GEOLOGY
AND THE
HISTORY OF LIFE

AN INAUGURAL LECTURE
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by
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THE CREATION of a new chair of geology within the University of Leicester gives some indication of the place that geology holds in the hierarchy of the sciences. Geology is a junior science. Its roots go deep into the history of human thought, but it did not arise as an independent and cohesive discipline until the dawn of the nineteenth century. In those early days, its rise to eminence was astonishing, and the part it was to play in the emergence of science in the world of learning was not at all that of a child tagging along behind its elders; rather were geologists in the lead. It was through geologists that science became established as a recognized part of university learning. Even in those days, geology straddled the physical sciences, and embraced the biological disciplines. It may be said to have given birth to the doctrine of evolution, for it was by applying geological principles to the facts of biology that Darwin formulated the theories he gave to the world a hundred years ago. Since those early days, geology has lost nothing of the excitement of new discovery, withdrawn not at all from the width of the disciplines it embraces. It is true that special disciplines have been established, and geologists are now designated as geophysicists, geochemists, petrologists, stratigraphers and palaeontologists, and this address is concerned with only one of these several aspects. Nevertheless, it will, I hope, become apparent that the subject has in no sense been atomized by the specializations that it has incorporated. Every trend of research in recent years has been a trend of synthesis between diverse branches of an ever-expanding field. I have suggested that a hundred and fifty years ago geology led the movement which profoundly influenced the position of science within our universities. It is my belief that the time has now come for geology to lead a new movement, a movement that I hope will abolish the gap that still yawns between science and the humanities.

Astronomers tell us that the earth was formed some 4500 million years ago. Although geologists have no direct evidence in support of that age, this does agree well with the inferred age of meteorites, and with other indications. The oldest rocks we have been able to discover, and of which the age has been conclusively established, seem to have been formed about 3000 million years ago. We have discovered no rocks which we can be sure were in existence during the first 1500 million years. Perhaps we shall do so before long; perhaps the rocks that lie

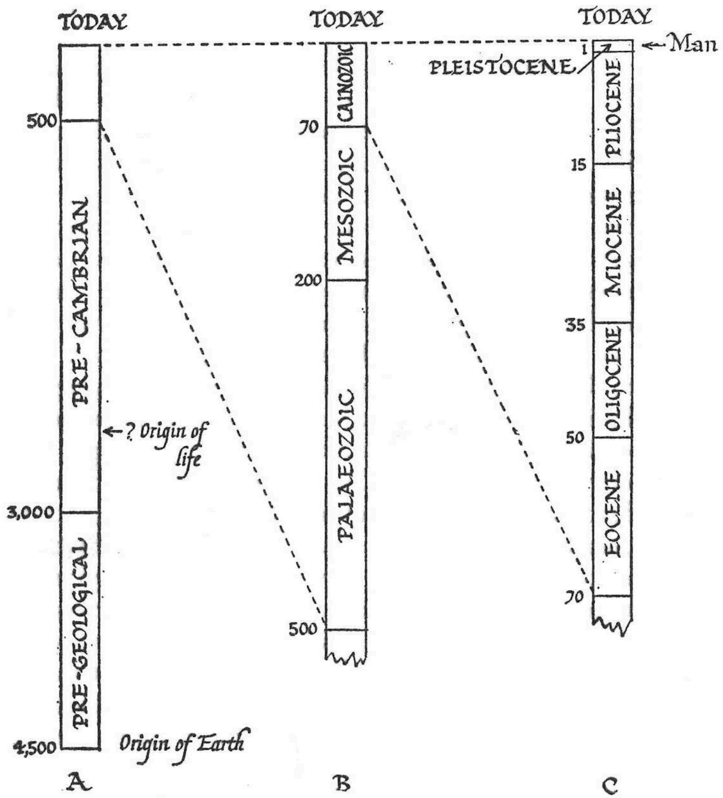

Fig. 1. *The Geological Time Scale.* Column A represents the 4500 million years that have elapsed from the formation of the Earth till today; Column B represents the 500 million years from the dawn of the Palaeozoic till today; Column C represents the last 70 million years, known as the Cainozoic Era or Age of Mammals.

in the mantle of the earth, below the crust on which we live, are as old as that, and perhaps the present plans to drill deep down through the crust will mature, and bring to light some of the primeval matter of the earth. Until then, we must call this first period of earth history the 'pre-geological' period (Fig. 1).

Geological time therefore begins 3000 million years ago. Evidence of life having been in existence during this time gets more and more scanty the further we go back. Fossils are abundant in rocks formed during the last 500 million years, extremely rare in rocks older than this. Thus geological time can conveniently be split into two portions. Precambrian time, from 3000—500 million years ago, and Cambrian and post-cambrian time, from 500 million years ago to today. Fossils are rare in Precambrian rocks, but not quite absent. It was only in 1957 that

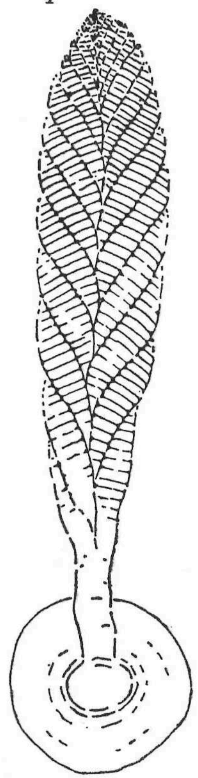

Fig. 2. *Charnia masoni* Ford, a Precambrian fossil from Charnwood Forest (after Ford, 1958).

Roger Mason, a Leicester schoolboy still at Wyggeston School, discovered a Precambrian fossil on the golf links near Woodhouse. This fossil was described by my colleague Dr T. D. Ford, and appropriately christened *Charnia* (Fig. 2; see Ford, 1958). A few months ago geologists working in Australia discovered, amongst another group of Precambrian fossils, a second species of *Charnia* (Glaessner and Daily, 1959). These are comparatively young Precambrian fossils. The oldest fossils so far discovered have been dated at something rather over 2000 million years and life must have originated before then.

