ART. V.—*The Formation of Vegetable Mould, through the action of Worms, with observations on their Habits.* By Charles Darwin, LL.D., F.R.S. London, 1881.

THIS work, which Mr. Darwin has produced at the age of seventy-two, is no unworthy culmination, notwithstanding its modest subject and moderate size, of the labours of one of the most remarkable of scientific careers. We have been obliged, on former occasions, to express our dissent from some important hypotheses with which Mr. Darwin's authority is associated, and we still remain convinced of the prematureness, to say no more, of what is commonly, whether with strict justice or not, styled the Darwinian theory of Evolution. But this difference of opinion respecting the conclusions to be drawn from Mr. Darwin's researches is no obstacle to our entertaining the highest admiration for those researches themselves; and we welcome an opportunity, such as the present work affords, for endeavouring to pay a tribute to them. They are marked by a continuity, alike of time and of subject, which is very rarely exhibited, and it would be difficult to say whether they are most distinguished by their industry or by the persistent purpose which pervades them. There is one other trait which is conspicuous in the volume before us, and which adds a particular grace to this single-minded career. Again and again Mr. Darwin refers to the researches of his sons as supplementing and assisting his own; and he seems to have inspired them with his own devotion, and to have enlisted filial sympathy and affection in the promotion of the scientific purposes of his life. It will be a great thing if they carry forward into another generation their father's methods of research and his habits of observation. We are not afraid of seeming fanciful, if we venture to say that science would be deeply benefited if there could be more of this kind of co-operation. It could rarely, of course, be afforded within the limits of a single family; but observations would be more likely to be successful if, instead of being conducted by one or two men of science, they could more often be carried out by companies, under the command of one skilled director. It needed more than even Mr. Darwin's extraordinary capacity for observation, to obtain the results of this book respecting so small a creature as an earthworm; and in proportion to the complexity of the subject, the necessity for such combination among observers must increase. The same result is, indeed, attained to some extent by the frankness with which men of science communicate their knowledge to each other; but what is needed is not merely the combination of independent re-

searches, but the organization of research. Mr. Darwin has the happiness to have reared a school of observers within his own household, and, though few can follow his example in this respect, it would be well if leading men of science could more often gather similar schools around them.

But we are mainly concerned with the unity and continuity of Mr. Darwin's own labours, which have now extended without interruption over a period of half a century. It was on the 27th of December, 1831, that at the age of twenty-two, just after taking his degree at Cambridge, Mr. Darwin sailed from Devonport on board H.M.S. 'Beagle,' upon his famous 'Naturalist's Voyage round the World.' It is seldom that a greater service has been unconsciously rendered to science and the world than when Captain FitzRoy, who commanded that expedition, asked that some scientific person might accompany him, and when the Lords of the Admiralty, at the instance of Captain Beaufort, accepted the offer which Mr. Darwin made of his voluntary services. The opportunity thus afforded him was not only the starting-point of his whole scientific career, but sowed in his mind the germs of the main ideas which he has since worked out with such patience and genius. Notwithstanding the long time which has elapsed since the publication of his Journal, it retains all its original instructiveness and interest, and few works are so calculated to give the reader a conception of the infinite variety and of the inexhaustible marvels of Nature. It exhibits all the closeness and accuracy of observation which have ever distinguished the author, and is marked at the same time by the lucidity and simplicity of style, which have contributed so largely to give currency to his speculations. His experience during the five years of that memorable voyage would seem to have contributed in more ways than one to the development of his scientific thought. It gave him, in the first place, a largeness of view which has checked any tendency to specialism, and which has taught him to discern the organic unity of Nature, and to realize the mutual co-operation of her innumerable forces in every part of her manifold productions. Those five years enabled Mr. Darwin to start upon his special researches with a wide survey, and a living personal knowledge, of the whole sphere of natural history and geology; and his work ever since has in great measure consisted in illustrating the incessant action and reaction of all the realms of Nature. His eye has ever been looking for unity and continuity of life, instead of being content to dwell on some distinct and separate field. Doubtless in this respect, as in others, he represents one of the most characteristic features of modern scientific thought.

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Under various forms, such as the conservation of force, or the convertibility of one kind of energy into another, as of heat into motion, the attention of men has been more and more directed to the organic unity of Nature; and the theory of Evolution itself is but a too sweeping and hasty generalization of this conception. Nothing is more curious than to observe, throughout the history of thought, how universal is the instinct of men to seize upon some large principle, and to insist, as it were, on its dominating the whole sphere of life. It is often a characteristic of even the most powerful inductive minds to leap to some such general truth, and to establish it as a sort of major premiss, which they then apply to all their minor premisses with the unconscious instinct of purely deductive reasoners. A tendency of this kind has in great measure animated Mr. Darwin's mind throughout his career. It has, in our opinion, overpowered in some of his works the rigid caution he endeavours to practise in drawing conclusions from his observations; but it has had the immense advantage of giving him a clue for what we may call his cross-examination of Nature. It is Plato, we think, who says that if a man is to ask questions with advantage, he must previously have some surmise of the answer of which he is in search; and Mr. Darwin's surmise has evidently been, from the first, that which was suggested to him during the voyage of the 'Beagle.'

