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803RD ORDINARY GENERAL MEETING.

HELD IN COMMITTEE ROOM B, THE CENTRAL HALL, WESTMINSTER, S.W.1, ON MONDAY, JANUARY 11TH, 1937, AT 4.30 P.M.

ALAN STUART, Esq., M.Sc., F.G.S., IN THE CHAIR.

The Minutes of the Meeting of May 18th, 1936, were read, confirmed, and signed, and the HON. SECRETARY announced the following elections: As Associates, V. E. G. Hussey, Esq., B.A., Commander K. B. M. Churchill, R.N., Major C. E. Salvesen, J.P., and R. S. Timberlake, Esq.

The CHAIRMAN then called on Sir Ambrose Fleming, D.Sc., F.R.S., to read his paper entitled "On Some Methods of Determining the Age of the Earth and their Assumptions."

The meeting was then thrown open to discussion, in which the following took part: Mr. Alan Stuart, Mr. Douglas Dewar, the Rev. Dr. Hart-Davies, Prof. A. S. Eve, C.B., D.Sc., F.R.S., the Rev. H. A. Edwards, L.Th., and Dr. J. Barcroft Anderson.

After a vote of thanks had been passed to Sir Ambrose Fleming, Lt.-Colonel T. C. Skinner moved a vote of thanks to the Chairman, which was passed unanimously.

ON SOME METHODS OF DETERMINING THE AGE OF THE EARTH AND THEIR ASSUMPTIONS.

By SIR AMBROSE FLEMING, F.R.S. (President).

1.—INTRODUCTORY REMARKS.

THE question of the age of the earth is a problem which has engaged much scientific attention of late years because of its importance in relation to the theory of organic evolution. The attempt to look backward or forward in time in regard to natural events is one which has a considerable fascination for mankind, but it is one which requires great caution and restraint. This is especially the case with respect to the great problem of the age of the earth and of the beginnings of life upon it.

In dealing with such questions it is usual to assume that events took place in the past time and causes operated exactly as in the present. It must, however, be borne in mind that the

assumption of an uninterrupted continuity in Nature is an hypothesis and not a certain deduction from facts. In assuming it we are liable to find ourselves building on a foundation of doubtful strength.

In discussing the question at issue we have first to ask from what event or state is this "age" to be calculated? Is it to be reckoned from the time when the earth first began to exist as a separate globe, or from the time when the seas were formed and sedimentary strata laid down, or when life first appeared on the earth?

There seems to be a tendency on the part of some scientific writers to assume that religious thought, based on statements in the book of Genesis, is pledged to the opinion that the date of the Creation of the earth has been fixed by Ussher's Chronology at about 4000 B.C. It is hardly necessary to say here that the genealogical statements in the fifth chapter of Genesis, in conjunction with other data, tell us nothing but the date of appearance of the Adamic man made in the Image of God, and no information is given to us to enable us to interpret the "Days" of creation in terms of our time reckoning in solar years or the date of the "Beginning" mentioned in the first verse of the Bible. Nothing is there stated which can conflict with any certainly ascertained facts of scientific research.

In the first place, then, we may inquire what science has to say about the beginnings of the solar system of which our earth is a small member. The fact that all the planets rotate round the sun in the same direction and also that the spectroscope shows us a large number of chemical elements common to the matter of the earth and sun justifies the hypothesis that the sun and all its planets may once have formed part of a single mass of rarefied incandescent matter in rotation. Its cooling and contraction then caused an increase in angular velocity, and this again, according to the French astronomer Laplace, would have caused rings to be thrown off which broke up and coalesced into planets. But the total angular momentum must have remained constant. We now know that 95 per cent. of this angular momentum of the solar system resides in the orbital revolution of the planet Jupiter. An arithmetic estimate of this shows that the solar nebula could never have had sufficient angular velocity to throw off any rings at all. Hence this hypothesis of Laplace is now abandoned. Then another one originating

with Sir James Jeans, called the Tidal theory, has taken its place. It has been assumed that in the far past some other star approached the mass of matter then forming the solar system and drew out from it a long protuberance or tidal elevation. This being detached broke up into masses of matter revolving round the central sun which formed the planets. In order that this might happen it was necessary that the wandering star should come within a certain distance, neither too large nor too small, of the solar mass or else no permanent protuberance would have been formed, or, on the other hand, the two masses of sun and star might have coalesced or else formed a double star.

The vast distances between the stars compared with their size would render such an exact approach very unlikely, although the greater the age of the stellar universe the greater would be the probability of such a rare event as above described occurring and resulting in the formation of a planetary system.

Mathematical investigation starting from certain assumptions has enabled Sir James Jeans and Dr. Harold Jeffreys to make a very rough estimate that such planetary formation may have taken place between 1,000 and 10,000 million years ago. When we ask for any more definite or less vague estimate we are compelled to start the age of the earth from the time when sedimentary strata began to be formed.

As long as the earth's mass was at a higher temperature than about 100° C., all the water must have existed in the form of dense clouds enveloping an extremely hot earth. Such a condition seems now to exist in the case of the planet Jupiter. Then, when the temperature had fallen sufficiently for the water vapour to be condensed, it fell in terrific rain forming the oceans, lakes and rivers, and beginning the denudation of the igneous rocks and the formation of the stratified or sedimentary rocks.

Some estimates of the time when this event took place are now based on arguments from (i) geological, (ii) geophysical, and (iii) radio-active investigations.

2.—Geological Estimates of the Earth's Age.

At any one place on the earth's surface excavations, artificial or natural, show layers of various kinds of sedimentary rocks superposed on one another, and in a general way it may be said that the uppermost are the most recent. Strata of the same

kind or nature do not extend right round the earth like the coats of an onion. Nowhere can we expose the whole series of sedimentary strata lying one over the other in order of deposition. All that can be done is to compare at different localities the order of two or three types and assume in the absence of disturbance that the uppermost is the youngest.

