The NEW EVOLUTION

ZOOGENESIS

AUSTIN · H · CLARK

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By

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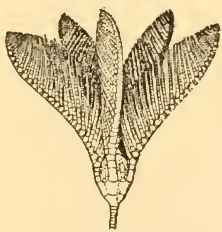
AUTHOR OF ANIMALS OF LAND AND SEA, THE BIRDS OF THE SOUTHERN LESSER ANTILLES, THE CRINOIDS OF THE INDIAN OCEAN, DIE CRINOIDEN DER ANTARKTIS, ETC.



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PREFACE

FOR more than thirty years the author has been engaged in the study of the interrelationships of the different forms of animal life. This study has included both intensive research on the forms within certain restricted groups, particularly the birds, insects, onychophores, echinoderms and certain other types of marine invertebrates, and extensive investigations concerning the relationships of all of the various groups of animals each to the other.

It has also included a detailed survey of the fossils of the Cambrian, with the late Dr. Charles D. Walcott, the Secretary of the Smithsonian Institution, and more or less intensive investigations of other fossils, especially the past representatives of the great group of sea-lilies—the Crinoidea—in cooperation with the late Mr. Frank Springer.

Intensive laboratory work has been supplemented by extensive field work in various parts of North America, in South America, in the West Indies (particularly in the Lesser Antilles), in Europe, in eastern Asia and Japan, and in the Aleutian and Hawaiian Islands.

Studies on land and along the sea coasts have been broadened into detailed investigations of the animals of the open ocean and of the sea bottom down to a depth of 11,838 feet beneath the surface. These investigations were carried out during the cruise of the United States Bureau of Fisheries steamer *Albatross* in the north and northwest Pacific in 1906, on which cruise the author served as acting naturalist in charge of the scientific work of the vessel.

No proper appreciation of the conditions under which life in the sea exists is possible without some acquaintance with the subject of oceanography, and this subject has therefore somewhat extensively engaged the attention of the author.

Of itself the personal history of any individual means nothing. It merely indicates that the individual has had a certain range of opportunities for becoming interested in, and later following out, certain lines of investigation. Whether the individual has shown himself alive to those opportunities and has profited by them can be judged only by his work.

The subject of the interrelationships of animals involves an extensive acquaintance with all types of animals in their adult, young and embryonic stages. It also involves an acquaintance with the fossil remains of the animals which have existed in past ages. So any presentation of this subject in a volume of reasonable size means a very rigid selection of essential facts from an enormous mass of pertinent material.

Fifty years ago it was possible to include in a volume of this kind a series of footnotes or a bibliography giving an adequate list of references to original records and sources of information. But such a procedure is no longer possible. An adequate list of references to the thousands of books and articles consulted in the preparation of this work would occupy more pages than the book itself.

For assistance in the preparation of this volume I am indebted to many of my colleagues, particularly to Dr. Leland O. Howard, Principal Entomologist (until recently Chief), Bureau of Entomology, Department of Agriculture; to Dr. William M. Mann, Director of the National Zoological Park and formerly of the Bureau of Entomology; Dr. Adam Bøving of the Bureau of Entomology; Dr. Waldo L. Schmitt, Curator of Marine Invertebrates, U. S. National Museum; Mr. Charles W. Gilmore, Curator of Vertebrate Palæontology, U. S. National Museum; and Dr. Carl Heinrich, of the Bureau of Entomology; all of whom were so kind as to read the entire manuscript. To Dr. James W. Gidley, Assistant Curator of Vertebrate Palæontology, U. S. National Museum, I am under obligations for checking my statements regarding fossil mammals, and for his kindness in verifying my statements concerning the fossils of the Cambrian and immediately following periods I am indebted to Dr. Charles E. Resser, Associate Curator of Invertebrate Palæontology, U. S. National Museum.

INTRODUCTION

MAN is today the central figure in the living world. Therefore the study of the life about us must be approached through the application of the human yardstick. First of all we must appraise the living world in terms of its direct relationship to man. Beginning with the known—ourselves—we may measure the nearer portions of the unknown; and not till this is done may we with any confidence take up the broader problems of the world of animals and plants.

But the human yardstick has its limitations. To a very large extent we are detached from the world in which we live. Our environment we modify to suit ourselves. We are therefore quite unfamiliar with the terrible realities of existence that must be faced by all other living things—that were faced also by our ancestors.

So overwhelming are the odds against all living things, so precarious is the existence of any individual, that it is not practicable to discuss the varied contacts of all forms of life from the human aspect. Yet an appreciation of these contacts is essential to an understanding of the living world. In order to overcome this difficulty we shall present this subject in terms of its relation to the life of a butterfly. From the infinity of different contacts which we find in our contemplation of a butterfly we shall select a few for more detailed exposition.

All animals must eat. It is essential therefore that we understand the origin of foods and just how the necessary foodstuffs are continuously provided for the plants and animals. We must also understand the very varying conditions under which foodstuffs are available and which therefore must be met by any animal or plant making use of them. The very diverse ways of meeting these conditions and nature's safeguards which prevent the increase of any form of life to a point endangering its food supply have a most important bearing on the origin and development of animal forms. Especially important is an adequate understanding of the differences in the conditions which affect the animals living on the land and in the sea.

In addition to the animals living at the present time we know many other kinds which flourished in past ages, the remains of which have been preserved as fossils in the rocks. As we go back further and further into the geologic past we find that animal life becomes more and more different from the animal life we know today. This fact is obvious and undeniable. Equally obvious and undeniable are certain other facts which hitherto have passed unnoticed. A rather detailed survey of the fossils is therefore essential to a proper understanding of the development of animal forms.

Fossil or living, all animals are divided into different kinds or species. The species is the unit by which the animal world is measured and in terms of which it is discussed. How may this unit be defined? Is it a fixed and stable entity, or is it a repressed force kept within bounds by rigid limitations which it is unable to escape?

But the discussion of a species is quite inadequate and meaningless without a survey of the life histories of animals and a mention of the varied and complex forms more or less widely different from the adult form which most animals assume at one time or another in the passage from the egg to the final stage. And in addition we must review the varied processes by which the continuity of life from one generation to the next and from one individual to another is assured and the significance and relative importance of these processes.

Such is the background with which any tenable theory of the development and diversification of animal forms must harmonize. The idea that the earliest forms of life were feeble helpless things existing in an ideal world especially adapted to them has nothing to support it. So far as we can learn the conditions on the earth since life began have always been essentially the same—varying widely in climatic and other details from age to age and from place to place but always in their broader features essentially the same.

No matter what they are, all animals arise from a single cell, and the body of every animal is composed of one or many cells which are always similar in structure. All animals must therefore be interpreted in terms of a single cell. Furthermore, all living things arise only as the children of other living things.

So the problem is to construct a figure which, beginning with a single cell, contemplating unbroken continuity of life from parent to child indefinitely, having due regard for the rigorous conditions of environment which all forms of life must meet, and taking account of all the known peculiarities of animals, shall allocate in its proper place each and every form of animal life, and give us as a finished picture man in the dominant position in the world which he holds today.

CHAPTER I

MAN AND HIS RELATION TO THE LIVING WORLD

UNDISPUTED master of the world, man dominates the earth at the present time. But this was not always so. In the geologic age just past, the Pleistocene or Ice Age, the earth was dominated by a great array of different mammals many of which were of large size and occurred in great abundance.

Though man existed at this time, his potentialities for development were restricted and more or less closely circumscribed by the competition of these four-footed creatures which threatened his food plants and his meager crops and menaced his relatively feeble body.

So during the Pleistocene man played only a minor part and left scarcely an imprint beyond mere records of his existence which in the earlier portion of the Pleistocene become extremely scanty.

Long before the Pleistocene, in those far distant periods known to geologists as the Cretaceous and Jurassic, there was no trace of man. The mammals, though numerous—at least in the Cretaceous—were all very small and insignificant. Then the earth was dominated by a vast and formidable array of reptiles, on the land, in the sea, and in the air, many of which were very large and some of gigantic size, several times as large as the largest elephants.

The successive domination of the earth by the reptiles, by the mammals, and by man, is an illustration—the most striking illustration—of the successive and more or less intermittent changes that have taken place in the balance of animal life upon the earth since the earliest times of which we have a record.

In a consideration of the relationships of the various types of animal life each to the other and of the changes in these relationships at different periods in the past, the first essential is accurately to determine the position of man in regard to all other forms of life.

Man is a mammal, and it is indubitable that in his structure and anatomy man is very close to the man-like or anthropoid apes. This is an easily demonstrable fact which is quite beyond dispute. But a knowledge of the structure and anatomy of man is not sufficient in itself alone to enable us to judge of his true relations to the other forms of life and correctly to appraise his status in the world today.

Unfortunately at the present time the broader viewpoint of man's relation to the world at large has among biologists been almost completely superseded by the very narrow viewpoint that the position of man is to be explained entirely on the basis of his dissected body.

This narrow viewpoint has been developed in such a way and to such extremes as to lead to conclusions which in their total disregard of man as man cannot but give offense and arouse antagonism.

No one can deny that a detailed comparative knowledge of the structure of any creature is essential to the determination of its position in relation to the other animals. But those who study animals both in the field and in the laboratory soon become aware of the important fact that no animal form can properly be understood from the facts revealed by the study of its structure and anatomy alone. An animal is something more than the sum total of the organic compounds, the secretions and the deposits that make up its body. There is something in addition to the tangible physical complex represented by its structure and anatomy.

The bodily mechanism of every animal in life is operated and controlled by a mental mechanism which as yet we are unable to explain in terms of physics and of chemistry. In each sort and kind of animal this mental mechanism takes the form of a definite complex peculiar to the species.

These mental complexes are as much a part of the individuality of each species as are the tangible structures of the body. To base our conclusions upon a single set of characters and to dismiss others as irrelevant is simply to confess our inability to comprehend and to interpret the whole in its true relations.

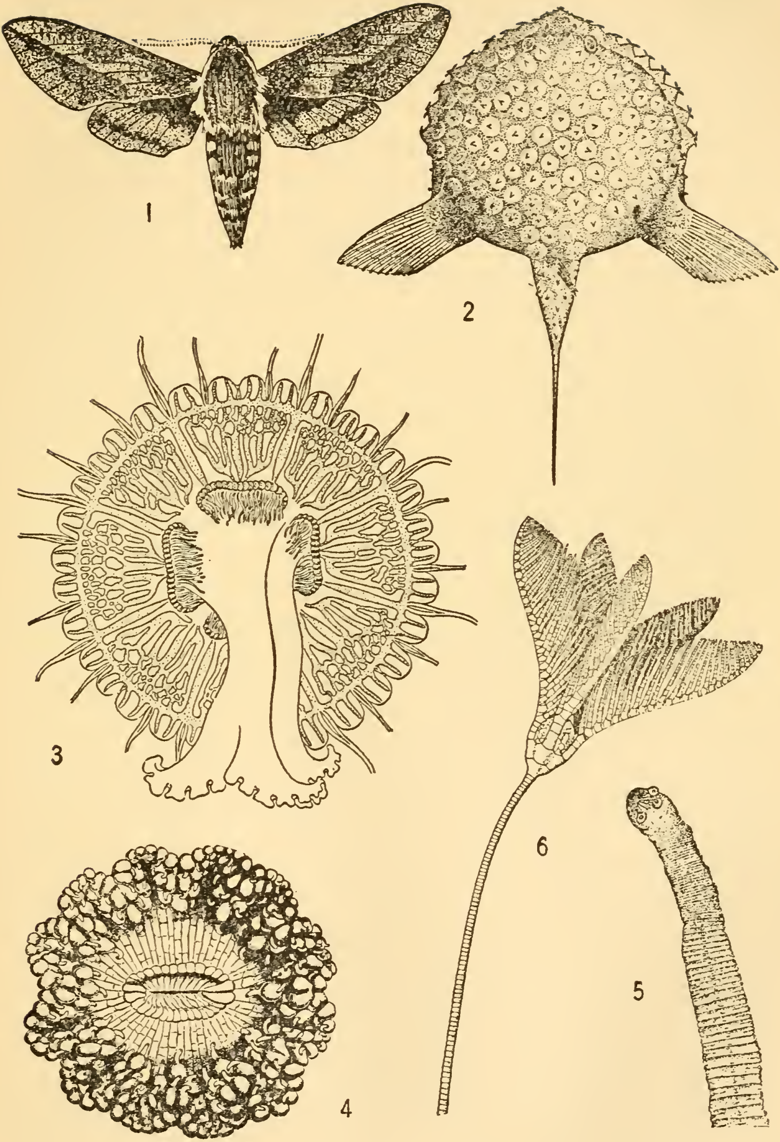
Descriptions of the different breeds of dogs would be considered wholly incomplete without some mention of the mental traits of each. This is because we appraise the dogs on the basis of all the characters which enter into their relations to us. The diverse mental traits peculiar to the different breeds of dogs therefore become a matter of great interest.

But if in the case of dogs we are always careful to consider the mental differences as well as the structural variations more or less peculiar to each of the several breeds, why should we not admit that the habits of all animals should be considered in connection with their structure? Why should we be so careful as to emphasize the terrier's peculiar propensity for digging, the spaniel's curious love for water and occasional dexterity in catching fish, the stupidity and ferocity of bull-dogs, and all the other traits characteristic of the other breeds of dogs and then maintain that man in his relation to the apes must be considered solely on the basis of his structure?

How can we acknowledge the importance of the mental differences between the greyhounds and the hounds, between both of these and collies, and between all three and bull-dogs, and then deny, or at least minimize, the importance of the mental differences between the orangs and the chimpanzees, between both and the gorillas, and between all three and man?

To do this is to admit that the science of biology—the science which deals with living things—has crystallized into a narrow orthodoxy, a science of dead remains, a sort of common meeting ground of geology, chemistry and physics, a science with no bearing upon those deeper problems which concern cosmic qualities and values.

If we regard the relationship of man to the world in which he lives, and to the other forms of life with which he lives, from the broader viewpoint of man



Illustrations of Animal Symmetries

FOR AN EXPLANATION OF THE FIGURES SEE P. 277

as a living being we at once uncover a whole array of most interesting facts.

Of these interesting facts perhaps the most important from the point of view of man as man is that man is the only vertebrate which has a family normally composed of a series of dependent young in all stages of development ranging from newly born and wholly helpless through various stages of decreasing dependency to subadult or adult. This serial family of dependent children requires the continuous care of both parents or its equivalent for a long period of years.

In all the other vertebrates—the other mammals, the birds, the reptiles, the amphibians and the fishes—the young, whether born singly or in a litter or issuing from eggs, are always under normal conditions independent of the parents before new young are born.

So far as we are able to judge from the actual evidence, the use of fire and the use of tools were human attributes from the very first appearance of mankind. It may with reasonable assurance be assumed that the same is true of speech and the use of clothing and of ornaments. There is not the slightest evidence that these human attributes were acquired one by one as man departed more and more widely from an apelike ancestor.

While these attributes separate man sharply from the apes, greatly accentuating the distinct and clean-cut, though rather slight, structural differences between man and the apes, they are by no means confined to man. Incredible though it at first may seem, nevertheless it is a fact that the closest parallel to the activities of man is to be found in the activities of the insects and their allies and not among the vertebrates or backboned animals. And furthermore, among the vertebrates the birds as a whole come rather nearer to man in the scope of their activities than do the other mammals, while among the mammals the rodents—rats, mice, squirrels, beavers and their relatives—are the most similar.

The use of fire and of fashioned tools is confined to man. Certain ants and other insects, some reptiles, as the crocodiles and alligators, and certain of those strange birds called brush-turkeys or megapodes (Megapodidæ) make use of artificial heat of bacterial origin derived from decaying vegetation consciously and knowingly gathered and assembled for that purpose. But the ignition point is never reached.

Certain digger wasps use little pebbles or little bits of stick held in the jaws to smooth down the earth over a buried victim. The spinning ants of the Old World tropics build their silk nests by using their own grubs which they hold in their jaws and pass back and forth from leaf to leaf. The grubs have silk glands which the adults lack, so that the construction of silken nests by ants is only possible through a curious system of enforced child labor. There are various other cases of the use of tools and implements by insects. But the tools they use are never made by them.

Very many insects in their early stages clothe themselves. They encase their bodies in a little jacket (fig. 13, p. 21) made of various substances bound together with a web of silken threads. For instance, the caterpillar of the common clothes-moth makes a little tubular jacket for itself out of hairs cut from your furs or woollen clothes. The larvæ of the caddis-flies, which live in water, make somewhat similar coverings out of sticks or parts of leaves or sand grains. Very many insects construct an elaborate cocoon, which may be waterproofed inside, as a protection during the pupal stage.

Many youthful insects, as the larvæ of certain lace-winged flies and the caterpillars of some lycænid butterflies, cover themselves with the empty skins of the aphids or other insects they have eaten or with foreign substances which they impale upon or entangle among their spines. This may be primarily for the purpose of concealment or deception, but in many cases it seems to be simply for adornment. At any rate, the larva of a lace-winged fly or the caterpillar of an aphid-feeding butterfly draped in dead aphids' skins strongly brings to mind a primitive human being draped in furs.

Many insects have highly developed social systems which, superficially at least, seem much like those of man. Such social systems are to be seen among the ants, wasps, bees and termites. Some of these social insects seem to be able to exchange a considerable range of information, though on principles which are quite different from those of articulate human speech.

Some social ants make use of slaves, just as man used to do—and still does in some places. Many make use of other types of insects—aphids (figs. 7–9, p. 21), coccids (figs. 16, p. 21; 17, p. 33), jassids, membracids and the caterpillars of various lycænid butterflies—much as we make use of cattle. From these insect-cattle they obtain honey-dew or other sweet or sometimes spicy liquids of which they are inordinately fond. They often tend these insect-cattle with the very greatest care, building shelters over them and looking after them in various ways and protecting them from their enemies. A number of different kinds of ants have developed elaborate forms of agriculture.

All insect societies are protected by formidable armaments consisting of poison stings, squirt-guns filled with acid, or powerful cutting jaws. But these armaments are always parts of the bodies of some or all of the insects in the social units.

All insect societies support scavengers and parasites (fig. 14, p. 21) of various characteristic and peculiar types. Many ant colonies contain queer helpless insects which the ants assiduously feed with substances gathered for their own young, though they get nothing in return.

Some insects make use of others which are much more powerful than themselves in traveling from place to place, somewhat as we make use of horses, yaks and camels. For instance, the young of some of the oil beetles are transported to their victims on the bodies of the parents or the attendants of the latter.

Chemical processes are extensively used by insects. These are, however, almost entirely concerned with special bodily secretions. There are the various types of silk produced by insect larvæ and by spiders, the paper made by wasps, the wax produced by bees, aphids (figs. 7–9, p. 21) and other insects, sweet substances secreted by aphids and other types, narcotics used to stupefy the prey, poisons used to kill the prey, antiseptic substances used to protect the eggs of internal parasites, and various kinds of poisons and reagents for special and restricted uses.

But here we become involved with the chief difference, other than the structural, between the insects and the vertebrates. In their relations to the world about them the insects are mainly guided by the chemical senses which in us are represented by taste and smell, whereas in the vertebrates the eyes and ears are commonly the main controlling organs, often combined with a delicate sense of touch, and smell and taste are relatively unimportant, even though the former may be, as in the dogs, highly developed. So the extensive use of chemical processes by the insects is quite in line with the largely chemical nature of their external contacts.

The very diverse, ingenious and effective snares of spiders and of some insect larvæ, as the young of some caddis-flies and the New Zealand glow-worm, are really most extraordinary structures. They show, most of them at least, an almost perfect adjustment in the relation of each part to the strains and stresses which that part must meet. The pit-falls dug by the young of ant-lions are equally effective and ingenious.

The tunnels and galleries made by many insects in wood or in the ground, which are often very complicated, and the tunnels and chimneys made by spiders, the former sometimes provided with a strong hinged lid, show an engineering skill and a knowledge of many of the laws of physics which is really quite remarkable.

The sometimes enormous nests of termites, the mud and other cells of solitary wasps, and the cells of carpenter, leaf-cutting, varnisher, and other solitary bees and of wood-boring wasps also may be mentioned as structures which are mechanically and physically perfect, or at least very nearly perfect.

Interesting as are these parallels between the activities of man and of the insects, they are perhaps not so surprising as the fact that, except in man, serial families of helpless and dependent young are found only in certain insects. Successive and overlapping broods of helpless young requiring continuous attention are characteristic of the social ants, bees and wasps and, elsewhere than in man, occur among these insects only.

The only birds to make use of artificial heat are some of the megapodes or brush-turkeys which are found in the Malayan and Australian regions. These brush-turkeys scratch together a loose mound of leaves, rubbish and earth, lay their eggs in it, and then cover them. The heat arising from the decaying vegetation in this natural incubator furnishes the warmth necessary for the hatching of the eggs. The same procedure is followed by the alligators and the crocodiles.

Other kinds of brush-turkeys, as those in the Solomon Islands, and the crocodile-bird of northern Africa, simply bury their eggs in warm sand, like turtles.

In the formation of their nests birds display the most extraordinary skill in the use of fibers, sticks and mud, or in some cases of the secretions from their salivary glands. They also show great skill in hewing out holes in the trunks and branches of dead trees and in constructing burrows in banks and in the ground.

Extraordinary ingenuity often is exhibited in selecting situations for their nests, both when they do the work of making them themselves and when they appropriate the deserted nest or nesting site of some other species.

Many types of nests are very complicated, especially such nests as are entered from the side. Among the most curious are the ingeniously sewn nests of the oriental tailor-birds, the long pendent nests of the cassiques, related to our orioles, and the more or less similar nests of some of the weaver-birds of Africa. A few birds, as a certain weaver-bird and a small parrot in Argentina, build community nests, like apartment houses.

Some birds show much flexibility in the construction of their nests. For instance in Bermuda where there are no suitable holes in the native cedars, the blue-birds build open cup-shaped nests in trees, like our chipping-sparrows. But in Bermuda I once found a blue-bird's nest in a hole in a capstan of a wrecked ship, suggesting that they would build in holes if only they could find them. The English sparrow, which is not a true sparrow but a weaver-bird, if it cannot find a hole suitable for a nest will construct a bulky nest of straw with a side entrance in a tree, thus indicating its affinities. Flickers in treeless regions will burrow into cliffs, and robins in sandy regions make their nests without the usual cup of mud. Many other similar cases could be cited.

Some of the grebes build floating nests, like rafts, that can be towed from place to place. The motmots build their nests in the nests of termites, and certain kingfishers of southeastern Asia make their nests in holes in trees which are tenanted by bees.

Many birds ornament their nests. Our common Baltimore oriole often weaves into its pendent nest bits of bright colored yarn or string, the indigo bird incorporates bits of paper, the crested flycatchers use the case skins of snakes, and other birds use other objects, such as shells or bits of shiny stones or brightly colored pebbles. One bird in India enlivens the vicinity of its nest with fire-flies stuck in the ground.

But it is not only in the formation of their nests that birds show mental traits which are more or less parallel to those of man. The bower-birds of Australia build curious runs or play-houses which they ornament with bright and conspicuous objects of all sorts and which have no connection with their nests. Many other birds, particularly of the crow family, as ravens, crows, magpies and jays, are very fond of gathering and secreting bright and conspicuous objects, especially metallic objects.

It may perhaps be mentioned that many different kinds of birds, especially among the larger parrots, crows and mynahs, are able to duplicate more or less extensively and correctly the sounds, though not the intent, of human speech. They are the only creatures which are able to do this.

Among the mammals only the rodents can be compared to birds in the diversity of their mental traits. Many make rather elaborate nests on or in the ground, in grass or rushes, or among the branches or in holes in trees. The nests of rodents are almost always entered from the side or from below and are seldom open above like the nests of many birds. Perhaps the most interesting of the peculiarities of rodents is to be found in the construction of dams by beavers.

Some of the insectivores, as the moles and shrews, make more or less perfect nests, and some of the Madagascan lemurs make rather complicated nests entered from the side high in the trees, like birds. But in neither of these groups is this habit so general or so well developed as it is in rodents.

A number of rodents, as the wood-rats and the Norway rat, have the interesting habit of accumulating bright and conspicuous objects more or less after the fashion of the crows.

Very many rodents have the hoarding habit, storing up large quantities of food to last them through the winter, or through the dry season, or through some other time when food may be expected to be scarce.

Among the mammals this hoarding habit is entirely confined to rodents and to man. But it is characteristic of some birds, as the California woodpecker, and of various insects, particularly of the bees and ants.

CHAPTER II

FEATURES COMMON TO MAN AND THE LOWER ANIMALS

THE existence in man, in the insects, in the birds, and in the rodents of so many strikingly similar mental traits which are conspicuously absent in the monkeys and in nearly all the other mammals must have some significance. There must be some underlying basic reason for this curious distribution of corresponding mental attributes. What have these various groups in common wherein they differ from the other creatures inhabiting the land? Can such diverse types of living things have anything in common?