He tells us, in fact, in the Introduction to his most famous work—that on 'The Origin of Species by Means of Natural Selection'—that when on board the 'Beagle' he was much struck with certain facts in the distribution of the organic beings inhabiting South America, and in the geological relations of the present to the past inhabitants of that continent. 'These facts,' he says, 'seemed to throw some light on the origin of species—that mystery of mysteries, as it has been called by one of our greatest philosophers.' On his return home, it occurred to him, in 1837, 'that something might, perhaps, be made out on this question by patiently accumulating and reflecting on all sorts of facts which could possibly have any bearing on it.' After five years' work, he allowed himself to speculate on the subject, and drew up some short notes; these he enlarged in 1844 into a sketch of the conclusions which then seemed to him probable: and 'from that period,' he adds, 'to the present day, I have steadily pursued the same object.' This was written in 1859; but it would remain substantially true up to the present time. Even the monograph now before us on Vegetable Mould and Earthworms has, as we shall see, its bearing on Mr. Darwin's main conception, and has been in great measure inspired by kindred ideas. The same conception is

is equally conspicuous in the other works, which have from time to time borne witness to his extraordinary industry and to his fertility of thought. Not to mention his monographs on particular subjects, such as the Cirripedia,—his volumes on 'the Variation of Animals and Plants under Domestication'; on 'the Various Contrivances by which British and Foreign Orchids are fertilized by Insects'; on 'Insectivorous Plants'; on 'the Movements and Habits of Climbing Plants'; on 'the Effects of Cross and Self-fertilization in the Vegetable Kingdom'; on 'the Different Forms of Flowers in Plants of the same Species;' and on 'the Power of Movement in Plants;'—all combine to illustrate, among other things, two central points: the incessant and infinite interaction of the various parts of nature upon each other, and the manner in which the most conspicuous and most comprehensive results are produced by the gradual accumulation of the slightest influences. It has been justly said that any one of his books, however apparently special its subject, would give an intelligent reader a conception of the main principles which he has developed into the doctrine of Evolution. There are some of his works, besides the 'Origin of Species,' in which this doctrine is carried out to the full, and definitely applied to solve the problem of the origin and descent of man. These volumes, on 'The Descent of Man,' and Selection in relation to Sex,' and on the 'Expression of the Emotions in Man and Animals,'—while among the most interesting of his works, from the wonderful mass of minute and skilled observation which they contain,—are not, as we venture to think, those in which his judgment appears to the best advantage. They seem to us to afford some of the most conspicuous examples in our time of that method of reasoning on natural subjects which Bacon condemned under the name 'anticipatio.' His hope for the progress of science ('Nov. Org.,' i. 104) depended on men being content to ascend, as it were, by a ladder, and by continuous steps, without intermissions or gaps, from particulars to the lower axioms, and from these to the middle ones, in due succession, 'and last of all to the most general ones'—'et postremò demum ad generalissima.' But Mr. Darwin has unfortunately in this class of his works forgotten this last caution; and, notwithstanding the admitted fact that there are numerous steps 'intermissi aut hiulci,' in the ladder of his observations, he has sprung at one bound to the widest generalization conceivable, and has proclaimed the discovery of the ultimate law of natural development. But his vast collection of observations, and very many of his intermediate conclusions, retain all their value and interest, and no such rich storehouse

storehouse of facts respecting the natural history of vegetable, animal, and even human life, has perhaps ever been accumulated by a single man.

Connected, perhaps, with this continuity of thought in Mr. Darwin's writings is another characteristic not less remarkable —the continuity of the observations themselves. Each work is the result of years and tens of years of patient labour; the clue has never been dropped; and, however tortuous and obscure may be the labyrinth through which Mr. Darwin is wandering, he is at length able to trace back for us every step of the process. What is more remarkable, he will hold two or three clues in his hands at the same time, and track out simultaneously different paths through the one great labyrinth of nature. The present work on Earthworms, for instance, has been slowly growing for nearly half a century. As long ago as 1837, Mr. Darwin read a paper before the Geological Society of London 'on the Formation of Mould,' in which he stated the main elements of his present conclusions. It attracted but little regard at the time, being treated, for instance, by a French naturalist as no more than a 'singular theory.' But he has been patiently working at it ever since, and gradually accumulating from all quarters facts which illustrate and confirm his views. It is this which, after all, gives such unique value to his works. Sufficient honour, perhaps, is rarely done to the faculty of patient observation, nor is it realized to what an enormous extent human life and human science are built upon it. Astronomy, for instance, has now, in great measure, reached the stage of a deductive science. For a very wide range of celestial phenomena we possess the primary law, and we can announce what is, from our knowledge of what ought to be, the fact. But it is seldom remembered that this scientific knowledge reposes upon an enormous mass of observations which were accumulated through long generations of mankind. From the ancient Babylonians and Egyptians the heritage of these facts descended through tens of centuries to Greece and Rome; and fifteen centuries more of the Christian Era had to pass before they were sufficiently sifted, arranged, and tested, for a scientific conclusion to be drawn from them. Looking out upon the heavens on some starlight night, there seems something even more wonderful than the triumphs of modern astronomy in the fact that patient watching of those innumerable and apparently confused orbs should have enabled men to disentangle them, to discover a fixed order in their movements, and eventually to know them so well as to be able to predict those movements with more unerring certainty than we can feel with respect to any other occurrences. Mr. Darwin's

Darwin's observations have not yet, as we think, placed us in a position to form a trustworthy scientific theory respecting the natural history of species, similar to the law of gravitation respecting the heavenly bodies. But he has perhaps—and that in great measure by his own herculean labours—placed us in much the same position as that to which astronomy was brought when Kepler had shown, by the laborious observations to which his genius inspired him, that the planets moved in ellipses. We now know, as it were, in what orbits species have moved, and we know, within certain limits, the methods of their variation. To this extent it may be said that we know the fact of evolution. But what are its causes, what is the law which impels the variation of species in known directions—whether it is by an inherent principle of development, like that which determines the growth of an individual, or by the pressure of external circumstances, or by both combined, that the observed results are produced—this, as it seems to us, is as unknown as was the law of gravitation before Newton divined it. But it is Mr. Darwin's achievement to have finally established the facts, and also to have shown that a vast number of them can be accounted for by natural causes now in operation. There remain many, especially in relation to man, which have not thus been explained, and it is rash and unscientific to assume, without direct evidence, that they can be so. This, as we think, is Mr. Darwin's error. His strength is exhibited in the wonderful grasp with which he has brought all the facts in question together, with which he has arranged and organized them, and has revealed to us, with a clearness which had never before been approached, if not the causes which determine the order of natural history, at least that order itself. What he has done, to recur to the illustration first offered, may be said to be, that he has abolished the kind of Ptolemaic theory of natural history which previously prevailed, and has established a Copernican theory, substituting for an ingenious artificial account of the order of nature one which corresponds to the actual facts. But it is another thing to make the further step which was made by Newton, in the discovery of a universal law, and it is this which, as we believe, has not yet been done.

