"On the Comparative Value of certain Geological Ages (or groups of Formations) considered as items of Geological Time." By A. C. Ramsay, LL.D., V.P.R.S. Received December 16, 1873*.

There are several methods by which attempts have been made to estimate the value of minor portions of geological time, one of which is founded on calculations of the probable age of deltas, deduced from estimates, more or less accurate, of the quantity of matter annually carried in suspension in rivers, in relation to the area occupied by, and the thickness of, any given delta, such as that of the Mississippi. But as none of these deltas are completed, and as it is unknown when, in the course of terrestrial changes, such completion may take place, no one can, as yet, successfully attempt to apply this kind of knowledge to the amount of time that was occupied in the formation of any of the ancient geological deltas, such, for instance, as that of the Purbeck and Wealden area.

Mr. James Croll has, with considerable success, attempted to measure that portion of geological time which relates to the last great Glacial epoch, founding his conclusions on astronomical data calculated backwards for a million of years; but, as yet, the precise beginning of that epoch has not, in my opinion, been shown; and in the absence of precise data respecting the number of local glacial episodes that may have preceded the last, and the complicated calculations that would be necessary to measure these intervals, even if all these episodes were known, no data are yet accessible for the application of Mr. Croll's method to the greater part of geological time.

There are other ways in which the subject has been approached, but always, of necessity, with a total want of definiteness with regard to their value in the measurement of time. The relative thickness of different formations gives no clue, or only a very slight one, to the solution of the question. Again, when in great and thick formations that spread over wide areas, such as those of Silurian age, an upper part of the series is found to lie quite unconformably on the lower half, it requires but little experience in geology to infer that the unconformity indicates a long lapse of unknown time, unrepresented by strata over a given area. When we link such phenomena of striking unconformity with the disappearance in that area of some of the genera and most of the species in the older strata, and their replacement by new and, to a great extent, generally of closely allied forms, this addition to our data gives no clear help in the absolute measurement of time; for no one as yet has even dared to speculate on the length of time that may have been necessary for the production of results so remarkable as those deduced from the theory of evolution.

I am well aware of much that may be said on the other side of this particular question, such as that the incoming life of the later epoch

* Read Jan. 29, 1874. See *antè*, p. 145.

may be merely the result of migration from some other area or areas, where it lived contemporaneously with the forms imbedded in the older strata; but this by no means gets rid of the question of time, with those who may believe in an hypothesis so uncertain, if it so happen that they also uphold the doctrine of evolution. Looked at in this light, it is obvious that the balance of probability is largely in favour of the greater proportion of the specific forms in a new formation being, in the common meaning of the word, of later date than those of an older formation, on which the newer strata lie unconformably.

Neither is the main question altered by the circumstance that a proportion of Palæozoic genera are, in some parts of the world, occasionally and unexpectedly found along with Mesozoic associates. The fact remains, that changes in life have been produced, during lapses of time, in specific and consequently in generic forms, and that such contrasts of specific, and often of generic, forms are always most striking where marked unconformities are found of a kind which prove that the lower strata had previously been much disturbed, and, as land, had suffered much denudation before being again submerged.

Seeing that speculations such as those enumerated, even when founded on well-established facts, afford but little help in the absolute measurement of geological time, it has occurred to me to look at the question from another point of view, and, in a broad manner, to attempt to estimate the *comparative value* of long and distinct portions of geological time, all of which are represented by important series of formations.

In two papers* I have attempted to show that the Old Red Sandstone, Permian, and New Red series were all deposited, not in an open sea, but in great inland lakes, fresh or salt; and this, taken in connexion with the wide-spreading terrestrial character of much of the Carboniferous series, showed that a great continental age prevailed over much of Europe and in some other regions, from the close of the Upper Silurian epoch to the close of the Trias. The object of the present memoir is to endeavour to show the *value* of the time occupied in the deposition of the formations alluded to above, when compared with the time occupied in the deposition of the Cambrian and Silurian rocks, and of the marine and fresh-water strata which were deposited between the close of the Triassic epoch and the present day.