Among the insects man-like mental attributes are almost exclusively confined to types in which the young are very different from the adults, either soft, delicate and apparently headless grubs as in the case of the ants, bees, and social, parasitic and predacious wasps—the mud-daubers, digger wasps and others—or soft bodied worm-like things as the young of caddis-flies and the caterpillars of small and feeble moths and butterflies. But they also occur in the white-ants or termites, which are weak and feeble in all stages, and in a few other types. What may be considered as the clothing of the insect body—the construction about it of a more or less dense cocoon of silk, of itself alone or used as a binder for other substances—is common to nearly all insects which have an inactive helpless pupal stage.

Among the birds mental attributes which parallel the human are almost exclusively confined to those types with helpless young which for their upbringing require the constant attention of both parents, and among these they are most obvious and marked in the smaller and weaker forms such as the tailor and the weaver-birds and in the wrens and swallows. Birds with active and more or less self-reliant young which are tended by one parent only, large and powerful birds, and sea-birds nesting where they are safe from enemies, as a rule show little or no skill in making nests and scorn the use of ornaments.

Weak and helpless young are especially characteristic of the rodents, particularly of the small mouse-like or rat-like rodents, in which the man-like mental attributes are particularly to be remarked.

The nests of rodents, like the nests of birds, are primarily incubators designed to facilitate the maintenance of a proper temperature. Many rodent nests, as those of various mice, the muskrats, and some squirrels, would seem to be constructed in such a fashion as to create within them a temperature higher than that outside through bacterial action. Whereas among the birds nests are used only as incubators for the young, many northern rodents pass the winter in their nests in a state of hibernation. Correspondingly in Madagascar some lemurs pass the hot dry season in their nests in a state of æstivation.

So a survey of the animal world seems to point to the conclusion that mental alertness and ingenuity wherever it is found is developed as an offset to some physical weakness in the animals involved. This physical weakness usually has to do with helpless younger stages, as in the social and other insects and in the birds and rodents, but it may involve the later stages, as the inactive helpless pupal stage of those insects having such a stage, all stages in the termites, and the hibernation period in rodents.

Thus physical weakness in the animal world is counterbalanced by the appearance of mental attributes comparable with, or at least parallel to, those of man, and the more pronounced the weakness the more man-like do these attributes become.

No one can deny that at the present time the insects are the most formidable competitors of man. There are more than three times as many different kinds of insects as there are of all other types of animal life taken together. Among the insects by far the most numerous, both in kinds and in number of individuals, are those forms, as the ants, bees, wasps and their allies, flies and moths, and many beetles (fig. 10, p. 21), which have weak and feeble worm-like young. They are the most successful and resourceful of the insects. They include the largest as well as the smallest of all the insect species, but their average size is considerably less than that of other insects.

Among the mammals the dominant type at the present day is the rodent type, and especially the murine or rat-like rodents. Here again we find as the dominant group, most numerous both in species and in individuals, a group including forms of which the average size is very small, and which have helpless young.

Among the birds the dominant types, most numerous both in species and in individuals, are again those of small size with helpless young.

Here we seem to be confronted with a paradoxical situation. For we find, in the animal world taken as a whole, that where the greatest weakness lies there also lies the greatest strength—evidenced by the greatest degree of material success. Everywhere we see as the dominant types of animal life, at least on land, types with marked inherent weaknesses—small feeble bodies and dependent helpless young—which we might offhand assume would imperil their existence.

But in all these types weakness of body and the many liabilities resulting from the helpless young are more than offset by the occurrence of more or less manlike mental alertness and ingenuity.

Do the physical liabilities give rise to the mental alertness and ingenuity? Do the mental attributes permit the existence of liabilities? Or are mental alertness and physical liabilities both correlated in some way with definite structural features? These questions we shall answer later.

From the physical viewpoint man is relatively one of the least efficient of all living creatures. His feeble body is no match for the powerful bodies of the great grass-feeding mammals which in the relatively recent past roamed all the open areas of the world and also wandered through the forests. Unarmed, he is no match for the great cats, wolves and other predacious creatures which preyed upon these other mammals. He is relatively slow of foot, and is a poor and inexpert climber. And in addition to all this the young of man are at first helpless and then dependent for many years, while the human family consists of a series of several or many of these helpless and dependent young.

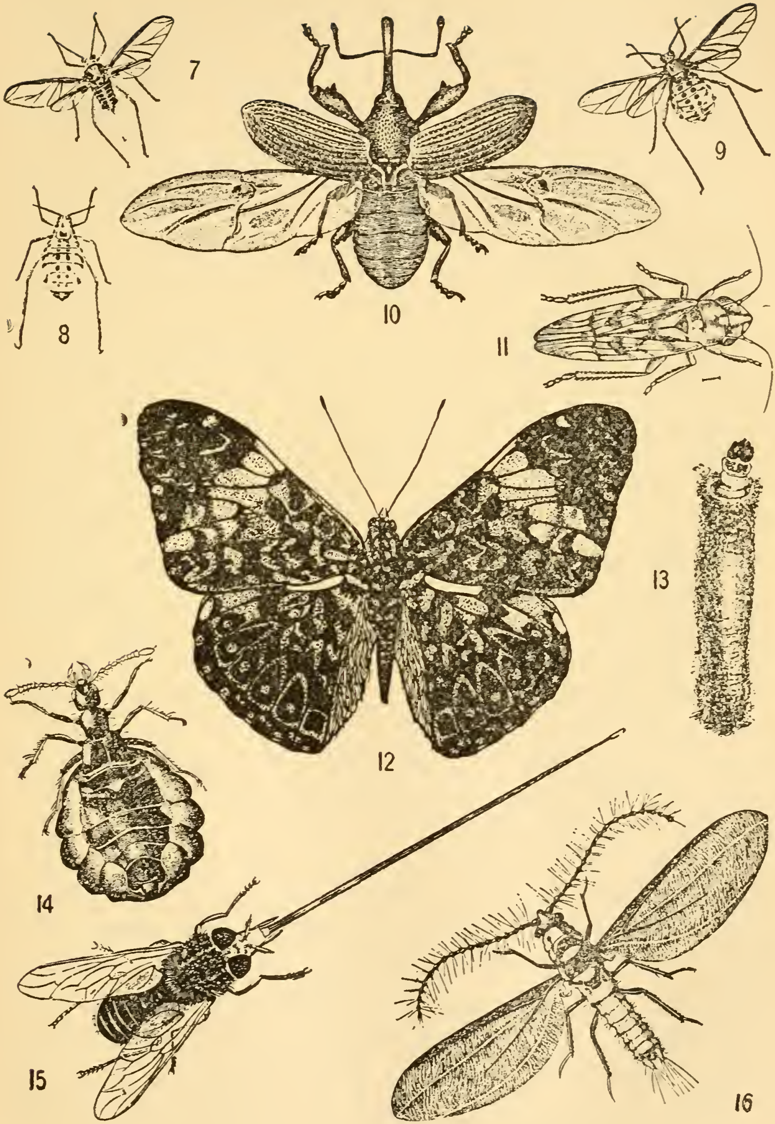
Feeble and frail of body, with helpless and dependent young and the further handicap of a serial family, man is the dominant living creature in the world today by virtue of his extraordinary mental attributes. Man must have an intellect superior to that of all other living things because he has the maximum number of liabilities to meet.

In the insects, birds and rodents, and in a lesser degree in other forms of life, we see foreshadowed here and there, appearing in a curiously sporadic, isolated and disconnected manner, many of the mental attributes of man. But in man we find all of the mental attributes found in all other living things combined, together with greatly augmented curiosity, inventiveness and ingenuity.

Is there a physical basis for the development of this superior intellect in man?

Strange as it may seem, one of man's greatest weaknesses appears to have been his greatest asset. For the serial family of dependent young probably lies at the base of all human societies and probably was responsible for the development of human culture.

Elsewhere than in man a serial family of dependent



Different Types of Insects

For an Explanation of the Figures See p. 277

young is found only in the social ants, bees and wasps, and it is impossible not to see in this an important and far-reaching correlation. It is impossible not to believe that the serial family lies at the foundation of the development of social systems, alike of men and of the hymenopterous insects. It is impossible also not to wonder what may be the cause of or reason for the serial family.

Seen from the point of view of predacious creatures, a society composed of numerous individuals means abundant food. So a society, either of social insects or of man, must at all times be adequately defended. Insect societies are defended by the use of formidable and poisonous stings, acid-squirting apparatus, or more rarely strong cutting jaws. Human societies are defended by the use of man-made weapons, which grow more and more effective with the increase in size of the social units.

It is commonly asserted that the mental reactions of insects, birds and rodents are due to instinct and not to intelligence as in the case of man, and therefore that the mental attributes of the insects and of man are in no way comparable.

We marvel at the fact that every insect at birth and at the commencement of every subsequent stage thereafter is endowed with a technical education which for its particular needs is quite sufficient—indeed it is complete. Very much the same is true of birds and rodents, though they do not pass abruptly from one stage to the next as do the insects.

Instinct is defined as "a special innate propensity, in any organized being, but more especially in the lower animals, producing effects which appear to be those of reason and knowledge, but which transcend the general intelligence or experience of the creature." In the Century Dictionary we read further that "instinct is said to be blind—that is, either the end is not consciously recognized by the animal, or the connection of the means with the end is not understood." Intelligence is defined as "discernment or understanding," and as "cultivated understanding."

Now if intelligence is really discernment or understanding, as according to definition it is, it is difficult to see wherein it differs from instinct as displayed by insects, birds and rodents.

For instance, the mud-daubers, the fossorial, or digger, and other solitary wasps (fig. 20, p. 33) display great discernment and understanding in providing for the welfare of their young, which they will never see. Their actions are certainly based upon definite and detailed knowledge of the conditions which must be met. How they acquired that knowledge is wholly unknown to us, but it is indubitable that the knowledge is there. Whether their actions have anything to do with reason or not is a matter of opinion.

Reason is variously defined, but all definitions of reason are based upon the general idea that reason is a faculty characteristic of and peculiar to man, or perhaps shared in a small way with the more familiar domestic animals, such as dogs and cats. As a comparative term, therefore, the word reason is quite without meaning.

Whether the actions of the solitary wasps transcend their general intelligence or experience we do not know. We have no measure whatsoever of their intelligence, and we cannot tell how much or how little they may remember from their larval life.

There is no object in prolonging this discussion. On examining the facts we see that intelligence and reason are supposed to be peculiar to man. Actions which in man are acknowledged to be the result of intelligence and reason, such as the use of heat, tools and clothing, if duplicated in insects are assumed to be the result of blind instinct. But in the absence of indubitable proof the same or very similar actions cannot be supposed to arise from wholly different causes. So after all we are forced to admit that intelligence and reason are simply mental attributes we think we understand, while instinct is a mental attribute we know we do not understand. That seems to be the only tangible difference between them.

This raises some very interesting questions. Can it be possible that after all the animal world is really a much more unified whole than it is commonly considered? Can it be possible that all forms of animal life, although so very widely different in their structure, are merely diverse and concurrent manifestations of the same broad principles? Are we to look upon the numerous animal types not as higher and lower but as representing a different grouping of features, both physical and mental, inherent throughout the animal world and in some way combined in the original prototype? Or is there some other explanation?

CHAPTER III

MAN AND THE APES

UNDENIABLE is the fact that man and the man-like apes—the chimpanzees, the gorillas, the orangs and the gibbons—show numerous points of similarity. Man is obviously much more nearly like these apes than he is like any other living creatures. Yet equally undeniable is the fact that the differences between man and the apes are significant and striking.

The most interesting and the most significant of the differences between the apes and man are connected with their very early life.

Although they develop very slowly, none of the apes or monkeys have a true baby stage except of relatively brief duration. Their young very soon acquire what might be called a subadult mentality. Early in life the actions of young apes and monkeys begin to resemble more or less closely the actions of their parents—or perhaps it should be said recall the actions of their parents. This is not at all the case with human children in the normal human family, though neglected or abandoned children rather quickly leave behind them the typical child stage.

All human children have one marked peculiarity which seems to be confined to them. When babies first begin to touch and to hold objects they seem to show an extraordinary preference for hard, and especially rough, objects. Babies are very fond of passing their fingers over sand-paper, which they usually much prefer to ordinary paper. So far as I know this is not at all true of young monkeys.

When they are given a hard object, such as a watch, babies usually first put it to their mouths, and when they begin to lose interest in it they commonly end by whacking it against something. Of course they sometimes simply drop it. If monkeys lose interest in anything which they are holding in the hand they always simply drop it. The whacking propensity of babies certainly is not learned from their parents. Indeed, it commonly results in tangible forms of parental resentment. It is, perhaps, the most important and significant instinctive reaction of babies, at once proclaiming them as fundamentally different from young monkeys. Their preference for hard and rough objects tells the same story.

It is probably safe to assume that these two reactions of young babies lie at the bottom of all material human progress. For we see in these reactions an inherent and characteristic impulse to acquire hard rough objects and, holding them in the hand, to make use of them. Apparently blind and undirected as this instinct is, it is easy to suppose that it would lead directly to the use of tools.

Another peculiarity of babies is a more or less marked desire constantly to hold something in the hand. Young monkeys like to cling to the mother, but show little, if any, desire to hold anything in the hand. In man this curious desire to have something in the hand is continued throughout life. We notice it in both men and women, and we find it equally conspicuous in the streets of a large city and along country lanes.

The predilection for hard and rough objects, the whacking propensity, and the constant desire to hold something in the hand are so very characteristically human and appear so very early that there must be something of fundamental import and significance behind them. They seem to point especially to the human hand and in some way to show that there is a deep seated and a far-reaching difference between the human hand and the monkey's paw.

Every parent has noticed that at times babies are fearfully destructive. They delight especially in destroying books and magazines and flimsy toys. Destruction for destruction's sake seems to be a peculiarity of the baboons, for baboons if they gain entry to a house will more or less completely wreck everything that can be wrecked. But it is not a peculiarity, so far as can be learned from the literature, of the more man-like monkeys.

Leaving the individual baby, let us now consider the human family. Perhaps the most important social difference between man and the apes is correlated with the fact that in man the ministrations of both parents or their equivalent are necessary in the raising of a family. A woman cannot raise a family unaided. She must have the assistance of a husband or, in the more complicated social systems, of other members of the social unit. Interdependent with this we find in man a socially effective sentiment of love which creates and makes a unit of the family.

So far as the available information enables us to say, all monkeys live together in promiscuous hordes or troops in which each female raises her own young unaided. Family attachments are not necessary and do not occur.

That family life was from the first a fundamental human institution would seem to be shown conclusively by the existence in all human races of taboos and laws directed toward the maintenance of the family or of some social form to be interpreted as derived from the family. Now so far as we know taboos and laws are not invented to mold society into new and preconceived forms, but on the contrary they are designed to correct evils recognized as possessing disruptive or destructive tendencies which from time to time appear.

Through a natural process of development from the human family arose the various human social units. In highly developed social units including large numbers of individuals the human social system tends more or less extensively to break down. Promiscuity becomes frequent, attachments between individuals of opposite sex become increasingly transient, families commonly consist of a single child or of two children of very different ages, and in general the human society seems to approach the system characteristic of the apes.

From this it has been argued that the human social system was originally derived from that of the apes and that such a breakdown simply indicates a return to fundamentals. This is not at all the case. The breakdown of the human social system, which orginated from large serial families of dependent children, is invariably the result of economic causes arising from the complexities of the system itself when so very highly developed as to become artificial. It arises from the love of gain or show and the associated desire to be free of the liabilities inherent in family ties which becomes so exaggerated as to thrust into the background the normal sex relations. It is rendered possible by the fact that in large communities family responsibilities, instead of remaining localized and concentrated in the heads of families, become increasingly distributed over the social unit as a whole. It is actually the reverse of a return to fundamentals.

It is not necessary here to discuss the use of fire, tools, ornaments and clothing, or the development of articulate speech. It is sufficient to point out that the origin of all the distinctively human attributes must be satisfactorily explained by any adequate theory of the development of animal forms, and further that these cannot be explained by any theory which assumes the origin of man from the manlike apes.

CHAPTER IV

THE WORLD AND THE BUTTERFLY

Man's contacts with the world about him are singularly limited. To a large extent he himself creates the environment in which he lives. Houses or other shelters or appropriate clothing or sometimes a simple covering of grease protect him from the rain. Clothing and fire provide warmth, and fire also light. Most of man's food is produced under his control. Man is therefore more or less completely independent of many factors that have a most important—indeed a vital—bearing on the existence of every other living thing.

True appreciation of any form of animal life is quite impossible unless we constantly bear in mind the intricate and varied contacts of that form of life with other forms of life, both animal and vegetable, and also with the inanimate or inorganic world.

In order to understand and to appreciate the intricate nature of the complex, both living and non-living, that enmeshes every living thing, holding it rigidly to its proper and appointed place in the cosmic plan, let us briefly consider the numerous and varied contacts of a butterfly (fig. 12, p. 21).

Did you ever realize that for their existence butterflies depend upon the sea? The young of butterflies are known to us as caterpillars. Caterpillars eat leaves—or at least the great majority eat leaves.

Leaves are produced by plants. In order to grow plants must have water. To them water comes in the form of rain. Rain is moisture condensed from the air passing in the form of winds above the earth. Most of this moisture gets into the air through evaporation from the surface of the seas which cover seven-tenths of the area of the world.

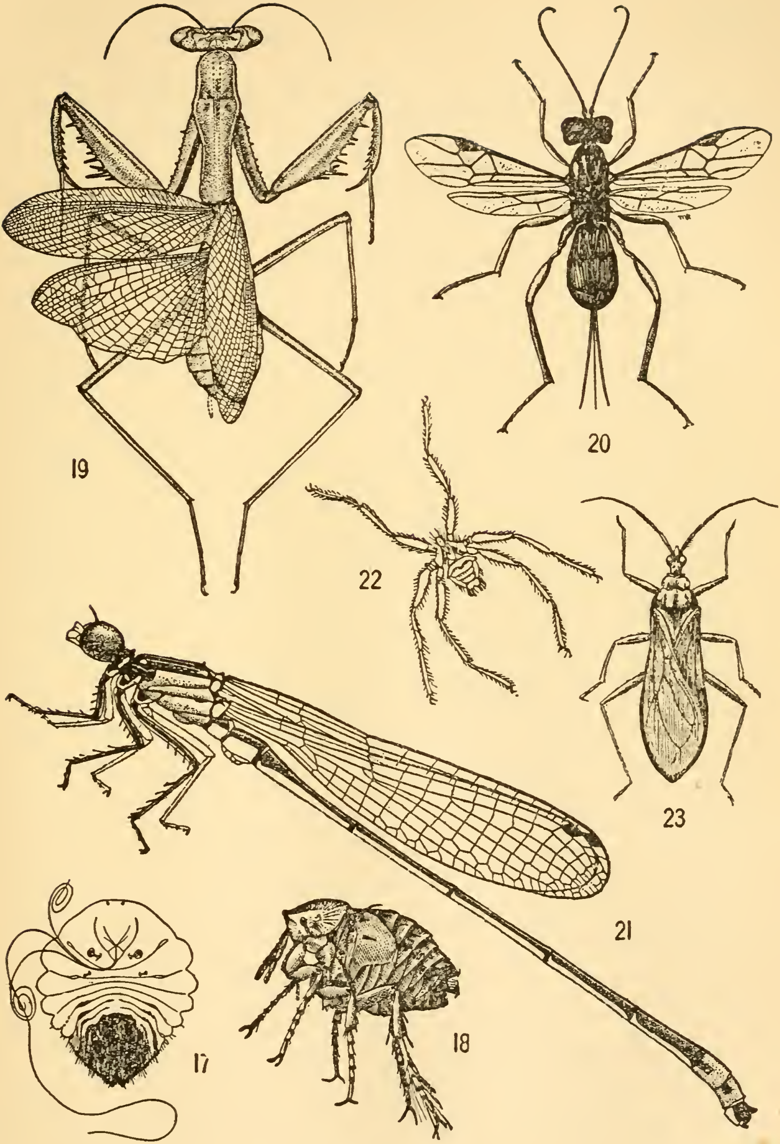
So there really is a close connection between the butterflies and the ocean. This connection is made up of many links which involve almost every line of science. For instance, astronomy plays a part. The emanations from the sun provide the energy by means of which the water is evaporated from the surface of the sea, which causes the winds to blow, and which, acting on the green substance in the leaves of plants, enables them to form organic out of inorganic substances. In other words, the emanations from the sun make possible the physical processes and chemical reactions on which the existence of the butterflies depends. And besides this, the element of time, so far as it affects life, is an astronomical phenomenon dependent upon the spinning of the earth upon its axis and on its course about the sun.

Weather and climate play an important part in directly affecting the lives of all the butterflies. They also affect them indirectly through their action on the sea, in some cases thousands of miles away. As an example, the alpine butterflies on the mountain tops in south central Asia depend on snow and rain which is brought to that region in the form of water vapor by the higher currents of the air from the Atlantic ocean across the plains of Europe and of western Asia.

Soils are formed from the disintegration of the rocks. Rocks are continually breaking up and being washed away as mud or sand or gravel. In this way there is formed the basic food of the plants which support the butterflies.

Besides this, the muds and sands and gravels deposited in water are continually being reformed and consolidated into the so-called sedimentary rocks. Once in a while a butterfly gets stuck in mud and covered up. This mud may later turn to rock. When this happens we have a record of the sort of butterflies that existed at the time when that rock was mud. It is quite unusual to find butterflies as fossils in the rocks, though a fair number have been found and studied. These all belong to that far distant period known as the Miocene and lived many millions of years ago. In spite of their very great antiquity, they differ very little from the kinds we know today. Most of their living representatives, however, are found in different regions. Thus in Colorado we find a type now confined to Africa, and in Germany we find other types which today live only in America.

Most caterpillars are able to subsist only on a very limited number of different kinds of plants which are closely related to each other in their chemical composition. Thus the cabbage butterfly feeds only on cabbages and a few closely related plants, and on nasturtiums. Some enormous groups of butterflies feed only on a single type of plant, as the so-called *Aristo-*



Different Types of Insects

For an explanation of the figures see p. 278

lochia (or pipe-vine) swallowtails which feed only on *Aristolochias* and on very closely allied plants, and also our fritillaries which feed almost exclusively on violets. Very many kinds of butterflies feed only on a single kind of plant, like our beaked butterfly and tawny emperor which as caterpillars are found only on hackberry trees. But a few kinds of butterflies, like our common yellow swallowtail, feed on a very great variety of different and unrelated plants.

From this it becomes evident that female butterflies must be expert botanists, for they must be able accurately to identify those plants which are suitable for use as food by the caterpillars of the coming generation. Or perhaps it should be said that they must be expert chemists, for not infrequently they will pick out a plant chemically suitable as food, but botanically widely different from any other plant which they or their ancestors, at least for thousands of generations, could be supposed to know.

As an illustration, the female of the common cabbage butterfly will freely lay her eggs on garden nasturtiums (*Tropæolum*) which belong to a family of plants (Tropæolaceæ) confined to Central and South America and not at all like any of the plants of the cabbage family (Brassicaceæ) upon which ordinarily this Old World insect feeds.

Butterflies have very many enemies of every conceivable description. The Australian natives are very fond of certain kinds of butterflies, and grow fat on them if they can get them in sufficient quantities. In Central and South America and especially in Africa the caterpillars of several different kinds of butterflies used to be, and in some places are still, in much demand as food. Certain bats are very fond of butterflies, and mice and shrews eagerly devour them. Some birds feed partly, and in the tropics largely, on them. Certain small lizards and some of the smaller snakes are very fond of them. Among their insect enemies are mantes (fig. 19, p. 33), various predacious bugs (fig. 23, p. 33), robber-flies, dragon-flies (fig. 21, p. 33), hornets, ants, and the so-called caterpillar wasps.

But their worst and most destructive enemies are various sorts of small wasp-like flies which lay their eggs upon or in their eggs, their caterpillars, or their chrysalids. The small maggots which hatch from the minute eggs of these small parasites feed upon the contents of the egg of the butterfly or upon the juices of the caterpillars or upon the contents of the chrysalids. Some of the true flies which in their appearance are much like little blue-bottles also have this parasitic habit.

Many of the parasitic grubs which live unseen within the bodies of the caterpillars have parasites that feed on them. Although these live within the caterpillars, they feed only on the parasites which are themselves engaged in feeding on the caterpillars.

And besides these enemies butterflies have many more, for instance nematode worms (cf. fig. 81, p. 161), bacteria and protozoans (cf. fig. 87, p. 161), spiders and mites, sometimes even mosquitoes. Indeed so numerous and varied are the enemies of the butterflies that one often wonders how it is that any butterfly is left alive.

Such in brief are the more important contacts of a butterfly. In considering the living world it is important constantly to bear in mind that every sort of animal no matter what it is has just as many and just as varied contacts as has a butterfly.