But to turn to the particular volume before us, the reader will find in it a condensed display of all these characteristic qualities. Perhaps, indeed, part of its excellence is due to a legitimate exercise of the very quality, which in another respect Mr. Darwin seems to us to have unduly indulged. Notwithstanding what we have said above in depreciation of the mental habit which Bacon stigmatized as 'anticipation,' it must be

be admitted that Mr. Darwin has abundantly justified the employment, in its due place, of what Professor Tyndall has described as the function of the Imagination in Science. A more conspicuous exercise of the scientific imagination than that which gave rise to this book cannot easily be conceived. It appears from it that at the very commencement of his scientific career, fifty years ago, some casual observations suggested to Mr. Darwin the idea, that worms were possibly among the most considerable forces in nature, and that they had played a very large part in the natural history of the world. To how few persons could such a conception have occurred! It would be one thing if, as the result of years of laborious enquiry, the conviction had been slowly forced on a naturalist, that worms had played this part in nature. But it is another thing, that Mr. Darwin divined it from a few facts and proceeded to work out the evidence for it. He acknowledges, indeed, with his usual justice, that he received the first suggestion of the idea from Mr. Wedgwood, of Maer Hall, in Staffordshire. But Mr. Wedgwood seems to have applied it only to the explanation of the sinking beneath the earth of bodies lying on its surface, while Mr. Darwin appears at once to have sprung to the imagination '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,' so that the term 'animal mould' would be in some respects more appropriate than that of 'vegetable mould.' Mr. Darwin must have been already deeply imbued with the cardinal idea of his subsequent investigations, to have entertained such a conception. Not merely to unscientific, but to scientific men, the earth-worm had hitherto appeared one of the most insignificant of all creatures. As we have already noticed, distinguished French naturalists almost scorned Mr. Darwin's suggestion when it was first propounded. Even as late as 1869, Mr. Darwin tells us, Mr. Fish, in the 'Gardeners' Chronicle,' rejected his 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. 'Considering,' said Mr. Fish, 'their weakness and their size, the work they are represented to have accomplished is stupendous.' Mr. Darwin's observation on this objection is characteristic and instructive, and indicates the connection of his study of this subject with the main work of his life. 'Here,' he says, '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

principle of evolution.' But if it was rash to doubt in 1869 a theory supported by Mr. Darwin's authority, and confirmed by the striking proofs he had already adduced of the immense effect produced in nature by the accumulated effect of small causes, it was none the less one of the boldest strokes of the imaginative faculty—unless we should call it an extraordinary exercise of the scientific instinct—to discern in the burrows and the castings of worms the instruments of some of the most important of all the changes which the surface of the earth undergoes. It may be doubted whether anything in Mr. Darwin's work exceeds in brilliancy this faithful conception; and it is only equalled in merit by the patience which through all the subsequent years has gradually accumulated the evidence, at length, in his old age, presented to the world in this fascinating volume. Bacon has somewhere said that 'God hangs the heaviest weights on the finest wires,' but we know of no such illustration of the truth as is afforded by the facts here established.

Mr. Darwin commences with an account of the habits of the humble creatures whose feats he is to describe. They seem to flourish wherever there is any moisture in the soil. A layer, though a thin one, of fine earth, Mr. Darwin believes to be necessary for their existence; and he also thinks the mere compression of the soil in some degree favourable to them. They must be considered terrestrial animals, but they are in one sense semi-aquatic. Exposure to the dry air of a room for only a single night has been found fatal to them, whereas several large worms have been kept alive for nearly four months completely submerged in water. When the ground is dry in summer, or when it is frozen in winter, they penetrate to a considerable depth, and cease to work. They crawl about chiefly at night, though usually with their tails still inserted in their burrows. Their bodies are armed with short bristles, slightly reflexed; and with the aid of these bristles and an expansion of their tails they hold so fast, that they can seldom be dragged out of the ground without being torn to pieces. Mr. Darwin confirms, however, the observation of White of Selborne, that they do completely leave their burrows by night in certain circumstances. In the morning, after heavy rain, the film of mud, or of fine sand, over gravel walks is often plainly marked with their tracks. Mr. Darwin has noticed this from August to May, and he thinks it probably occurs during the remaining two months of the year when they are wet. He doubts, from what he has observed of their organs of sense, whether a worm could find its way back to its burrow after having once left it; and he thinks that they leave their burrows,

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as it were, on a voyage of discovery, and thus find new homes. They have one habit to which they are greatly addicted, and which seems a curious exception to the law of the development of habits with a view to self-preservation. They will lie for hours almost motionless close beneath the mouths of their burrows. Mr. Darwin does not think they do this for the sake of breathing fresh air, since, as we have seen, they can live a long time under water; and he believes they lie near the surface for the sake of warmth, especially in the morning. But the result is that they present themselves in the most convenient position to the birds which feed on them. 'This habit,' says Mr. Darwin, '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 could not be done unless they lay close to the surface. We cannot but observe, in passing, that if this be so, it would seem that we have an instance of a tendency which is unaffected by 'the struggle for existence.' The battle between worms and birds has not led, as might have been expected on the principles of Natural Selection, to the development of a race of worms who do not lie near the mouths of their burrows. They continue to present themselves as food for their foes; and they multiply in sufficient numbers to render the devastation thus wrought among them insignificant. It may well be surmised that their productive power of species is in many other instances similarly sufficient to render unnecessary, and even to supersede altogether, the development of special characteristics for the purpose of maintaining the 'struggle for existence.' In such species there is practically no struggle for existence. No matter how many individuals may be destroyed, there are abundantly sufficient remaining to perpetuate the race without any modifications. We should imagine, for instance, that nothing would be more superfluous than for herrings, as a species, to disturb themselves about the struggle for existence. They solve the problem by an unlimited capacity for breeding.