We have no evidence, however, that strata of the same kind such as the chalk of Southern England and the chalk of Southern India were deposited at the same time. Nevertheless, geologists have been able, as they think, to arrange a series of some 15 or 16 great successive systems, arranged in four main groups or eras called Cainozoic, Mesozoic, Palæozoic, and Archæozoic as regards age, and determine more or less roughly the average thickness of each set or system.

The conclusion is that the total amount of the sedimentary rocks may be from 100,000 to 500,000 feet in thickness produced by aqueous wearing down of primal or igneous rocks, or other strata.

It is then assumed that if we could find out how much sediment is brought down by all the rivers in the world per annum and then divide the weight into the total weight of all the sedimentary strata we should have a number which might be taken to be the overall age of the sedimentary rocks.

But it is at once evident that any assumption of uniformity of deposit as derived from recent data may lead to the most erroneous conclusions. The rate of denudation will depend upon the rate of flow of river water and this upon steepness of channel slope and also upon rainfall, and this last is governed by many indeterminable factors. We know from other facts that there have been many elevations and depressions of continental areas, and hence any attempt to estimate rate of denudation or deposit must be largely guess work. Thus very widely different estimates have been made of the time which the Falls of Niagara have taken to cut their way back along the gorge or channel connecting Lake Erie with Lake Ontario. These lakes are separated by a distance of about 34 miles and the Falls are now about 7 miles from Lake Ontario. Estimates varying from 30,000 to 7,000 years have been given by geologists for the time of this recession. Also estimates varying from 300,000 years to 250 years have been given for the formation of certain stalactite deposits in caves.

Thus in the case of Kent's Cavern at Torquay, Mr. Pengelly, who made a great study of it, asserted that the deposit of 1-inch thickness of stalagmite might have taken 5,000 years. But Professor Boyd Dawkins estimated its rate of growth as a quarter of an inch per annum. Mr. Bruch Clark found in a Buxton cavern stalagmite coating had formed on some iron pipes at the rate of 1 inch in thickness in 4 years.

It is perfectly clear, then, that we are not in possession of any generally agreed scientific modes of geological time measurement, but only with estimates which are based for the most part on individual response to certain evidence, at any rate so far as regards times of denudation or deposit of strata. The great difficulty of any approximation to truth in regard to the rate of deposit of solid matter in stratified rocks or its removal by water power turned attention to the employment of the salinity of the ocean as a geological chronometer.

3.—Determinations of Age by Salinity of the Sea.

It is clear that the oceans of the earth as first formed by the condensation of water vapour must have consisted of fresh water. Ordinary sea water contains about $4\frac{1}{2}$ to 5 pounds of solid matter or a little more in every 100 pounds of water, chiefly chlorides of sodium, potassium, calcium, and magnesium, with some sulphate of magnesium and bicarbonate of soda, and very small amounts of other salts. We then can calculate the percentage of metallic sodium in sea water at present, and this, according to some authorities, is 1·08 per cent., and the total of sodium in all the oceans of the world is estimated at 12,600 billion tons. Then a rough estimate has been made of the amount of sodium brought down per year by all the rivers which is taken as 156 million tons. Lastly an assumption is made as to the uniformity of the deposit rate over millions of years, and the result of dividing 12,600 billion by 156 million is to give 81 million years as the age of the earth from condensation of the oceans. Very similar figures are given by the *United States Geological Survey Bulletin*, as quoted by Mr. D. J. Whitney in his Paper to the Victoria Institute in 1933 (vol. 65, *Transactions of the V.I.*, p. 30). He gives 14,130 billion tons for the sodium content of the ocean and 158 million tons added per year by the rivers, thus giving 89 million years as the age of the oceans.

It is clear that if the method and the measurements are correct we ought to obtain the same age, whether we take sodium or potassium or magnesium as our index. But as a matter of fact the use of potassium gives us only an ocean age of 8·8 million years or only one-tenth of that given by sodium. It is evident, then, that there is something entirely misleading in the figures for age so obtained. This is confirmed if we consider the sulphates rather than the chlorides of the metals above mentioned. We then obtain other quite different figures for the ocean age. Professor Arthur Holmes, in his book *The Age of the Earth* (Benn's Sixpenny Series), dismisses this 89 million years as "hopelessly wrong" on the ground that the estimate of the amount of sodium brought down by the rivers, on which this age is based, is more than the amount contained in the total material denuded, and hence that the age of the ocean so reached is vastly underestimated. But against this we have the opinion of others, such as Mr. D. J. Whitney (*loc. cit.*), stating that the 89 million years is the "outside limit" for the oceanic age by salinity. Professor Holmes gives reasons in the above-named book for considering that this 89 million years should be increased to 330 million years as an appropriate estimate of the age of the oceans, but even this is considered by many to be too short to satisfy the demands of the theory of organic evolution.

It is clear, however, that we have not yet reached any certain basis for agreement. A little consideration will show that there is a source of error which has not been sufficiently considered and that so far from these sea-salinity ages being too short they may, in fact, be too long. The assumption made in obtaining them is that all the salt in the sea has been brought down to it by the rivers, and the age is obtained by dividing the total amount of salt in the sea by the estimated annual contribution of all the rivers. But the sea waves on all the coasts of the world pound up the coastal rocks and dissolve out the soluble matter and the tidal motions carry it out and mix it up. Hence a not inconsiderable amount of salt in the sea may have been contributed to the sea by the action of the sea itself, and the assumption that the only source is by the rivers will then lead to an overestimate of the distance of time at which the sea was first formed. Again we shall note presently that modern computations from radioactive transformations give ages for the earth vastly in excess of the longest obtained from the salinity of the seas. If, then, these

radio-ages are correct, the present oceans of the world have been accumulating salt for far vaster periods of time than 89 million years and they should by now have become as salt as the Dead Sea or even more so. We are not entitled, then, to say that the age of the sea obtained from its salinity is too short and to give preference to the longer ages as formed from radio-active transformations. It may be noted in passing that the shorter ages for the oceans obtained from the potassium and calcium contents may be and probably are partly due to the removal of these elements from the sea water by animal and vegetable matter. There are in sea water an immense number of small organisms called *foramenifera* which make for themselves a coating or house of calcium carbonate, the calcium being obtained from calcium salts dissolved in the sea water. Also the sea weeds or vegetable organisms withdraw the potassium salts to some extent. Hence this diminishes the total amount of potassium and calcium at present in the form of soluble salts in sea water.