The fundamental premise of the theory of evolution—that the present diversity of life in the world has arisen as a result of 'descent with modification'—is now established beyond doubt. No evidence can be found to support the hypothesis that life is still being originated. It seems certain that the early and most primitive stages of life are no longer in existence and are not now in the process of formation; perhaps they cannot exist in the presence of more specialized animals and plants; perhaps they can only form under conditions which are no longer extant on the face of the earth. Whatever the cause, we are drawn to the conclusion that life originated in the dim recesses of Precambrian time. It is just possible that various different and unrelated primitive forms of life gave rise to various more advanced animals and plants which survived through the geological record and are still with us today. But such a postulate is unlikely, and falls, in the absence of evidence to the contrary, by the principle of Ockam's razor, in favour of the currently accepted theory, that all present day life, and all life of which we have fossil evidence, has descended from a single ancestral form that existed somewhere between 2000 and 3000 million years ago.

Fossils are too rare in the Precambrian to throw much light on what happened during the first 2000 million years. But the evidence for the last 500 million is so overwhelming that it would be quite impossible to give even an outline of its course or its complexities in this address, and it is not my purpose to provide a guide to the course of this history, fascinating though it is. Rather, I want to explore the geological evidence concerning the processes that were involved in producing, from a single common ancestor, the multitudinous diversity that exists among the animals and plants of the world today.

It is clear that there are two processes. The first of these is that which leads a descendant to differ from its ancestor. This is the process of 'descent with modification'. Any continuous lineage is technically termed a phylogeny, and the process of descent, with or without modification, is phylogenesis. Now, the first lesson on the process of phylogenesis taught by the study of fossils is that modification, when it occurs, occurs at very diverse rates (Fig. 3). Some lineages hardly change at all even when examined in the exaggerated perspective of geological time. Some

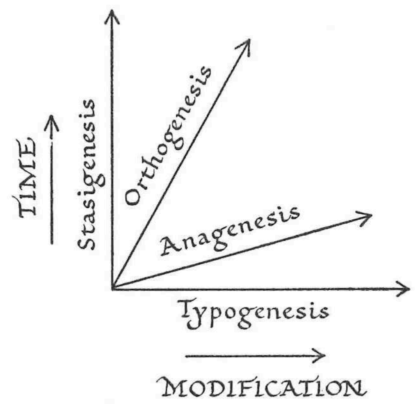

Fig. 3. *Kinds of Phylogenesis.* Phylogenesis can be divided into four modes, which arbitrarily express different rates of evolution, and which can be distinguished by the four terms *stasigenesis* (very slow or stable evolution), *orthogenesis* (steady evolutionary adaptation), *anagenesis* (rapid evolutionary modification), and *typogenesis* (instantaneous or discontinuous evolutionary modification by 'saltation').

genera have changed hardly at all for 400 million years. Evolution, for them, has been stable. Other lineages show rapid and continuous change, often following morphological trends which adapt them ever more successfully to a limited environment. Such trends may be accompanied by a general increase in size, by the production of ever more exaggerated specializations. Records of this type are common in the fossil record, and this pattern of evolution has been given the name *orthogenesis*. The term was first introduced by Haacke in 1893 as descriptive of this particular pattern of evolution. Four years later Eimer used the term both as descriptive of the pattern and as designating a theory attempting to explain the process that produced it. It has since been used in both senses by many authors. Various theories explaining how the pattern of orthogenesis might have arisen have now been shown to be untenable, and in consequence anything termed 'the theory of orthogenesis' is properly regarded as suspect. A secondary consequence has been that the palaeontological evidence, correctly described as 'the phenomenon of orthogenesis', which the theories attempted to explain, has in recent years been overlooked. This is unfortunate, for the operation of evolution along trend-lines is responsible for the most characteristic evolutionary pattern that palaeontologists have discovered. An example is given by the evolution of an extinct race of herbivorous mammals that roamed North America some 45 million years ago, the Titanotheres (Fig. 4). Early forms were small and without horns. Late forms were gigantic, and had incredibly long outgrowths from their skulls. These large forms became extinct, and brought the line to an end. Amongst the various mysterious mechanisms that were once invoked by palaeontologists to account for orthogenesis, was the concept that evolution possesses an irresistible momentum that forces an orthogenetic trend to follow a path to certain extinction. It has now been convincingly demonstrated that such hypothetical processes are an unnecessary postulate (e.g. Simpson, 1944, pp. 150 ff.). Natural selection is a sufficient explanation for increasing specialization in an evolutionary stock. Indeed, I would contend that all lineages, if they are evolving at a rate above a certain minimum, proceed by the adoption of trends, and in that sense are orthogenetic. Phylogenesis, in fact, proceeds by an alternation of periods of stasigenesis, when modification is reduced to a minimum, and orthogenesis, when change proceeds at a steady rate. But there is yet a third variety of phylogenesis revealed by the geological record. This is represented by what, at first sight, appears to be a jump in the record. A new species or genus of fossil suddenly appears, and no intermediates can be found which connect it to its nearest relative, entombed in the rocks below. Such jumps, or saltations, can be accounted for in two ways. Evolution may proceed in the same way as orthogenesis, but much faster, so that the intermediate stages are lost in the imperfections at the fossil record. This type of evolution has been called *anagenesis*. Alternatively, there may be a real jump, a new form being introduced between one