The structure of these obscure creatures is far more complicated than would be supposed by any one but a naturalist. The body of a large worm, we are told, consists of from 100 to 200 almost cylindrical rings or segments, each furnished with minute bristles, and the muscular system is well developed. The mouth, which is at one end of the body, has a little lip for prehension. Behind it is a pharynx, which can be pushed forward at pleasure, and which worms expand for the purpose of enlarging their holes as they burrow into the ground. Behind this

this is a long œsophagus, in which there are three pairs of large glands, which Mr. Darwin says 'are highly remarkable, for nothing like them is known in any other animal.' They secrete a surprising amount of carbonate of lime, and, although their use is not certain, 'it is probable that they primarily serve as organs of excretion, and secondarily as an aid to digestion.' Worms consume many fallen leaves, and these have been sometimes known to contain as much as 72 per cent. of lime. Unless, therefore, there were some means for excreting this earth, worms would be liable to become overcharged with it. Accordingly, large concretions of carbonate of lime are found in these glands—so large, that 'how they escape from the gland is a marvel'; but that they do escape is certain, for they are often found in the gizzard, intestines, and in the castings of worms. But besides this use, Mr. Darwin deems it highly probable that the calciferous discharge from the glands into the alimentary canal of worms serves to neutralize the acids which are generated within it by the half-decayed leaves they consume. The œsophagus ends in a crop, and behind this is a gizzard, in which grains of sand and small stones may generally be found; and it is probable that these serve, like millstones, to triturate the food. The gizzard leads to the intestine, which runs in a straight course to the vent at the posterior end of the body, and this intestine again presents a remarkable structure. The circulatory system and the nervous system are both fairly well developed. Worms possess no respiratory organs, but breathe by their skin. They are destitute of eyes; but are not insensible to light, which affects them partly by its intensity, and partly by its duration; and when a sudden blaze of light is directed upon a worm, it will sometimes dart like a rabbit into its burrow. They are thus enabled to distinguish between day and night, so as to escape danger from the many animals which would prey upon them by day. They possess no sense of hearing, and when placed on a table close to the keys of a piano, which was played as loudly as possible, they remained perfectly quiet; but, though they are indifferent to modulations in the air, they are extremely sensitive to vibrations in any solid object. The following passage is a characteristic instance of the many curious experiments which Mr. Darwin has made upon them (p. 27):—

'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

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.'

Indeed, of all their senses that of touch seems the most highly developed; and Mr. Darwin seems inclined to believe that, by moving about the anterior extremity of its body as an organ of touch, a worm is enabled to gain a general notion of the form of an object. Their sense of smell is feeble; but they seem to be able to discover by means of it strong-smelling foods, of which they are fond, such as onions and decayed cabbage-leaves. In respect of food, however, they are omnivorous. Their importance in the economy of nature depends mainly on the fact that they swallow an extraordinary quantity of earth, extracting from it any digestible matter which it may contain. They also consume a large quantity of half-decayed leaves of all kinds, and fresh leaves also. They will eat sugar and liquorice, dry starch, raw and roasted meat, and above all raw fat. They are, moreover, cannibals, for Mr. Darwin found that two halves of a dead worm, placed in their pots, were dragged into their burrows and gnawed. However, they live chiefly on half-decayed leaves, which they moisten before devouring with a fluid which they secrete; the effect is to disintegrate the leaves, and thus partially to digest them; and Mr. Darwin knows no other instance of partial digestion outside the stomach.

But the most curious point in their habits, and that which Mr. Darwin says occasioned him most surprise, is the apparent intelligence they display in seizing leaves and other kindred objects. They use them not only as food, but for the purpose of plugging up the mouths of their burrows. This is one of their strongest instincts, and very young worms exhibit it. They will use for this purpose not only leaves, but decayed twigs of trees, bits of paper, feathers, tufts of wool, and horse-hairs. Many more leaves are sometimes collected over the mouth of a burrow than can be used, and a small pile of unused leaves is thus left like a roof over those which have been partly dragged

dragged in. Each leaf is drawn in exteriorly to the first one, until all are closely folded and pressed together. The interstices between these leaves are often filled up with moist viscid earth ejected from their bodies, and thus the mouths of the burrows are securely plugged; but the leaves are also used for the sake of lining the upper part of the burrows, and of thus, as it would seem, protecting the worms from contact with the cold earth. Where they cannot obtain leaves for these purposes, they will often protect the mouths of their burrows by little heaps of stones, and a stone weighing as much as two ounces has thus been dragged over a gravel walk. Mr. Darwin suggests several possible objects for this instinct. The plugs or piles of stones may conceal their burrows from scolopenders, which are said to be their bitterest enemies; or they may thus be enabled with greater safety to indulge their habit, already mentioned, of lying close to the mouths of their burrows; or lastly, they may thus protect themselves from the cold air at night; and from observation of them when kept in pots, Mr. Darwin is inclined to believe that the latter is the real reason. The most remarkable part of the practice, however, is, as we have said, the intelligence displayed in the process. Mr. Darwin introduces the subject by the following parallel (p. 64):—

'If a man had to plug up a small cylindrical hole, with such objects as leaves, petioles, or twigs, he would drag or push them in by their pointed ends; but if these objects were very thin relatively to the size of the hole, he would probably insert some by their thicker or broader ends. The guide in his case would be intelligence. It seemed therefore worth while to observe carefully how worms dragged leaves into their burrows; whether by their tips or bases or middle parts. It seemed more especially desirable to do this in the case of plants not natives to our country; for although the habit of dragging leaves into their burrows is undoubtedly instinctive with worms, yet instinct could not tell them how to act in the case of leaves about which their progenitors knew nothing. If, moreover, worms acted solely through instinct or an unvarying inherited impulse, they would draw all kinds of leaves into their burrows in the same manner. If they have no such definite instinct, we might expect that chance would determine whether the tip, base, or middle, was seized. If both these alternatives are excluded, intelligence alone is left; unless the worm in each case first tries many different methods, and follows that alone which proves possible or the most easy; but to act in this manner and to try different methods makes a near approach to intelligence.'