CHAPTER V

LIFE'S BACKGROUND

All animals must eat. Therefore in a consideration of the living world it is important clearly to understand the origin of the food which supports the animals. It is essential that we appreciate just how the necessary substances are made available for them. It is important that we understand the mechanism of the formation of the food of animals.

Air, water, rocks—from these three ultimate sources do all living things secure those substances which are necessary for their existence and their increase. The energy by means of which these substances are released and through recombination made available for use by living things comes from the sun. This energy radiated from the sun reaches the earth in the form of sunlight and of similar but invisible emanations of wave lengths longer or shorter than those which our eyes are able to perceive.

The interaction of the water and air upon the rocks which is made possible by the energy provided by the sun is perhaps best understood by the consideration of a bleak and desolate mountain top. The exposed summit of a mountain would seem to be the last place in the world in which to contemplate life's mysteries, but from the crags and rough and broken rocks drenched by the rain or covered with snow or ice or wrapped in clouds or mists we may learn first hand very many things which are by no means so evident elsewhere.

The most important thing we learn is that rocks, no matter how solid they may seem, are far from indestructible. The rocks of the bare mountain tops are always cracked and broken. The expansion caused by the sun's heat and the contraction caused by the cold of night or of the winter and the freezing and thawing of such water as penetrates the fissures are continually chipping off larger or smaller bits from their exposed surfaces. Besides this, the various minerals which compose the rocks are all more or less soluble in water so that part of the substance of the rocks is continually being washed away.

The bits chipped off fall down the mountain side and gradually are reduced to smaller and smaller fragments. The substances dissolved are partly held in the water in the soils, and partly are carried by the rivers to the sea.

This process of rock destruction in most mountainous regions is hastened by earthquakes which by shaking the fragments down into the valleys expose new surfaces to the destructive forces.

In many places volcanoes are continually, or from time to time, bringing to the surface great masses of rock in the form of lava or of dust or ash and together with this water vapor and other gases of various sorts which add to the supply of substances available for the support of life on the earth's surface.

Rocks appear to us as solid, unyielding, and more or less unattractive objects. But they contain, securely locked up in the various minerals of which they are composed, all of the chemical elements which make up the substance of the bodies of the plants and animals. These are released and freed by the destruction of the rocks by air, water, heat and frost. It is the continuous destruction of the rocks and the release thereby of the elements necessary for the formation of their bodies that makes possible the existence both of plants and animals.

The finely divided particles of rock form soils which cover the mountain sides and the valley floors, and more deeply all of the more level regions of the land. Soils are of many different types, and their ability to support life is dependent upon the temperature, seasonal changes and rainfall of the region as well as on the type.

On the soils grow plants of all descriptions, sometimes in small amount as on coarse gravels or on areas of shifting sands, but sometimes in great abundance forming extensive forests and broad grass covered plains.

Obtaining all the materials necessary for their growth from the soil and air and water are the green and comparable plants alone. By means of the green substance, known as chlorophyll, and allied substances, these plants are able to form organic out of inorganic compounds. No form of animal life is able to exist on inorganic foods.

So all of the animals living on the land depend for their existence on the green plants, either directly or indirectly. Every portion of a green plant—leaves, stems, trunk, roots, seeds and flowers—is used as food by some animal type or other.

Not only are all the animals supported by the green plants, but multitudes of other kinds of plants, such parasitic plants as the mistletoes and gold-threads and many other less familiar sorts, and especially the fungi, molds and rusts and many bacteria, live either on them or on their dead remains.

Such animals as are not plant feeders live on other animals that feed on plants or on the parasitic or saprophytic plants feeding on the living or the dead green plants, or on the partially decomposed remains of plant or animal substances. A few animals have been described as capable of existing on mineral material alone. But it is doubtful whether any animal can do this without the intervention of some associated plant.

And besides all these there are numerous kinds of parasitic plants, particularly bacteria and molds, which live on or within the bodies of every sort of animal, whether plant feeding or carnivorous.

In short, we find plant feeding plants, plant feeding animals, animal feeding plants and animal feeding animals of every conceivable variety. There is no reservoir or source of food of any kind, permanent or temporary, that is not utilized by some sort of living thing.

At the beginning of the winter, or in the tropics of the dry season, the leaves of the green plants cease to function. In most of our plants and in many in the tropics they wither and drop off. The dying and falling of the leaves in autumn and at the beginning of the dry season, and more or less constantly at other times as well, means the accumulation of a vast reservoir of foodstuffs for anything capable of making use of it.

Bacteria and fungi thrive on this detritus, and earthworms and many other kinds of snails and slugs and insects, as well as other creatures, feed either on this decaying vegetation, or on the bacteria or fungi in it, or on the living things that feed on them.

Much of this material is consumed where it lies upon the ground, but a vast amount is washed into the rivers, especially by the floods of spring and at the breaking of the rains, and is carried to the sea. A large part of this is still in a condition to be eaten by detritus feeding animals, while a great deal more, especially in the form of organic substances in suspension or solution, is available as food for the marine plants.

Our knowledge of the origin of the substances on which the plants of the sea depend for their existence is rather vague. But the evidence seems to indicate that very largely, possibly for the most part, life in the oceans is dependent, through the necessities of the ocean plants, on food substances brought down from the exposed land areas.

The plants of the sea, at least those which support the greater part of the ocean's animal life—minute free floating plants invisible to the naked eye (cf. fig. 86, p. 161)—seem to require the presence in the water of something that comes to them from the land.

This is presumably some organic substance chiefly derived from the decayed remains of land plants. Whatever it may be, if it is not essential at any rate the oceanic plants grow much more luxuriantly if it be present, exactly as many of the plants on land will grow much better if they are well manured.

Strange as it may seem, life in the sea is for the greater part confined to the regions bordering the shores of continents, though also abundant about large mountainous and wooded islands such as those of the Malayan archipelago. So we find all of the important fisheries of the world situated in shallow water near the land. Furthermore, these are all in the northern hemisphere along the coasts of those continents which have the greatest area exposed to the action of the sun and rain and frost.

With increasing distance from the land life in the sea becomes progressively less and less abundant, and toward the middle of the oceans, especially in the southern hemisphere, it almost completely, perhaps even entirely, disappears. Sea animals are largest and most abundant on those shores which have a copious rainfall, and especially on rugged and on cold coasts where it may be assumed that material from the land would reach the sea in the greatest quantity and would remain unaltered for the longest time.

CHAPTER VI

FACTORS AFFECTING ANIMAL LIFE

VARIATIONS in the several different types of animal life from place to place on the earth's surface or in the oceans, and from one geological epoch to another, are directly or indirectly brought about as a response to variations in the factors which bear more or less directly upon the animals involved.

Frogs are not found in deserts, nor are there any lizards in cold regions. Elephants, rhinoceroses and tapirs now live only in restricted areas in the tropics, but in the Pleistocene all three ranged far to the northward of their present habitats. On the New Siberian Islands in the Arctic Ocean the bones of Arctic elephants or mammoths are to be found in great abundance.

So before we can discuss the problem of the changes in and the development of animal forms it is essential that we understand just what the most important of these factors are.

The chief factors affecting all living things are the great diversity in the form in which the supply of necessary new materials is offered, and the great diversity in the chemical and physical environment or surroundings in which they must be taken up and used.

Only the plants containing chlorophyll or some similar substance are able to build up organic out of inorganic substances. As they can do this only with the aid of sunlight, the animal life of the entire world is supported by plants growing on the surface of the exposed land areas, or attached to the bottom, freely floating, or suspended in water of not more than six hundred feet in depth. So the sun-lit surface of the land and the sun-lit surface of the sea provide the basic food for all forms of life from the highest mountain tops to the depths of the deepest caves and down to the great abysses in the sea.

The plants containing chlorophyll or a comparable substance get the materials necessary for their growth from substances dissolved in the water in the soil, or in the water of ponds, lakes, rivers, or the sea, and from gases in the air or dissolved in water.

Just as water is essential to the life of every plant, so also is it essential to the life of every animal. Since foodstuffs are available for use by animals and plants only when they are accompanied by an adequate supply of water, the very unequal distribution of this liquid is the chief controlling factor affecting all life on land.

Some regions are extremely wet, while others are extremely dry; in others the supply of water is very variable at different seasons of the year, or the humidity may vary very greatly between the night and day. In the north for a greater or lesser portion of the year the water becomes ice—in other words it changes over into a form in which it is not available for use by the very great majority of plants and animals.

So every living thing on land, whether plant or animal, must have some provision to counteract the variability in the available supply of water, and especially to guard against the loss of moisture.

Thus all adult insects living in the open, like house-flies, June-bugs, wasps, bees, moths and butterflies, are protected by a tough impervious covering. Among the backboned animals or vertebrates the reptiles and the birds are best protected against the loss of moisture. Consequently reptiles and birds with a few insects having an insatiable thirst for nectar, sap or blood are the characteristic creatures of hot and extremely arid regions in the daytime.

In the cool and relatively damp nights in the same regions mammals take the place of reptiles, issuing from their holes and other hiding places and ranging widely everywhere, while many different kinds of insects take the place of the very few that are abroad by day. In less arid regions mammals become more varied and abundant, and are seen by day as well as after nightfall; birds and insects also become more varied and abundant, and amphibians (toads) appear. In still moister regions frogs are also found.

The young of insects—maggots, grubs or caterpillars, or, in the case of grasshoppers, bugs (fig. 23, p. 33) and other types, small wingless replicas of the fully grown—are always less well protected against a loss of moisture than are the adults. The young of house-flies, which live in moist decaying substances, the young of June-bugs, which live in moist soil and are commonly called "white-grubs," and the young of bees and wasps which live in cells carefully prepared so as to avoid a loss of moisture, are soft and flabby, more or less like earthworms.

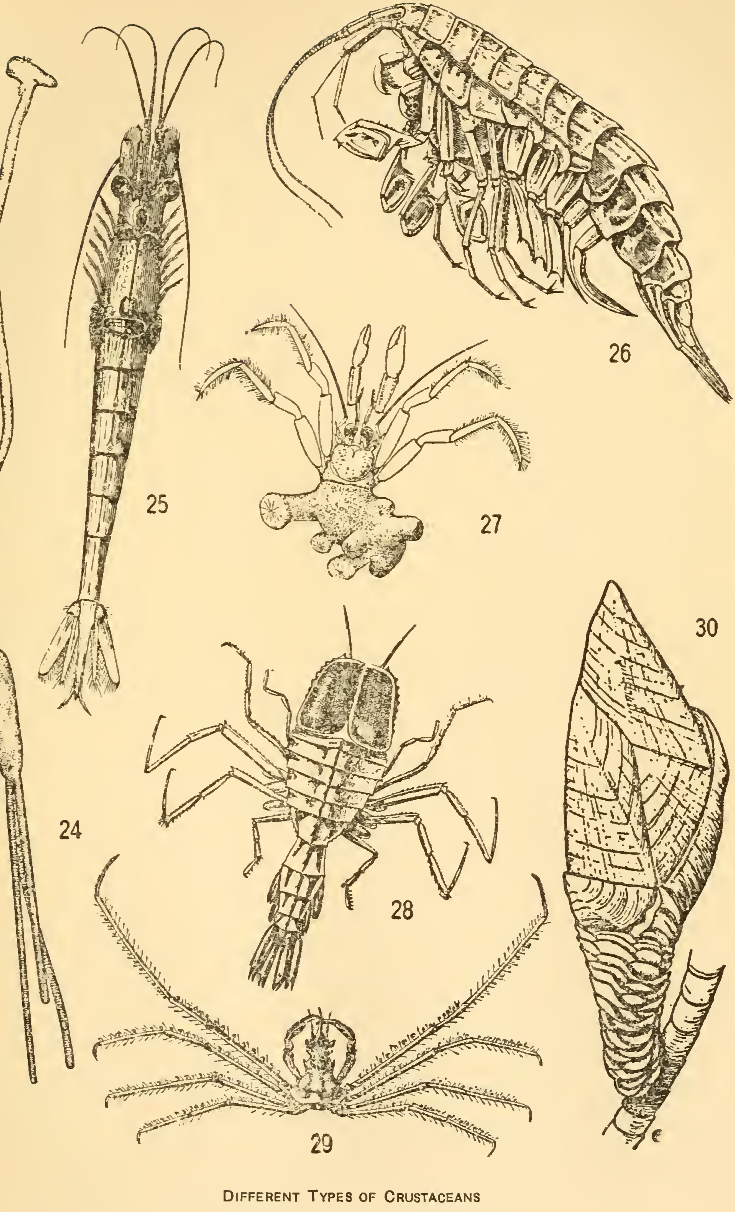
Compared with the grubs of bees and wasps most of those caterpillars which are the young of butterflies have a thick tough skin, though they nearly all live in more or less humid situations and of course take in water all the time with the portions of the leaves they eat. Many caterpillars, like those of the fritillaries, conserve their moisture by feeding only in the night time, in the day hiding beneath sticks and stones or among fallen leaves.

The caterpillars of some of those curious butterflies that feed on ants live in the ants' nests mostly below the surface of the ground. They are soft and their skin is very thin, so that they look much more like the grubs of beetles than they do like the young of butterflies.

Much as the soft and thin skinned young of house-flies, June-bugs, bees and wasps differ from their parents do the marsh-living and aquatic frogs and salamanders differ from the toads.

It is the same with plants as with the animals. All the plants on land have some special adaptation to prevent damage through their drying up. In many cases plants flourish in the rainy or the warm summer season and when that passes go into a drought-resisting resting stage, or go to seed, the seeds living over, on or in the ground, until the rainy or the summer season comes again.

Very many insects do about the same. They live



DIFFERENT TYPES OF CRUSTACEANS

FOR AN EXPLANATION OF THE FIGURES SEE P. 278

their active life in the wet or summer season and pass the dry or winter season in a resting stage, commonly the pupa, buried in the ground or in some other situation where they will not lose their moisture.

Temperature is commonly regarded as an important factor in controlling life both on the land and in the sea. And so it is. Yet it seems to be not so important of itself as in its indirect relation to organic life. On land, changes in temperature, seasonal or diurnal or irregular, profoundly affect every living thing. This is due in part to their effect on the chemical processes taking place within the body, but probably in equal part to the complexities they create in the vital problem of securing and conserving water.

So far as plants and animals are concerned, one of the most important things concerning water is that at low temperatures it suddenly changes over into ice—that is, it passes over into a form in which it cannot be used without a considerable expenditure of energy.

So in the northern winter when the ground and ponds and streams are frozen the plants cease to grow and become dormant. The turtles, snakes, lizards and frogs, the butterflies, bees, ants and other insects, and the snails and earthworms, all pass into the long sleep known as hibernation. All birds are perpetually active, and all that cannot find sufficient food fly south. But some mammals, like the bears and woodchucks and certain of the mice, sleep like the insects, while others, like the squirrels, sleep most of the time but appear at intervals on warm and sunny days.

When the weather gets extremely cold the air, with any rise in temperature, becomes extremely dry and, speaking generally, dryness is more dangerous to life than cold. This raises an interesting question. Why do the small birds that visit us each winter from the north, such as the horned larks, snowflakes, kinglets, creepers and others, leave their summer homes? Is it not probable that they are induced to visit warmer regions not so much on account of the cold itself as because of the dryness which accompanies the cold?

For most of these birds there is quite as much food available in winter in their northern homes as there is with us, but the water content of that food is considerably less. It is to be remarked that when they visit us these little birds keep mainly in damp localities, in low damp woodlands, about ponds and streams, or near the sea coast.

Much as the animals and plants with us pass through the winter do tropical animals and plants pass the dry hot season. For instance, some of the lemurs in Madagascar spend the dry season in a state of torpor coiled up in a cavity of a tree or in a nest just as some of our squirrels spend the winter.

In some places in the tropics at the end of the wet season the trees for the most part shed their leaves, and the insects almost completely disappear. A photograph of such a region at this time much resembles one of a snowless day in winter in the north. Conditions are the opposite in that in one case nature is sleeping from the effect of excessive heat and in the other from the effect of excessive cold, but they are the same in that in both cases the plants and animals are sleeping over a period when they are unable to obtain sufficient water.

Temperature affects directly only such animals as are so very delicately balanced that they require a fixed and usually high degree of heat for the maintenance of their internal chemical reactions. In this category fall the most active vertebrates, the mammals, birds and reptiles.

In the mammals and birds the body is insulated from the temperature changes in the air about it by a layer of air which is held in place by a covering of hair or feathers. Their body temperature is high and constant and, excepting in the monotremes or egg-laying mammals, and in hibernating mammals, it is quite independent of the outer temperature. The bodies of whales are insulated from the temperature of the surrounding water by a layer of fat, while the seals have both hair and fat.

Reptiles require a relatively high temperature, but have no mechanism for controlling it. Therefore all of the more active and all of the larger reptiles are tropical or subtropical, only the smaller representatives of less active types, the turtles and the snakes, occurring in the colder regions. The amphibians are all relatively inactive and the frogs, toads and salamanders range far into the colder regions.

Among the other forms of life temperature seems to have the most effect in delimiting the activity of bacteria and protozoans, many of which will thrive only within curiously narrow limits and most, though by no means all, of which require a considerable degree of heat.

It is a curious fact that these very features which are characteristic of bacteria and of protozoans are equally characteristic of the reproductive cells of all other animals. Reproductive cells in their temperature relations as well as in the broader features of their structure are always more like protozoans than they are like the animals from which they were derived.

This is well illustrated by the narrow temperature range within which the different sorts of fishes and amphibians will spawn, and within which normal development of their ova will take place, and on land by the narrow temperature range within which the different kinds of insects lay their eggs.

This interesting disharmony between the temperature range of adult animals and that of their eggs and very early stages probably has played an important part in the diversification of animal life.

CHAPTER VII

MORE ABOUT ANIMAL LIFE

THERE is a most important trinity of factors affecting life in general that is not sufficiently appreciated. For all living things, no matter what they are, water, air and food are the prime necessities. Everything else is in importance wholly secondary.

Physiological adaptations enable both animals and plants to exist through the entire range of temperatures found upon the earth, and also through the entire range of illumination. Indeed, in the absence of light many animals and plants are able to produce themselves, through the phenomenon known as luminescence, a sufficiency of light of the quality necessary for their well being, just as the birds and mammals are able to create and to maintain the temperatures necessary for the proper functioning of their bodily reactions.

While by various bodily adaptations, and especially by diverse habits, certain types of animals are able to store up and to conserve an adequate supply of water, or at a time when water lost cannot be replaced to enter, sometimes abruptly, a resting stage, none can do without it. Furthermore, all living things when active require a considerable amount of water. It is the same with air, and again the same with food.

From this it naturally follows that life, or rather living substance, will be most abundant for each unit of area—for instance per acre—where there is a maximum of water permanently in the liquid state, a maximum of air, and a maximum of food.

Thus on land the optimum conditions for the greatest development of plant and animal life, so far as concerns mere bulk alone, are to be found in the moister regions of the tropics where the rains are not so heavy as to be destructive by the weight of water falling, and the temperature is high and constant.

But in the sea these factors find their most perfect balance in a region wholly different. Here the chief problem is securing a sufficiency of air. Now the colder water gets the greater the amount of air it is capable of holding in solution. Everyone has noticed that in a glass of cold water standing in a room bubbles of air appear on the sides and bottom as the water warms. So in the sea the optimum conditions for both plant and animal life are in the coldest oceans, in the polar seas in the summer time when the sun is at its highest, and in the cold currents flowing out from these.

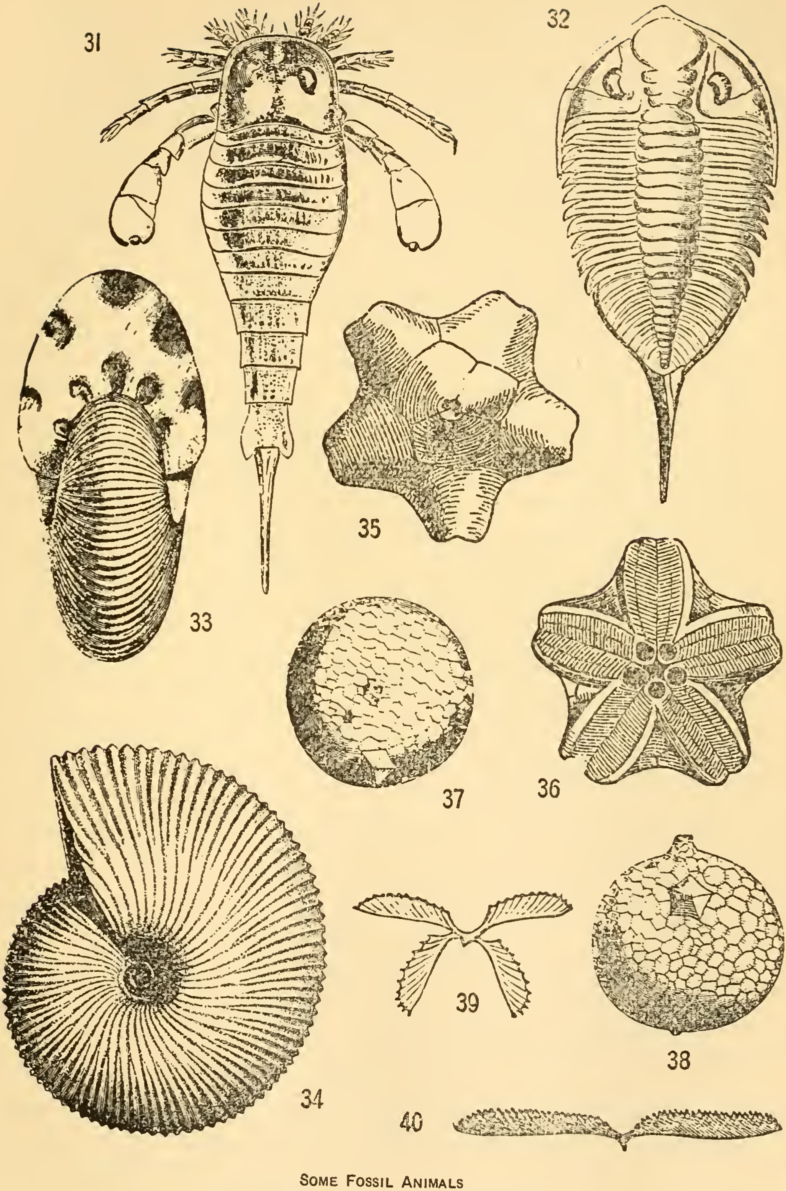
In the hot wet portions of the tropics chemical disintegration of the rocks takes place with great rapidity, continually replenishing the mineral constituents in the food supply of the endemic plants. In the cold polar seas the dead organic matter either in suspension in the water or lying on the bottom is preserved, as in an ice-box, for the longest time.

So on land food supplies, in the form of new materials made available for use by plants, are especially abundant in the tropics, while in the sea, due to conservation by indefinite preservation, they are most abundant in the coldest water.

The regions supporting the greatest density of life both on the land and in the sea are the regions showing the least deviation from the optimum conditions. Naturally in the regions showing the least deviation from the optimum conditions there is the least incentive to or necessity for variety among the endemic types of plants and animals. Therefore the regions wherein is to be found the greatest density of life are not the regions where animals and plants occur in the maximum variety. The greatest variety both in plants and animals is to be found in regions where there are the most diversified conditions to be met which may be met through minor adaptations.

Conditions which involve the passage by animals and plants through a resting stage, more or less prolonged, necessitate what might be termed major adaptations. For an enforced resting stage necessitates ability to prepare for it, or to recover from it, or for both previous preparation and subsequent recovery. The necessity for such major adaptations renders life impossible for many types which are quite capable of meeting the requirements for minor adaptations, as for instance those called for to counteract daily variations in the essentials for existence.

The fact that minor adaptations may take many different forms whereas the possible variety in major adaptations is rather closely circumscribed furnishes the explanation of the interesting fact that the great-



Some Fossil Animals

For an explanation of the figures see p. 279

est variety of life is found where conditions vary more or less extensively, but not too widely, from the optimum.

On land the greatest variety in the plants and animals is to be found in the less humid and cooler regions of the tropics where seasonal change is slight or absent, but the temperature and humidity vary considerably between the night and day, and in those regions in the tropics with a more or less marked, though not severe, dry season.

Among the animals of the sea the greatest variety occurs on tropical and subtropical coasts at moderate depths where the temperature of the water is just about half way between the temperature of the abysses and the temperature at the shore line. This region is a sort of meeting ground wherein are found many representatives of abyssal types which rise no higher, and also representatives of many shore line forms which descend no lower, while at the same time very many different creatures occur in this band alone. Much the same conditions are to be found on land in mountainous regions in the tropics.