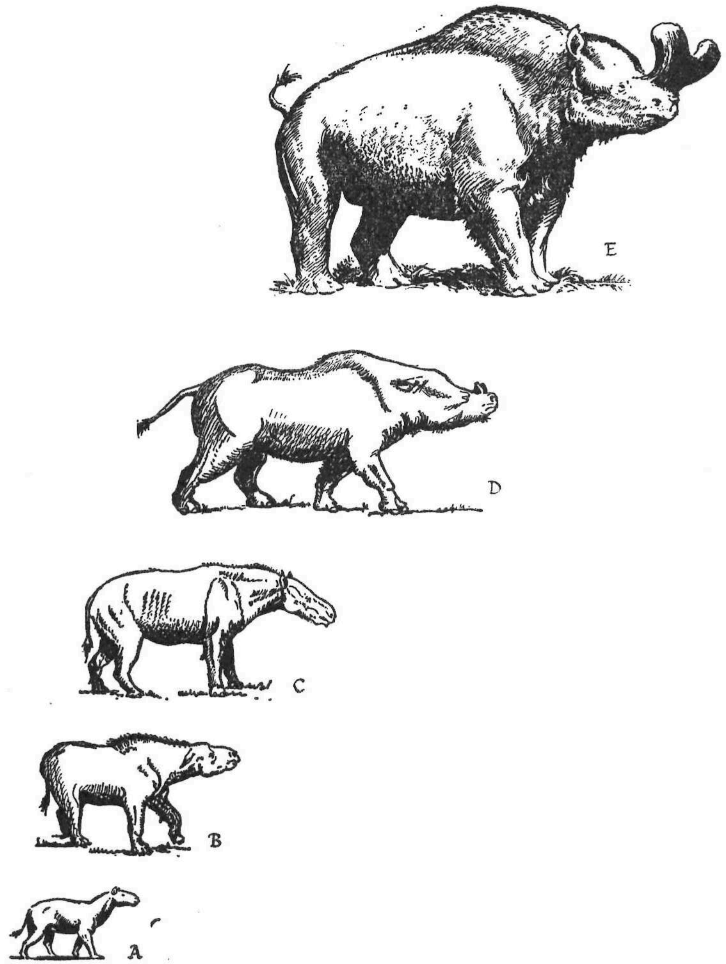

Fig. 4. *Orthogenesis in the Titanotheres*. The ancestral forms were small, and much like the contemporary ancestral horses; the final forms were huge, bulky, browsing herbivores. The two most noticeable trends are increase in size, and, during the late stages only, the acquisition of horns by accelerated (allometric) growth. The forms figured are, from below upwards: *Eotitanops*, *Palaeosyops*, *Dolichorhinus*, *Brontotherium leidyi*, and *B. platyceras*. First and last reproduced by permission from E. H. Colbert (*Evolution of the Vertebrates*, Wiley & Sons, 1955); remainder redrawn from Osborn.

generation and another. Such a saltation can appropriately be called *typogenesis*. The test of whether anagenesis or typogenesis has taken place is difficult to apply, and many of my friends regard the existence of typogenesis unproven and unlikely. But I shall hope to suggest below reasons for regarding it as an important evolutionary process, as common in the record as is anagenesis.

If the phylogenetic picture of orthogenesis is examined in detail, it becomes evident that any suggestion of a linear series of individuals, each showing progressive modification with the passage of time (Fig. 5a), is a simplification of the true state of affairs. The evidence of palaeontology shows that each time-plane

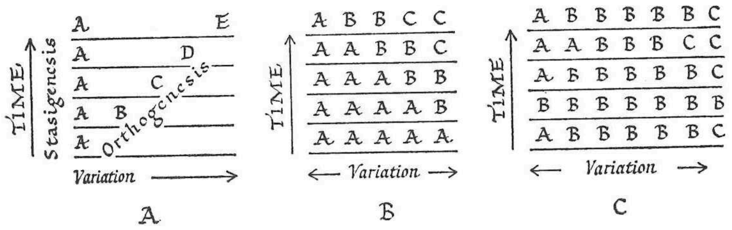

Fig. 5. *Succeeding generations in phylogenesis.* (*A*) An over-simplified picture of orthogenesis suggests that each generation of individuals differs uniformly from its parents; an over-simplified picture of stasigenesis suggests an unvarying succession of generations; (*B*) in fact, succeeding generations undergoing orthogenesis show variable populations, in each of which new varieties appear and old varieties disappear; but the majority of varieties in each generation are shown in both the preceding and succeeding generations; (*C*) fluctuating selection pressure in stasigenesis leads to diversity in the variation displayed by each generation, but the favoured modal variety remains the same throughout.

is characterized by a variable population. Succeeding time-planes are marked by the appearance of new varieties, but there is always overlap with the ancestral population (Fig. 5b). Some of the descendants are always similar in morphology to their immediate ancestors. The theory of natural selection postulates that the old fashioned individuals are less successful than some of the newer varieties, which therefore increase in proportionate numbers in succeeding generations. The continuation of such a tendency has appropriately been termed *directional selection* (or 'ortho-selection'), and results in orthogenesis.

In stasigenesis, the effect of selection is different. It results from *stabilizing selection* (Fig. 5c). Its action has been demonstrated by the comparison of snails at two stages of growth (Cesnola, 1907). An adult snail carries at the top of its shell a record of its shape when young. A collection of young snails was found to demonstrate more variation than was exhibitied by the young stage of a collection of adults. The more extreme variants among the young never reached maturity. They were eliminated by selection in favour of the less variable. The action of selection must

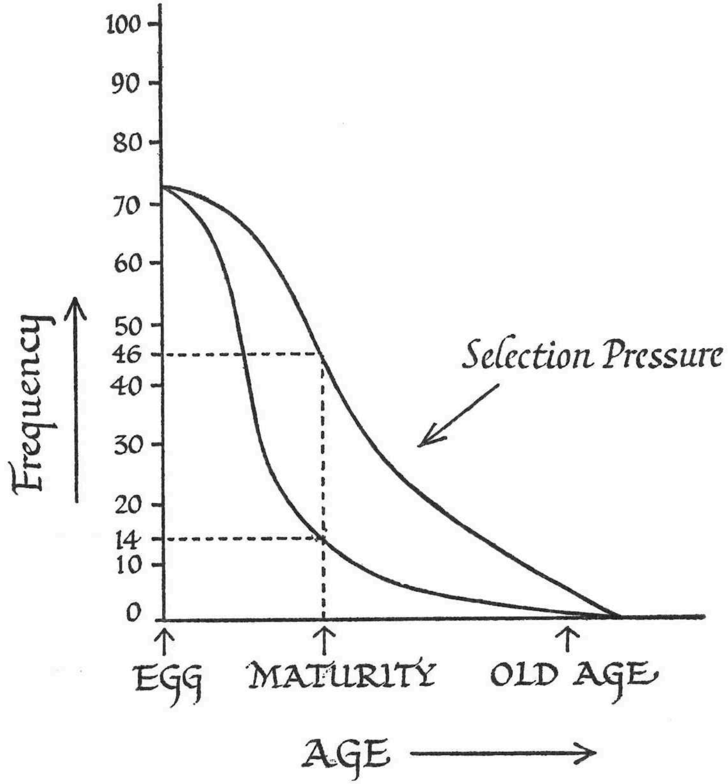

Fig. 6. *Effect of fluctuating selection pressure on mortality curve.* The curves represent the percentage survival of two sample generations at two levels of selection pressure. In both, 73% of the eggs hatch. At high selection pressure, only 14% of the eggs laid reach maturity, and contribute, by breeding, to the next generation. At low selection pressure, 46% of the eggs laid reach maturity.