To apply this test, in the first place 227 withered leaves of various kinds, but mostly of English plants, were pulled out of worm-burrows in several places. Of these, 181 had been drawn

drawn into the burrows by or near their tips; 20 had been drawn in by their bases, and 26 had been seized near the middle. This exhibits the general rule; but worms will break through this habit of avoiding the footstalk, if that part of the leaf happens to offer them the most convenient or otherwise most desirable means for drawing leaves into their burrows. Rhododendron leaves, for instance, are often narrower towards the base than towards the apex; and of 91 of these leaves, which had been dragged by worms into their burrows, two-thirds had been drawn in by the base or footstalk; so that, although the worms could not have inherited any familiarity with this plant, they judged at once with a considerable degree of correctness how best to drag its withered leaves into their holes. A still more curious case was their treatment of some pine-leaves, which consist of two needles united to a common base. Of course, if the worm seized one of these needles alone, the other would catch against the ground. Accordingly they are almost invariably drawn into the burrows by the common base. Watching them by night, it seemed to Mr. Darwin and his son as if the worms instantly perceived as soon as they had seized a leaf in the proper manner. Once a leaf stood nearly upright, with the points of the needles partly inserted into a burrow; 'and then the worm reared itself up and seized the base, which was dragged into the mouth of the burrow by bowing the whole leaf.' But here we meet with a striking instance of the caution and thoroughness of Mr. Darwin's experiments. He prepared these pine-leaves in such a manner that it was equally convenient to the worms to drag them in by their base or by their apex, expecting that when the obstacle of the double needles had been removed, the worms would have fallen back upon their usual habit of seizing the leaves by their apex. But they still attacked the base; and Mr. Darwin is thus led to conclude, that with pine-leaves there must be something attractive to worms in the base. Not content with these and other experiments with leaves, he made a large number of elongated triangles of writing-paper, and observed with the utmost minuteness how these were seized by the worms. The general result was that 62 per cent. were seized near the apex, 15 per cent. by the middle part, and 23 per cent. near the base. There certainly seems justice in the conclusion that these various objects are 'seized in too uniform a manner, and from causes which we can generally understand, for the result to be attributed to mere chance,' and that we must therefore admit that worms exercise some degree of intelligence in the process. This result is the more remarkable, as many higher animals exhibit

exhibit no similar capacity for adapting means to circumstances. 'Ants, for instance, may be seen vainly trying to drag an object transversely to their course, which could be easily drawn longitudinally;' and even a beaver will follow its instinct in a senseless and purposeless manner, cutting up logs of wood and dragging them about, though there is no water to dam up. In short, to quote Mr. Darwin's summing up of this interesting discussion (p. 98):—

'As chance does not determine the manner in which objects are drawn into the burrows, and as the existence of specialized 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 organization, possess some degree of intelligence. This will strike every one 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 worker-ant.'

It remains, in giving an account of the habits of these wonderful creatures, to mention the way in which they excavate their burrows, for upon this their position in natural history principally depends. They effect this excavation in two ways; by pushing away the earth on all sides, and by swallowing it. In the first case, the worm stretches out its attenuated head into any little crevice or hole, and then pushes its pharynx forward into this part of its body, which thus swells and pushes away the earth; so that it uses the anterior extremity of its body as a wedge. But where worms cannot penetrate in this way, they swallow the earth and eject it from the vent at the end of their bodies. Doubts have been expressed by some observers whether worms ever swallow earth solely for the purpose of making their burrows; but the observations made by Mr. Darwin leave no doubt of the fact. Nevertheless it seems to him certain, that they swallow a larger quantity for the sake of extracting any nutritious matter which it may contain than for making their burrows. There is evidence of their existing for at least considerable periods of time solely on the organic matter contained in the earth. It may be true, as one German naturalist concludes, that they could hardly live in ordinary vegetable mould, though the nutriment they would derive from leaf mould is unquestionable. But, as we have seen, they are omnivorous, and ordinary mould, Mr. Darwin observes (p. 109), can

can hardly fail to contain many 'ova, larvæ, and small living or dead creatures, spores of cryptogamic plants, and micrococci, such as those which give rise to saltpetre. These various organisms, together with some cellulose from any leaves and plants not utterly decayed, might well account for such large quantities of mould being swallowed by worms.'

In illustration he mentions the interesting fact that 'certain species of Utricularia, which grow in damp places in the tropics, possess bladders beautifully constructed for catching minute subterranean animals; and these traps would not have been developed unless many small animals inhabited such soil.'

The burrows thus formed are very far from being mere holes, and are really somewhat remarkable constructions. In dry weather or severe cold, they are sometimes carried to a considerable depth. In Scotland they have been observed to run to a depth of from seven to eight feet, and Mr. Darwin has often met with worms at depths of from three to four feet. The burrows run down perpendicularly, or, more commonly, a little obliquely, and they rarely branch. Mr. Darwin believes that they are invariably lined with a layer of fine dark-coloured earth, which is voided by the worms. This lining becomes very compact and smooth when nearly dry, and closely fits the worm's body. The bristles which project from the body on all sides have thus excellent points of support, and the burrow is well adapted for the rapid movement of the animal. Mr. Darwin also thinks that the lining serves to strengthen the walls, and perhaps saves the worm's body from being scratched. He is led to this opinion because several burrows, which passed through a layer of sifted coal-cinders spread over turf to a thickness of an inch and a half, had been thus lined to an unusual thickness. The worms seemed to have pushed the cinders away on all sides, and not to have swallowed any of them. Towards the mouth, the burrows are also often lined with leaves for a length of several inches, and these are sometimes so plastered together by viscid castings as to form coherent structures. Mr. Darwin succeeded in removing one of these with only a little earth adhering to it. It consisted of a slightly curved cylindrical case, and in one point the worms had shown special skill. The leaves in this instance were those of the Scotch fir, and the sharp points of its needles had been pressed into the lining of voided earth. It has been already mentioned that worms are fond of remaining close to the mouths of their burrows, and it would almost seem as if these basket-like structures were expressly designed for their comfort in this position.