There is still to be considered the region producing the greatest amount of life, that is, the maximum amount of living substance. One might suppose that this would be the region where the greatest amount of disintegration of the basic rocks is constantly taking place. And so it is. On land the maximum amount of living substance is found in the northern hemisphere between about the Tropic of Cancer and about 60° north latitude where there is the greatest exposed land area under conditions of rapid chemical and physical disintegration. This region includes by far the greater part of all the forests of the world and of the fertile grassy plains. In the sea the region that supports the greatest amount of life is that which receives the drainage from this same area, that is, the north Atlantic and the north Pacific oceans. Here the maximum intensity of life is in bands along the shores, narrow in the south but broadening in the north, lying mostly in water of not more than six hundred feet in depth.

CHAPTER VIII

LAND AND SEA COMPARED

In order properly to understand the conditions under which life in the sea exists it is necessary first of all to compare them closely with conditions on the land in order to bring out the corresponding features and to emphasize the contrasts.

We all have a pretty good idea of conditions on the land. On land life exists at the bottom of a sea of air which entirely surrounds the earth. The thickness of this blanket of air about the earth is such that each square inch of the earth's surface supports a weight of nearly fifteen pounds of air. So we say that at the surface of the earth there is an air pressure of approximately fifteen pounds to each square inch.

Air is very light, much lighter than the living substance—protoplasm—of which the bodies of the plants and of the animals are composed. Consequently all land living things, both plants and animals, must live on or just beneath the surface of the ground at the bottom of the sea of air.

But in spite of its lightness as compared with flesh, air is fairly heavy. Therefore it has considerable supporting power. Besides, it is constantly in motion in one direction or another, and this constant motion gives it transporting power.

The transporting power of air is of very great importance both to the plants and to the animals. Very many plants depend on air to carry the pollen from one flower to another. We see this best in such trees as oaks, chestnuts, alders, willows and birches in which the male or staminate flowers are in long catkins. From such trees we sometimes see the pollen blown away in a thick cloud by a sudden gust of wind.

The spores of molds and fungi and of more or less similar types of plants and the spore-like stages of many of the microscopic animals, especially the protozoans and the rotifers, and also of a number of the minute organisms that cause disease in man, in animals and in plants, are almost constantly present in the air floating about in the same way as, and together with, minute particles of dust.

Air in stronger motion is essential for the distribution of those plants which have wind transported seeds. Such seeds may, like the seeds of orchids, be of such extremely minute size as to act like particles of dust. More commonly, however, they are provided with various devices such as the wings of the seeds of pines, elms and maples, or the tuft of hairs or "coma" of the seeds of the dandelion and the milkweed, which delay their falling and aid in their transportation.

Some insects, so far as their capabilities for transportation are concerned, are comparable to specks of dust. Such for instance are the excessively minute wasp-like things that live as parasites mostly in the eggs of other insects or of spiders, and certain equally small fungus-living beetles. Some of these little parasitic wasps and fungus beetles are scarcely more than one one-hundredth of an inch in length, and some of the wasps are wingless. If these were forced to depend on their own ability to travel they would be placed under an insuperable handicap, for what is a single mile for us is the equivalent of six million miles for them. We, however, have to walk that mile while for them the wind performs the labor.

Very many living creatures have discovered that the air is sufficiently dense to enable them to use it to support their bodies in passing rapidly from place to place. In other words, they have learned to fly. This is the case with all of the bats, most of the birds, and most of the insects in the adult stage.

Many creatures, although they do not actually fly like the birds and bats, have their body surface increased by expansions of various kinds whereby they are enabled to glide diagonally downward through the air from one place to another. We see this especially in the flying-squirrels, and in the flying lemur (*Galeopithecus*) and the flying lizards of the oriental regions.

Still other creatures have various adaptations which, by acting on the air, serve to protect them in one way or another. Thus a cobra when it strikes rises on the extreme end of its body and falls forward; as it falls the expanded hood acts as an air-brake and lessens the shock of its contact with the ground. Tree-living squirrels have long and bushy tails. They can fall from almost any height without danger to themselves. If they fall out of a tree they keep their tail waving, and the tail acts as a drag lessening the shock of landing.

I have remarked that in their last stage when they are fully grown and sexually mature most insects are capable of flight. In this stage most of them eat but little, and many of them do not eat at all. Most insects eat enough, or nearly enough, in their early or larval stages to last them all their lives.

For young insects rapid or extensive locomotion in most cases is not necessary. Their preoccupation is to keep as close as possible to their food supply, which usually is localized. Young insects, especially in the later stages, gorge themselves so that when adult they can fast. It is in the adult stage that, in most insects, all the traveling is done; the adults wander far and wide searching for new supplies of food for the coming generation. Through their capacity for long continued flight, which is greatly increased by the absence of the necessity for feeding, the insects largely overcome the handicap to their powers for distribution imposed by their small size.

Most spiders are distributed by a different method. All of the spiders are predacious, feeding on creatures weaker than themselves, mostly on insects. Naturally in catching prey strong spiders have the advantage over weaker ones, and large ones over smaller ones. Therefore the logic of the case would seem to be that spiders should fly in their early weaker stages and not as fully grown and powerful adults, and this is what actually happens.

Spiders are wingless, but their lack of wings is counterbalanced by uncanny ingenuity. On a calm warm day in the late summer you will often see a little spider standing on a stone or post with the abdomen elevated and spinning out a thread or group of threads of silk which by the warm air rising up the sides of the stone or post is carried upward. When the spider feels a strong enough upward pull from the rising threads of silk it lets go its hold and is drawn up into the air often to a great height where it is wafted about for a greater or lesser distance before it comes to earth again.

It should perhaps be mentioned that there are many caterpillars which in their youngest stage are provided with numerous long hairs. Such, for example, are the caterpillars of many of the moths in which the females are incapable of flight. These caterpillars are wind distributed after the same fashion as the seeds of the milkweed and the dandelion, and the young of spiders.

Flight in one form or another is common to about two-thirds of all known kinds of animals, and to about three-fourths of all the kinds of animals inhabiting the land. Most creatures fly simply in order to get rapidly from place to place, but some, like dragon-flies, most bats, and many of the birds, are especially adapted to feed on other flying things.

Being much heavier than air, a greater or lesser part of the food of plants and all of the food of animals lies on the ground or buried in the ground or supported by it. It is therefore fixed in its position. To utilize this food land animals and plants must be capable of locomotion, or in some form or other they must be adaptable to transportation by the winds or other agencies.

Plants are distributed almost exclusively as seeds or spores, chiefly by the winds. But a few seeds are adapted to become attached to the fur of animals and thus to be transported, while some are carried about in various other ways. Animals mostly get about by walking or by flying, either throughout their lives or at some special stage, but some are wind-transported in a spore-like or other special form after the manner of the plants.

The immobility of the food supply and the necessity of seeking or being carried to it are the chief controlling features governing all types of life on land. Therefore land animals are almost wholly of those types, arthropods or jointed footed creatures—the insects, spiders and their allies—and backboned animals or vertebrates, which are best adapted for locomotion, with a few representatives of some other types with fair locomotor powers, as the mollusks—snails and slugs—and earthworms.

While powers of active locomotion or else capacity for transportation in some form or other through a medium much lighter than themselves during at least one period of their existence is an essential requisite for all animals living on the land, no such necessities present themselves in the case of the animals living in the sea.

For water is about 814 times as heavy as air. It is almost as heavy as protoplasm, the material making up the living portion of the bodies of the plants and animals. Since water, and especially sea water, is nearly as heavy as protoplasm, it naturally follows that plants and animals may live suspended in it maintaining a position at any desired distance beneath the surface with little effort on their part. A drop or two of oil or a little gas or some other minor adaptation is sufficient to enable small animals or plants to maintain hydrostatic equilibrium. This simple fact is of immense importance.

As in the case of plants on land, the plants living in the sea require sunlight to enable them to build up their tissues. All sea plants, therefore, are confined to a thin surface layer of water of not more than six hundred feet in depth, below which there is not sufficient light to permit their growth.

Within this thin illuminated surface layer of water there are found along the shores attached firmly to the bottom many different kinds of algæ, commonly known as sea-weeds, some of which are very large. On muddy bottoms in quiet bays and estuaries the eel-grass and some other types of flowering plants belonging to the pond-weed family (Najadaceæ) often occur in great abundance, rooted in the mud. But the sum total of all the marine plants growing along the shores in water of less than six hundred feet in depth yields only a small fraction of the vegetable material which is required to support the animals of the sea.

How, then, are the sea animals supported? Most of the vegetation in the sea is in the form of microscopic plants which are quite invisible to the naked eye. These float suspended in the water all the way from the brightly illuminated surface down to the greatest depths at which they are able to secure enough effective light to enable them to grow.

So life in the sea for the most part is supported by plants which are invisible to us. This gives us the impression as we view the sea at some distance from the land that all sea life is animal life, consisting of fish, jellyfish (fig. 3, p. 5), whales, porpoises and other creatures. Conditions in the sea may perhaps best be understood if we compare the sea, in its richest portions, to a sort of fog or mist in which each little particle is a minute plant.

Many different kinds of creatures feed upon these little plants. Of these the most important and most numerous are various minute crustaceans of the sort known as copepods (fig. 64, p. 111). Crustaceans belong to the same group (Arthropoda) as the insects, and it is interesting to find that in the sea crustaceans, as on the land the insects, are the chief plant feeders—at least the chief plant feeders which serve as food for other types of life.

Drifting about suspended in the water swarming with minute plants, and the crustaceans and other creatures feeding on them, are many other types of animals, such as many kinds of jellyfishes (fig. 3, p. 5) and the curious arrow-worms (fig. 62, p. 111) and pyrosomas (fig. 59, p. 111) which thus exist surrounded by and suspended in their food supply. And together with these live many creatures possessed of powers of active locomotion, especially squid (fig. 45,

p. 97), fishes, whales and porpoises, while in the air above live many sea-birds.

Besides being almost as heavy as protoplasm and thus rendering easily possible free floating or suspended life, sea water is constantly in motion, though in the deep sea this motion may become extremely slow. This means that everywhere in shallow water where the waves and tides create a constant movement animals are able to attach themselves firmly to the bottom (figs. 60, 63, 67, 68, p. 111; figs. 76, 80, p. 143) or to root themselves or burrow in the mud and then let the motion of the restless water do the work of bringing food to them.

In progressively deeper water where the motion gradually becomes so very slight as almost to be absent, the wanderings of suspended creatures endowed with feeble locomotor powers render attached existence for such larger creatures as are able to overcome and feed on them just as advantageous as attached existence is along the shores.

So we are not surprised to find that various types of animals which, attached firmly to the rocky bottom or rooted in the mud, both grow and look like plants, are especially characteristic of the sea. Such types of animals are the corals (fig. 80, p. 143), sea-pens (fig. 77, p. 143), sea-fans, gorgonians, sea-squirts, hydroids (figs. 75, 76, p. 143) and sea-mosses (figs. 67, 68, p. 111), belonging to a great array of different groups. More familiar to us are the oysters, barnacles (fig. 30, p. 47) and mussels, the mud-boring clams and razor-clams, the sponges, and various sorts of encrusting and plant-like polyzoans, all common and familiar objects on our shores.

While not an essential as it is for all animals inhabiting the land, yet power of locomotion is a useful asset for the creatures of the sea. So in the sea we find great numbers of swimming creatures, as whales, porpoises, seals, fish, squid (fig. 45, p. 97) and various other types, and numerous crawling creatures, as for instance worms (fig. 85, p. 161), crabs (fig. 29, p. 47), starfishes (fig. 42, p. 71) and sea-urchins (fig. 41, p. 71).

It is important to remember that while on land all animals must seek their food and hence must be endowed with powers of locomotion, or must in some stage be capable of transportation, the animals of the sea have a choice of three different methods of securing food.

First, sea animals may secure their food through searching for it by crawling or by swimming, in other words by the use of locomotor powers. *Second*, they may attach themselves and let the motion of the water do the work of bringing food to them. *Third*, they may simply float and drift about suspended in the midst of their food supply.

Three different ways of securing food instead of one means three times as many possibilities for major variations in the structure of the animals involved. So we are not surprised to find that in the sea there are three times as many major groups of animals as are found upon the land. In the relative proportion of the major groups found in the sea and on the land we seem to find a close agreement with the relative possibilities for major diversifications offered in each of these two regions.

But while three times as many major groups of animals are found in the sea as are found upon the land, the relatively few major groups of animals inhabiting the land include more than three times as many different kinds of animals as are found in the sea.

This curious discordance results mainly from the enormous diversity which occurs among the insects, these creatures in number of different sorts exceeding all other forms of life together by about three to one.

How can this condition be explained? It is in simple correlation with the fact that conditions on the land are almost infinitely more diversified than the conditions in the sea.

In the first place the range of temperature from the hottest desert region in the tropics under the noon-day sun to the coldest spot under the Arctic winter night in northern Siberia or in northern Canada is vastly greater than the range in temperature from the warmest to the coldest seas. In the second place diurnal variations in the temperature, which are always present and sometimes extreme on land, in the sea are absent, or at least quite negligible. In the third place seasonal variations, which are more or less marked everywhere on land and are very important in the northern regions, affect the sea only in limited areas and there only in relatively slight degree and only in shallow or superficial waters. In the fourth place the available supply of water on the land is extremely variable, from place to place, from season to season, and at different hours of the day and night. It is always constant in the sea.

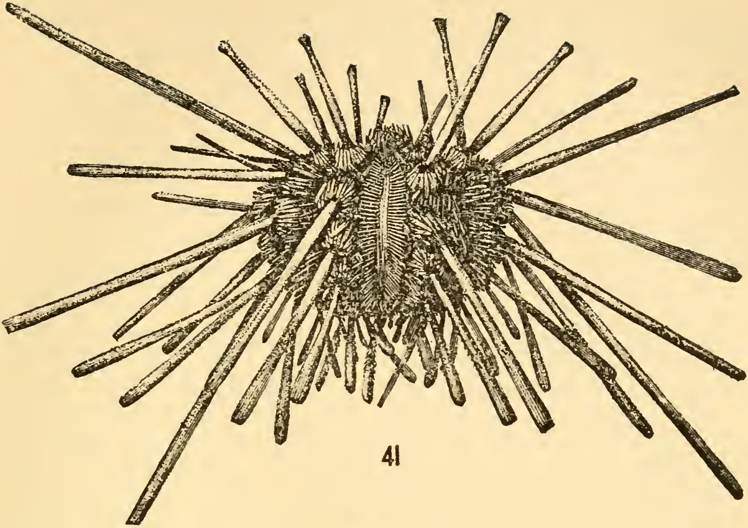
These physical variables on the land, which are much reduced in importance and almost or even wholly absent in the sea, create an infinite number of different combinations each of which must be met by a special complex of defensive or protective adaptations in the land living animals. Not only that, they must also be met through adaptations by all land living plants as well. These adaptations on the part of land living plants affect all the animals that feed on them, but especially the insects which feed upon all parts of plants. Diversity among plant feeding insects means a corresponding diversity among their parasites and the creatures feeding on them.

The enormous diversity of conditions on the land, both in regard to physical conditions of environment and to food supply, is reflected in the diversity of all land living types of animals, but particularly of the insects which, because of their small size, are able to penetrate into almost every economic niche.

Zoology abounds with apparent paradoxes. In spite of the great difference between conditions on the land and conditions in the sea the dominant animal types are the same both on the land and in the sea. These are the backboned animals or vertebrates, the arthropods or jointed footed animals—insects, spiders, crustaceans and their allies—the mollusks, and the jointed worms or annelids. These, with the protozoans and the nematodes (fig. 81, p. 161), are the most successful and most widely spread of all animal types. Other animal types which we commonly regard as characteristic of the sea, as the cœlenterates (figs. 69–73, p. 127; figs. 75–80, p. 143), the polyzoans (figs. 67–68, p. 111) and the nemerteans, are represented in fresh water.

It is worthy of special note that of the phyla or major groups of animals no less than ten are exclusively marine, having no representatives either on the land or in fresh water. Of these ten major groups seven are each composed of a very small number of related and very similar species and play a wholly insignificant part in the economy of the sea. These seven groups which are structurally and anatomically of the greatest interest, but otherwise of no importance, are the priapulids, the sipunculids, the phoronids, the chætognaths or arrow-worms (fig. 62, p. 111), the balanoglossids, the cephalodiscids, and the cephalochordates. All are bottom livers except the chætognaths, which live suspended in the water from the surface down to a considerable depth. Except for a single chætognath, none of these are known to have any fossil representatives. But this means little, as all are soft bodied creatures whose preservation in the fossil state could result only from the merest accident.

Another group which is exclusively marine includes the brachiopods or lamp-shells (fig. 60, p. 111). They live on the bottom attached to rocks or other solid objects, or burrowing in mud. There are less than two hundred different kinds of brachiopods in the present seas; but in the distant past they were vastly more numerous and important.



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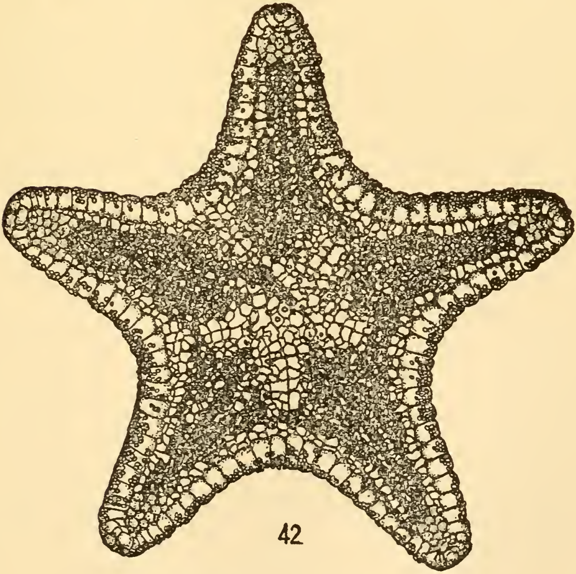

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SEA-URCHIN AND STARFISH
FOR AN EXPLANATION OF THE FIGURES SEE P. 279

Also exclusively marine are the echinoderms—the starfishes (fig. 42, p. 71), brittle-stars (fig. 44, p. 87), sea-urchins (fig. 41, p. 71), sea-cucumbers and sea-lilies (fig. 6, p. 5) and feather-stars (fig. 43, p. 87), or crinoids. There are many hundreds of different kinds of these, and they are found from between tide marks down to the greatest depths at which animal life exists. They are relatively most important in the deeper portions of the seas, but on all coasts they are among the most familiar and characteristic of sea animals. A single type of curious sea-cucumber (*Pelagothuria*), which is shaped more or less like an umbrella, lives floating freely in the sea some distance beneath the surface. All other echinoderms are bottom livers.

The last group of animals which is exclusively marine includes the ascidians or tunicates. Some of these, as the sea-peaches and the sea-squirts, are familiar to every fisherman. Like the echinoderms, the tunicates live from the shore line down to the deepest portions of the seas; but in contrast to the echinoderms many different kinds, such as the salps (fig. 58, p. 111), pyrosomas (fig. 59, p. 111) and appendicularians (fig. 56, p. 111), live suspended freely in the water.

The great differences and at the same time the curious correspondences between the animals of the land and the creatures of the sea are important to remember in considering the problem of the development of animal types.

CHAPTER IX

SPECIAL RELATIONSHIPS AND CONTACTS

THE broad relationships of animals to the world in which they live are often characterized by an extraordinary development of certain special contacts which may become the dominating and controlling influences to which all others are more or less subordinated. These special contacts are commonly overlooked, or at least minimized, and are not considered in their true import and perspective.

Perhaps the most interesting of these special contacts is that having to do with light. Light in some form and in some degree seems to be essential for all animal life. It may well be doubted whether any animal lives in absolute darkness. Those inhabiting deep subterranean streams appear to do so, but the subject has never been investigated. They certainly live in a minimum of light.

In the deeper portions of the sea there is no light, or at least no effective light. But sea creatures, especially those remaining always beneath the illuminated surface layer of water, are remarkable for the luminescence developed in all types save for a few that feed on luminescent organisms.

This general occurrence of luminescence among the creatures of the sea has never been satisfactorily explained. Luminescence is not known to occur in any of the animals of fresh water excepting in the aquatic young of certain Old World fire-flies.

Luminescence certainly would not be of such general occurrence in the creatures of the sea if there were not some outstanding reason for it common to all groups of animals. The only possible explanation is that luminescence fulfils some function of importance for the well being of every type of animal. In other words, the type of light produced by luminescence must be a physiological necessity.

The black color so general in the deep sea fishes, sometimes replaced by red, which is also common in certain other deep sea creatures, probably serves primarily to retain within their bodies the light from the luminous things on which they feed. Were this black color merely correlated with the darkness of the regions where they live, we should expect to find it also in cave living creatures. But all of these are colorless or pink.

A very striking illustration of the necessity of light for certain animals is afforded by the hard shelled (but not the soft shelled) pond and river turtles. All of these, no matter where they live, spend a considerable portion of their time, especially in spring and early summer, sunning themselves on logs or sandbars. Their skeleton is extremely heavy, the heaviest in proportion to total body weight that is found among the vertebrates, excepting in certain land tortoises. The land tortoises all live in sunny regions, and all of the larger ones in arid or semi-arid regions. These creatures seem to have developed the maximum amount of internal living bony structure that can be nourished and maintained by animals of their size. Their skeleton therefore is in a state of very delicate adjustment to their general bodily condition. This is particularly true of rapidly growing young.

Young hard shelled pond turtles kept in a house and deprived of sunlight in spring or early summer show within two days a noticeable deterioration in their skeletons, and within a week the deterioration has become marked. Older individuals of some species are affected almost as quickly.

When replaced in sunlight the affected individuals almost at once begin to show improvement, and unless the deterioration has progressed too far soon return to normal.

Since light is so essential for the well being of the turtles, all turtles have good eyes, and none of them is blind.

The crocodiles and alligators seem to be almost as dependent upon sunlight for their well being as are the turtles.

While light in some form and in some degree is apparently essential for all animal life, an excess of light, especially of certain types of light, is distinctly harmful.

There are two ways of guarding against the possible injurious effect of too much light. In the first place, the possession of a transparent glassy body permits the passage of light through it without injury. We find such transparent bodies in many of the jellyfishes, salps (fig. 58, p. 111), crustaceans, young fishes, mollusks, arrow-worms (fig. 62, p. 111) and other creatures which live at or near the surface of the sea.

But we find no transparent creatures on the land. All land mollusks and land crustaceans are opaque, though some of their relatives in the sea are beautifully transparent. The reason seems to be that all land animals must of necessity rest upon an opaque surface. They therefore must be protected against light as it comes to them from the sky and also as it is reflected in modified form from beneath and all about them. Besides, on land transparency would not mean invisibility, for the difference in the refractive index between air and protoplasm is too great ever to be overcome. So any transparent creature on the land would be as readily visible as a glass model of itself. But in the sea, especially if the light be dim, transparency means from partial to almost complete invisibility.

The second means of protecting the animal body against an excess of light is through the development of pigment or coloring matter in the superficial body covering or its outgrowths—in the skin or in hair, feathers, plates, scales, or other structures. This method is seen in all the animals which live exposed on land, and in most of the animals of the sea. Even the transparent marine creatures develop pigment more or less extensively about such internal organs as would be injured by too much light.

Thus all land animals as well as most sea creatures really exist in darkness more or less complete, for all is dim twilight within the outer body covering.

From its original function as a protection against an excess of light, coloration has secondarily been developed toward the end of making sunlight useful through the formation of endless varied and often complicated color patterns by which the eyes of enemies are more or less deceived.

Animals with bodies adequately protected against harm from sunlight find sunlight extremely useful in enabling them to find their food and to avoid their enemies. This they do by means of eyes.

Every land creature living in the open, no matter what it is, possesses eyes which, though they vary greatly in perfection, are always adequate for the needs of each. Even nocturnal creatures possess eyes, most of them good eyes and some extraordinary eyes, though a few have eyes which are only serviceable in distinguishing night from day.

Taken collectively, eyes serve three different purposes. They may be, as with us, organs of vision giving a continuous photographic record of the surroundings. This is the usual type of eye found in the creatures of the land, as in all the vertebrates and in practically all insects in the adult stage. Eyes may simply be organs to record the varying intensity of illumination and without a visual function, or at least with a very limited visual capacity. Such are the eyes of snails, slugs and caterpillars. Or eyes may simply record the relative intensity of heat. In this case they are usually represented by black spots more or less scattered over the surface of the body. In the birds and in some reptiles which have the body unusually well insulated from the surrounding air there is a special heat recording apparatus called the pecten within the visual eye.

It is obvious that good vision is without value to any creature with a bodily structure of such a nature as to render it incapable of rapid locomotion. It is of no advantage to be able to see food if a creature cannot reach it, or to be able to see an enemy if escape from that enemy is impossible. So all fixed animals, like corals (fig. 80, p. 143), sea-pens (fig. 77, p. 143), hydroids, polyzoans (figs. 67, 68, p. 111), clams and oysters, are either wholly blind or have eyes without a visual function. Creatures with feeble locomotor powers, like caterpillars, scallops, snails (fig. 51, p. 97), sea-urchins (fig. 41, p. 71) and starfishes (fig. 42, p. 71), have eyes with at most a very limited capacity for vision, and are often blind.