Partly for the same reasons that I consider the Old Red Sandstone to have been a lake formation, so I think it probable that the red and purple Cambrian rocks of Scotland, Shropshire, and Wales were also chiefly deposited in inland waters, occasionally alternating, as at St. David's, with marine interstratifications, generally marked by grey slaty fossiliferous shales, somewhat in the same manner that several bands con-

* Quarterly Journal Geol. Soc. 1871 (vol. xxvii. pp. 189–198 & 241–254), "On the Physical Relations of the New Red Marl, Rhætic Beds, and Lower Lias," and "On the Red Rocks of England of older date than the Trias."

taining marine fossils are interstratified among the freshwater strata of the Miocene rocks of Switzerland. The probability of these Cambrian strata being partly of lacustrine origin is increased by the occurrence of analogous beds beneath the Silurian strata of the Punjab. There, in what is known as the Salt Range, I am informed by Professor Oldham, are certain red marly and sandy strata believed to be the general equivalents of our purple Cambrian rocks. They contain several thick beds of rock-salt, such as could only have been deposited by supersaturation due to solar evaporation, in the manner that rock-salt seems to have been formed in the Keuper Marl.

If the red Cambrian beds of Britain were partly deposited in inland waters, then it appears likely that our Silurian formations, from the so-called Menevian and Lingula beds upwards, were all deposited under marine conditions between two continental epochs, the close of the first of which is indicated by the nature of the Cambrian rocks, and the beginning of the second by the passage of the Upper Ludlow beds into the base of the Old Red Sandstone.

The physical conditions and long duration of the second continental epoch have been described in my two memoirs on the Red Rocks of England *. The faunas of the Cambrian and Lingula-flag series (which pass conformably into each other), in the comparative paucity of species and their fragmentary character, seem partly to indicate occasional inland shallow seas, possibly comparable to the great inlet of the Bay of Fundy; and this scanty life probably gives but a poor idea of the fuller fauna of the period, hints of which we get from the equivalent formations of Sweden and Bohemia.

In the 'Geology of North Wales' (1866) I have shown that there is a gradual passage between the Cambrian rocks and that portion of the Lingula-flag series now sometimes called Menevian; and, for some years, I have held that the whole series of formations, from the lowest known Cambrian to the top of the Ludlow beds, may, in Britain, be most conveniently classed under three groups: Cambrian, Lingula, and Tremadoc slates form the lowest group, succeeded *unconformably* by the second group, consisting of the Llandeilo and Bala, or Caradoc, beds; above these we have the Llandovery, or May Hill, beds, overlaid by the Wenlock and Ludlow series, the Llandovery beds lying quite *unconformably* on any and all of the formations of older date, from the Cambrian to the Caradoc strata inclusive. With each unconformable break in stratigraphical succession there is a corresponding break in the succession of species, very few (about $2\frac{1}{4}$ per cent. out of 68 known species) passing from the Tremadoc slate into the Llandeilo beds, while

* Also in a lecture subsequently given at the Royal Institution, in which this piece of geological history was put into a more consecutive form, and the substance of which was published in full in the 'Contemporary Review' for July 1873, and (in Paris) in the 'Revue Scientifique' of 14th June.

from the Caradoc Sandstone only about 11 per cent. pass onward into the Upper Silurian strata. These phenomena indicate gaps in geological time unrepresented in the Silurian series of Britain by stratified deposits, and, therefore, also unrepresented by genera and species, that, did we know them, might serve to link together the life of the unconformable formations in a more graduated succession of forms. I recapitulate these opinions, which were in part originally given in my first Presidential Address to the Geological Society (1863), because they bear on the arguments that follow.

Like the Cambrian and Silurian rocks, the Devonian strata have also been classified in three divisions by palæontologists—Lower, Middle, and Upper. In Britain the Lower Devonian fauna is poor in numbers, while it is rich both on the continent of Europe and in North America. In England both the Middle and Upper Devonian fossils are plentiful enough. According to Mr. Etheridge, out of 74 English forms 25 per cent. pass from the Lower into the Middle division; while, out of 268 forms, 25 per cent. pass from the Middle into the Upper Devonian strata. No one has yet proved that these breaks in palæontological succession in the Devonian strata are accompanied by unconformable stratification; but the entire region has never been accurately mapped according to the detailed methods of modern work. However this may turn out, the vast thicknesses of these strata, characterized, like the great Silurian divisions, by three marine faunas, of which the species are mostly distinct, would seem to indicate that the time occupied in their deposition may be fairly compared with that occupied in the accumulation of the Silurian series.