position. The burrows, when deep, sometimes end in a small chamber, and it would be interesting to enquire whether this is connected with another fact mentioned by Mr. Darwin, that they have the power of turning round in their closely-fitting burrows. There can be no doubt of this fact, for when they come to the surface to eject earth, their tail protrudes, but when they collect leaves their head protrudes. It is rash to make a suggestion which has not been anticipated by Mr. Darwin himself; but if they twisted round at the bottom of their burrows for this purpose, they would naturally produce such a 'little enlargement or chamber' as he describes.

Such are the creatures, whose agency in modifying the surface of the earth it is Mr. Darwin's object to elucidate in this work. They are found in all parts of the world, and some of the genera have an enormous range. Their agency is therefore practically universal, and the facts Mr. Darwin establishes have a proportionately wide application. The question is, to what it practically amounts; and to determine this by indisputable evidence was Mr. Darwin's main design. The interesting details we have sketched respecting the habits of worms are merely incidental and introductory, the main point at issue between Mr. Darwin and his previous critics being whether, as a matter of fact, worms perform the immense amount of work with which he was disposed to credit them. Instead, therefore, of leaving the matter to conjecture and deduction, he determined to ascertain by direct experiment what amount of earth worms bring up to the surface of the ground. With this view he resolved to weigh all the castings thrown up within a given time in a measured space, instead of being content with ascertaining the rate at which objects left on the surface were buried. There can be no question of the conclusiveness of such evidence, or of the firm basis which it was calculated to afford for Mr. Darwin's subsequent deductions. Accordingly, he ascertained the weight of the castings thrown up at the mouths of single burrows in various situations, the whole of them appearing to have been ejected in no long time, as was certainly the case in several instances; the castings, moreover, being carefully dried. On a Kent down, with a subsoil of red clay, full of flints, and overlying the chalk, the largest casting weighed 3·98 ounces. In three other similar cases they weighed 3·87, 1·22, and ·7 ounces respectively; but in the latter instance the casting had suffered some loss of weight from being exposed during a considerable length of time to rain. Near Nice in France, the average weight of twelve castings of ordinary dimensions was 1·37 ounces. In Lower Bengal the average weight of twenty-two castings was 1·24 ounces,

1·24 ounces, the heaviest being 2·09 ounces. In the Nilgiri Mountains of South India the average weight of the five largest castings collected was 3·15 ounces, one being as much as 4·34 ounces. Thus fresh castings at the mouth of a single burrow were found generally to exceed an ounce in weight after being dried, and sometimes nearly reached a quarter of a pound. The largest castings in England were found on very poor pasture-land, and it would seem that worms have to swallow a greater amount of earth on poor than on rich land, in order to obtain sufficient nutriment. The amount to which these castings accumulate within a given space and time is next shown. In a field at the bottom of a valley in the chalk, a square yard was measured, at a spot where large castings abounded, and it was found that within forty-five days the castings within this space weighed 1 lb. 13½ oz. Now worms do not work in dry weather during the summer, or in winter during severe frosts, and therefore, taking a very low estimate, Mr. Darwin is content to assume for the purpose of calculation that they work for only half the year. But, on this assumption, they would eject during the year in the field in question 8·387* pounds of earth per square yard, or no less than 18·12 tons per acre. Castings similarly collected near Nice within about a year on a square foot of surface showed an annual amount equivalent to 14·58 tons per acre. Castings similarly collected on an old terrace near Leith Hill, in Surrey, were found annually equivalent to 7·58 tons per acre, and others collected at a different spot in the same neighbourhood represented an annual amount of 16·1 tons per acre. The amount of castings such as these in the last two cases, if spread evenly over the surface of the ground, would make in the course of a single year layers amounting to ·09 inch and 1·429 inches respectively; or, in round numbers, the thickness in the former case would amount in ten years to nearly 1 inch, and in the second to an inch and a half.

These amounts are next to be compared with observations of the rate at which small objects left on the surfaces of grass-fields become buried. Two instances will suffice to illustrate the method of observation; and we will give them in Mr. Darwin's words (pp. 130 and 143).

'Near Maer Hall in Staffordshire, quick-lime 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

* The figures as printed in the 2nd edition are 83·87. But this is an unquestionable error. If we take 8·387, it corresponds exactly to the calculated amount per acre in tons; and answers to the assumption of the worms working, not indeed for exactly half a year, but for about 200 days.

field in the beginning of October 1837; and the sections showed a layer of turf, formed by the matted roots of the grasses, ½ 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 three or four years, the cinders formed a line of black spots round the holes, at a depth of one 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 among 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 4¾ 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, we will say by 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.'

* * * * *

'A field, which adjoins the one just described, slopes in one part rather steeply (viz., at from 10° to 15°); this part was last ploughed in 1841, was then harrowed and left to become pasture-land. For several years it was clothed with an extremely scant vegetation, and was so thickly covered with small and large flints (some of them half as large as a child's head) that the field was always called by my sons "the stony field." When they ran down the slope the stones clattered together. I remember doubting whether I should live to see these larger flints covered with vegetable mould 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 (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. To anyone who remembered the appearance of the field in 1842, the transformation was wonderful. This 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. In the year 1871 a trench was dug on the above slope, and the blades of grass were cut off close to the roots, so that the thickness of the turf and of the vegetable mould could be measured accurately. The turf was rather less than half an inch, and the mould, which did not contain any stones, 2½ inches in thickness. Beneath this lay coarse clayey earth full of flints, like that in any of the neighbouring ploughed fields. This coarse earth easily fell apart from the overlying mould when a spit

spit was lifted up. The average rate of accumulation of the mould during the whole thirty years was only ·083 inch per year (*i.e.* nearly one inch in twelve years); but the rate must have been much slower at first, and afterwards considerably quicker.'