always be towards the reduction of variation. In this case selection favours in each generation the same variety as in the ancestral population. The more intense the selection, the more uniform the population becomes. An increase in selection pressure results in the early death of any young individuals that differ too much from the preferred norm (Fig. 6). Conversely, a decrease in selection pressure results in the survival to maturity of a greater number of the variable young. Another well known example makes this clear (Ford, 1945, pp. 268-269). An isolated colony of a butterfly, the Marsh Fritillary, was kept under observation by the distinguished geneticist E. B. Ford and his father. During the period of observation, the numbers of the colony fluctuated between extremes as shown in Table 1. These

TABLE I

1881-1897 First period of abundance	Constant form A
1897-1913 Period of decline	
1913-1919 Period of rarity	
1920-1926 Period of increase	Extreme variation
1926-1935 Second period of abundance	Constant form B

Fluctuating population in a butterfly colony (Marsh Fritillary). Extreme variation was only exhibited during the period (1920-1926) in which the colony was rapidly increasing in numbers. Much more restricted variation, approximating to a constant form, was shown during periods of stable population, and while the numbers of the colony were declining. (Data from Ford).

fluctuations were accompanied by a marked effect on the variation exhibited by the population. While the population was stable, and during its period of decrease, variation was at a minimum; but during the period of its increase, variation ran rife. Even deformed young, hardly able to fly, survived to maturity. As soon as the population had built up to its maximum size, and once more became stable in number, this variation ceased. A new constant form was established. Surprisingly, this new constant form B was not at all like the old constant form A, which had been established before the burst of variation took place in 1920. This is a very important observation, for its explanation may well hold the secret of the mechanism that lies behind the least understood of the evolutionary patterns, that of typogenesis. In this case, in fact, two different varieties of the same species, one ancestral, one descendant, differ from each other discontinuously. They are separated from each other by a short period of phenomenal variation. Otherwise they exhibit just the kind of saltation that the name 'typogenesis' is intended to denote.

The various evolutionary patterns which have been described above are all varieties of phylogenesis. They are variations on a single theme, 'descent with modification'. I now want to turn to the other main process of evolution, that which leads to the diversification of life. A phyletic line not only exhibits changes in the rate of modification; it also repeatedly throws off branches, so that a single ancestral population gives rise to a number of descendant groups, each of which remain discrete from each other throughout their subsequent history. This branching of a phyletic line has been termed cladogenesis. The biological sciences have investigated the mechanism of cladogenesis in some detail. It is known that in most cases there is an important geographical factor. If one species is to give rise to two it does so in four phases (Fig. 7a). First, in the phase of stabilization, the ancestral species is confined to a constricted habitat, with a closely controlled population size. Second is the eruptive phase; the species increases in numbers, and so spreads over a wider geographical area than before. This results in a wider range of environmental conditions. The increase in numbers also results in a reduction of selection pressure, and so an increase of variation. In the third phase, conditions deteriorate. During this phase there is a drastic drop in numbers, and individuals inhabiting many of the less favourable parts of the environmental range get wiped out. If cladogenesis takes place, two or more groups survive in slightly contrasting environments, and there remain isolated from each other. This is the phase of isolation. In the fourth phase,

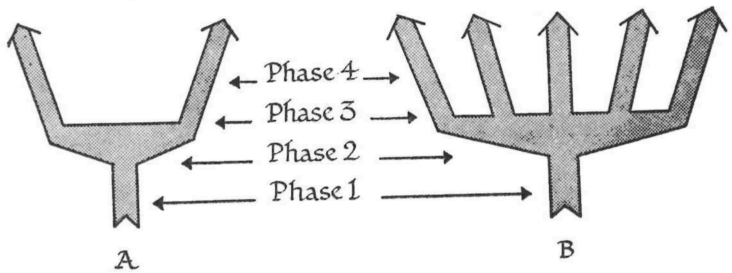

Fig. 7. *Cladogenesis.* (*A*) Cladogenesis resulting in two divergent species; (*B*) cladogenesis resulting in adaptive radiation ('explosive evolution'). In each case there are four phases: 1. The Phase of Stabilization, in which stable selection pressure reduces evolutionary modification to a minimum. (stasigenesis); 2. The Phase of Eruption, in which selection pressures are reduced, population numbers increase suddenly, migration to new environments ensues, and variation greatly increases, thus initiating evolution by typogenesis; 3. The Phase of Isolation, in which disruptive selection pressures are asserted, and the original continuous population is split up into two or more isolated units (cladogenesis); 4. The Phase of Divergence, in which directional selection pressures result in orthogenesis.

directional selection sets in, and the surviving groups start to diverge from each other. At first they remain only subspecifically distinct, but they continue to become more and more different until they reach specific, generic or even familial distinction. This is the phase of divergence.

The process of cladogenesis is universal, and has been in operation since diversification began. But it does not always proceed in quite the same way. There are two variables, both of degree. The number of branches produced at one time is variable; there may be two, or more than two, descendant branches. And the initial morphological difference between the branches varies in degree. The second or eruptive, phase of cladogenesis is always, in fact, accompanied by some degree of typogenesis. The discontinuity that arises may be so small as to be undetected, or it may be so considerable as to give rise to doubts about its validity. The degree of cladogenesis achieved is influenced by the biological material and by the environmental