Perfect visual eyes are of advantage only to animals able to profit by an acute visual capacity, which means animals whose structure renders rapid locomotion possible. Such creatures are extremely few, and are entirely confined to three of the major groups, the vertebrates, the arthropods and the mollusks.

All vertebrates are capable of locomotion which, because of their large size, is always relatively rapid. But not all of the vertebrates are capable of sight. Blind forms with defective or quite sightless eyes are found among the mammals, reptiles, amphibians and fishes, though not among the birds.

Practically all insects in the adult stage are capable of active locomotion either by flying or by running. Most adult insects therefore have exceedingly good eyes, though the structure of the insect eye is very different from the structure of the eyes of the vertebrates. But many sluggish insects incapable of flight have eyes of very limited capacity and some, chiefly cave insects, have no eyes at all. Active crustaceans, such as the land-crabs, crabs (fig. 29, p. 47), hermit-crabs (fig. 27, p. 47) and lobsters, have good eyes which are patterned after the insect model. The inactive kinds have much reduced, simple, or more or less rudimentary eyes, or else are wholly blind.

Among the mollusks the cuttle-fish and squid (fig. 45, p. 97), which are powerful and active creatures, many of them capable of swimming with great speed and a few even of flying like the flying-fishes, all have large and perfect eyes. So do the octopuses which are very active crawlers and also, for short distances, swimmers of no mean ability. Superficially the eyes of the squid and of the octopus appear quite the same as the eyes of fish and other vertebrates, but their development is very different.

The eyes of the vertebrates, arthropods and mollusks, all equally efficient for the purpose which they serve, are wholly independent structures. Each of these types of animals has a type of eye wholly confined to it and differing in origin from the other two. But regardless of their origin all three types of perfect visual eyes are the same in function and in purpose.

When well developed visual eyes occur they usually are the chief reliance upon which the animal possessing them depends for the discovery of its food, the avoidance of its enemies, and the recognition of its fellows.

This is especially the case with birds which, taken as a whole, have the most perfect vision of any group of animals. No birds are blind, though forms which invariably are blind occur in all the other groups of vertebrates—the mammals, reptiles, amphibians and fishes. It may be added that, together with extraordinary sight, the birds also possess extraordinary hearing. No birds are deaf. Smell, taste and touch, however, are poorly developed in the birds.

Birds might almost be described as wonderfully efficient organic mechanisms activated and controlled by light and sound waves to which they react with a speed and an inflexible accuracy not seen in any other creatures.

The life-long powers of flight both by day and night possessed by the great majority of birds, the extraordinary development of sight and hearing, and the correlated ability to seek out and find their food and to detect and to escape from danger in unfamiliar regions have made the birds, considered as a whole, the most independent of their immediate surroundings of any group of animals. Many different kinds of birds are equally at home in far northern regions in the summer and in the tropics in the winter. Such an extensive economic range, involving great changes in the immediate environment of the individuals, is not possible in any other group of land living vertebrates.

This relative independence of their surroundings resulting from the extreme keenness of their sight, coupled with the capacity for very rapid locomotion, is correlated with a definite dependence on certain physical conditions which is by no means so strongly marked in any other creatures.

Sight being all-important for the birds, the relative length of day and night becomes an important factor in their lives. For some birds, particularly in the southern hemisphere where the seasons are not so strongly marked as in the north, this probably has an important bearing on migrations, since a longer day means a greater proportion of the time when sight is an aid in securing food and in avoiding enemies.

Such migrations as those of the golden plover and of the Arctic tern, which annually pass from far northern to far southern regions and back again, may perhaps largely be explained as an endeavor always to keep within the longest possible day.

While in the great majority of birds their interrelationships with other living things and with the other objects in the world about them are governed mainly by the sense of sight, all birds have wonderfully good ears. For instance we notice the large thrush that we in America call the robin listening at an earthworm burrow to find out whether or not the prospective victim is at home. It is probably listening for the high pitched sounds made by the small chitinous hooks on the earthworm's body which in small ones such as ours are quite inaudible to us, though in the huge oriental earthworms we can hear them easily.

In many night-flying birds, especially in most owls, the ears seem to be almost as important as the eyes. To anyone familiar with owls it seems quite evident that the very soft plumage of most kinds which gives them a ghostly almost noiseless flight is primarily adapted to prevent any interference with external sounds coming from their prey and not so that they may steal up upon their prey unheard.

As aerial creatures feeding chiefly on insects and on fruit the mammalian bats compete with birds. But bats, except apparently for the large fruit-eating kinds called "flying-foxes," living in the oriental regions, are guided mainly by their hearing and have, at least when compared with birds, very deficient sight. They have, however, a high degree of sensitivity to touch, well developed smell, and well developed taste.

Bats find their way about through the analysis of echoes and of all the myriads of different kinds of sounds made by the insects and the foliage. As the very high pitched sounds give the best indication of direction, the activities of bats mainly are controlled by sounds which are too high pitched for us to hear.

Among the bats the flying-foxes correspond to the owls among the birds in that their activities are controlled after a manner differing from that of the great majority of their relatives. These enormous bats are to a large extent diurnal, at least in the more unsettled regions. They are sometimes seen in the hottest portions of the day circling in great numbers over open grassy country close to the ground. Such flights are probably for the purpose of cooling themselves through increasing evaporation from their wings and bodies. It may be mentioned that the African elephant cools itself in somewhat the same way by flapping its enormous ears. The oriental fruit-bats seem to be guided mostly by their eyes which are larger and much more perfectly developed than are those of the great majority of bats.

Our common small red bat in still hot weather often flies by day in glades and clearings in the woods. But as its actions in the daytime are in no way different from what they are at dusk there is no reason to suppose that in its daylight flying it is not guided by its ears as it is at night. As in the case of the great fruit-bats, it probably flies by day merely to cool its body.

The birds and bats furnish excellent illustrations of creatures guided almost entirely by sight and hearing. These two senses play the major part in controlling the actions of many other types of vertebrates.

There is another aspect of bodily control through sight that is worthy of passing mention. This is the effect on us of such control in other things. Subconsciously we recognize the fact that our actions are mainly controlled by sight, and we betray this recognition in many different phrases. Since eyes control our actions and also the actions of all the familiar animals about us, eyes seem in some indefinite and indefinable way to be the seat of the "spirit," or the focal point of the vital force which animates and activates the body.

This concept greatly interferes with a true appreciation of the various types of animals. We unconsciously regard blind creatures as unintelligent and stupid—as deficient in an undefinable essential—even though they may be quite as capable in meeting competition as animals with eyes.

The blind dolphins of the upper Ganges and the blind cave and deep sea fishes and crustaceans are able to make their way in life against strenuous competition quite as effectively as their relatives with eyes. They are therefore quite as intelligent in spite of the fact that their intelligence is a response to stimuli which we ourselves find incapable of adequate interpretation and analysis. Just the same is true of oysters, starfishes and earthworms. In their own way and so far as concerns their special needs they are as intelligent as any other creatures, and as they need to be.

But all creatures with eyes do not look the same to us. For instance an octopus in a tank fascinates us with its large unblinking eyes which to us seem baleful and uncanny. The reason is that the octopus is so strange a creature we have no notion of what he is going to do. Hence an element of fascination based on fear colors our concept of an octopus.

To us, depending as we do chiefly on our eyes, bodily control through hearing as in the case of bats seems incomprehensible and mysterious, and hence uncanny. Besides, bats chiefly fly by night when because of the imperfect functioning of our eyes we are more or less fearful and suspicious. We regard the bats with awe because they are primarily controlled by senses which with us play a more or less secondary part, and are most active at a time when our chief controlling sense is least reliable. But the great fruit-bats with their more or less dog-like heads and large and perfect eyes we can understand, so they appear to us simply as flying mammals.

Because of their large eyes both of which are directed forward as is the case with us, wisdom is commonly attributed to owls. Yet they are almost universally regarded with superstitious dread. This fear or dread is based not on their structure or incomprehensible bodily control as in the case of bats, but arises from their unusual and often shrieking cries and their mostly nocturnal habits.

"Just as the vertebrates are so frequently creatures of the visual and auditory senses" writes Professor Dwight E. Minnich, "so the insects are largely creatures of the chemical senses. For it is chiefly by means of these senses that most insects find their food, their mates, and the food of their offspring, and that the social insects are able to make the manifold discriminations necessitated by their highly complex social organization."

Professor Minnich says that a comparison between the chemical senses of insects and the corresponding senses of the vertebrates, including man, shows many rather fundamental similarities. But between the chemical senses of man and of the insects there appears to be one outstanding difference, and that is the greater acuteness of these senses in many insects.

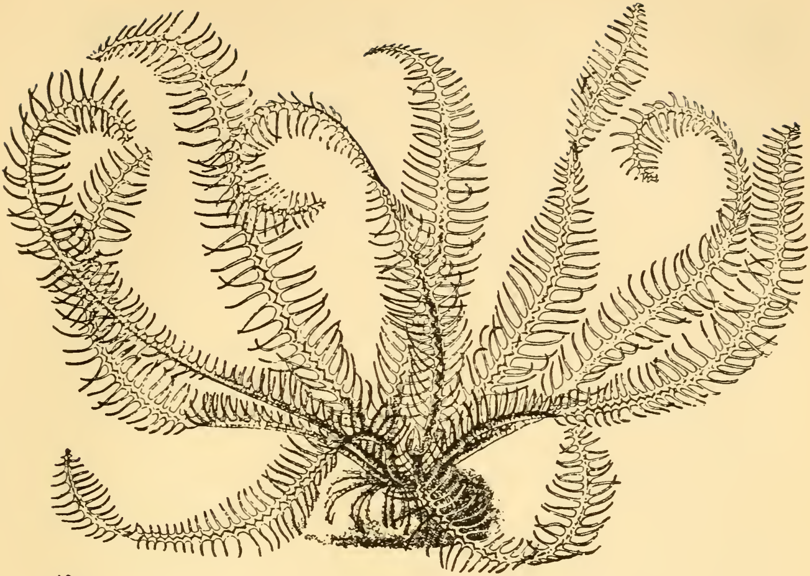
He found that the sensitivity to saccharose of the organs of taste situated in the tarsi (feet) of that common butterfly known as the red admiral (*Cynthia atalanta*) may be on occasion two hundred and fifty-six times as great as that of the human tongue.

Dependence on special senses, which is well illustrated by birds, bats and many insects, is an important factor in biology. For such close dependence on a narrow range of stimuli carries with it both great advantages and great disadvantages.

The chief advantage is that extraordinary development of a special sense overcomes competition in all lines of activity which are dependent on or are chiefly aided by that special sense—provided, of course, that bodily structure and control are of such a nature as to permit that special sense to function to the best advantage.

The chief disadvantage is that dependence on a special sense limits bodily control largely to that sense and hence renders the animal dependent in greater or lesser measure upon the maintenance unchanged of those external conditions by which that sense is activated. Let those conditions change, and become such that the special sense no longer functions to the best advantage, and the animal is placed at once under a serious handicap due to the under-development of all the other senses.

Dependence on a special sense or on a relatively narrow range of special conditions always results in a more or less marked subordination of all the features of the animal type involved to the requirements of



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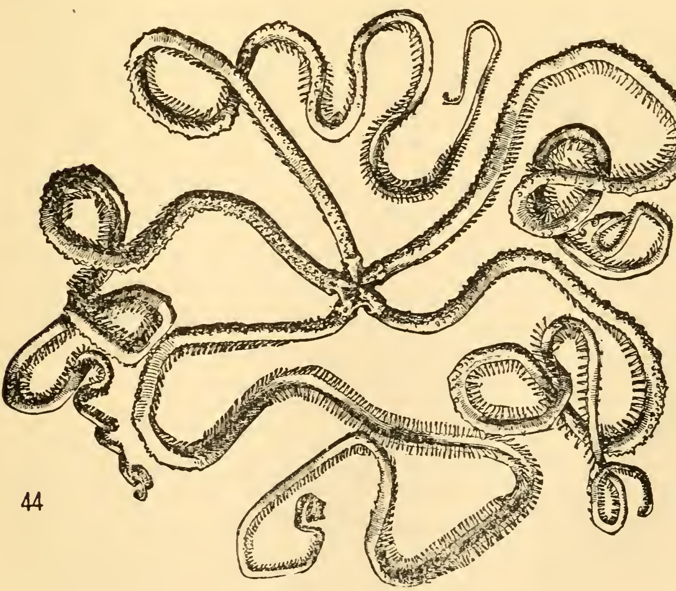

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FEATHER STAR AND BRITTLE STAR

that special sense or of those special conditions. The entire organization of the type tends to become concentric about the organs which are most important for its welfare. The necessary uniformity in these organs seems to impose a corresponding uniformity in all other features. So there results a more or less fixed uniformity of structure in all the animal types which are activated mainly by a single special sense or are confined within a relatively narrow range of special conditions. An excellent illustration of this is afforded by the birds.

Among the vertebrates the least diversified of the included classes is that which includes the birds. All birds exhibit a similarity in the broader features of their structure which, considering their numbers and the very great diversity in the minor structural details, is surprising. In conformity with this, birds in their later embryonic stages and in their preadult existence exhibit a uniformity which is without parallel among the vertebrates.

All birds lay eggs which are enclosed within a rigid and at the same time brittle calcareous shell. There are among them no viviparous forms such as occur among the mammals, reptiles, fishes and amphibians. The eggs are always large, and are provided with abundant food material. From the egg the chick emerges in a well developed—sometimes in a very highly developed—stage.

In all birds except the megapodes the young are assiduously tended by their parents, or by one parent, until nearly or quite the full size is reached. In all birds the embryo develops within a rigid envelope permitting but little deviation from the general type represented by the parents. Furthermore the young, dependent on the ministrations of one or both the parents, must be of such a nature as to be able to receive and to profit by parental care, and also to stimulate it. This still further restricts the possibility of wide deviation from a general type.

As a class the birds, especially the smaller birds, are the most constantly active of all the vertebrates. They have a fixed body temperature which is always high, in the smaller birds more than ten degrees above our own.

All of the birds, both fossil and living, excepting for the ancient toothed birds of the Cretaceous period and the two genera included in the old term *Archæopteryx*, are very closely allied, and in spite of the vast range in size from Princess Helen's hummingbird to the ostrich the birds form a much more unified group than do the mammals, reptiles, amphibians or fishes.

Like the birds, the turtles and the crocodilians show a remarkable uniformity of structure, a corresponding uniformity in their early stages, and a similar curious zoological isolation from all related types. In agreement with the birds, there are no viviparous crocodilians or turtles. The eggs of turtles may have a hard and brittle shell, like the eggs of birds and crocodilians, or the shell may be tough and parchment-like. When compared with the eggs of birds the eggs of turtles and of crocodilians are small, but they are much more numerous. They are carefully placed by the female in suitable situations, but the young receive no parental care.

These few examples of the extreme development of special contacts and of the tendency of the entire organization and life history of an animal type to become concentric about the organs most concerned in the interpretation and reception of the stimuli or the physical benefits received through special contacts show the necessity for a careful appraisal of each animal type in terms of the details of its environment.

CHAPTER X

THE MOST ANCIENT AND THE LIVING ANIMALS

FOR many millions of years animals have existed on the earth just as they exist today. But the animals of past ages were not the same as the animals we know at the present time. Some of them were only slightly different from their modern representatives, but some were very widely different. Generally speaking, the further back we go in geologic time the greater the difference between the animals then existing and those of the present day.

The animals of the past are for the most part known to us as fossils in the rocks. Fossils are the remains or traces of animals or plants that formerly existed. Fossils may be of any age. They may be the remains of animals or plants that lived millions of years ago, or only a few years previously.

Once in the West Indies I was riding along a sandy beach when suddenly I felt my horse to be on hard rock instead of sand. There seemed to be no change in the aspect of the beach, but when I dismounted I found that that particular portion had been changed to limestone rock in which were embedded several different kinds of shells and the remains of various other sorts of marine animals.

But this portion of the beach had not been rock for very many years, as some of the shells still had cling-ing to them bits of their skin-like covering. In the mountains of Tennessee I have seen somewhat similar sea beaches, also with shells and other marine objects, turned to stone; but it has been a very long time since this region was part of any sea coast.

When animals die and after death lie on the surface of the ground they gradually decay and their bones become scattered and broken up. In order to be preserved they must be buried.

In the frozen ground of northern Siberia the woolly arctic elephant or mammoth and the woolly rhinoceros are occasionally found with the skin, hair and wool and even the flesh preserved. The flesh can still be eaten although it has been in cold storage for something like fifteen thousand years. From the plant remains found in the stomachs and in the mouths of these frozen mammoths we even know what they fed upon. Their food was furnished by the same plants that now flourish in the region.

But it is only very seldom that the flesh, skin or hair of the animals of the distant past have been discovered. As a rule only the skeleton is preserved. Yet imprints of birds' feathers have been found in several places, and indeed the first trace of the most ancient bird we know, the so-called *Archæopteryx*, was the imprint of a feather.

The most spectacular of all the regions where fossils have been found in North America is Rancho la Brea, within the city limits of Los Angeles, California. Here over a vast period of time asphalt has been accumulating from escaping oil. In this sticky asphalt animals that lived during the Pleistocene or Ice Age were caught like flies in sticky fly paper and slowly sank beneath the surface.

Animals struggling in the sticky mass served as bait for beasts and birds of prey, and these in turn were trapped and perished in great numbers. Water birds were caught along the edges of the pools of water that collected on the asphalt.

More than three thousand giant wolves, two thousand saber-toothed tigers, sixty giant ground sloths, and mammoths, mastodons, lions, camels, tapirs, short-faced bears, bison, peccaries, and many other mammals, and a great variety of birds, already have been dug out of this deposit.

In a locality recently discovered in southern Arizona mastodons were found which had been mired in boggy mud holes about springs, just as they frequently were mired in the peat bogs in the northern states.

Dust blown by the wind sometimes kills and buries animals, occasionally in great numbers. At a locality in western Kansas the skeletons of nine peccaries or American wild pigs were found huddled together with their heads all pointing in the same direction. Apparently they had been overtaken, killed and buried by a sand storm. The wind blown dust deposits of the pampas of Argentina contain the remains of many animals now extinct which seem to us most fantastic and bizarre.

Cave deposits have yielded many interesting fossils. Some of these caves were the homes of beasts of prey and the bones found in such caves are the bones both of the tenants and of their victims. Other caves are crevices in the rocks into which unfortunate creatures fell or into which carcasses and bones were washed by rains.

In fossil bone deposits complete skeletons of any kind are very rare. Most deposits consist of detached bones and broken fragments.

In a locality in Bavaria very fine calcareous muds were deposited in quiet lagoons behind protecting reefs. These muds are now turned to stone which is quarried for use in lithographic printing. In quarrying this stone many fossils which are most remarkably preserved have come to light, including the imprints of the bodies of such delicate creatures as squid (fig. 45, p. 97) and jellyfishes, and of a feather of an ancient bird. In this locality the remains are those of animals that flourished in the age called the Jurassic which was a very long time before most of our modern animals appeared.

By far the most abundant of all fossils are the remains of animals and plants that in the past lived in the sea. It makes no difference where they live, whether on the bottom or swimming freely in the water, when sea creatures die and after the scavengers have done their work the hard parts that are left collect on the bottom muds or sands. Here they are gradually covered up by gravel, sand or mud brought down by streams and distributed by the currents of the sea.

Battered shells and various remains of other creatures—just such as we see on the beaches of the present time—are often found in ancient beach deposits. If the remains lie in quiet water or at a depth below the effect of waves the fossils that we find may be as perfect as the corresponding parts in living animals.

Many sea animals and plants die and are buried in the place in which they lived. For example, corals (fig. 80, p. 143) and other reef forming animals and plants are sometimes killed by changes in temperature or depth or by some other cause or smothered by mud and sand.

Incredible numbers of fossil fish are found in thin layers of rock or other deposits in California and elsewhere. In some cases these probably were killed by stranding in shallow bays into which they had been driven by their enemies.

Similar calamities are not infrequent at the present day. In August, 1925, I was so fortunate as to witness one at Manchester, Massachusetts. Immense numbers of small herring ran into the little harbor where by the falling of the tide they were stranded on the mud flats. These they almost completely covered —indeed in some places they lay two or more layers deep. The weather was hot and they decomposed with great rapidity. Their decomposition fouled the water and this killed the larger fish, pollack and hake, that had originally chased them in.

If these had been covered with mud and buried before decomposition had progressed too far, they eventually would have formed just such a thin layer of fossil fish as we find in the rocks.

Fish are also destroyed wholesale in another way.

Sometimes a minute free floating sea plant, one of the so-called peridinians (usually or perhaps always *Goniaulax*), becomes enormously abundant and then suddenly dies away. The billions of dead plants foul the water and give off a sulphurous odor like that from a volcano. The fish in the affected area are killed and go to the bottom or wash up on the shores in enormous numbers.

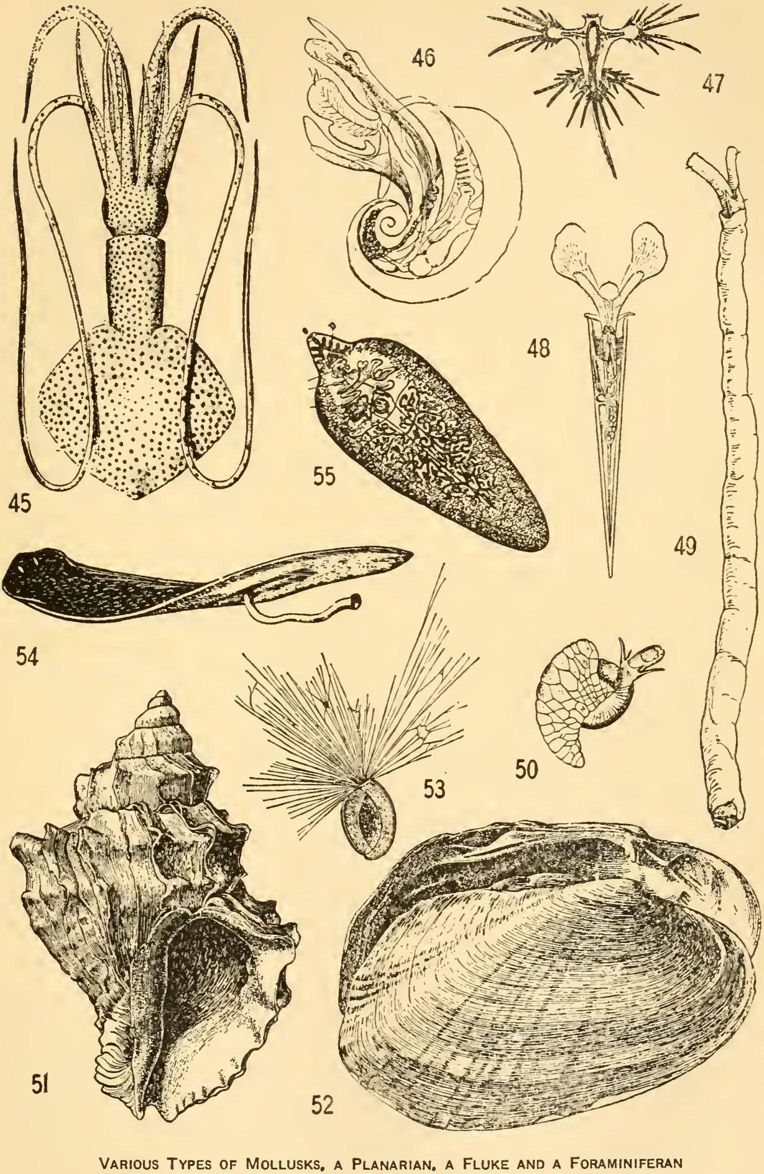
Such calamities are occasional on the coast of southern California and of southern Japan, in southwestern Africa and elsewhere. On the coast of Venezuela between Margarita island and the mainland, where I have witnessed this phenomenon, it takes place every summer.

If the fishes poisoned by the fouling of the sea resulting from the death of the peridinians should be covered up and buried and the sea bottom should later turn to rock that rock would contain a continuous thin layer of fish.

Remarkably perfect sea reptiles showing the outlines of the body which have been found in England and in southern Germany represent carcasses stranded on fine mud and subsequently buried.

When the deposits laid down in the sea are, through the elevation of the land, brought above sea level, then the fossils can be seen. Often in the intervening time the originally loose muds or sands or gravels have been changed to solid rock, and the fossils in this rock are in their composition wholly different from what they were originally.