I accept the view that the Old Red Sandstone, as a whole, is the general equivalent in time of the Devonian formations, and probably of a good deal more; for our Lower Devonian beds have no defined base, and, therefore, their precise relation to the British Upper Silurian rocks is unknown, whereas the Upper Ludlow rocks of Wales and its borders pass conformably, and somewhat gradually, into the Old Red Sandstone. If the Devonian rocks be the equivalent of the Old Red Sandstone, it follows that *the time occupied in the deposition of the latter may have been as long as that taken in the deposition of the Cambrian and Silurian series.* This position is greatly strengthened by the thorough specific, and in great part generic, differences in the fossils of the Upper Ludlow and those found in the marine Carboniferous series—differences that, to my mind, indicate a long lapse of time, represented by the deposition of the marine Devonian strata, during which time the Old Red Sandstone was being elsewhere deposited in the large lakes of an ancient continent. These palæontological comparisons seem to me to indicate the vast length of time necessary for the accumulation of these old lacustrine strata.

The next question to be considered is, what time the deposition of the Old Red Sandstone may have taken, when compared with the time

occupied in the deposition of certain members of the Mesozoic series. This may be attempted, partly on stratigraphical and partly on palæontological considerations.

The Lower Lias, at its junction with the Middle Lias, or Marlstone, passes gradually into that formation on the coast-cliffs of Yorkshire, where it is impossible to draw a boundary-line between them, either lithologically or palæontologically. Both contain beds of the same kind of ironstone; and the marly and somewhat sandy clays, through about twenty feet of strata, are similar in character, while a good proportion of the fossils in these passage-beds are common to both formations. Higher up, where the Marlstone becomes more sandy, a suite of fossils, to a great extent new, appears, due apparently to altered conditions of the sea-bottom: the water was shallower and nearer shore; and the topmost strata of sandstone often contain many stem-like bodies, sometimes two or three feet in length, lying on the surfaces of the beds in curved lines, the same stems sometimes bending and crossing each other in a manner that strongly reminds the observer of the broken stalks of Laminarian seaweeds lying on a sandy shore, within close reach of a Laminarian zone. Taking these things into account, there seems to be a much more intimate connexion between the Lower and Middle than there is between the sandy beds of the Middle Lias and the Upper Lias clays of Yorkshire, between which, though there is a perfect conformity, yet a sudden break in lithological character occurs, accompanied by a nearly complete change of fossil species. But the three divisions being conformable to each other, the diversities of fossil contents, more or less, seem to be owing to changes in the physical condition of the sea, caused, in the case of the Upper Lias shale, to sudden depression of the area, which resulted in the deposition of the muddy sediments of the Upper Lias in deeper water than that which received the uppermost sediments of the Marlstone. In the Midland Counties, however, the lithological break between the Middle and Upper Lias is not so sudden, and, in that region, there is a greater community of species.

In Yorkshire the strata immediately above the Lias are of mixed terrestrial, freshwater, and marine beds; but even there and in the middle of England, as shown by Dr. Wright, there is a certain community of fossils in the passage-beds that unite the Upper Lias to the Inferior Oolite. There is no perfect stratigraphical or palæontological break between them; and when we pass in succession through all the remaining members of the truly marine Oolitic series of Gloucestershire, Somersetshire, and Dorsetshire, no real unconformity anywhere exists. The same species of fossils, in greater or less degree, are apt to be common to two or more formations; for example, such community exists between the fossils of the Inferior Oolite and those of the Cornbrash, between those of the freestones of the Inferior and Great Oolites, of the Stonesfield and Collyweston slates, and between those of the Kimmeridge and Portland Oolites.