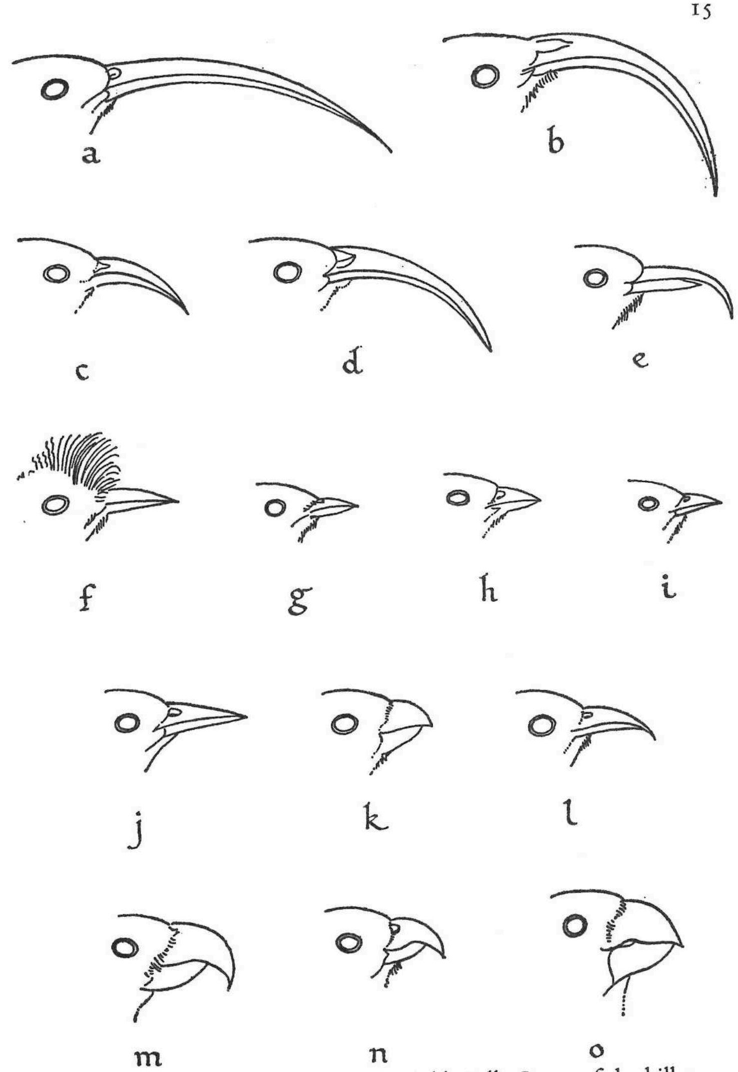

Fig. 8. *Adaptive radiation in Hawaiian Sickle-Bills.* Some of the bill-types developed in the Drepanidae of Hawaii and all derived from a post-Pliocene common ancestor. Each type is adapted to a different food collecting habitat, and each has been regarded by at least some taxonomists as generically distinct. Some of those with curved bills suck nectar from the base of the corolla tubes of the lobelias. Others probe for the insects that are to be found in these same corollas. Others catch insects on the wing, or pick them off branches, or from under bark. And there are wood-peckers, seed-eaters, fruit-eaters and nut-crackers. (After Rothschild)

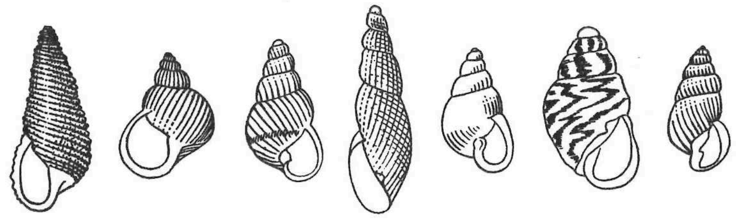

Fig. 9. *Adaptive radiation in Hawaiian snails.* The shells of some of the countless variety of Achatinellidae, an endemic family known only from Hawaii. (After Pilsbry)

conditions. During the immediate geological past, from late Tertiary time to the present day, there have been two special environments which have always resulted in an extreme degree of cladogenesis. These are, first, the sudden eruption of volcanic archipelagos in isolated regions of the great oceans; and, secondly, the sudden appearance of large lakes in the interiors of the continents. The finest example of the first is given by the Hawaiian archipelago (see, for example, Gulick, 1932). This seems to have risen above sea level first during Pliocene time. It was subsequently colonized by plants and by animals which arrived by chance by various means from the continent. All the first arrivals reacted in the same way. There was a complete absence of competition, population numbers soared upwards, and they spread and filled the whole archipelago. Variation ran rife. But as soon as the maximum population that the archipelago could contain was reached, selection pressure was reasserted, and the population split up into groups isolated on each island. Cladogenesis was extreme. Each ancestral species gave rise to a swarm of new and astonishingly diverse descendants, all endemic to Hawaii. Among the plants, the lobelias have been classified into 7 genera and 146 species, and include trees, shrubs and herbs. Among birds, the Sickle Bills have been divided by some authors into as many as 18 genera and 22 species (Fig. 8), including warbler-like forms which catch insects on the wing, forms with long, curved beaks, nicely adapted to the curve of the lobelia corollas from which they suck nectar, forms with parrot-like beaks with which they prise off the bark of trees in search of boring insects, forms with heavy beaks for cracking nuts, or finch-like beaks for solid seeds. Even a woodpecker is included. Other endemic swarms include

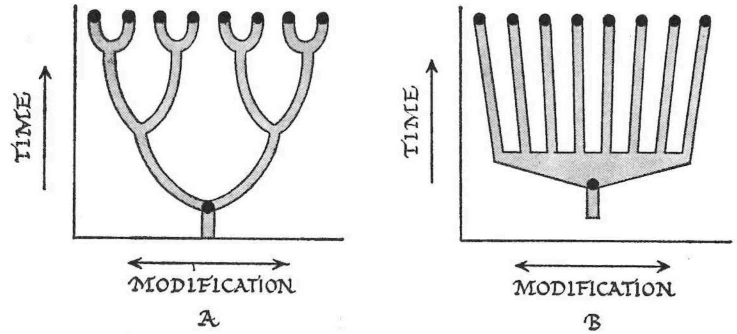

Fig. 10. *Contrasted patterns of diversification in phylogenesis.* Two ways in which eight descendant species can be derived from a single common ancestor: (*A*) phyletic dichotomy; (*B*) explosive evolution.

two groups of snails (Fig. 9), weevils, groundbeetles, moths, ants, grasshoppers, dragonflies, hemiptera and neuroptera. These are all complexes with at least 30 and, in some cases, over 400 endemic species.*

The same thing happens in other volcanic archipelagos, and in continental lakes like those of the East African rift valleys and Lake Baikal in the U.S.S.R., in which occur endemic swarms of fish, gastropods, shrimps, worms and protozoa. In these lakes, a fluctuating level seems to achieve the necessary condition of isolation. Such phenomena are called evolutionary explosions. The environments in question seem always to produce the same phenomena, which pass through an orderly sequence. As in simple cladogenesis, there are the same four phases (Fig. 7). The phase of stabilization exists before the ancestral species reaches the new environment. Then, during the eruptive phase, the species proliferates, migrates over a wide area, and exhibits a diversified morphology. The disruptive phase is asserted as soon as selection pressures build up to a state leading to isolation. The fourth, divergent phase sets in as soon as isolation is established. In the fossil record such evolutionary explosions have occurred in other environments and on a grander scale. Usually they accompany the initiation of a major taxonomic group, and often they follow the extinction of a former dominant competitor. Thus the extinction of the reptiles is followed by the explosive

* The number and grade of taxa recognized in the various groups is, of course, a subjective matter, and varies according to the authority.