4.—Radio-Active Transformations.

We turn, then, to consider the third method of determining geological time, viz., that by radio-active changes of elements.

Very soon after Röntgen had discovered the X-rays and found they could pass through many so-called opaque substances, the French chemist Becquerel noticed that compounds of Uranium had the power of fogging nearby photographic plates even when placed in black paper envelopes. M. and Mdme. Curie, two skilled chemists, soon found that Thorium compounds had the same powers as Uranium, and a long research by them ended in proving that a substance, afterwards called Radium, extracted from Pitchblende, a Uranium ore, had vastly greater but similar powers to Uranium. Then the result of innumerable researches by eminent men proved that both Uranium and Thorium spontaneously produced a series of substances each of which in a time longer or shorter changed into another, the final result in each case being the metal Lead. One of the series of such bodies is the metal Radium. The explanation formulated to explain this phenomena was that a chemical atom consists of a nucleus built up of smaller particles of matter, some called protons having a charge of positive electricity, some called electrons having an equal charge of negative electricity but a mass of only 1/1838·2

of that of the proton. The mass of all the protons in the nucleus taken together gives us the so-called atomic weight. The number of orbital electrons in a neutral atom gives the atomic number.

In atoms with very complex nuclei or of large atomic weight the nucleus of some of them spontaneously breaks up after a certain time; the result is to form a new kind of substance, and this again undergoes a similar change in due course. The time in which half the atoms of any mass of substance break up is called its "life," and it may vary from millions of years to a few seconds. At each of these changes or explosions of the nucleus one or other of two kinds of particles is thrown out. One called an *Alpha* particle is the nucleus of a Helium atom and consists of 4 protons held together by 2 electrons.* If this particle can pick up 2 more electrons it becomes converted into an atom of Helium gas.

The other kind of particle, called a *Beta* particle, is simply an electron. Thus if Uranium with an atomic weight of 238 and atomic number 92 throws out an *Alpha* particle it becomes converted into a substance called Uranium X1. The "life" of Uranium is about 5,000 million years. But Uranium X1 changes into Uranium X2 and that into Uranium II much more quickly by the loss of a *Beta* particle. Then this again loses an *Alpha* particle and changes to Ionium, and finally Ionium changes to Radium. This process of nuclear reduction then continues so that after the loss of 8 *Alpha* particles and 10 electrons the atom of Uranium of weight 238 finally produces an atom of Lead with atomic weight 206 and atomic number 82.

Now it has been found that chemical atoms can exist with similar chemical properties but slightly different atomic weights. Atomic weights are now reckoned on a scale which makes the atomic weight of Oxygen 16. These similar atoms of different atomic weight are called "Isotopes." Whenever an atomic weight comes out as not an integer number it is taken to be a sign that it is a mixture of various isotopes. Thus Chlorine has an atomic weight of 35·46. But it has been shown to be a mixture of two isotopes; one of atomic weight 35 and the other of weight 37. In the same way ordinary commercial lead has an atomic weight of 207·2 and it is said to have three isotopes of

* The *Alpha* particle may also consist of 2 protons and 2 neutrons. The neutron has the same mass as a proton but no electric charge.

weight 206, 207 and 208. The Uranium series ends in the production of 1 atom of lead of atomic weight 206 for every atom of Uranium broken up accompanied by the liberation of 8 atoms of Helium. The Thorium series of transformations ends in the production of Lead of atomic weight 208 and the liberation of 6 atoms of Helium for every atom of Thorium broken up.

One of the most impressive facts connected with the isolation of Radium by Mdme. Curie was the discovery by M. Curie that it maintains itself at a temperature much above that of surrounding matter. This is due to the bombardment of neighbouring atoms by the *Alpha* particles hurled out from the exploding Radium nuclei with a velocity of 12,000 miles per second. All this kinetic energy must be converted into heat. This discovery, and also that radium in small quantities is very widely distributed through the earth's outer strata, created immense interest and was hailed with joy by geologists and naturalists who had been dismayed by a firm previous assertion of Lord Kelvin that the interval of time between the present and that at which the earth's surface was at a temperature of 100°C., at which all organic life on earth was impossible, was not much more than 20 million years. They declared such limits left no sufficient time for organic evolution to act. It was therefore very important for the evolutionists to give, if possible, some valid proof other than mere assertion that the oldest fossil-bearing strata of the earth have ages which are consistent with the demands of an automatic process of evolution for the development of animal life on our globe.

5.—Radio-Active Changes as Chronometers for Geological Time.

The accumulation of knowledge regarding radio-active transformations of matter rendered it hopeful to make applications of it in fixing absolute geological time periods.

Lord Rayleigh made determinations of the amount of Helium generated in various rock and mineral specimens containing Uranium and Thorium by experiments extending over several months. His conclusion was that a kilogram or 1,000 grams of Uranium, equal to about 2¼ lb., would generate 1 litre (=1,000 centimetres cube) of Helium in 9 million years. It will be realised that even with the greatest care there must be some possibility of uncertainty in such a slow rate of generation.