As a summary of several experiments of this kind, Mr. Darwin states that the thickness of the mould accumulated over objects left on the surface in the course of ten years was in one case 2·2 inches, in another nearly 1·9 inches, in another 2·1 inches, in another 2·2 inches, and in a fourth, where the soil had for some years been in a condition unfavourable to worms, ·83 inch. It will be seen that in all these cases, except the last, the amount of earth brought to the surface during the ten years is somewhat greater than would be estimated from the castings actually weighed; but this may be partly accounted for by the loss which the weighed castings had undergone, and partly by the consideration that earth is brought to the surface by other agencies besides worms, such as burrowing insects, ants and moles; while in some places even the wind, by carrying dust from one place to another, appreciably adds to the surface mould. On the whole, the results obtained by these two independent methods are sufficiently in agreement, and leave no doubt whatever of the large amount of earth which the worms are perpetually bringing up to the surface. It may appear at first surprising that their work should be so uniform as to bury objects in such horizontal layers; but, not to dwell on the action of wind and rain, this seems in great measure accounted for when we learn the extraordinary number of worms which live within a given space. Mr. Darwin quotes a German authority for an estimate that 53,767 worms exist in an acre of land. But this estimate was founded on the number found in gardens, and the same authority believes that about half as many live in cornfields. In short, there seems good evidence that on each acre of land adapted for the work of worms, a weight of more than ten tons of earth annually passes through their bodies and is brought to the surface. In England and Scotland, the land which is cultivated and is well-fitted for these animals has been estimated at 32,000,000 acres. The astonishing, but inevitable conclusion is, that in Great Britain alone no less an amount of earth than 320,000,000 tons is annually brought by worms from underground to the surface of the earth. Well may Mr. Darwin lay stress on such an illustration of the enormous effects which may be produced by continually recurrent causes, however small.

With these facts before us, there can be no difficulty in realizing the part which worms have played in the burial of ancient

ancient buildings. They have thus, as Mr. Darwin observes, been among the best friends of archæologists. Coins, gold ornaments, stone implements, and similar objects, dropped on the surface of the ground, are infallibly buried by their castings in the course of a few years, and are thus safely preserved. They have had, indeed, nothing to do with the gradual accumulation of rubbish over the sites of great cities such as Rome, Paris and London, and such accumulations are sufficiently explained by the mass of matter which is daily brought into a great city for building, fuel, clothing, and food, and by the neglect of scavenging in former times. But Mr. Darwin adduces several interesting instances of the manner in which the floors and other remains of many ancient buildings in England have been so effectually buried, mainly by the action of worms, that they have been discovered by accident alone. It would be necessary to reproduce the drawings which Mr. Darwin furnishes, in order to follow him in detail; but he describes excavations at the sites of Roman villas at Abinger, Chedworth, and Brading, and at the old Roman towns of Silchester and Wroxeter, and shows how they have been covered in the course of centuries with mould of various depths up to 30 inches. Worms have sometimes penetrated the hardest walls in a most surprising manner. In one wall at Silchester, from which much force was needed to wrench out a large flint, the mortar was found friable behind the flint in the middle of the wall, and here there were worm-burrows. In his examination of these ruins, Mr. Darwin was assisted by the late Rev. J. G. Joyce; and we cannot mention this gentleman's name without paying a tribute of respect to his memory, both as an admirable country clergyman, and as one who rendered valuable services to archæological science. Mr. Darwin says that both Mr. Joyce and his own sons were surprised at the blackness of the mortar in this and other instances, and at the presence of the mould in the interior of the walls. Open spaces, however, would almost certainly have been occasionally left between the large and irregular flints, and the worms would fill up these spaces with their castings as soon as they were able to penetrate the wall. Mr. Darwin adds, that Mr. Joyce was at first very sceptical about the amount of work attributed to the worms; but he ended his notes with reference to the wall just mentioned by saying: 'This case caused me more surprise and brought more conviction to me than any other. I should have said, and did say, that it was quite impossible such a wall could have been penetrated by earth-worms.' But the principal method by which worms have buried these buildings appears to have been by simply bringing up earth from below them and depositing

depositing it on their surface, and this has operated in a twofold manner. The withdrawal of earth from below has gradually undermined the supporting ground; the worm-burrows have continually collapsed, and thus the stones have gradually subsided. The process may be seen in the gradual sinking of heavy stones like those at Stonehenge, and a paved walk will often subside in the same manner within the course of a few years. These observations, in short, abundantly bear out Mr. Darwin's conclusions, as stated in the following passage (p. 228):—

'The cases given in this chapter show that worms have played a considerable part in the burial and concealment of several Roman and other old buildings in England; but no doubt the washing down of soil from the neighbouring higher lands, and the deposition of dust, have together aided largely in the work of concealment. Dust would be apt to accumulate wherever old broken-down walls projected a little above the then existing surface, and thus afforded some shelter. The floors of the old rooms, halls, and passages, have generally sunk, partly from the settling of the ground, but chiefly from having been undermined by worms; and the sinking has commonly been greater in the middle than near the walls. The walls themselves, whenever their foundations do not lie at a great depth, have been penetrated and undermined by worms, and have consequently subsided. The unequal subsidence thus caused probably explains the great cracks which may be seen in many ancient walls, as well as their inclination from the perpendicular.'