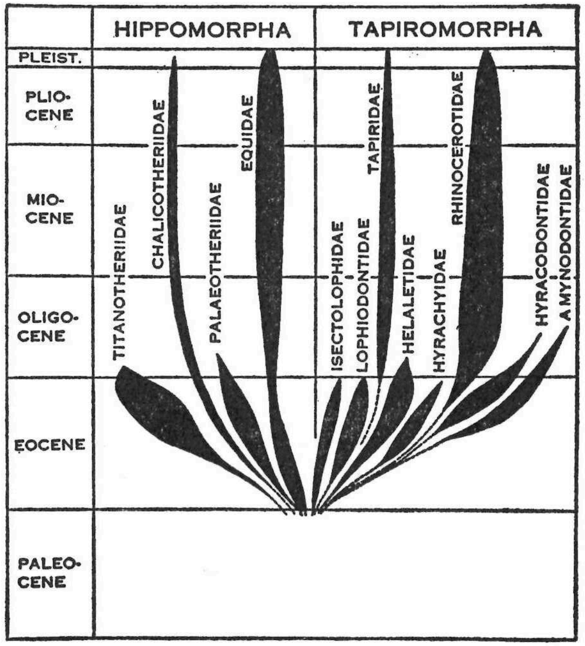

Fig. 11. *Radiation in the Perissodactyls.* Each of the families into which the group is divided was originated at about the same time. Only three have survived to the present day—the horses, the rhinoceroses and the tapirs. (Reproduced by permission from A. S. Romer, *Vertebrate Paleontology*, Copyright 1945 by the University of Chicago).

deployment of the placental mammals. Such explosive phases can be recognized by the pattern of the phylogenetic tree. Instead of showing a steady phyletic dichotomy, it deploys simultaneously along several divergent lines, originating from an obscure and rare or unknown common ancestor (Fig. 10). This pattern of 'adaptive radiation' occurs at intervals throughout the fossil record. One of the most characteristic examples is that exhibited by the Perissodactyls during Eocene time (Fig. 11). These odd-toed ungulates include the horses, the titanotheres, the rhinoceroses, the tapirs, and a large number of families which occurred in Eocene times but which are now extinct. Only four of these families, in fact, survived to Pleistocene time, and only three of them till today.

The pattern of the carnivores' evolution is rather different (Fig. 12).

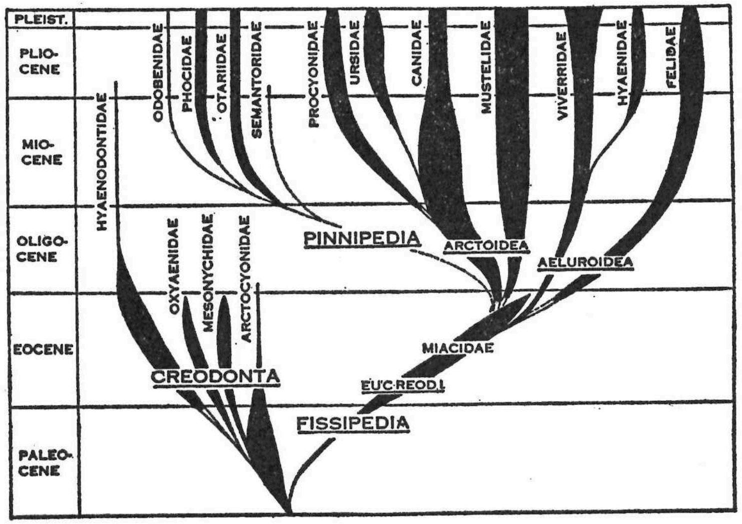

Fig. 12. *Radiation in the Carnivora.* In contrast to the Perissodactyls, there are two periods of explosive radiation in the carnivores. (Reproduced by permission from A. S. Romer, *Vertebrate Paleontology*, Copyright 1945 by the University of Chicago).

There is an Eocene radiation as there was in the perissodactyls, and (also as in the perissodactyls) many of the families become extinct at the close of Eocene time. But in post-Eocene time there is a change. Immediately *after* the extinction of the competing families, one of the remaining groups initiates a second radiation. It seems that the mere removal of competitors provides an environment in which a carnivorous animal may exhibit explosive evolution. Herbivorous animals seem to need the absence or scarcity of both competitors and predators before conditions are suitable for an evolutionary explosion. This supposition is to some extent supported by a consideration of the ammonoid cephalopods, a group of carnivorous invertebrates (Fig. 13). The ammonoids were derived from a nautiloid ancestor during Middle Devonian time. There was an immediate radiation, but throughout the rest of the Upper Palaeozoic diversification seems to have proceeded more by the process of phyletic