We know that 4 grams of Helium gas occupy a bulk of 22·4 litres at normal pressure (760 mm.) and temperature (0° C.), and also that 32 grams of Helium are created by the destruction of 238·2 grams of Uranium, and results also in the production of 206 grams of Lead. It follows that a million grams of Uranium (about 1 ton) would produce in one year 1/7400 of a gram of Lead of atomic weight 206. That is about 1/500th part of a grain. If, then, we can find out in any Uranium-Lead ore the amount of Lead of atomic weight 206, Pb (206), and also the weight of Uranium (Ur), and if *we assume the accuracy* of the figure 1/7400, we can deduce the age in years starting from the beginning of the transformation from the formula $T = Pb\ (206) \times 7400 \times 10^6/Ur$. Thus in a certain ore quoted by Professor Satterly (*Trans. Devon Assoc.* 1935) a Pitchblende from St. Ives, Cornwall, Ur was 27·59 and Pb(206) was 0·39, thus giving the age as 110 million years.

The question is, however, from what epoch does this 110 million years' start Did the conversion of Uranium to Lead begin even before the detachment of the earth mass from the sun ?

In the above case the whole of the Lead was not of atomic weight 206 but 70 per cent. of it was ordinary Lead. In another sample of ore from Quebec, Canada, the whole of the Lead had an Atomic weight of 206 and the ratio of Lead to Uranium was 10·84 to 73·08, thus giving an age of 1,030 million years. The accuracy of these figures depends, however, upon that of the determination of the Lead ratio, and this again upon the experimental figure for the Helium evolved per year from 1 gram of Uranium, which is an excessively small amount. Furthermore, how can we be sure that the whole of the Lead of atomic weights 206 or 208 has been produced from the Uranium or Thorium ?

The amount of Lead ores in the world is enormous, and this metal has been used from very remote times. Moreover, large deposits of Lead ore in the form of sulphide or oxide are not in contiguity to the Uranium ore deposits such as Pitchblende. Lead is also found native, that is in the metallic condition in the Kirghiz Steppes embedded in hornstone.

The present deposits of Uranium and Thorium ores are quite moderate in extent, and it seems most unlikely that all the lead in the world has been produced *in situ* from the rarer metals by radio-transformation. If that is the case we have no certain

means of proving that all the lead found in contiguity to Uranium and Thorium in any rock specimen has been produced from them. Neither can we say that all Lead comprises only two isotopes of 208 and 206 atomic weight. The method employed as described in Professor A. Holmes' book, *The Age of the Earth*, for calculating the age of the Uranium, Thorium-Lead samples necessitates the assumption that only two isotopes of lead are present in the lead, because the equation is insoluble if more than two isotopes are assumed. Thus if we assume or know that there are only the above two isotopes present and if x denotes the percentage present of 208 lead, and A denotes the mean atomic weight of all the lead then we have the equation

$$208x + 206\ (100–x) = 100\text{A}.$$

This equation can always be solved, no matter what the value of A may be, and it gives us the percentages of the two isotopes present. If, however, we assume three isotopes are present, say of atomic weights 206, 207 and 208, then we should have the equation,

$$208x + 207y + 206\ (100–x–y) = 100\text{A}.$$

This equation with two unknown quantities cannot be solved unless we know the ratio of x to y.

It has recently been found, however, that Lead has 16 isotopes varying in atomic weight from 201 to 216. Hence it may be a very doubtful statement with regard to any rock sample to say that all lead of atomic weight 206 in it is derived by radio-active transformation from Uranium and that of 208 from Thorium and that no other isotope of lead is present. When Thorium, Uranium and Lead are present together in ores and when the average atomic weight of that Lead is known, it is not, then, quite a simple matter to decide how much of that Lead shall be considered as derived from the Uranium and how much from the Thorium present in the sample and how much from neither of them. Neither can we be certain as to the date when each transformation began. Since these Uranium Thorium Lead ores occur in igneous rock formations we are not able to fix with certainty the relation between the calculated age of the Uranium-Lead specimen and that of the stratified rock through which it intrudes, which is, after all, the chief matter of interest. It has

been found that the rate of transformation of Thorium into Lead takes place far more slowly than that of Uranium into Lead. Also that the ages calculated from the Thorium-Lead transformation are in general much lower than those given by the Uranium-Lead transformation. Thus Professor Arthur Holmes, in his book on *The Age of the Earth*, gives several instances of this. In three cases the Uranium-Lead times were 562, 614 and 577 million years, but the Thorium Lead ages from the same mineral samples gave ages of 500, 450 and 410 million years. If two clocks in one house show different times we can conclude certainly that one of them must be, and both may be, wrong. In either case we cannot be certain of knowing from them what children call "the right time." Here, then, we may have two radio-active clocks which show very different times. Professor Holmes puts forward an ingenious explanation, viz., that the Lead of atomic weight 208 has by some means been removed from the ore so that its amount is unduly small, whereas that of atomic weight 206 has not been similarly reduced. With all due respect, it would seem to require a precise confirmation of this before the hypothesis can be accepted.

The upshot of the work so far done on this subject seems to have enabled geologists to append to each geological formation in the stratified series an age in millions of years gradually increasing from the youngest to the oldest of the series. For the Tertiary series an age from 30 to 35 million years is given and for the old Lower Pre-Cambrian an age of 1,260 million years, whilst for what is termed the age of the earth a period of about 1,600 million years is affirmed. The precision of these ages and the manner in which the figures given show a regular progressive advance in magnitude in passing from geological formation to formation recent to oldest raises much doubt in the mind as to the degree to which they correspond to actual fact. The effort of many scientific minds is to find neat, simple, easily understood explanations of natural processes which are or can be considered to be automatic and involve no direct application of a Purposive Will. But the chief characteristic of Nature as we find it is a marked irregularity, and regularity does not prominently present itself. The really important question is whether there are any vital objections to these vast periods of time being asserted as the ages of the geological fossil-bearing strata of the earth?

6.—Conclusions and Assumptions.

We may attempt an answer to the above question by summing up the already mentioned uncertainties regarding radio-active determinations of geological age.