Under very exceptional conditions it may happen



VARIOUS TYPES OF MOLLUSKS, A PLANARIAN, A FLUKE AND A FORAMINIFERAN

FOR AN EXPLANATION OF THE FIGURES SEE P. 279

that extremely delicate things such as sea worms, squid, or even jellyfishes, are buried in fine mud in such a fashion as to prevent bacterial decay. In such cases even imprints revealing the finer details of the internal structure may be preserved. Such perfect preservation is to be seen in some of the very earliest fossils that have been discovered.

This briefly stated is the way the remains of the earlier life upon the earth have been preserved. From these remains of the animals of earlier epochs in the earth's history we can now form a pretty good idea of the types of life that flourished at various periods in the more or less distant past.

How are we able to determine the relative age of the different fossils that we find?

Ever since rain began falling on the earth muds and sands and gravels have been continuously washing down into the sea. While in certain places the sediments now exposed may reach a thickness of about two miles, in no one place has this deposition been continuous. How, then, can we measure and correlate these sediments?

Movements of the surface of the earth subsequent to the deposition of the sediments, such as those involved in mountain building, often cut them through or tilt them up on edge so that their cross sections may be studied. The erosion of streams by carving great canyons through the rocks also assists us in our study of them.

By piecing together the information gathered from very many regions it has proved possible to arrange the fossil sediments in a continuous series from the very earliest to those now forming. We can tell with great exactness the relative age of any fossil bearing rock in reference to other fossil bearing rocks elsewhere.

By studying the various fossils in formations of different ages we are able to compare the animals of one period with those of another and thereby to form a picture of the ever changing aspect of animal life as it has existed on the earth.

Table Showing the Sequence of Geological Time

Recent Pleistocene	Post-tertiary or Quarternary
Pliocene Miocene Oligocene Eocene	Tertiary or Cenozoic
Cretaceous Jurassic Triassic	Secondary or Mesozoic
Carboniferous Devonian Silurian Cambrian	Primary or Palæozoic
Pre-Cambrian or Algonkian	Archæan

CHAPTER XI

THE PAST AND THE PRESENT

One of the most striking and important facts which has been established through a study of the fossil animals is that from the very earliest times, from the very first beginnings of the fossil record, the broader aspects of the animal life upon the earth have remained unchanged.

When we examine a series of fossils of any age we may pick out one and say with confidence "This is a crustacean"—or a starfish, or a brachiopod, or an annelid, or any other type of creature as the case may be.

In the details of their structure these fossils are not necessarily like the crustaceans, starfishes (fig. 42, p. 71), brachiopods (fig. 60, p. 111), annelids (fig. 85, p. 161) or other creatures living in the present seas. Nevertheless, if they are sufficiently well preserved we have no difficulty in recognizing at once the group to which each and every fossil animal belongs.

How do we recognize these fossils as members of the various groups? We are able to recognize them because they fall within the definition of a particular group. But the definitions of the phyla or major groups of animals are all drawn up on the basis of a study of their living representatives alone.

Since all the fossils are determinable as members of their respective groups by the application of definitions of those groups drawn up from and based entirely on living types, and since none of these definitions of the phyla or major groups of animals need be in any way altered or expanded to include the fossils, it naturally follows that throughout the fossil record these major groups have remained essentially unchanged. This means that the interrelationships between them likewise have remained unchanged.

Strange as it may seem, the animals of the very earliest fauna of which our knowledge is sufficient to enable us to speak with confidence, the fauna of the Cambrian period, were singularly similar to the animals of the present day. In the Cambrian crustaceans were crustaceans, echinoderms were echinoderms, arrow-worms (fig. 62, p. 111) were arrow-worms, and mollusks (figs. 45–52, p. 97) were mollusks just as unmistakably as they are now.

In order to illustrate the diversity of life in the Cambrian seas and to bring out its striking general similarity to the life of the present time, let us briefly note the types of animals which flourished at that far distant period.

In Cambrian times crustaceans were represented by phyllopods, trilobites (fig. 32, p. 55) and merostomes (fig. 31, p. 55); among the echinoderms there were crinoids (fig. 6, p. 5), cystideans (figs. 37, 38, p. 55), and elasipod and other holothurians; chætognaths (fig. 62, p. 111) or arrow-worms, lamp-shells (fig. 60, p. 111) or brachiopods, and graptolites (figs. 39, 40, p. 55) were present; of the annelids or jointed worms we know polynoids, nereids (fig. 85, p. 161), gephyreans, and *Tomopteris*-like forms (fig. 65, p. 111); of the mollusks we find pteropods (fig. 48, p. 97) and gastropods (fig. 51, p. 97); and there were corals and other cœlenterates, and sponges.

Most of the fossils mentioned in the preceding list are from a single locality in British Columbia where they were found by the late Dr. Charles D. Walcott in the Burgess shale. I had the pleasure of being associated with Dr. Walcott when he was working on them.

These fossils are remarkable not only on account of their great age, but also because of their wonderfully perfect preservation. In many of the most delicate among them—creatures so very fragile that their modern representatives can scarcely be satisfactorily preserved in alcohol—even the details of the nervous system may be made out.

In order to avoid possible criticism that too broad generalizations are being drawn from fossils mostly from a single locality, let us consider as a supplement to this varied Cambrian fauna the fossils from the Ozarkian and Ordovician rocks, representing periods somewhat less distant than the Cambrian.

From the Ozarkian rocks come cephalopods (fig. 45, p. 97) and pelecypods (fig. 52, p. 97) or bivalved mollusks, and from the Ordovician polyzoans (figs. 67, 68, p. 111), echinoids or sea-urchins (fig. 41, p. 71), ophiurans or brittle-stars (fig. 44, p. 87), starfishes (fig. 42, p. 71), insects and fishes. There is no evidence that these were not also present in the Cambrian. Indeed, it will be most surprising if future investigation does not prove their existence there.

The significance of this imposing list of Ordovician and pre-Ordovician animals becomes more evident if we contemplate the missing animal types. These missing types are the ctenophores or sea-walnuts (fig. 66, p. 111), the flat-worms (figs. 54, 55, p. 97) and round-worms (fig. 81, p. 161), the rotifers (fig. 136, p. 203) and gastrotrichas (fig. 134, p. 203), priapulids and sipunculids, heteropods, archiannelid, oligochæte, myzostomid (fig. 84, p. 161), hirudinid (leeches) and onychophorid (*Peripatus*) worms, nemerteans, phoronids, cephalodiscids (figs. 61, 63, p. 111), balanoglossids, tunicates, and vertebrates except for fishes.

Except for the missing vertebrates—amphibians, reptiles, birds and mammals—which are primarily land living, all of these various types are soft bodied creatures which would be preserved as fossils only under the most extraordinary circumstances. Recognizable traces of them would only be present in the rocks by the merest accident.

While from what has just been said it is evident that there has been no change whatever in the interrelationships between the phyla or major groups from the very earliest times of which we have an adequate fossil record up to the present day, this is not of itself conclusive evidence that these groups have always borne the same relation to each other. For it is undoubtedly true that the Cambrian period is nearer to the present epoch than it is to that far distant time when life on earth began.

Indeed, fragmentary and in some cases fairly satisfactory fossils have been found in rocks of much earlier date than those of the Cambrian period. But in so far as these are determinable all of them, like the fossils of the Cambrian, fall into major groups on the basis of the definition of the major groups drawn up from living types.

The fact that these very early fossils are the remains of calcareous algæ, corals, crustaceans and protozoans is simply correlated with the circumstance that these types of life, as is well seen in the calcareous algæ, the corals and the foraminifera of the present day, build exceptionally heavy skeletons. The existence of these types alone in these very ancient rocks cannot be regarded as indicating that no other types of life existed in those ancient seas.

Since all our evidence shows that the phyla or major groups of animals have maintained precisely the same relation with each other back to the time when the first evidences of life appear, it is much more logical to assume a continuation of these parallel interrelationships further back into the indefinite past, to the time of the first beginnings of life, than it is to assume somewhere in early pre-Cambrian times a change in these interrelationships and a convergence toward a hypothetical common ancestral type from which all were derived. This last assumption has not the slightest evidence to support it. All of the evidence indicates the truth of the first assumption.

To this plain statement of fact the objection might be raised "This is all very true so far as it goes, but we must admit that the earliest evidences of life are the traces of simple and primitive forms; and, anyway, there was an enormous lapse of time between the first appearance of life and the period wherein are found the earliest fossil remains. So it is easier to believe that life gradually developed from simpler to more complex forms than that the major groups arose simultaneously."

The answer to this is that science is based upon ascertained facts. We take the facts as we find them and coordinate them into broad generalizations. The facts are that all of the fossils, even the very earliest of them, fall into existing major groups. This is indisputable.

CHAPTER XII

MORE ABOUT FOSSILS

CONTRASTING strongly with the inflexibility and the permanence of the fundamental characters which delimit and identify each of the phyla or major groups of animals and the consequent absence of any change in their relations to each other from the very earliest times of which we have a record up to the present day is the very great diversity which we see *within* every major group when we compare the different ages of the past.

As we trace further and further back the record in the rocks we see fewer and fewer of the kinds of animals we know today and more and more unfamiliar forms, until nearly all the animals are strange and unfamiliar and we find ourselves, lost in astonishment, viewing the relics of a world which seems to have been entirely different from the world we know today.

And so it was. For instance, in that period known to geologists as the Cretaceous the mammals, though numerous, were all very small and unimportant. The earth was dominated by a most extraordinary and formidable array of reptiles. Chief among these were the dinosaurs of very many different kinds, some of them no larger than a hen, but some of enormous size and in appearance most fantastic and grotesque.

There were huge horned dinosaurs, strange armored dinosaurs, duck-billed dinosaurs, and, together with these, terrible predacious dinosaurs with a formidable array of long sharp teeth. The giants of this group were the great swamp-living dinosaurs with absurdly small heads, enormously long necks and tails, heavy bodies, and ponderous legs.

The birds which lived in the Cretaceous period were curious things with teeth like reptiles, quite different from any of the birds we know at the present time. But more important than the birds were strange flying reptiles with wings much like the wings of bats. These bat-like reptiles are known as pterosaurs. Some of them were small, no larger than a sparrow, but some were very large, as much as twenty-seven feet across the expanded wings.

Competing with fishes in the sea were plesiosaurs of various kinds, and also mososaurs, as well as large sea-turtles. Some of these last were more than twelve feet long.

Together with these curious types of reptiles lived many other forms almost equally bizarre, but also many of the more familiar types, as for instance crocodiles and alligators.

In spite of the great and striking differences between most of the vertebrates of the Cretaceous period and those of the present day, they are all instantly recognizable as vertebrates as vertebrates are defined on the basis of their representatives of the present day.

Of all invertebrate fossils none are more familiar than the remains of those curious crustaceans known as trilobites (fig. 32, p. 55). All of the trilobites are now extinct—in fact the last of them disappeared many millions of years ago.

The remains of trilobites are extremely common in the very oldest rocks in which are found fossil remains of animals in a satisfactory state of preservation. They are abundant in the rocks of the Cambrian period, in which they exceed in number and in diversity the remains of all the other forms of animal life. In the succeeding period, the Ordovician, they were also very numerous and varied. They were less numerous and varied in the Silurian, and during the Devonian they declined in numbers and in variety. In the Carboniferous only a few, all rather closely related to each other, are found, and at the end of this period they entirely disappeared.

Over two thousand different kinds of trilobites are known. These vary in length from less than half an inch to nearly two feet. The trilobites represent the only large subdivision of the jointed-legged animals or Arthropoda which has become extinct.

In the phylum Arthropoda there is another much smaller group now wholly extinct which is of special interest as it includes the largest members of the phylum. This group is that containing the so-called eurypterids (fig. 31, p. 55), some of which were nearly ten feet long. The largest member of the phylum Arthropoda at the present time is the Japanese giant spider-crab which measures eleven feet or more from claw to claw, but its body is relatively small. The eurypterids are first known from the Cambrian, and the last of them are found in the Carboniferous.

They were related to the still living king- or horse-shoe crabs which still are to be found on the eastern shore of North America and in the west Pacific.

Curious and unfamiliar as are the eurypterids and the trilobites, they are quite obviously crustaceans as crustaceans are defined on the basis of the living species.

In the old days of sailing ships the chambered nautilus was a very common ornament in the parlors of the houses in the sea-port towns and cities. The chambered nautilus is to be found only in the Indo-Malayan seas, and there are scarcely half a dozen different kinds, all of which are very much alike.

But in the past the nautiluses were creatures of much importance as inhabitants of the sea, and about 2,500 different kinds have been described which have been found as fossils in the rocks. In some of these the shell was straight, in some it was partly straight and partly coiled, in others it was loosely coiled, and in many it was tightly coiled as in the still living chambered nautilus. In the coiled types the coil was sometimes flat—in a single plane—as in the chambered nautilus, and sometimes in a spire as in a gastropod or snail.

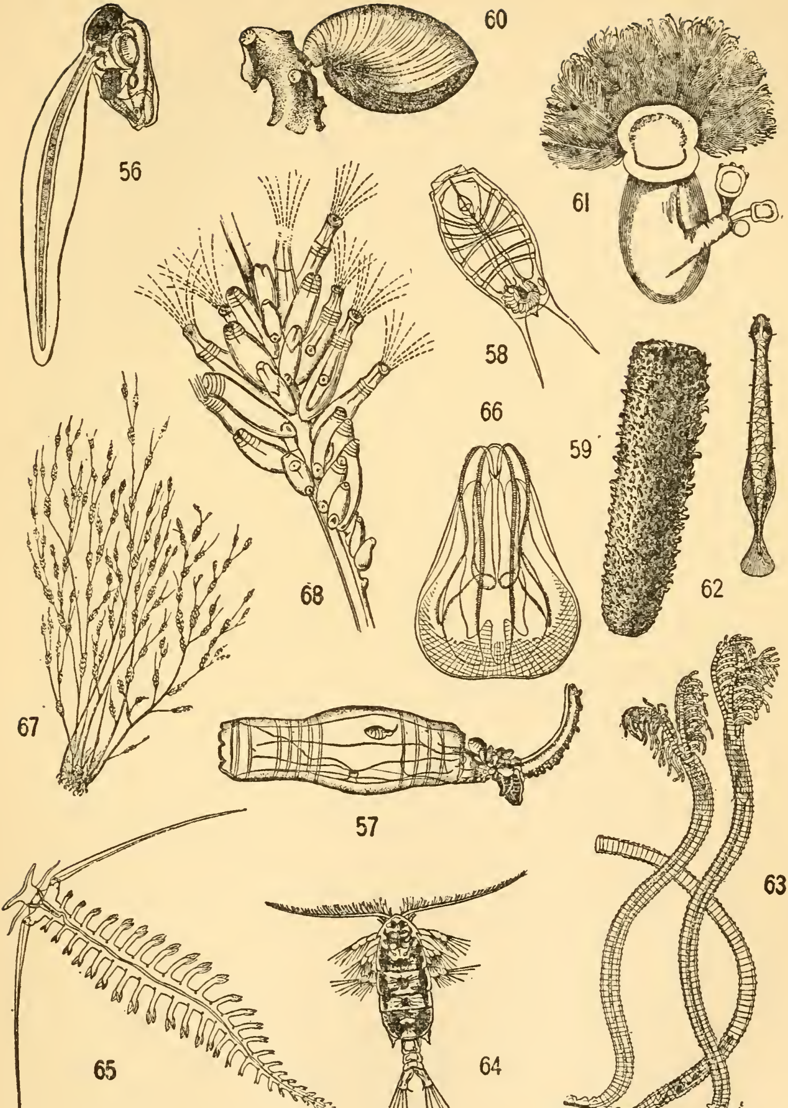
These creatures first appeared, so the fossil record tells us, in the Ordovician, in which period they were found in very great variety. They were still more numerous in the period just following—the Silurian. They then declined, and since the time when the giant reptiles were the dominating creatures on the earth (the Cretaceous period) only two types persisted one of which died out in the relatively recent past, leaving the present seas with only the chambered nautilus and its few close relatives.

Together with the nautiloids in the very ancient seas there flourished the ammonites (figs. 33, 34, p. 55), creatures which were very similar but vastly more numerous and varied. Of these more than 5,000 different kinds have been described. All of the ammonites are now extinct—in fact none of them survived beyond the end of the age of reptiles (the Cretaceous period).

A curious thing about the ammonites is that they first appeared after the nautiloids had begun to wane. After the end of the so-called palæozoic era they increased with great rapidity both in numbers and in variety. At the end of the Cretaceous they suddenly disappeared, just as did the giant reptiles, for what reason we do not know. Some of the ammonites were very small, appearing as mere specks, but some were very large forming a close spiral four feet or more across.

In few groups of animals is the fossil record so complete and satisfactory as it is in the ammonites, and in few groups are progressive developmental lines so clearly indicated.

The history of the brachiopods or lamp-shells (fig. 60, p. 111) is an interesting one. More than 7,000 different kinds are known of which only about 160 are to be found living in the present seas. Brachiopods are well represented in the very earliest rocks which contain recognizable fossils—the rocks of the



VARIOUS TYPES OF ANIMAL LIFE

FOR AN EXPLANATION OF THE FIGURES SEE P. 280

Lower Cambrian. They increased markedly in numbers in the Middle Cambrian and reached a maximum of diversity in the Ordovician and Silurian from which periods we know more than 3,000 different kinds. They continued plentiful in the Devonian and also in the Carboniferous, but toward the end of the latter period they began to decline and since the end of the age of reptiles (Cretaceous) they have been of small importance.

This parade of facts showing the very different balance of life upon the earth in the distant past might be indefinitely extended. But we have said enough to show that in the different periods and the different eras the continuous changes affected only the forms within each phylum, and never the interrelationships between the phyla.

Most interesting in this connection are the ammonites, for they begin as ammonites, become enormously diversified, and then disappear without ever being anything but ammonites. Here we have a group, a division of the cephalopod mollusks allied to the nautiloids, of which the entire history seems to be laid bare for our inspection. The early portion of the history of the ammonites is not lost in the unknown pre-Cambrian as in the case of the trilobites, the eurypterids and the lamp-shells.

This constant change from age to age involving the animal types within each major group or phylum combined with the unchanging constancy of those broader features of animal life by which the members of each phylum are distinguished from the members of all the other phyla demonstrates a dual nature in the relationships of animals to the world in which they live that has hitherto been unrecognized.

CHAPTER XIII

THE DUAL RELATIONSHIPS OF ANIMALS

A CRITICAL study of fossil animals taken as a whole brings out two apparently contradictory facts.

In the first place all the major groups of animals have maintained the same relationship to each other from the very first. The characteristic features of these major groups have undergone no change whatever. Crustaceans have always been crustaceans, echinoderms have always been echinoderms, and mollusks have always been mollusks. There is not the slightest evidence which supports any other viewpoint.

Yet on the other hand *within* each major group there has been constant and continual change from age to age. All of the crustaceans, echinoderms and mollusks of the present day are more or less, and often very widely, different from the representatives of those groups which flourished in the distant past.

How can such a dual relationship of animal forms— fixed and inflexible major groups each including constantly changing types— be possible? Not only is it possible, but it is to be inferred from the facts of geology and geography as we understand and interpret them.

At the very earliest time at which life in any form could be presumed to have existed on the earth there was water in abundance, and there must have been land rising above the water. There must also have been winds, if only feeble winds, carrying the water vapor back from the seas and lakes and marshes over the land areas.

Chemical and physical disintegration of the rocks was taking place in exactly the same way in which it is taking place today. The elements which are essential for the growth of plants were being released and recombined, and soils were being formed just as they are at the present time. Muds and sands and gravels were being washed into the sea, there forming sediments.

Of course most of the rock disintegration taking place today is affecting the so-called sedimentary rocks which are themselves made up of the more or less selected and consolidated residues which have resulted from the previous disintegration of archæan rocks and of earlier sedimentary rocks. But this does not in any way affect the truth of the statement that rock disintegration is releasing the same elements and forming soils in the same way now as in the past.

The fact that, in so far as it concerns the sedimentary rocks, geological history is interpreted entirely by comparison with what is occurring at the present time is an acknowledgment of the truth of this. Yet if it be true then it is evident that at the time of the first beginnings of life there were the same potentialities for the support of a varied fauna that there are today.

To deny this would mean to deny the validity of the comparisons between the geological processes of the present day and those of the past, the accuracy of which comparisons forms our sole criterion for the interpretation of the latter.

All of the major groups of animals may be supported either by the algae or related groups of plants, or by the flowering plants, or by a mixture of plant types. Thus in the sea we find the walrus and the seals and whales feeding upon animals dependent for their existence upon the diatoms, while on the land we see the elephant and the dogs and wolves supported wholly by flowering plants or by creatures feeding on them.

So with an abundance of plant food quite regardless of the kind the possibility exists for the appearance of some representative or representatives in every major group of animals.

In regard to plants the situation is quite different, for in the case of plants there is a direct relation to the amount and quality of sunlight. The amount and quality of sunlight plays but a minor part in the animal world taken as a whole. It is largely a negligible factor. For instance some fishes and some crustaceans are found along the shores and on the beaches in the sunniest portion of the tropics, while others live in the deepest and darkest portions of the sea and also far under ground in lightless—or practically lightless—caves. Sunlight is essential only for relatively small groups of animals, as for instance birds and many of the reptiles, especially the turtles and the crocodilians. Animals as a whole are dependent only on an adequate supply of plant food, air and water. An amount of light sufficient to permit the growth of any type of green or comparable plant appears to be sufficient for all, most, or at least some, of the members of all the phyla or major groups of animals.

If we examine the major animal groups we discover a very interesting fact. Broadly speaking their relationships to each other are very different from the relationships between the major groups of plants. The major groups of plants are in the main competitive with each other, as they feed on the same substances in the same way. The existence of one or another of these major groups, or if they occur together the balance between them, is largely determined by the amount of water and by the amount and quality of the available light.

The major groups of animals in their relation to each other are on quite a different basis, for in the main they are non-competitive, or perhaps it should be said that they are fundamentally non-competitive. While in their economic range the major groups, at least the larger major groups, more or less overlap, still there is always a certain section of their range in which, as a result of differences in bodily structure, they are safe from competition.

The three largest and most important of the phyla or major groups are the backboned animals or Vertebrata, the jointed-legged animals or Arthropoda (including the insects, centipedes, millepeds, spiders, crustaceans, and their allies), and the mollusks or Mollusca.

All three of these groups include both plant-eating and animal-eating forms. Many vertebrates prey on other vertebrates, as for instance hawks, owls, cats and barracudas, very many vertebrates feed on insects, and many, particularly many fishes, some mammals and some birds, are mollusk feeders. Insects, spiders and crustaceans prey largely on each other; many are parasites on vertebrates, as lice, fleas (fig. 18, p. 33), bot-flies and fish-lice (fig. 24, p. 47), the last being curious crustaceans, and some, both on the land and in the sea, are mollusk feeders. Predacious mollusks prey mostly on each other, as for instance oyster drills and whelks, though some feed on small crustaceans and a number on other forms of life. The young of most of the fresh-water clams (fig. 52, p. 97) are for a time parasitic on the fishes.

In view of this, how can the members of these three great phyla be said to be fundamentally non-competitive?

The structure of a vertebrate with its internal almost invariably jointed skeleton is such that the smallest possible size permitting of effective functioning is relatively large. Vertebrates range between about three-quarters of an inch in length for the smallest fish to about 110 feet for the largest whale. But very few vertebrates are less than two inches in their total length.

The structure of an arthropod with its external jointed skeleton is such that the maximum size permitting of effective functioning is small. Arthropods range from about one one-hundredth of an inch to about ten feet in length. But relatively few, either in the sea or on the land, exceed two inches.

So we find that the vertebrates and the arthropods in the great majority of their included species are really non-competitive. Each of these two major groups for the most part occupies its special economic niche which is determined by its structure and the correlated limitations in efficient size.

The structure of a mollusk with its unjointed body does not permit the development of jointed supports or supports articulated with the body, like the legs and wings and the paired fins of vertebrates and the legs and wings of insects. So the mollusks cannot compete with vertebrates or with insects in running or flying on the land. On the other hand, since their motions are very slow they require much less food and air and so are able to exist in situations impossible for any members of these other groups.

So also in the sea and in fresh water the mollusks are capable of existing in many different ways and under many different sets of conditions not possible for any vertebrate or arthropod.

On the land the mollusks compete more or less directly with some insects and a few vertebrates, such as the small land tortoises, in consuming fungi and soft vegetable material. In the sea some, as mussels, oysters and others, live attached to firm supports and feed on the same materials as the barnacles (fig. 30, p. 47), which are curious distorted arthropods. Others live suspended in the water of the open ocean (fig. 48, p. 97) and feed on the minute suspended plants, such as the diatoms and peridinians (fig. 86, p. 161), as do some arthropods and the young of very many fishes. A few, like the octopus, crawl about the bottom and feed more or less after the fashion of the crabs and lobsters. Still others, like the cuttle-fish and squid (fig. 45, p. 97), live swimming freely in the sea and successfully compete with fish.