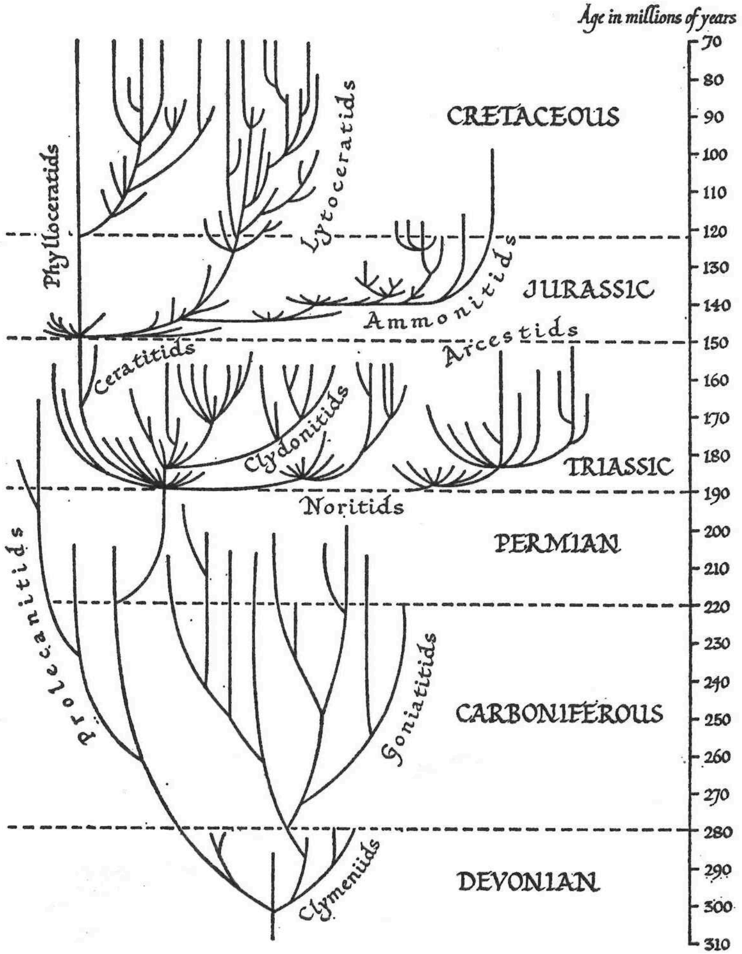

Fig. 13. *Radiation in the Ammonoids.* A minor radiation occurred during the Devonian, when the first ammonoids were derived from their nautiloid ancestors, but the first truly explosive radiation occurred at the beginning of the Triassic, after a critical period which few of the Permian families survived. Only a single family survived a second critical phase, which brought the Triassic to a close, and a new radiation followed at the beginning of the Jurassic. (Data from the *Treatise of Invertebrate Paleontology*).

dichotomy than by explosive radiation. At the close of Permian time the ammonoids entered upon a very critical phase of their evolution, and all but three families failed to survive into the Trias. Of the survivors, two continued without diversification, and not so long afterwards, became extinct. But the third family to survive underwent what is perhaps the most astonishing burst of explosive evolution known in the record of the invertebrates. Before the close of the Lower Triassic, about forty-five *families* had been differentiated from this single stock. Many of the diverse branches failed to survive for long, but the place of those extinguished is taken by a new burst, originating in one of the stocks that did survive. This pattern continues until the end of the Triassic, when the ammonoids entered the second critical period of their evolution, and all families but one died out. The progeny of the surviving family duplicated the patterns of the Triassic. Repeated radiations re-populated the seas each time widespread extinction occurred.

No ammonoids survived a third critical phase, which took place at the close of the Cretaceous, and brought their story to an end.

Most, if not all, animals and plants exhibit similar periods of explosive evolution during at least some part of their phylogeny. Those which during Tertiary time, effected the stock from which Man is derived are shown in Fig. 14.

The history of life is, then, characterized by certain recurring patterns. Grounds have been given for believing that these patterns are controlled by general processes, processes that can be recognized and tabulated. If this is so, it may be possible to survey the patterns of life as they exist in the world at the present. Perhaps we may be able, from their study, to recognize some of the stages in the patterns described. It may even be possible to forecast, from such studies, the future course that evolution may take. For example, if the pattern of distribution and variation in an animal species showed a sudden change in its recent history, if an ancestral form that has been restricted and localized suddenly erupts, with a vast increase in population numbers, if it invades wide areas of the earth's surface, occupying varied habitats, and if, at the same time, it exhibits an extensive range of variation, almost uncontrolled by selective forces, then we may well suppose that it has reached Phase 2 of an evolutionary explosion.

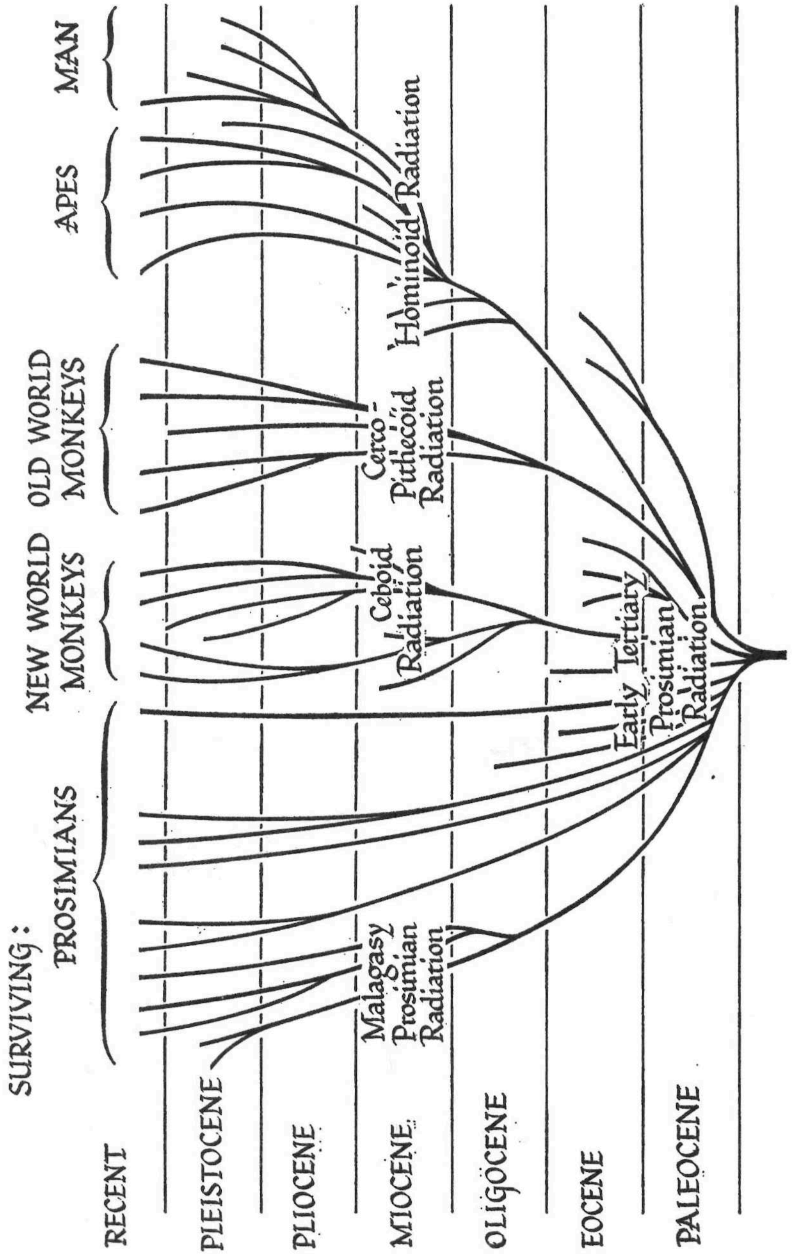

Fig. 14. *Radiation in the Primates.* The phylogenetic history of the Primates, including Man himself, viewed as a series of radiations. (Reproduced by permission from G. G. Simpson, *The Meaning of Evolution*, Copyright 1950 by the Yale University Press).