(1) Since all conclusions rest on the accuracy of the fundamental constant, viz., the weight of Lead of atomic weight 206 produced in one year by a million grams of metallic Uranium, which is now taken at 1/7400 or 1/7600 gram, and the similar constant for Thorium and Lead of 208 atomic weight, which is now taken at 1/19500 of a gram, and as the amount of this transformation is very small, it is most necessary that these numbers should be checked by experiments made on many different samples and over as long a time as possible.

(2) No deductions as to the age of Uranium, Thorium, Lead ores can be considered as entirely trustworthy for age determination unless it has been proved by the use of the mass spectrograph or the magneto-optic method that only Lead of atomic weights 206 and 208 are present in the sample tested. Even then there is some degree of uncertainty whether the whole of this Lead has been produced by radio-active transformation from the Uranium and Thorium present in the sample. Unless these facts are certainly known the age may be greatly over estimated.

(3) Even when the above precautions are taken, we have always an uncertainty as to the chronological correspondence between the age of the Uranium, Thorium, Lead mineral sample itself and the age of the stratified rock into which it has intruded. If, for instance, an igneous rock containing Uranium or Thorium intrudes into a sedimentary formation near to the lowest part of the latter, how can we tell at what stage in the "life" of the radio-active mineral specimen or at what stage in the age of the stratified rock this intrusion has taken place? If we cannot definitely ascertain this our conclusion as to the age of the stratified rock may be quite erroneous.

(4) When every care is taken we may still have to explain the great apparent discrepancy between ages of early stratified rocks as indicated by the salinity of the oceans and the much longer periods indicated by the radio-active transformation. Owing to the influence of evolutionary theories, there seems generally to be a tendency to welcome and accept results which give great ages to origins in geological history, whilst any shorter times are

regarded with suspicion and considered to need explanation or rejection.

(5) It is quite possible that between the time when the earth was solidified and began its history as an independent planet revolving round the sun and the time when it had cooled sufficiently for the oceans to be formed and the sedimentary rocks began to be laid down, a very long interval of time may have elapsed. During this pre-sedimentary period the radio-active transformations in the igneous rocks may have been taking place. We have, then, no data fixing the beginnings of these processes. It must also be remembered that Uranium and Thorium have to pass through many stages before they end in Lead.

The question which is most interesting to those who disagree with current opinions on organic evolution is the fixing of the time when animal life began on the earth and especially when rational human life began. It does not help us, then, in the solution of these questions to fix a possible date for the beginning of changes in mineral samples which contain radio-active substances whilst the relation of their age to that of fossil remains in sedimentary strata is still uncertain. In this connection it should be noted that in the far past the amount of radio-active matter in our earth must have been greater, and perhaps vastly greater, than it is at present. If radio-active atoms such as those of Uranium, Thorium, Radium, etc., are being perpetually transformed into non-radio-active atoms such as Lead, and if the process is non-reversible, then it follows that there has been a steady decrease in the number of radio-active atoms present in the earth. In fact, Mdme. Joliot, the daughter of Mdme. Curie, said in 1934 at a Conference in Cambridge that radio-active matter must once have been so abundant on our earth that it would have prevented the appearance of animal life or at least of human life because the radiations from it are destructive of living animal tissue. She also expressed the opinion that there may have been atoms of a far more powerful emission than any now existing on our globe. If this was the case, then it raises the question whether the powerful emanations from one atom may not have assisted and provoked the destruction of others. In short, whether the abundance and power of radio-active matter in the past may not have hastened the rate of transformation or shortened the " life " of such elements as Uranium or Thorium which ultimately transform into Lead. In the absence of proof

to the contrary, it may be quite erroneous to deduce the age of a few isolated specimens of Uranium, Thorium, Lead ore from laboratory experiments made in periods of a few months at the present time and from rates of transformation thus determined to deduce ages of millions of years for these samples or for the strata in which they are found embedded. We know how greatly the "lives" of various radio-active elements differ from each other, ranging from a few seconds or minutes to thousands of millions of years. We do not know the reason for this difference nor why one atom should break up rather than another of the same kind in the same mass. It therefore seems rather a hazardous assumption to make that there has been no variation of life period in the past in radio-active atoms.

It is as if we were to use the birth-rate and death-rate at present prevailing in European countries to determine the population at the time of the Roman Empire without taking note of large possible changes in these rates due to improved sanitation and progress of medical and surgical knowledge in the interval. If these radio-active transformations are to be used as geological clocks, then the *onus* rests on those who use them to prove first that there has been no change in the rate of going of these clocks over spans of time reckoned in millions of years, and that is an impossible achievement. Any omission in this respect endangers entirely our confidence in the numerical results.

The confident assertion of a few eminent scientific men of the validity of the results of these age determinations is sufficient to encourage the general press and popular writers to put them forward as definitely ascertained facts. It can hardly be denied that the readiness on all hands to accept these great ages of strata and ther fossil contents as proved is the outcome of a belief that the widely accepted but unproved doctrine of evolution demands a vast period of time for its operation in generating the animal and human species.

Taking all the arguments together which have been advanced in the foregoing discussion, it would seem that the great ages for the stratified rocks and their fossil contents derived from radio-active measurements must be received with a considerable degree of reserve and not admitted as giving us an unquestionable solution of the problem of the time of first appearance of life upon the earth. On the contrary, the true conclusion seems to be that those large drafts on the bank of time which automatic evolution

demands are not justified in fact but rest on assumptions which have not been demonstrated to be genuine scientific truth.

Discussion.

The Chairman (Alan Stuart, Esq., M.Sc., F.G.S.) said: There are one or two things I would like to say about this most interesting paper, especially where it touches geological science. First of all, in regard to the assumption of uniformitarian principles in geology, which are looked upon with so much suspicion by many people. The geologist is justified by certain facts, that the processes of Nature have moved with velocities roughly comparable to those that are in operation to-day. In fact, if any correction must be made of estimates of the age of the earth based on the rates at which denudation is proceeding, it must be to lengthen the process, for wear and tear of the surface is going on at present somewhat quicker than is the average, as comparatively new and high mountain ranges are exposed to weathering agencies. The fact that in all the many miles of sedimentary rocks which have accumulated, the grains of sand in arenaceous beds are of the same order of size as those on our beaches and in our rivers to-day, argues that the currents of water and the winds blew with about the same velocities as they do to-day.