The change of life in the sea-bottoms was, so to say, partly local, and due more to minor accidental physical causes than to that larger kind of change that is marked by great disturbance of a lower set of strata, long-continued denudation, and the subsequent unconformable deposition of a newer set of beds upon them, thus clearly indicating a long lapse of time unrepresented by stratified deposits over a given area. I therefore infer that the whole of the Liassic and Oolitic series must be looked upon as presenting the various phases of one facies of marine life, belonging to one geological epoch, marked by boundaries below and above which depended on definite physical conditions over a large area. Such a state of things in this Mesozoic epoch is comparable to the changes in the fossil contents of the various subformations of the Cambrian and Lingula-flag series, of which the Tremadoc slates form an upper member; and, in my opinion, the comparison holds good even partly in the manner of their deposition, parts of both series having been locally deposited in waters not marine. On these grounds, therefore, the Jurassic formations, as a whole, may be compared with these early Palæozoic formations *in the length of time occupied for the deposition of each.*

If this inference be just, then, in like manner, they may be compared with the Lower Devonian strata—in England poor in fossils as far as is yet known, but rich on the continent of Europe and in North America; and this (assuming that the Devonian and Old Red Sandstone strata are equivalents) implies that *a lower portion of the Old Red Sandstone may have taken as long for its deposition as the whole of the time occupied in the deposition of the Liassic and Oolitic series.*

It is now generally allowed that the Wealden beds of England are the freshwater and estuarine equivalents of the Lower and Middle Neocomian strata of the Continent, which, in a palæontological sense, may be said, in some degree, to be related to the uppermost Jurassic strata, in so far that a certain proportion of the species of Mollusca are common to both, as shown by Forbes and Godwin-Austen; while, in our own country, from the Lower Greensand (Upper Neocomian) about 14 or 15 per cent. of the fossils pass on into the Upper Cretaceous strata. The same kind of proportion, but in less degree, is found in the relations of the Tremadoc to the Llandeilo and Bala series, and of the latter to the Upper Silurian formations, and also of the Lower to the Middle, and of the Middle to the Upper, Devonian strata. Those last named being representatives in time of parts of the Old Red Sandstone, it follows *that the whole of the time occupied in the deposition of the Old Red Sandstone may have been equal to the whole of the time occupied in the deposition of all the Jurassic, Purbeck, Wealden, and Cretaceous strata collectively.*

The next term of the continental era under review is the Carboniferous epoch, which, in its various conditions and numerous local subdivisions, may with considerable propriety be compared to the Eocene period. The deposits of both are locally of marine, estuarine, freshwater, and

terrestrial origin, and both are clearly connected with long special continental epochs.

Next come the various members of the Permian series, which, if my published conclusions are correct, were partly formed in great inland lakes, analogous to the Caspian Sea and other salt lakes of Central Asia at the present day. Having been deposited in lakes, these subformations may, in this one respect, be compared to the lacustrine strata of Miocene age; and if Gastaldi's conclusions with regard to part of the Italian Miocene beds, and my own opinions respecting part of the Permian strata, be correct, each series shows evidence of having included a glacial episode.

Later than the Permian comes the New Red, or Triassic, series, which, in this region, is not directly connected with the Permian strata, in so far that, where they occur in contact, the New Red Sandstone is generally unconformable to the Permian beds. In the threefold division of the New Red series in France and Germany, the marine beds of the Muschelkalk (unknown in England) may be compared to the Lower or Coralline Crag strata; and, though the Keuper Marls of Britain and of much of the Continent were evidently deposited in inland continental salt lakes, in the region of the Alps the St. Cassian and Hallstadt marine beds, being equivalent to the Keuper Marls, may in this respect be compared to the Red Crag series. No one is, I think, likely to consider that the marine strata of Triassic age took a shorter time in their deposition than the marine beds of the Crag; and, if we take the New Red Sandstone into account, the probability is, that the whole of the Triassic series occupied in their deposition a much longer time than that taken in the deposition of the Pliocene marine strata.

In my opinion, a great Tertiary continental phase began with the Eocene strata; and that continent having undergone many physical changes, has continued, down to the present day, with a certain amount of identity; and an analogous, though not strictly similar, state of things prevailed for an older continent, during the deposition of a large part of the formations treated of in this memoir.

