excellent manner for the growth of fibrous-rooted plants and for seedlings. The bones of dead animals, the harder parts of insects, the shells of land-mollusks, leaves, twigs, etc., are before long all buried beneath the accumulated castings of worms, and are thus brought in a more or less decayed state within reach of the roots of plants. Leaves are digested by them and converted into humus. Their burrows, penetrating to a depth of five or six feet, are believed to aid materially in the drainage and ventilation of the ground. They also facilitate the downward passage of roots of moderate size, which are nourished by the humus with which the burrows are lined. Many seeds owe their germination to having been covered by castings; others, buried more deeply, lie dormant till they are brought under conditions favorable to germination. "The plow," says Mr. Darwin, in conclusion, "is one of the most ancient and most valuable of man's inventions; but long before he existed the land was in fact regularly plowed, and still continues to be thus plowed, by earthworms. It may be doubted whether there are many other animals

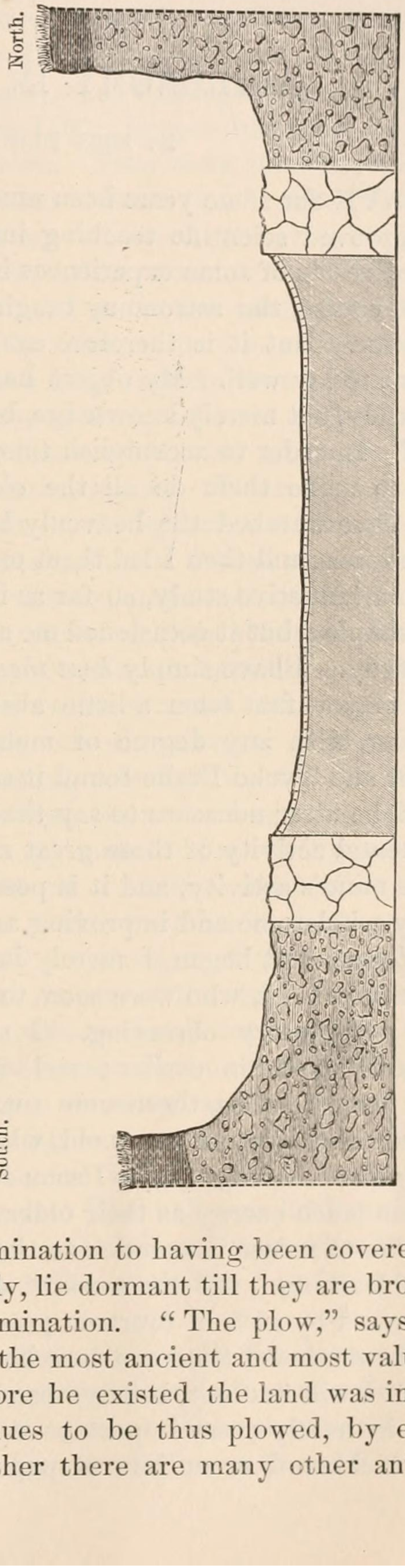

FIG. 9.—A NORTH AND SOUTH SECTION THROUGH THE SUBSIDED FLOOR OF A CORRIDOR PAVED WITH TESSERÆ. Outside the broken-down bounding walls, the excavated ground on each side is shown for a short space. Nature of the ground beneath the tesserae unknown. Silchester. Scale, $\frac{1}{36}$.

which have played so important a part in the history of the world as have these lowly-organized creatures." The coral animal is their most conspicuous rival in this claim.

ASTRONOMY IN HIGH-SCHOOLS.

By MISS ELIZA A. BOWEN.

I HAVE for some years been much interested in trying to introduce improved scientific teaching into girls' schools; and I propose to tell the result of some experiences in teaching astronomy.

Of course, the astronomy taught has been of the most elementary character. But it is therefore exactly the foundation which it is important to lay well. My object has been to gain for my pupils from this study, not merely knowledge, but all the mental discipline it could afford. In order to accomplish this, I have made it an invariable principle to make them do all the *observing*, all the *thinking*, possible. They have watched the heavenly bodies to discover their appearance and motions, and then I led them on to discuss the causes. It has been genuine inductive study, so far as it has gone. My own work seemed very simple; but it occasioned me a great deal of observation, thought, and study. I have simply *kept them on the track.*

It may at first seem a little absurd to talk of a set of school-girls treading, with any degree of mental independence, the path which Kepler and Tycho Brahe found it so difficult to walk in. Of course, it would be utter nonsense to say that they could exercise anything like the mental activity of those great men. But there are various degrees of the mind's activity, and it is possible to arouse, even in school-girls, a very wholesome and improving amount of it.

When I first began, I merely intended to make some girls of seventeen years old, who were soon to study Lockyer's "Astronomy," do some preparatory observing. I soon saw that it would have been desirable to begin earlier; and, in the room in which I talked to these young ladies, there were seated at desks some young girls of thirteen and fourteen years old, who listened to my talk and directions with great interest, and, as I soon found, were observing and thinking with as much energy as their older companions. It became out of the question to refuse instruction to those who showed themselves so capable of learning. All the work of which I am about to tell was well performed by girls of fourteen years old.

The method I tried can best be understood by one or two illustrations. I will first say, briefly, that they found for themselves the chief stars in nearly every important constellation by drawings I made on the blackboard or on bits of paper (aided by my hectograph). As