I feel that, in spite of what Sir Ambrose says about the methods of estimating the age of the earth based upon radio-active transformations, the fact that the results do, in fact, fall largely in the correct order, that is, according to the relative ages of the rocks from which the specimens were taken, that there must be something in the method, and that the results are of the right order. The dating of igneous rocks is done on the same principles as for fossils. If an igneous rock is intruded into a sedimentary one, it can be said that the igneous intrusion is later than the sediment. If the igneous rock has been denuded, and then covered with later sediment, it can be dated more precisely, as younger than the first sediment, and older than the second.

I must say that I am surprised that Sir Ambrose should, in a paper denouncing a method as being liable to great inaccuracies, support his statements by an argument based upon a theory which is not even accepted by a very large number of geologists! Wegener's

theory is highly suspect, and I am sure that no reliable estimates as to length of time in years can be based upon it.

I must say how much I myself have enjoyed listening to the reading of so interesting a paper. It does us good to have our assumptions questioned from time to time. I ask you all to accord to our speaker a very cordial vote of thanks.

Mr. DOUGLAS DEWAR said: I am exceedingly glad that Sir Ambrose Fleming has exposed the absurdity of the dogmatic statements regarding the age of the earth made by scientific men. T. H. Huxley rightly described science as organised common sense. Unfortunately, it is now rapidly becoming arrant nonsense. The wilder any new theory happens to be, the more readily does it seem to be swallowed by so-called scientists. A striking example of this is the way in which eminent men of science have adopted Einstein's theory of relativity, which Professor Eagle, lecturer in mathematics at the University of Manchester, describes as "the most absurd idea that has ever suggested itself to mankind."

Coming now to Sir Ambrose Fleming's remarks. He seems to accept the theory that that oceans were formed by the condensation of water vapour surrounding the earth that took place when the temperature fell. There seems to be a very serious objection to this theory, viz., the very different proportions of the various salts in the ocean and in river water. Julius Roth gives the following proportions in any given volume of water:

	Carbonates	Sulphates	Chlorides
River water ...	80%	13%	7%
Sea water	0·2%	10%	89%

Moreover the proportions of salts are also different in the ocean and in salt lakes. Thus:

PERCENTAGES OF THE TOTAL SALTS.

	Magnesium Sulphate	Magnesium Chloride	Calcium Sulphate
Caspian Sea ...	23·6	4·5	6·9
Ocean	4·7	10·9	3·6

Therefore there is every reason to think that the sea was salt from the very beginning. This fact, of course, very greatly diminishes the age of the oceans as deduced from their sodium content.

Sir Ambrose has dealt very effectively with the objections to the radio-active method of determining the age of rocks. The Chairman says that it is not asserted that these radio-active calculations are accurate. I have not seen Professor Holmes' big book which he mentions, but there is no such warning in the smaller book, *The Age of the Earth*, published by Benn, and these figures are quoted in popular books as if they were firmly established. Thus, on page 28 of MacCabe's *The Riddle of the Universe To-day* (1934), the following words occur: " the fact that we now have four types of men earlier than 200,000 years ago."

A probable source of error lies in the existence of 16 isotopes of lead; for all we know each of these may be an end product of the disintegration of a radio-active element, and some of these elements may have disintegrated so rapidly that they have disappeared from the earth. We know that radium is one of the stages in the disintegration of uranium. For all we know, both uranium and thorium may be stages in the disintegration of such elements of higher atomic number than uranium. That this may well have happened is shown by these facts: (*a*) Ferni reports having made artificially a radio-active element heavier than uranium having an atomic number 93. (*b*) Lawrence has manufactured what he calls radio-sodium by bombarding sodium with atoms of heavy hydrogen. This radio-sodium disintegrates into ordinary magnesium in about 24 hours.

In the paper read before the V.I., to which Sir Ambrose has referred, Mr. Whitney said that the beautiful figures of the ages of the various geological epochs based on radio-active figures are what he called hand-picked. Knowing that much evidence for evolution is " cooked," I determined, when I had time, to go into this matter and did so. I came upon an article in *The American Journal of Science*, by Professor Holmes, in which he states that the lead ratios of several specimens of uraninite from the same geological formation in Gordonia, South Africa, gave lead ratios varying from 0·118 to 0·172, a variation of nearly 50 per cent. Holmes thinks the correct ratio is 0·131, but he has to admit that the ore which gave the highest ratio was specially selected on account of its fresh appearance, and that neither its chemical nor its physical properties are such as to suggest that its lead ratio is too high by over 30 per

cent. Facts such as these show how unreliable this test is and indicate that some of the supposed uranium lead in these ores is not such. The truth is that there is no known reliable test of the age of the earth: all estimates, no matter on what ground they are made, are worthless.

The Rev. Dr. D. E. HART-DAVIES congratulated Sir Ambrose on the vigour and the lucidity with which he had presented the subject. He quoted the dictum of the late Prof. T. H. Huxley: "The ever-recurring tragedy in the realm of science is a beautiful theory killed by an ugly fact." He was amazed when he contemplated the changes in the realm of scientific theory in recent years, especially in chemistry. Less than half a century ago, he used to be impressed with the scientific emphasis which was laid upon the laws of Nature which could never vary, and the constitution of the chemical elements which could never be changed. But now it transpires that elements like uranium can be transmuted into lead! And apparently there is more than one kind or *isotope* of lead! Sir Ambrose had demonstrated the uncertainty of the data upon which calculations of the age of the earth are based. In fact, there is apparently only one date which we can accept with any degree of assurance—a date which occurs in a very ancient volume: "In the beginning." At present it would seem that science can add little thereto.