If the method founded on the foregoing comparisons be of value, we then arrive at the general conclusion, *that the great local continental era, which began with the Old Red Sandstone and closed with the New Red Marl, is comparable, in point of geological time, to that occupied in the deposition of the whole of the Mesozoic, or Secondary, series, later than the New Red Marl, and of all the Cainozoic, or Tertiary, formations, and, indeed, of all the time that has elapsed since the beginning of the deposition of the Lias down to the present day.* To attempt to prove this theorem is the special object of this paper; and if I have been successful, the corollary must be deduced that the modern continental era which followed the oceanic submersion of a wide area, during which the greater part of the Chalk was being deposited, has been of much

shorter duration than the older continent mentioned above in italics; and which, to us, seems so ancient, when we think that the Alps and the Jura had then no more than a rudimentary existence.

There are other points that bear on the comparative value of different epochs of geological time. During the older local continental epoch there flourished four distinct floras, those of the Old Red Sandstone, Carboniferous, Permian, and Triassic series. Of these the first three, notwithstanding considerable generic and complete specific differences, may yet be said to be of one Palæozoic type. The Triassic flora, as far as it is known, is of a mixed character, with generic affinities, however, that unite it more closely to the Jurassic flora than to that of the Permian age. The whole series may therefore be considered as resolving itself into two types—the first extending from the Old Red Sandstone to the Permian times, and the second belonging to the Trias.

During the later period that elapsed, from the beginning of the deposition of the Lias down to the present day, we have also four distinct floras—the first of Jurassic type, embracing the little we know of the Neocomian flora; the second, Cretaceous, which, as regards the Upper Cretaceous strata of Aix-la-Chapelle and of Greenland, is to a great extent of modern type; third, an Eocene, and, fourth, a Miocene flora—the last three being closely allied, and the Miocene flora of Europe, in its great features, being nearly indistinguishable, except in species, from the kind of grouping incident to some of the modern floras of the northern hemisphere. The whole of this series may, therefore, in European regions, be also considered as resolving itself into two types—the first Jurassic, and the second extending from the later Cretaceous times to the present day. In this respect, the analogy to the floras of two types of the more ancient continent is obvious; and, in both epochs, this kind of grouping is clearly connected with the lapse of time, which, in my opinion, may for each be of approximately equivalent value.

The evidence derived from terrestrial Vertebrata is not quite so simple. In the Old Red Sandstone none are yet known. In the Carboniferous rocks all the known genera (fourteen in Britain) are Labyrinthodont Amphibia. The same is the case, though the known genera are fewer in number, with the Permian rocks, excepting two land-lizards of the genus *Proterosaurus*. Labyrinthodonts seem to decrease still more in the number of species in the Trias; but Crocodiles appear, together with seven named genera of land-lizards, two genera of Anomodontia (*Dicynodon* and *Rhynchosaurus*), three genera of Deinosauria, and two of Marsupial Mammalia. As far as we yet know, therefore, this ancient continental fauna pretty nearly resolves itself into two types; and, just as the Triassic type of flora passed into Jurassic times, so the Triassic land-fauna does the same. The oldest, or Palæozoic, type (Carboniferous and Permian) is essentially Labyrinthodontian, and the second, or Triassic is, characterized by the appearance of many true land-lizards and other terrestrial reptiles, together with marsupial mammals; and this typical

fauna, as regards genera, with the exception of Labyrinthodontia and the appearance of Pterosauria, is represented, pretty equally, through all the remaining members of the Mesozoic formations, from Jurassic to Cretaceous inclusive. After this comes the great Pachydermatous Mammalian Eocene fauna, and after that the Miocene fauna, which, in its main characters, is of modern type.

The general result is that, from Jurassic to Cretaceous times inclusive, there was a terrestrial fauna in these regions, chiefly Reptilian, Saurian, and Marsupial, and, in so-called Cainozoic or Tertiary times, chiefly Reptilian and Placental. In brief, the old continental epoch that lasted from the beginning of the Old Red Sandstone to the close of the Trias, locally embraces two typical land-faunas—one Carboniferous and Permian, and one Triassic; while the later epoch, from the beginning of the Lias to the present day, also locally contained two typical land-faunas, the latter of which is specially Placental. (See Table.)

I am aware that such inferences are always liable to be disturbed by later discoveries, and I therefore merely offer the above suggestions as being in accordance with present knowledge.