It is somewhat curious that while on the land the creatures capable of the most rapid locomotion, the running and flying animals, which are the dominant types, are all vertebrates or arthropods, in the sea the creatures with the greatest powers of locomotion, the dominant swimming types, and all the flying types, belong to the vertebrates and mollusks. In view of the correspondence which exists on land between the vertebrates and the insects in the matter of rapid locomotion we might expect that in the sea there would be a similar correspondence between the vertebrates and crustaceans. But instead we find that in the sea the mollusks take the place of arthropods as effective swimmers.

Perhaps the next most important of the major groups, and a very large one, is that which includes the jointed worms or annelids (fig. 85, p. 161). These live mostly in the sea, but some live in fresh water and a few upon the land—the earthworms, land-leeches and onychophores (*Peripatus*).

The jointed worms have the advantage over the vertebrates and the arthropods in lacking a rigid skeleton, either internal or external, which gives them great flexibility. They have the advantage over mollusks in possessing a jointed and usually much elongate body in which each segment is, to a greater or lesser degree, a semi-independent unit.

While many of the jointed worms live swimming freely in the water or crawling on the surface of submerged objects, they are especially adapted to a burrowing life, either boring through mud or winding their way through the canals in sponges or through crack and crevices in rocks, in coral heads, or in any other objects. Their slender bodies, which are usually soft and extremely flexible and are made up of a more or less long series of semi-independent units, fit them for a manner of life impracticable for the vast majority of the vertebrates, the arthropods, or the mollusks.

The echinoderms, which include the starfishes (fig. 42, p. 71), brittle-stars (fig. 44, p. 87), sea-urchins (fig. 41, p. 71), feather-stars (fig. 43, p. 87) and sea-lilies (fig. 6, p. 5) and their allies, and the sea-cucumbers or holothurians, are peculiar in having when their final form is reached a radial symmetry with almost invariably five divisions of the body, a usually heavy outer—though not properly external—skeleton which is composed of pavement-like or reticulated or vertebra-like plates and is wholly unlike the jointed external skeleton of the arthropods, and a curious hydraulic system called the water-vascular system by means of which they operate their tube-feet, which are their locomotor organs, and comparable and other structures.

The heavy outer armor of the echinoderms, which is usually reinforced with numerous sharp spines, or the tough and leathery skin filled with limy plates or spicules, provides a very effective defense against aggression. They are therefore relatively safe from enemies. This enables them to live exposed upon the bottom in those places where food is most abundant, there to consume it at their leisure. Many of them simply swallow mud which is rich in the dead remains of plants or animals.

Almost perfectly protected and living with their food supply, or at least near it, rapid locomotion is not an essential for the echinoderms. But they make up for the absence of the capacity for rapid locomotion in their ability to move equally well in any direction, an ability not possessed by animal types with a definite head end at which the main sense organs are collected as is the case with the active types in all the phyla we have just considered.

While one echinoderm, lacking all traces of a skeleton, lives freely suspended in the sea, a number bore in mud more or less like worms, others have a more or less definite head end in spite of their radial symmetry, and still others, permanently or temporarily attached, feed more or less after the fashion of the barnacles and oysters, still the echinoderms as a group fill an economic niche which is quite different from that occupied by the vertebrates, the arthropods, the mollusks or the annelids.

There is no object in carrying this recitation further. It is evident that a considerable part of the economic range of each of the groups we have considered belongs to it alone. From this it is clear that each of these groups is safe from complete extinction by any of the others.

The relative number of different forms in the various groups may vary from time to time and from place to place. We see this in the present seas where the mollusks are mainly creatures of shallow water and the echinoderms are chiefly characteristic of the deeper portions of the oceans. We also see it in comparing the lamp-shells or brachiopods of the present day with those that flourished in the palæozoic seas. But however the relative numbers in the different groups may vary, each major group will always be present, and not only present but well represented.

All of the other major groups of animals have some special economic niche wherein they are safe from direct competition by creatures belonging to any of the other groups. The only possible exception to this rule is furnished by the graptolites, which have been long extinct. But whether these were of themselves a major group, or a division of the cœlenterates, or a division of the cestodes, we do not really know.

Now these special niches must have been present at the time when life on earth first began. None of them can be assumed to have been of recent origin. We recognize the fact that wherever there is a reservoir of food, permanent or temporary, capable of supporting animal life, there animal life of some sort or other will be found. If it is reasonable to apply a knowledge of geological processes based on the present to an interpretation of the geological processes of the past, it is no less reasonable to do the same with our knowledge of zoology. If we do this we must believe that all the various niches must have been occupied at the very first instead of serially.

Still another aspect of the problem demands consideration. No animal type can exist of itself alone. In the first place, it must be supplied with food through the medium of coexisting plants. In the second place, it must be held in check so as to avoid the danger of increasing to such an extent as to destroy its food supply and thus bring about its own extermination.

The necessary check on the excessive increase in the numbers of any type of animal is provided by predacious animals, by internal and external parasites, and by various types of animal feeding plants, principally bacteria and fungi.

We recognize the necessity for an intricate and delicate balance between the various types among the animals and plants of the present day. Is there any reason why in the remotest past a similar balance should not have been as necessary?

It is probably not without significance that no major group of animals includes exclusively plant-eating species, though in some of the major groups all of the included species are carnivorous; and besides these in several large groups, such as the cestodes or tapeworms (figs. 82, 83, p. 161) and the spiny-headed worms, all of the included forms are parasitic.

We cannot deny that at the time when the first appearance of animal life was possible the potentiality was present for the occurrence of some representative type or types in each of the phyla or major groups without at the same time denying the validity of our interpretations of the processes of geology so far as concerns the disintegration of the rocks and the building up of soils and sediments. And such fossil evidence as exists, fragmentary and unsatisfactory as it is, supports the assumption that this potentiality was an actuality and that animal life so far as the phyla are concerned at the very first appeared in essentially the same form as that in which we know it now.

While at the time of the first appearance of life the abundant water and the winds and the disintegration of the rocks rendered possible the existence of animals in all the major groups, conditions on the earth were very different from those at the present day.

We learn this from the constantly varying assemblages of fossils in the rocks of different ages. Thus in the Cambrian rocks we find occurring together animal types which now are exclusively marine, as the sea-cucumbers, brachiopods (fig. 60, p. 111), gephyreans and others, some of which live in shallow water and others only in the deep sea; types, such as the phyllopods which now are exclusively non-marine, living in rivers, lakes and ponds; and types, as the nereid worms (fig. 85, p. 161), with modern representatives both in the sea and in fresh water.

All of the creatures which we know from the Cambrian, with the possible exception of the trilobites, were very delicate and fragile. This suggests that at that time the water where they lived was quiet.

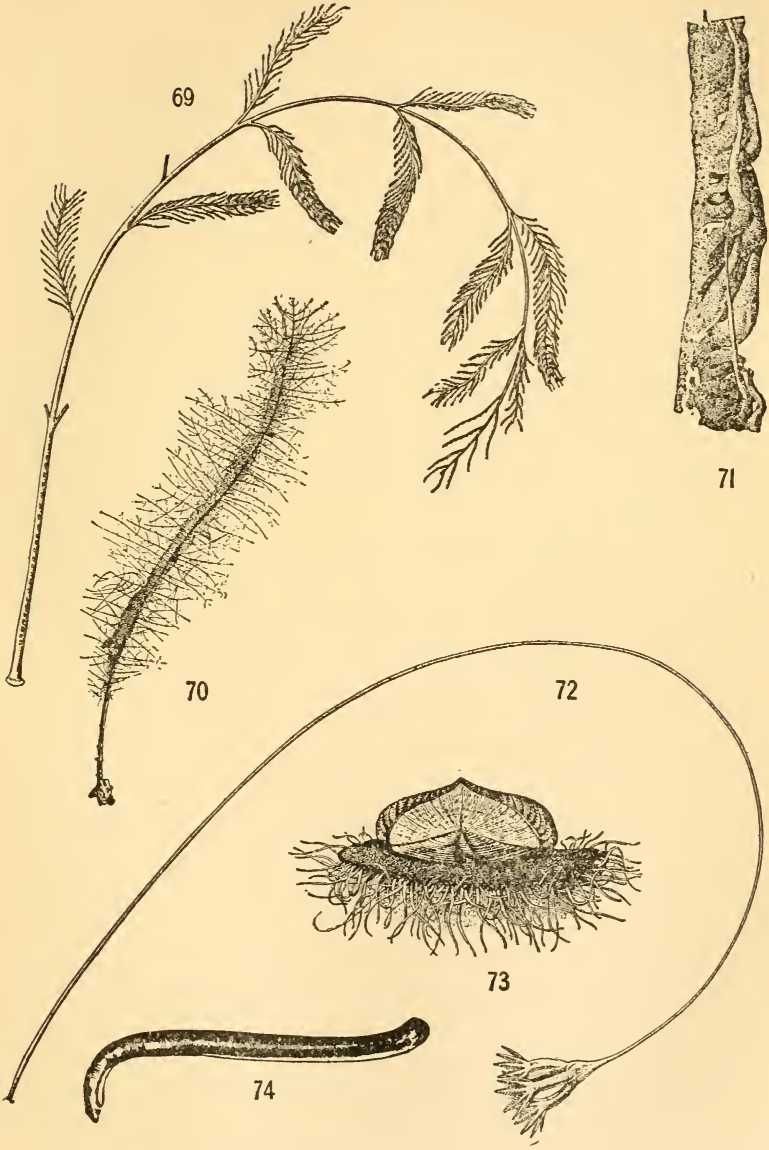
These Cambrian creatures could not have withstood the pounding of the surf along the shores of the present oceans. Absence of a surf line means absence of strong winds, or frequent violent storms, which further suggests a blanket of clouds resulting in more or less uniform temperatures over the greater part, or possibly all, of the earth's surface.

Speaking in less general terms, we learn from the rocks that in the palæozoic era coral reefs extended into high latitudes. The luxurious and uniform development of cryptogams over the earth during Carboniferous time indicates a warm moist climate which varied but little with latitude. In the Pleistocene or Ice Age the remains of reindeer, lemming, musk-oxen and other Arctic animals in central Europe show clearly that at that time the climate of central Europe was much colder than it is now.

In other words, climatic changes have been constantly going on. The present distribution of heat and cold, of dampness and of dryness, is but a passing phase in the history of the earth's surface.

All of the changes which take place in any region naturally affect all the animal inhabitants of that region. Some may die out and be replaced by others from another region, some may assume a more or less widely different guise, and some may be able to exist unchanged under the new conditions.

But changes in climatic conditions however severe do not affect the basic requirements of food, water and air, which are always present, at least up to the point of complete desiccation or of permanent frost.



Some Coelenterates and a Solenogaster
for an explanation of the figures see p. 281

So changes in climatic conditions affect not the existence or the occurrence of any of the major groups or phyla, but instead the balance and the details of the types included within the phyla, or in other words the various forms in which the structural complex characteristic of the several major groups is manifested.

We may illustrate this point by a comparison between different portions of the earth's surface. Every major group or phylum is represented in seas where the temperature of the water never rises above the freezing point of fresh water (32° Fahrenheit or 0° Centigrade). Every major group is also represented in the tropics.

But the representatives of the phyla in the very cold and in the very warm water are in practically all cases very different, just as on land arctic and tropical animals are almost always very different.

In the warm water of the tropics and in the hot tropical lowlands the number of different types of animals included in each of the various major groups is far greater than it is in the cold regions. But in spite of the enormous number of different kinds of animals found in the tropics, there is not the slightest indication of any tendency to produce new phyla, or intergrades between the phyla.

In regions intermediate between the two extremes of hot and cold all grades of intermediate conditions are to be found, and it is noteworthy that in comparing different intermediate areas on the earth's surface we find a curious disparity in the balance between the different divisions within the phyla which are quite comparable to the changes in the balance between the different divisions seen as we pass from age to age in the fossil record.

It is doubtful whether at any time in the past there has ever been such a great diversity of climatic conditions as is found at the present day. The present tropics are probably hotter than the climate in any past age since life began. This is suggested by the fact that animal types which from their geological history we recognize as ancient if they are of restricted distribution are mostly found not in the hot tropics, but in more or less warm temperate regions of equable temperature and humidity, at moderate elevations in the tropics, or at moderate depths in the tropical seas.

Somewhere or other on the earth today we probably find duplicated all, or nearly all, of the climates of the past so far as temperature and humidity are concerned. But we cannot be sure of duplication when it comes to the very important question of light or the strength and frequency of winds.

If we may judge the past from what we know of conditions at the present time we are in a position to understand the constancy of the major groups or phyla, and also the constant changes from age to age that took place within the phyla.

CHAPTER XIV

WHAT IS A SPECIES?

BEFORE proceeding further we must consider the basic unit in terms of which the animal world is measured. This basic unit is the so-called species. In everyday language a species is a distinct kind or sort of animal.

The accepted definition of a species is an assemblage of individuals which agree with each other in form, size, color and in other characters, in one or more of which they constantly differ from related assemblages of individuals; which normally and freely interbreed; and which transmit to their offspring their proper characters unchanged, or with that little modification which is due to conditions of environment.

While technically correct, this definition is deceptive. It is simply a broadening of the definition of an individual. It contemplates primarily material in museum collections and is based almost entirely upon the vertebrates, especially birds and mammals. It scarcely applies to other forms of life even as represented in museums.

What, then, is a species? That is difficult to say, for the different kinds of animals vary very greatly in the interrelationships of the included individuals, and in their relations to allied types.

Each species is always separate and distinct from every other species. But a species is not a static entity. Rather a species is to be regarded as a restrained and repressed force—an enigmatic potentiality—which, once released, will go to unknown and unsuspected lengths.

The peculiarities of species are best appreciated through the consideration of a few examples taken more or less at random from the animal world.

Some species are constant in their characters and practically invariable. Thus wherever it is found the American eel is always the same. There is no difference between Canadian and West Indian or Brazilian specimens. It is very closely related to the similarly constant European eel, from which it differs in having about seven less vertebræ in its backbone. The breeding ranges of the American and of the European eels broadly overlap, yet no American eel has ever been taken in Europe and no European eel has ever been taken in America. Although these eels are so very closely related the American eel passes through its larval stage in rather less than a year, while the larval stage of the European eel occupies from two to three years.

Among the butterflies the common painted lady, which is found throughout the world except in the polar regions, Australia and New Zealand, and South America south of the northern coast, is also everywhere the same. It shows temporary and individual variations resulting from temporary local factors, but no permanent local variation. The same is the case with the red admiral which is found in western Europe and over a large part of North America, and with various other butterflies, mostly with very limited distribution.

Other species, on the contrary, are so very highly variable that they can only be defined in negative terms. Being impossible of description, they can be identified only by the fact that they do not conform to the description of any other species.

Such a species is one of the commonest feather-stars (cf. fig. 43, p. 87) of the Indian and west Pacific oceans which is found from Japan to Madagascar. In this extraordinary creature the arms vary in number from eleven or twelve to about seventy, but are usually about twenty or about forty. The arms may be all of the same length, or the hinder arms may be only one-third as long as the anterior, or the anterior and posterior arms may be of any intermediate relative proportions. The arms may be short and stout, or greatly elongated and attenuated; sometimes the anterior arms are elongate and attenuated, and the posterior short and stout. The pinnule combs may be long and low, or short and high; they are usually confined to the first two or three pairs of pinnules, but sometimes they occur at intervals almost to the arm tips. The arm branches are typically of four segments each, but usually one or more of them are of two segments, and in rare cases all of them may be of two segments. The leg-like processes on the dorsal side—the cirri—may be numerous, rather stout, and well developed, or they may be few and weak, or they may be altogether absent.

In Madagascar and in southern Japan this species is only slightly variable; here it is always rather small with about twenty arms which are always rather short and stout.

All of the most closely related feather-stars are only slightly variable. But other feather-stars in widely different groups both in the East and in the West Indies show a comparable extraordinary variability.

Extreme variability is characteristic of very many creatures in the sea and in these variability is often carried to what seem to be fantastic lengths. But the creatures of the sea are known to relatively few so that a detailed discussion of them would be unprofitable. So we shall take our examples of variability chiefly from among the butterflies, as the variations of butterflies have been widely studied and are therefore fairly well appreciated. Furthermore examples of variation in the butterflies may be seen in any collection, and some, at least, are easily obtainable almost everywhere.

One of our common butterflies varies from light clear yellow with a wing spread of about $2\frac{1}{4}$ inches or rather less to deep brilliant orange with a bright violet iridescence in the males and a wing spread of nearly $2\frac{3}{4}$ inches. The males of the two extremes have a different wing form and a wholly different odor. There is no regular intergradation between the yellow and the deep orange types. The butterflies are yellow, yellow faintly flushed with orange on the fore wings, light orange, or deep orange. Intergrades between these color types are rare. The males of the first two types are very fond of sitting on mud and sucking up the water. The males of the light and deep orange types will not visit mud, and are much swifter, higher and stronger fliers. Giants and curious little dwarfs are found in all the forms.

In the yellow form one-quarter of the females are pure white, with the black borders of the usual yellow females. In the north these white females never occur in spring, being found only in the summer. In the south they occur equally both in spring and summer. In the deep orange form white females are infrequent, and in the light orange form they are still less common. In the yellow form which is faintly flushed with orange apparently the females are never white.

So far as I have seen mating takes place only between butterflies of the same color type. The young produced may be of the same color type as the parents, or of a different color type, or of two or more color types.

But in some localities this extraordinary butterfly shows only most insignificant variations, and some of its closest relatives are almost invariable.

A few butterflies exist in two quite different sizes between which intermediates are rare, at least in most localities. This is the case, for instance, in our common tailed blue. In many butterflies sporadic giants and dwarfs differing abruptly in size and more or less in habits from the normal type are not infrequent.

In many butterflies there is a regular alternation of forms from one season to the next. Thus in our common eastern angle-wings the summer individuals are dark in color with short wings. They are more or less sedentary and seldom stray far from their place of origin. The autumn individuals, however, which live through the winter, are much lighter in color than the summer individuals and have longer wings. These wander very widely. The dark short-winged and light long-winged forms are very different from each other and never intergrade.

A somewhat similar phenomenon is seen in the production of a long-winged migratory form from time to time, or more or less irregularly, by certain grasshoppers. Similar and comparable phenomena are also seen in other insects.

In various regions certain butterflies have very distinct alternative forms one flying in the wet and the other in the dry season. These forms are usually quite distinct, but in many cases intergrades occur, and in a few intergrades are common.

Some of our butterflies in certain years will produce typical wet forms in bogs or other damp localities which die out without leaving any progeny. Such forms with us are usually regarded as extreme varieties or aberrations according to their relative abundance.

In most of our butterflies the individuals of the spring brood increase gradually in size and change more or less noticeably in color—showing especially an increase in the dark markings—from the earliest to the latest. This change is very marked in the common cabbage and yellow clover butterflies, and also in the zebra and the yellow swallowtails. The color changes are perhaps most striking in the common blue. In all of these cases the latest individuals of the spring brood closely resemble the individuals of the summer brood in those species in which there is a summer brood.

In certain butterflies the individuals of the spring brood may be the same, or nearly the same, throughout the range, while the individuals of the summer brood or broods differ very widely in different regions. This is well illustrated by the common little copper butterfly as it occurs in Europe, North America and Asia.

Some butterflies are at all times very highly variable in both sexes in color or in wing form or in both features. Thus one of our common western swallowtails may be either predominantly yellow or predominantly black, or of any intermediate type. But the yellow form does not occur in Arizona, while the black form does not occur in Oregon or northward. Great diversity of color in one region, but the occurrence of only a single color type in the same species in another region, is a common phenomenon in the insects. In South America some of those curious butterflies called heliconians are so very variable that scarcely any two individuals can be found which are quite alike.

In most wide-ranging species there is more or less extensive variation in color, size, and wing form from one region to another. The different forms taken by the species in the different regions are recognized as subspecies or geographical varieties. These subspecies may grade imperceptibly into the corresponding forms in adjacent areas over a broad territory, or in a very narrow belt, or they may be wholly distinct though very similar. This last is especially the case if they occur on islands. Thus in one of the common *Aristolochia* (or pipe-vine) swallowtails a single subspecies is found from the south Atlantic states through Central and South America as far as Buenos Aires, while on each of the West Indian islands there is a well marked and distinctive form. Very many subspecies have been described, especially in birds, mammals, butterflies and mollusks.

Geographical variation usually affects both sexes equally, the sexes varying together. Thus the common northern butterfly known as the white admiral in southern New England and New York in both sexes passes over into a southern form which is much larger and in which the conspicuous white band is wholly lacking, while the hind wings are slightly angulated.

But sometimes one sex only is affected, or one sex is affected to a much greater extent than is the other. In the northern United States and Canada the common yellow swallowtail is rather small, and both sexes are almost alike in color. From New York southward the insect is much larger. The males remain almost the same in color, but the females become black, or if remaining yellow they acquire a large amount of blue on the hind wings. In the extreme south they are always black, and in some regions there are more or less well marked intermediate forms between the black and yellow females.

In several Indo-Malayan swallowtails the males are the same, or practically the same, throughout their range, but there are several or many different types of females which differ widely in their color and often also in their wing form. In the same species some of these female types will have an extensive range, while the range of others is very limited. In the two best known of these Asiatic butterflies both sexes are alike and constant in the northernmost portions of their range.

In a common African swallowtail there is a single type of male showing slight local variations, but there are more than thirty more or less widely different types of females nearly all of them lacking tails and showing no resemblance to the males. Some of these are very local, while others are widespread. In parts of Abyssinia females have been found with tails, though colored like other females. In Madagascar the females are like the males both in color and in wing form.

In one of the commonest South American swallowtails the males are everywhere the same, but the females are divisible into three well marked local races. In this butterfly the males are to be looked for in damp woods, while the females fly in more open places. The same sex difference in habits is found in other South American swallowtails, and in other butterflies elsewhere. It is characteristic of at least one of our common eastern skippers.

Diversity of females while the males remain the same is by no means confined to butterflies. It is even more strikingly seen in the ants, bees and wasps with their "queens" and one or more forms of female "workers." In the white-ants or termites the various "castes" are both male and female.

In a few butterflies the females are invariable, but the males are divisible into local races. In the common black swallowtail of the eastern states the males are much more variable than the females, and show a tendency to divide into local races which is not seen, or at least seen not so clearly, in the females.

Another form of geographical variation which is well illustrated by the butterflies is variation affecting some, most, or even all, of the animals of a certain type in a particular region.

For instance on the island of Celebes very many of the butterflies, including at least some in all the larger groups and all but one of the local swallowtails, have the fore border of the fore wings very strongly curved with a distinct elbow near the base. These butterflies are in no way related to each other, but each is related to a corresponding form in the Malay region which has the usual form of wing.

In tropical America very many butterflies, included in all but two of the larger groups, have wings of very curious form, the fore wings very long and broadly rounded at the tips and the hind wings very small.

The American *Aristolochia* swallowtails all differ from those of the Old World in having the sinus of the fifth tarsal (foot) segment, in which the claws are inserted, much less extended.

With the exception of two species, one from the

Amazon region and one from Ecuador, all of the species of American *Aristolochia* swallowtails with tails occur from Costa Rica northward, and from temperate Brazil southward. All the very numerous species in the region between Costa Rica and central Brazil except for the two mentioned are wholly without tails. Our common North American blue swallowtail loses its tails in the southernmost portion of its range. A number of Asiatic swallowtails gradually lose their tails toward the southeast, among the islands of the Malayan archipelago.

On the West Indian island of Jamaica there is a marked tendency toward an increase of the black markings in the local butterflies.

On the island of New Guinea the local representatives of wide-ranging butterflies are smaller than the forms found elsewhere; the largest forms are those which occur on the island of Amboina.

In high mountain regions butterflies become extremely variable, varying from peak to peak, from valley to valley, and frequently in different portions of the same valley. This is most evident in the Himalayas and the mountains to the northward, and in the Andes, but it is very noticeable in certain Rocky Mountain species.

It occasionally happens that a form which is a rare variety in one region is the sole representative of the species in a distant region.

A species of butterfly may feed on a very great variety of different plants, as does our yellow swallowtail, or it may feed on only a single kind of plant, like our beaked butterfly. Most butterflies feed on several or many closely related plants.

It often happens that a butterfly in its feeding habits shows an abrupt departure from its nearest relatives. Thus in that restricted group of swallowtails which includes our common black or parsnip swallowtail and the common yellow swallowtail of Europe all of the species except three feed on umbelliferous plants. One in eastern Asia feeds on plants of the rue family. Another in Sardinia feeds on garden rue. The third, in the Rocky Mountain region, feeds on *Artemisia*—a composite plant. All three live with another species of the same group which feeds on umbelliferous plants, and the last two are very closely related to the forms with which they live.