Professor A. S. EVE, C.B.E., M.A., D.Sc., F.R.S., said: Continuity in Nature has recently received remarkable confirmation in some work by G. H. Henderson, and others, at Dalhousie University. Specks of uranium or thorium in sheets of mica produce haloes of different radii caused by the ejection of the various alpha particles. The size of these rings proves that such particles had the same velocities in distant ages as they have to-day. The rocks are of pre-Cambrian period and were formed probably a few hundred million years ago. The authors, in the January, 1937, number of the *Proceedings of the Royal Society*, justly remark: "The good agreement of the alpha-particle ranges deduced from these ancient haloes with the results of present-day laboratory experiments furnishes striking proof of the invariability of physical laws throughout the vast extent of geological time."

It is possible to select ores of uranium, almost free from thorium, and to determine the atomic weight of the contained lead so as to ascertain whether it is " common " lead or that derived from the uranium-radium family. This has been done for ores from Bohemia and from the Great Bear Lake in Canada. The results indicate that these ores were formed from 700 to 1,200 million years ago.

On the other hand, the existence of uranium in the earth to-day shows that there is an upper limit to the age of the earth. Since uranium decays to half value in a period of the order of a thousand million years, it is fairly safe to say, for example, that the earth is *not* twenty thousand million years old.

Finally, it must be remembered that what are known as " values " —justice, honour, beauty, love, truth, holiness—have nothing to do with physical measurements, or the age of the earth ! They are beyond temporal or material things.

On the other hand, from the point of view of knowledge, that is science, it is important to make successive advances towards truth in all directions. The approach to correct estimates of the ages of strata in the earth is proceeding in a satisfactory manner which might be compared with the gradual discovery of the true distance of the earth from the sun. At present, the indications are that life appeared on this planet many millions of years ago, and it is difficult to conceive of any objection to this view, should it be confirmed by many converging lines of evidence.

Those who find these rather large figures difficult to credit may do well to remember that there was a time not many years ago when it would have been impossible to believe that the national debts of Great Britain and of the United States should each exceed seven thousand million pounds !

Rev. H. A. EDWARDS asked if the action of frost and glacial ice were not the real denuding agents, and suggested that the work of water and wind was more truly that of distributing matter already denuded.

Dr. J. BARCROFT ANDERSON said : Many scientists have addressed you this evening. For over twenty years I have had experience of courts of law as a Crown witness. I am a barrister. I have been considering this question of the age of the earth during the past

twelve years, and I am convinced that there is no evidence by which the physical matter of this earth can be proved to have been in existence for as long as eight thousand years. In Africa there is a verdict, " Absolution from the instance with costs." I believe such to be the only verdict that could be given in any legal attempt to prove a longer existence for the physical matter of this earth.

Written Communication.

Lt.-Col. L. M. Davies, M.A., F.G.S., F.R.S.E., wrote: I have read Sir Ambrose Fleming's paper with much interest. I feel unable to comment upon his criticisms of age as deduced from the relative amounts of radio-active elements and their apparent derivatives found in various rocks, since I do not know enough about that subject; but I agree with his conclusions regarding age-calculations based respectively upon the total amount of sediments now in existence and upon the present salinity of the sea, to which I would add the following considerations:—

1. *As to estimates of age from sediments:*
   (*a*) Most of the rocks now forming land surfaces are themselves composed of sediments; hence rivers and coastal waves are less often engaged in breaking down primitive igneous rocks and thus adding to sediments, than in simply disintegrating and redistributing existing sediments. This is bound to falsify any argument based upon dividing total existing sediments by the present rate of bringing sediments down to the sea. Great " unconformities " commonly exist in stratified sequences, and these are often due to the removal of masses of sediments from older beds and their rearrangement as newer ones. Fragments of older beds are often found in younger ones, and many sedimentary rocks have been broken up and reformed time and again.
   (*b*) Some deposits are not marine but terrestrial: lacustrine, fluviatile, vegetable, glacial and æolian.

These two considerations act in opposite directions: (*a*) increases, while (*b*) decreases, time calculations of this sort. But they unite to add uncertainty to the results obtained by such calculations.

2. *As to deductions from marine salinity :*

(*a*) We must again remember that rivers and coastal waves are not now generally engaged in attacking primitive igneous rocks, but in breaking up and redistributing sedimentary rocks whose associated salts have already been largely removed. In other words, the earliest river and sea action (when the earth's crust was almost exclusively formed of primitive igneous rocks, with full original complement of salts) must have added much more rapidly to ocean salinity than such action does to-day. This would tend greatly to reduce the earth's age as deduced from ocean salinity.

(*b*) It also seems to me that the first waters to settle, as torrents of almost boiling rain, upon the surface of an earth only just sufficiently cooled not to throw them entirely off again as steam, must have had a very solvent effect upon the salts in the heated surface rocks. It seems almost certain, upon any natural theory of earth origin, that the seas must have been very considerably charged with matter in solution before they first assumed fairly permanent form, and before the mechanism of river action was first established. Immense volumes of steam must have been rising all over the world, and floods of heated waters continually pouring over the early land surfaces, long before river and sea actions took their present distinctive forms ; and to neglect the powerful effects of these intermediate operations, and merely to consider annual increments of salt brought down by existing rivers, must tend to exaggerate estimates of age based upon total salts now in solution in the seas.

(*c*) As some offset to the above, we may remember that a quantity of former sea salts is now locked up in land deposits (*e.g.*, the Punjab Salt Range in India) ; and a quantity of sea brine is regularly blown hundreds of miles inland in some districts (*e.g.*, over the Rajputana Desert, whose sands are apparently becoming increasingly saline). On the other hand, these same former sea salts must again

return to the sea under river, etc., action ; and so a fraction of the salts now going down to the sea are probably just returning to it.