This raises the question of whether there is any animal alive today which does show such a pattern. What of ourselves? What of Man? Man's early history goes back into Miocene time, and into Africa, where we believe a considerable radiation took place. Some of the forms that were delineated then gave rise to the great apes of today. One of the others was the ancestor of Man. But for the next thirty million years or so, numbers of this ancestral form were so circumscribed that as yet no fossils have been found that represent the period. The first fossils of man's nearer ancestors are found in Pleistocene deposits, less than a million years old. And since that time we have the record of the most astonishing increase in population numbers ever recorded in such a large animal. Coupled with this increase, man has colonized almost every square inch of the earth's surface that is not covered with water or ice. And what of the variation he displays? Haldane has characterized man as the most polymorphic and most polytypic animal ever known. The pattern of our own species during post-Pleistocene time has, in fact, accurately reproduced every characteristic of Phase 2 of an evolutionary explosion.

It is possible to extrapolate; Phases 3 and 4 may lie in the future. It has been estimated that there were about 10 million humans in the world in 8,000 B.C., 200-300 million in Roman times, 2,500 million today; there are likely to be 5,000 million by the year 2000. If the development continues as it has begun, there will come a time when the population will reach the limit which the world can contain. At that point, there will be a change in the pattern. If this growth of the population cannot be controlled by man, it will be controlled by natural selection. The population will outgrow its food supply. Thousands will die of starvation. If climatic conditions change very markedly, as, in the long run, they are bound to do, whole populations may be wiped out. Such conditions of hardship favour competition between nations, and such competition is to the death. And so factors become favourable for Phase 3 of our evolutionary explosion, the phase of isolation.

The normal evolutionary pattern would thus be established, and conceivably might result in the further biological evolution of man. The result would be interesting, but hardly comfortable. And in fact man differs from other animals in a way that seems certain to change the normal evolutionary pattern. The most important feature of man's evolution is not now morphological, but psychological. Ideas are more important than brute strength, acuity of vision, or fecundity. And ideas are passed from man to man not by the process of sexual reproduction, but by the spoken and written word. There are those who believe that enlightenment cannot succeed if it is allied to a policy of controlled population size, for they fear that unenlightened multitudes from other nations will swamp the elect and obscure the light. Such fears seem unfounded when it is remembered how often martyrdom succeeds in propagating ideas. The future evolution of man will be controlled not only by natural selection, but also by whatever processes control the evolution and selection of ideas. We still know very little about what these processes are. Their study has for centuries been the province of religion. And now, in our universities, there are departments of politics, sociology and history, language, philosophy and psychology, music and fine art, all of which are engaged, to a greater or less extent, in studying the relation between man and ideas.

But let us, for a moment, turn back to the field of geology. In this lecture I have been emphasizing the speculative side of my subject. I make no apology for this, for the scientific method consists quite simply of testing hypotheses. Without speculations there can be no hypotheses, no tests, no science. And what I have been trying to describe to you is a small part of the programme of research that lies before us in the Department of Geology. Some people believe that universities are teaching institutes. I think they are wrong. Such a concept suggests that there is a cleavage occurring through the universities, a cleavage dividing us into two categories, the teachers and the taught. This is not as it should be. Universities are institutes of discovery. Students who come to universities come to learn. Staff appointed to universities are appointed, firstly, to discover, and, secondly, to communicate their discoveries to their fellows. So students and staff are both here to learn; to discover and to learn. Two processes are, in any university, in continuous action: discovery and communication. Much of what I have been talking about tonight has lain outside the strict limits of my subject. The field is one in which a wide range of scientists is actively engaged. Not only geologists and palaeontologists are thus employed, but geneticists, taxonomists, biochemists, geochemists, astronomers,

geophysicists, geographers and many more. Since the war, this wide attack on the problems of evolution has led to the emergence of what is often referred to as a 'synthetic theory'—a theory tested and corroborated by a synthesis of sciences. One of the problems that has had to be faced is the problem of communication. Language barriers have been formidable; not only do the languages of different countries differ, but so do the technical jargons of the different subjects. Sheer quantity is a problem of itself. Geology is one of the smaller sciences, yet even so the number of articles concerning geology which appear each year in the scientific periodicals of the world already exceeds 30,000. The problem is so great that we are having to invoke new methods to guide our reading and aid our understanding. Universities are now adopting methods of information-retrieval pioneered in industry. Abstracting, bibliographic and indexing services are being constantly modified and improved. Yet it is interesting to learn that at a recent conference on methods of scientific communication held by the Royal Society, it was generally agreed that the most valuable method of all was by word of mouth. Important opportunities of verbal communication are afforded by the meetings, conferences and symposia arranged by our scientific societies. But by far and away the most valuable of all the meeting grounds for scientific conversation are those provided by the universities. Leicester is the smallest, the youngest and the most rapidly expanding university in the country. We are likely to see, during the years ahead, many new appointments. Scientists representing an ever-widening field will be recruited to our staff. An expanding university provides an exciting environment in which to live. The University of Leicester has always been proud of its sense of unity. My colleagues have always known each other as persons. As we get larger, there will be difficulties. We must meet the difficulties, for unless we do, we shall fail in what I conceive to be our most important task. For a hundred years now we have been learning more and more about evolution, about its history, about its processes and about its control. What we have learnt, we have learnt as a result of synthesis. Now we must expand our field. The study of natural selection, of biological evolution, is no longer enough. The time has come for a new synthesis, a synthesis between the humanities and the sciences. When a geologist can understand a theologist, when history and chemistry, sociology and genetics, can work together, when philosophy and zoology, physics and politics, engineering and the languages can pool their results, then, and only then, shall we be able to move towards the solution of the greatest problem of our century, the problem of the destiny of man.

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