But perhaps the most remarkable view of the importance of worms is afforded by the part which it is evident from the previous facts that they must have played, and which they must still be playing, in assisting the great geological operation of the denudation of land. Now that the successive geological formations have been mapped and measured, calculations are possible, like one made by Ramsay, who showed in 1846 that in Wales from 9000 to 11,000 feet in thickness of solid rock had been stripped off from the face of the country. Until the last twenty or thirty years, the waves of the sea were regarded as having been the chief agents in this vast work of denudation; but Mr. Darwin says, 'we may now feel sure that air and rain, aided by streams and rivers, are much more powerful agents—that is, if we consider the whole area of the land.' Now the worms partly triturate the earth within their gizzards, and thus reduce it to a condition in which wind and water can act upon it; but they also assist the disintegration of various kinds of rocks by the acids which are generated in their bodies during the digestive process, and which are afterwards expelled with their castings. As the entire mass of the mould of any field, with

with some amount of earth not yet reduced to that condition, passes in the course of a few years through the alimentary canals of worms, minute fragments of rocks of many kinds, and mere particles in the soil, are continually exposed to the chemical decomposition thus mentioned, and the amount of soil tends constantly to increase. By the work of the worms, in fact, the mould is in constant though slow movement, and the particles composing it are thus rubbed together. 'By these means,' Mr. Darwin concludes,

'fresh surfaces are continually exposed to the action of the carbonic acid in the soil, and of the humus-acids which appear to be still more efficient in the decomposition of rocks. The generation of the humus-acids is probably hastened during the digestion of the many half-decayed leaves which worms consume. Thus the particles of earth, forming the superficial mould, are subjected to conditions eminently favourable for their decomposition and disintegration. Moreover, the particles of the softer rocks suffer some amount of mechanical trituration in the muscular gizzards of worms, in which small stones serve as mill-stones.

'The finely levigated castings, when brought to the surface in a moist condition, flow during rainy weather down any moderate slope; and the smaller particles are washed far down even a gently inclined surface. Castings when dry often crumble into small pellets, and these are apt to roll down any sloping surface. Where the land is quite level and is covered with herbage, and where the climate is humid, so that much dust cannot be blown away, it appears at first sight impossible that there should be any appreciable amount of sub-aerial denudation; but worm-castings are blown, especially whilst moist and viscid, in one uniform direction by the prevalent winds which are accompanied by rain. By these several means the superficial mould is prevented from accumulating to a great thickness; and a thick bed of mould checks in many ways the disintegration of the underlying rocks and fragments of rock.'

Among the most careful of the experiments recorded in this volume are some which were designed to estimate the result of the removal of worm-castings by the means above described. It was found that on a surface with a mean inclination of about ten degrees, 240 cubic inches of earth ejected by worms would cross in the course of a year a horizontal line one hundred yards in length, an amount which would weigh in a damp state nearly twelve pounds. A considerable amount of earth is thus continually moving down each side of every valley, and in time reaches its bed and is carried by the river flowing through it into the ocean. It is known from the amount of sediment annually discharged into the sea by the Mississippi, that its enormous drainage area is being steadily lowered

lowered by ·00263 of an inch each year—a rate which would suffice in four and a half million years to lower the whole area to the level of the seashore. So that, if a small fraction of the layer of fine earth 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.'

Not less interesting and useful, however, though on a less stupendous scale, is the work performed by worms in preparing the ground for cultivation. By periodically exposing the mould to the air, by sifting it so that no stones larger than the particles which they can swallow are left in it, and by mingling the whole intimately together, they do the very work which a gardener would prescribe in preparing fine soil for his choicest plants. 'The bones of dead animals, the harder parts of insects, the shells of land molluscs, leaves and twigs, 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.' The leaves worms drag into their burrows are torn into the finest shreds, partially digested, saturated with their secretions, and then commingled with earth; and it is this earth which forms the so-called vegetable mould. Add to this, that worm-burrows very probably aid materially in the drainage of the soil, allow the air to penetrate deeply into the ground, and facilitate the downward passage of roots. Seeds, moreover, often owe their germination to having been covered by castings, and others are buried until they are accidentally uncovered at some future time, and then germinate. Not the least striking passage in the book is the following paragraph, with which Mr. Darwin concludes it:—

'When we behold a wide, turf-covered expanse, we should remember that its smoothness, on which so much of its beauty depends, is mainly due to all the inequalities having been slowly levelled by worms. It is a marvellous reflection that the whole of the superficial mould over any such expanse has passed, and will again pass, every few years through the bodies of worms. The plough is one of the most ancient and most valuable of man's inventions; but long before he existed the land was in fact regularly ploughed, and still continues to be thus ploughed, by earth-worms. 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. Some other animals, however, still more lowly organised, namely corals, have done far more conspicuous work in having constructed innumerable reefs and islands in the great oceans; but these are almost confined to the tropical zones.'

Such

Such are the main results of this mature and masterly contribution to Natural History. It will be seen that its excellence and its value consist not merely in the sagacity and genius with which a most unexpected and, as some thought, far-fetched idea has been worked out, but in the patience and persistency with which the idea has been verified by incontestable experiments and observations. Mr. Darwin is here on the strongest ground of his genius. He tells us not merely, as in some other of his writings, what he can conceive may be done by forces of which he can partially follow the operation, but what beyond question actually is done. There can no longer be any doubt that the insignificant creatures, which have been proverbially quoted as types of worthlessness, and degradation, have rendered, and are still rendering, incalculable services to the human race and to the development of the surface of the earth and of the history of the world. The perpetual emblem of mortality and destruction—'The worm is spread under thee and the worms cover thee' (Is. xiv. 11)—is found to be also a regenerative power in nature. We cannot but conclude with one suggestion, which seems naturally to arise out of such a wonderful narrative. Is the accomplishment of such enormous results by an agency so insignificant, but at the same time so exactly adapted to the work to be done, explicable on any other supposition than that of positive design? It is observable that in this book we do not find any suggestion of the influences by which so singular an agency can have been evolved by natural selection. These infinitely numerous little ploughs seem to be expressly provided to prepare the earth for the sustentation of plants and of other animal life, and for no other purpose whatever. We can remember no more vivid illustration of the old argument which infers, from the perfect adaptation of means to ends, the action throughout nature of a Divine wisdom and will.