Here again the considerations act in opposite directions, although (*a*) and (*b*) would seem greatly to preponderate over (*c*). In my opinion the sea must have acquired salinity at an increasingly greater rate as we go backwards in time ; and any calculations which ignore this are bound to give excessive results.

Professor JOHN SATTERLY, D.Sc., F.R.S. (Can.), wrote : The questions which Sir Ambrose Fleming raises as to the validity of the arguments, based on radio-activity, which give the age of the earth as many millions of years, cannot be definitely answered. In my paper in the Devonshire Transactions of 1935 (Vol. LXVII), I specifically mention the assumptions made, and I also proceeded on the truth of these assumptions. If the assumptions are false, the method is unreliable. But I doubt if Nature is as irregular as Sir Ambrose Fleming suggests. The weather undoubtedly is variable but the vaster motions in the solar system would be called very constant except by the exacting astronomer But once we agree that the processes we use in our calculations require many millions of years for their working, there seems to me no objection to allowing them a thousand million years, since such periods are quite unrealisable to our finite minds. If the radio-active clock is the only one we have and if, as far as it has been tested, it is regular, then we might as well assume it has been regular ever since it started.

We might call our calculated ages the " effective " ages, just as we say the effective temperature of the surface of the sun is about 6,000 degrees C. (*i.e.*, as far as the effects we are mainly interested in, that is, its temperature). For any igneous rock we assume that while it was in the liquid form the lead separated out from the uranium, but, after the rock solidified, the lead remained *in situ*, unless chemically removed. Thus what we call the age of the rock is the age since solidification. The greatest calculated ages are naturally obtained with rocks from which there has been no removal of lead.

The multiplicity of isotopes of lead certainly makes the problem very nearly insoluble and, as calculators, we hope the experimenters on *isotopes* will soon find data more easily manipulated.

I welcome Sir Ambrose Fleming's paper as an endeavour to show that we must proceed cautiously in giving our age estimates. No one knows that better than those actually engaged in the work. Others not so engaged may, too readily, accept our estimates as final and to them Sir Ambrose Fleming's paper should be a valuable corrective.

LECTURER'S REPLY.

The Chairman has expressed his belief in the doctrine of uniformity in geology, and there was no doubt that a majority of geologists at the present day would agree with him. Nevertheless, it is certain that this doctrine is merely an hypothesis, and not yet demonstrated as a truth by unquestionable facts. Broadly speaking, it asserts that geological agencies effecting earth changes have not been more violent or rapid in the past than at the present time and catastrophic events are therefore excluded by it. It is proverbially a difficult thing to prove a negative proposition, namely, that some things or some kind of events have not happened.

We have illustrations in other sciences of the error of applying a doctrine of uniformity. Thus mathematicians are acquainted with many curves which exhibit perfect continuity over a large range except at one or more singular points. Then again, all the great physical discoveries of the last-half century (such as X-rays, radio-activity, the atomicity of electricity, and action and the propagation of long and short electromagnetic waves round the earth) have come as enormous surprises because completely discontinuous with the previously acquired knowledge. To cite yet another illustration, would any zoologist acquainted only with present-day fauna on this earth be justified in applying a doctrine of uniformity and saying that no animals have ever existed larger or more powerful than those now on earth? What would be his astonishment when shown the evidence for the existence of Baluchitherium, an extinct rhinoceros, which was nearly 18 feet high from foot to shoulders and must have weighed 3 or 4 tons! In view of all these vast exceptions to existing things, what justification is there for embracing a doctrine of uniformity which asserts the non-existence of exceptional geological events?

The application of radio-active transformations, employed as clocks to measure geological periods, depends entirely on the

measurement of the extremely small amounts of helium, emitted by the minerals used in experiments lasting at most a few months, and then assuming that this rate has been uniform over millions of years.

Professor A. S. Eve has drawn attention in his remarks to the observations of Mr. G. H. Henderson on the pliochroic haloes in mica as showing that the velocity of the alpha particles ejected from uranium had the same velocity in the past as at present. But that does not give a proof that the emissions were not more numerous in the past, and if so, that would mean a more rapid production of lead of a certain atomic weight as an end product, and, therefore, a shorter time for its generation.

It is perfectly certain that there must have been vastly more radio-active matter in the earth in the past than at present, because it is continually disappearing; and the onus rests on those who use it to measure geological time to prove it has not been more powerful.

I am glad to have the additional criticisms of Mr. Douglas Dewar on possible sources of error in the sea-salinity method of deducing ocean age. The torrential rain which fell on the earth on condensation of the water vapour must have been non-saline, but it fell on a hot earth and would instantly have dissolved out the soluble matter in it, and therefore greatly abbreviated the period of time in gaining the present degree of salinity of the oceans.

The remarks of Col. L. M. Davies also show how untrustworthy are the arguments for age depending on salinity.

With regard to the question put by the Rev. H. A. Edwards as to the relative action of frost, glacial action, water, and wind, as geological implements, I would refer him to the book *Scrambles Amongst the Alps*, by Mr. E. Whymper, who, on p. 268, discusses it, and decides that sun, frost and water had more influence in earth sculpture than glaciers.

The importance of opposing any incompletely proved extensions of the ages of sedimentary strata, especially the recent, lay in the fact that these possibly erroneous conclusions lent support to the theory of human evolution based on the assumption that fragments of skulls, or skeletons of human type, had the same great age as the strata in which they were found embedded. In conclusion, he did not consider the discussion had seriously invalidated any of the conclusions in his paper.

The Chairman expresses surprise that I have mentioned Wegener's theory in connection with the question of the age of the earth, but he will have noticed that I alluded to it in terms of great caution. As, however, I do not wish to weaken my arguments against the methods which are accepted by geologists by including one that is, as the Chairman says, highly suspect, I have, in the revised proof of my paper, excluded the paragraphs referring to Wegener's theory, but I contend that my other arguments against the conclusions drawn have not been effectively answered.