Another point remains. The earliest known marine faunas, those of the Cambrian, Lingula-flag, and Tremadoc beds, include many of the existing classes and orders of marine life, which are much more fully developed in the succeeding Llandeilo and Bala strata, such as Spongida, Annelida, Echinodermata, Crustacea, Polyzoa, Brachiopoda, Lamellibranchiata, Pteropoda, Nucleobranchiata, and Cephalopoda. This important fact was insisted on by Professor Huxley in his Anniversary Address to the Geological Society in 1862. The inference is obvious, that in this earliest known varied life* we find no evidence of its having lived near the beginning of the zoological series. In a broad sense, compared with what must have gone before, both biologically and physically, all the phenomena connected with this old period seem to my mind to be quite of a recent description; and the climates of seas and lands were of the very same kind as those that the world enjoys at the present day—one proof of which, in my opinion, is the existence of great glacial boulder beds in the Lower Silurian strata of Wigtonshire, west of Loch Ryan†.

This conclusion, not generally accepted, has since been confirmed by Professor Geikie and Mr. James Geikie, both with regard to the Wigtonshire strata and to the equivalent beds in Ayrshire. In the words of Darwin, when discussing the imperfection of the geological record of this history, "we possess the last volume alone, relating only to two or three countries;" and the reason why we know so little of pre-Cambrian faunas, and the physical characters of the more ancient formations as originally deposited, is, that, below the Cambrian, strata we get at once involved in a sort of chaos of metamorphic strata.

* Earliest known except the Huronian *Aspidella Terranovica* and the Laurentian *Eozoon Canadense*.

† See Philosophical Magazine, vol. xxix. p. 289, 1865.

The connexion of this question with the principal subject of this paper, that of *the comparative value of different geological eras as items of geological time*, is obvious. I feel that this subject is one of great difficulty; and, as far as I know, this is the first time that any attempt of the kind has been made to solve the problem. If my method be incorrect, it may yet help to suggest a better way to some one else; and in the meanwhile, even if partly heterodox, I hope it may deserve toleration.

Classification of Faunas (Terrestrial, Freshwater, and Estuarine) into Groups.

Formations.	Class.	Order.	Number of Genera.
Old Red Sandstone	.....	.....	No Vertebrata known except fish.
1 Carboniferous	Amphibia...	Labyrinthodontia	11 E.
	,,	,,	3 C.
1 Permian	,,	,,	3 E.
	,,	,,	1 C.
	Reptilia ...	Lacertilia.....	1 E.
2 Trias	Amphibia...	Labyrinthodontia	3 E.
	Reptilia ...	Crocodilia.....	1 E.
	,,	Lacertilia	4 E.
	,,	,,	3 C.
	,,	Anomodontia ...	1 E.
	,,	Deinosauria	2 E.
	,,	,,	1 C.
	Mammalia.	Marsupialia	2 E.
1 Jurassic	Reptilia ...	Chelonia	4 E.
	,,	Crocodilia	4 E.
	,,	,,	1 C.
	,,	Lacertilia	4 E.
	,,	Deinosauria.....	2 E.
	,,	,,	1 C.
	,,	Pterosauria.....	2 E.
	Mammalia.	Marsupialia	15 E.
	,,	,,	1 C.
1 Weald and Neocomian	Reptilia ...	Chelonia	4 E.
	,,	Crocodilia	8 E.
	,,	Deinosauria ...	9 E.
	,,	Pterosauria.....	1 E.
1 Upper Cretaceous	,,	Crocodilia	3 E.
	,,	Pterosauria.....	1 E.
	,,	Lacertilia	9 E.
2 Eocene	,,	Chelonia	4 E.
	,,	Crocodilia	3 E.
	,,	Ophidia	2 E.
	Mammalia.	Pachydermata...	11 E.
2 Miocene	,,	,,	Many more in France.
	,,	,,	No Vertebrata certain in England, but a large Mammalian fauna on the Continent, chiefly of modern type. The Pliocene and Post-Pliocene terrestrial faunas are of course still more modern.

The letter E. means English, C. Continental and not known in England; but as the physical phenomena connected with the Continental strata in which they are found are, in the main, identical with those that affect the English rocks, the European Continental genera are named in this Table.