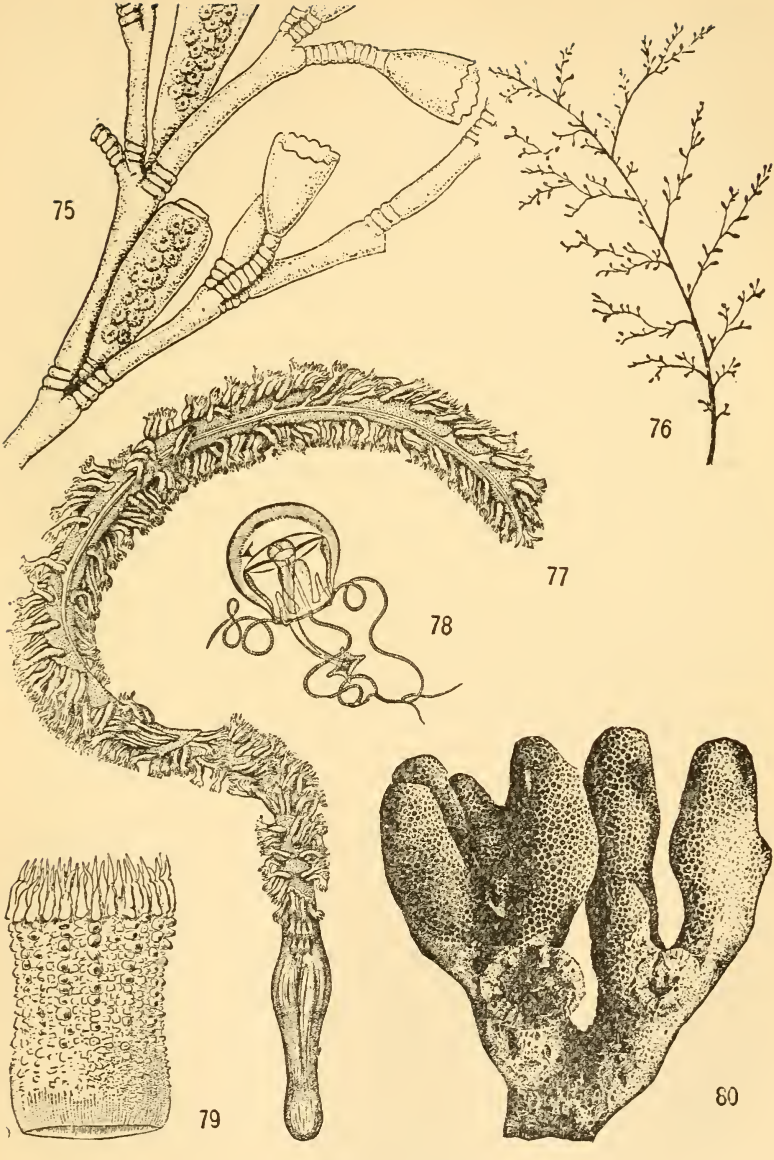
In the group of butterflies that includes the hair-streaks, blues and coppers there is very great diversity in food and feeding habits, with a corresponding diversity in the caterpillars, though not in the eggs or adults. In this group many of the species are carnivorous, feeding on ants, aphids or other insects, or are at first plant feeders becoming carnivorous in the later stages. Some feed on lichens or on algæ, or bore into fruits. Nearly all are cannibals.

In some butterflies sexual development is very slow and full maturity is not reached until some time after emergence from the pupa. In those butterflies that pass the winter as adults the eggs do not mature till spring, that is, until the butterflies have been in the adult stage for about six months. In the summer brood of the same butterflies, however, maturity takes place as rapidly, or almost as rapidly, as it does in other butterflies.

In very many butterflies mating takes place, or may take place, as soon as the wings are dry. In some species the males may be seen fluttering about the female chrysalids. In a few hair-streaks the full grown caterpillars exhibit strong sex attraction, and commonly form their chrysalids in pairs, a smaller male just behind a larger female.

Reviewing the peculiarities of species as just given we cannot fail to sense a temporary equilibrium. Some species are held in narrow bounds by the operation of internal or external forces. They vary only very slightly, or their geographical range is very limited. Others in one portion of their range are held in narrow bounds, but elsewhere are very variable. This variation may be correlated with a shifting of the bounds between which life is possible from season to season or from one region to another, or it may be correlated with a local separation of the limits between which the species can exist.

The most striking feature of this variation which we see within the species is that it is wholly, mainly, or at least largely, discontinuous, that is, the several forms do not intergrade, or if they do intergrade, intergrades are rare. A striking example of the complete absence of intergrades between very different alternative forms is seen in our common eastern angle-wings. Parents of one form will produce the same form, or the other form, or both forms, but never intergrades.



VARIOUS COELENTERATES

FOR AN EXPLANATION OF THE FIGURES SEE P. 281

The discontinuity of the forms within the species as they normally exist in nature is emphasized by very many cases in which the forms produced are extremely local, or are rare varieties, or are sporadic aberrations.

Professor William Bateson has brought together some significant cases of such variations. He pointed out that reversed varieties of animals are frequent. They are not uncommon in man. They are especially noticeable in the mollusks and the flat-fishes. Such varieties are formed as optical or mirror images of the body of the usual form. In both the mollusks and the flat-fishes some species are normally right-handed, while others are normally left-handed. But reversed examples are found as individual variations.

In the mollusks this is not confined to the gastropods or snail-like mollusks (fig. 51, p. 97), which have spiral shells, but occurs also in the slugs and in the bivalved mollusks (fig. 52, p. 97).

Bateson noted that the fact that the reversed condition may become a character of an established race is familiar in the case of *Fusus antiquus*. This shell is found in abundance as a fossil of the Norwich Crag. The individuals in the Crag are normally left-handed, though the same species at the present day is a right-handed one. Of the left-handed form a colony was discovered on the rocks in Vigo Bay, where the individuals were associated with certain other shells occurring in the Norwich Crag. The same variety occurs in Sicily.

Bateson remarked that from time to time there have been records of the capture of the "hairy variety" of the moor-hen (*Gallinula chloropus*) in which all the feathers were destitute of barbules and consequently had a hairy texture, greatly changing the general appearance of the bird. Owing to the absence of barbules, the general color of such birds is tawny.

A few feathers of this type have been found in hawks and gulls, and a jaçana is recorded in which a great portion of the body feathers were in this condition. The feathers of the *Apteryx* or kiwi and of the cassowaries are also partially destitute of barbules. A gray brahma hen has been reported with the same peculiarity.

Bateson said that the case of the silky fowl is similar in the absence of most of the barbules, but in the silky fowl the point of the shaft is produced to a delicate point and the barbs are fine and are sometimes bifid or trifid at the apex. In the silky fowl the skin and bones are purplish blue. The color of the skin and bones has not been recorded in the case of the "hairy" moor-hen.

Varieties of goats, cats, rabbits and other domestic animals with long silky hair are well known, and there are very similar breeds of guinea-pigs. This variety is not confined to domestic animals, for it has been reported in the common house-mouse.

Black mice are not infrequent. The so-called "rhinoceros mice" are very interesting, and have several times been reported. A male and a pregnant female found in a straw-rick at Taplow, England, were entirely devoid of hair except for a few dark colored whiskers. The skin was thrown up into numerous prominent folds which crossed the body transversely in an undulating manner. The ears were dark or blackish, the tail was ash-colored, and the eyes were black. There were no traces of hair follicles. The animals were active and healthy, and there was no suggestion of disease. The young when born were similar to the parents. Other "rhinoceros mice" have been recorded, both in England and in this country.

Three mice were caught in a house in the town of Elgin the bodies of which were completely naked. There was nothing peculiar about the snout, whiskers, ears, lower half of the legs, and tail, all of which parts had hair of the usual length and color. At least two others were killed in the same house where these were found.

Naked horses have often been exhibited. A horse taken from a half wild herd in Queensland had the skin black and resembling rubber. Careful examination showed no trace of hair, nor any openings of hair follicles. While in Turkestan, Professor Bateson heard of a naked horse but failed to see it.

According to Belt the hairless dogs in tropical America remain distinct and do not intergrade with other dogs.

In many different kinds of domestic animals races or breeds are known in which the bones of the face do not grow to their full size, while the bones of the jaw are, or may be, of normal proportions. Familiar examples are the pugs, the Japanese pugs, the bull-dogs, the Niata cattle of Argentina, short-faced pigs, etc. A bull-dog skull has been found in an ancient Inca grave in Peru, indicating that the bull-dog type arose independently in America.

"Bull-dog" cod, carp, chub, minnows, mullet, pike, salmon and trout have been described. In the case of carp and trout the "bull-dog" variety is very common in certain limited areas. "Bull-dog" forms of other vertebrates have also been recorded.

A very interesting case of discontinuity is furnished by the peach and nectarine. Darwin wrote that we have excellent evidence of peach stones producing nectarine trees, and of nectarine stones producing peach trees. We see the same tree bearing both peaches and nectarines. We find peach trees through bud variation suddenly producing nectarines, the seeds of which reproduce nectarines, as well as fruit which is in part nectarine and in part peach. Finally, we have a case of a nectarine tree first bearing half and half fruit and subsequently true peaches.

The variation from peach to nectarine or from nectarine to peach may be total. If it is less than total the fruit may be divided into either halves or quarters so that for each segment the variation is still total. There is no evidence of intermediate forms other than these divided fruits.

Bateson remarked that it is therefore a fair presumption that intermediate forms are either rare or non-existent, and that the peach state and the nectarine state are thus positions of organic stability between which intermediate states, if they are chemical and physical possibilities, are positions of instability.

Precisely the same phenomenon occurs among animals in which, however, it is usually overlooked or misinterpreted. One scarcely expects an animal to be partly one thing and partly another. This condition is most obvious and most easily demonstrated in the feather-stars (fig. 43, p. 87) and sea-lilies (fig. 6, p. 5) in which sometimes one or even two of the five rays will be replaced by rays of a type belonging to a widely different species. Several such cases have been described.

The more we study species the more clearly do we see that a species is a fluid unit, held to its present form by forces which it cannot overcome. The ability to expand and to produce new forms is inherent in almost every species at the present time; but the opportunity is lacking.

CHAPTER XV

ANIMAL FORMS

ANIMALS exist in an almost infinite multiplicity and complexity of form, and in most cases each single kind of animal exists in two or more different—often very widely different—forms. This is familiar to us in the case of the tadpole and the frog, and in the case of the caterpillar, the chrysalis and the butterfly. But these are relatively simple illustrations. In the case of the common eel we have the leptocephalus, the glass-eel, the elver, and finally the eel, while in a group of shrimps known as *Penæus* the young are at first a nauplius (cf. fig. 100, p. 175), then in succession a metanauplius, a protozoæa, a mysis-like creature, and finally an adult, there being in these shrimps no less than five different larval stages in addition to the adult form.

In only two of the major groups—the arrow-worms or chætognaths (fig. 62, p. 111) and the rotifers (fig. 136, p. 203)—are there no larval forms in any of the included species, the development leading directly from the egg to the adult form. But the same is true in many individual species, or larger or smaller assemblages of species, in many other groups. In the vertebrates true larval forms leading an independent life occur in most amphibians and a few fishes, but are not found elsewhere. Generally speaking, fresh water representatives of marine animals either greatly shorten the larval stages, or omit them altogether.

It is a curious fact that very closely related creatures may have widely different larvæ. For instance, the larvæ of nearly all the brittle-stars (fig. 44, p. 87) are strange looking things called plutei (cf. fig. 89, p. 175), but some brittle-stars have worm-like pelagic larvæ. The larvæ of most starfishes (fig. 42, p. 71) are of the form called bipinnariæ, later usually becoming brachiolariæ (fig. 88, p. 175); but starfishes which brood their young have worm-like larvæ.

On the other hand, very different creatures may have very similar larvæ. Thus the young of most, but by no means all, of the mollusks and also of the jointed worms or annelids are typical trochosphere larvæ. One adult rotifer has the same form. Larval forms which are commonly considered modified trochospheres are found in the echinoderms (fig. 109, p. 175), in the balanoglossids, in the phoronids (fig. 102, p. 175), and in the polyzoans (fig. 90, p. 175).

Extraordinary diversification of the larval forms is found in the echinoderms. Here we have the barrel-shaped larvæ of the feather-stars (fig. 109, p. 175), the auriculariæ of most of the holothurians or sea-cucumbers, which resemble most nearly the so-called tornaria larvæ (fig. 94, p. 175) of the balanoglossids, the bipinnariæ and usually later the brachiolariæ (fig. 88, p. 175) of most starfishes, the bizarre plutei of most sea-urchins (fig. 89, p. 175) and brittle-stars, and also some other larval forms.

Other curious larval forms among the marine animals are the actinotrocha larvæ (fig. 102, p. 175) of the phoronids, and the cyphonautes larvæ (fig. 90, p. 175) of most polyzoans. There are various other larval types among the marine animals.

Not only do the different types of larvæ vary very widely in their body form, but they also vary widely in the manner of their development. In most crustaceans, whatever may be the sequence of their larval forms, the development is more or less direct. In the nemerteans the development is usually direct, but in some there is a curious larva called a pilidium (fig. 106, p. 175) which transforms to the adult by a very complicated metamorphosis. There are also other forms of larvæ in the nemerteans.

In some of the trematodes the development is direct, but in others it is extremely complicated. Thus the first larva may be a miracidium (fig. 96, p. 175) which transforms into a sporocyst (fig. 98, p. 175), or rarely into a redia (fig. 97, p. 175). The sporocyst may produce other sporocysts, but usually produces rediæ, these last—sometimes also the sporocysts—producing curious tadpole-like larvæ called cercariæ (fig. 99, p. 175), which grow into the adults.

During the course of their development the echinoderms become transformed from a bilateral larva (figs. 88, 89, p. 175) into a radially symmetrical adult (figs. 41, 42, p. 71) with the body in five divisions.

In the passage from the larval to the adult form quite a number of the attached sea animals turn a half-somersault. The larva attaches itself at the anterior end just in front of the mouth and fastens itself firmly to the supporting surface. Then the mouth and the associated structures move upward to a position nearly or quite opposite the point of attachment. This curious process takes place in the feather-stars (fig. 43, p. 87) (but not in the other echinoderms), in the barnacles (fig. 30, p. 47) (though not in the parasitic barnacles or in the other crustaceans), in most tunicates, and in certain other types.

A curious feature of animals as a whole is the recurrence of similar or comparable forms in widely different groups.

Among the single celled animals or protozoans some are attached and more or less radially symmetrical, like *Stentor* and *Vorticella*. Others are attached and form colonies at the summit of a stalk, like *Codosiga* or *Epistylis*. Some, as *Amœba*, are free living and capable of locomotion, but are sluggish and creep equally well in any direction. Still others float about freely suspended in the water. Many are elongated and more or less bilaterally symmetrical, and swim with great rapidity. Some are naked, while others form beautiful regular and complicated shells of lime or other substances, or rough agglutinated tubes of sand grains, or other forms of body covering.

Among the radially symmetrical animals some—indeed most—are attached. Some of the attached types form colonies on the summit of a stalk (fig. 72, p. 127), as the umbellularians. Others, as many sea-anemones (figs. 4, p. 5; 79, p. 143), are free living and capable of locomotion, but are sluggish and creep equally well in any direction. Some, like the jelly-fishes (figs. 3, p. 5; 78, p. 143) and the ctenophores (fig. 66, p. 111), float freely suspended in the water. Others are elongated and more or less bilaterally symmetrical, like the Venus' girdle (*Cestus*) and the creeping ctenophores. Some are naked, while others construct beautiful and complicated bases, like the corals, or are even completely enclosed in protecting plates (*Primnoa*), or live in tubes of sand or mud. Thus these creatures repeat the bodily forms of the protozoans so far as their structure will allow.

Among the bilaterally symmetrical animals derived through a gastrula stage many are attached, as nearly all the polyzoans (figs. 67, 68, p. 111), most sea-lilies (fig. 6, p. 5), many crustaceans, like the barnacles (fig. 30, p. 47), most tunicates, and certain other types; some of the attached forms, as certain of the polyzoans, form colonies on the summit of a long stalk. Others, as most sea-urchins and starfishes, are free living and capable of locomotion, but are sluggish and creep equally well in any direction. Some, as certain rotifers, tunicates and holothurians, float freely suspended in the water. Very many are bilaterally symmetrical and swim, run or fly with great rapidity. Some are naked, while others, as the barnacles, brachiopods, mollusks and polyzoans, form regular and complicated limy shells or, as in the case of many worms, some rotifers, some phoronids, and some insect larvæ, construct rough agglutinated tubes of sand grains or other forms of body covering.

But whatever may be the form of any animal type either in its larval or adult stage the fundamental features of the group of which it is a member are in it found to be unchanged.

CHAPTER XVI

THE CONTINUITY OF LIFE

No understanding of animal life is possible without an appreciation of the ways in which the perpetuation of the species is assured. Continuity of life from one generation to the next is brought about by three apparently quite different processes.

In the first place, there is the usual sexual reproduction. Secondly, many animals are reproduced by females only, through the development of unfertilized eggs. In the third place, an animal may divide in two, or may produce buds which grow into new animals; these may separate from the parent, or may remain attached to it.

Many different kinds of animals, such as all sponges, all cœlenterates, many flatworms, some jointed worms or annelids, the phoronids, the polyzoans, some tunicates, the cephalodiscids, some brittle-stars and starfishes, and a few crustaceans, either form buds which become detached and develop into independent animals, or, usually at an early stage, divide into two or more parts, each of which develops into an independent animal.

Many of these types, especially the sponges, the cœlenterates, the polyzoans and the tunicates, besides producing buds which become detached, also produce buds which remain attached to the parent animal, and in this way build up more or less extensive colonies (figs. 59, 67, p. 111; figs. 69–72, p. 127).

There are very many variations of this process. For instance some sponges, including the sponges of fresh water, and most of the fresh water polyzoans, produce as they grow internal buds consisting of masses of cells encased in a tough and usually more or less complicated shell. After the animal dies these little seed-like structures are liberated through the decomposition and disintegration of the body and drift away, to grow into a new animal, or colony, if and when conditions become favorable.

In most polyzoans the tentacles, alimentary canal and nervous system of the individuals from time to time disintegrate, and a new set of these organs may be formed through internal budding from the persistent body wall of such partially disintegrated polypides.

In the insects in which the metamorphosis is incomplete, as for instance the grasshoppers, manties (fig. 19, p. 33) and bugs (fig. 23, p. 33), the body of the young grows gradually into the body of the adult, and the new organs, such as the wings, are formed as simple outgrowths.

In those insects, as the beetles, wasps, butterflies and flies, in which the young are very different from the adults a few of the systems of organs, such as the reproductive, the nervous and the circulatory, persist from the larva to the adult, but the other organs disintegrate, being later entirely rebuilt from special groups of cells called imaginal disks.

In connection with this so-called asexual reproduction the extraordinary powers of regeneration possessed by certain types of animals deserves a special mention. Some creatures may be cut into a great number of small fragments, and each fragment will subsequently grow into a perfect animal. In other creatures fragments above a certain minimum size, or including a greater or lesser portion of some essential structure, will grow into a perfect animal. In still other creatures division or mutilation of the body is followed by the replacement, by the central portion, of the parts removed. But the fragments not including this central portion die.

A curious form of reproduction is seen in certain minute parasitic wasps in which a single egg gives rise to from two or three to about a thousand larvæ. In somewhat the same way the egg of certain polyzoans develops into a multinucleated mass which buds off small pieces, each of which becomes a larva.

To a large extent asexual reproduction is especially characteristic of the early stages or the young of the animal types wherein it occurs, the individuals which are fully grown being capable only of sexual reproduction. Thus in certain brittle-stars very young individuals divide into two, and each half then grows into an adult. Certain starfishes when young divide themselves into five sections, the five arms separating at the base; subsequently each arm grows four more arms, and the original single little starfish becomes five adults. But in none of the brittle-stars or starfishes is such a procedure possible after the animal is fully grown.

While in many animal types asexual reproduction is carried to great lengths, it never wholly takes the place of sexual reproduction. Sometimes sexual and asexual generations alternate, or there may be several, many, or even very many asexual generations between two sexual generations, or asexual reproduction may be rare, or very rare, or merely casual.

Reproduction by females only through the development of unfertilized eggs is not infrequent in the animal world. In a number of different creatures young are produced by females in the absence of any males. This is true in all the rotifers (fig. 136, p. 203). Most rotifers, besides possessing this curious type of reproduction, also are known to show—though often very infrequently—the usual sexual reproduction. But in many kinds of rotifers males are entirely unknown.

Production of eggs and young by females in the absence of males occurs as a regular and constant feature in the life history of many different kinds of phyllopod and ostracod crustaceans, in many different kinds of hymenopterous and hemipterous insects, in some jellyfishes, in some moths, and in a few other creatures. In some of the crustaceans and in some insects no males have ever been discovered.

The production of young through the development of unfertilized eggs is by no means confined to full grown females. In a few kinds of flies young are produced by the pupal stage, or even by the maggots.

In certain insects, as in the social ants, bees and wasps, and in the termites or white-ants, individuals occur—the so-called workers—which have non-functional reproductive organs. In the ants, bees and wasps such individuals are always females, but in the termites they are both males and females.

Corresponding non-breeding forms are not infrequent in other types of insects, and also in birds and mammals, though in these so far as known they serve no useful purpose. Unsexed polyps or corresponding units are of course common in the cœlenterates and in the polyzoans, and occur also in some tunicates.

The production of fertile eggs or living young by females only is so extensively developed in some types of animals that sexual reproduction is a very rare occurrence—indeed in some it is entirely unknown. In others it is casual or rare. Between the two extremes almost every type of intermediate exists.

But throughout the animal world sexual reproduction is the usual and most widespread means of insuring the perpetuation of the species, and even in those animal types with extensive asexual reproduction or reproduction through females only sexual reproduction almost without exception plays an important part.

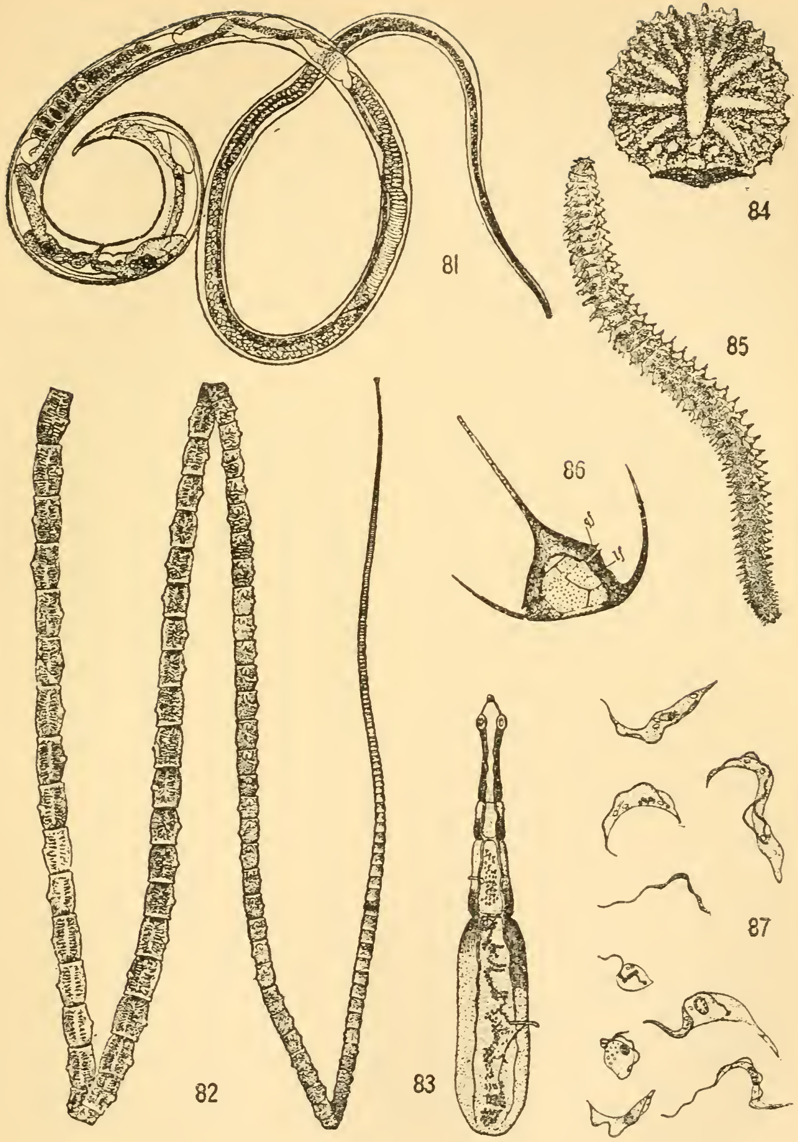
Asexual reproduction or division may take place at any stage, though it is most frequent in the early stages and in young animals. In the case of reproduction through the development of unfertilized eggs the eggs are usually produced by fully grown females, more rarely by young females, and very rarely by the preadult or larval stages.

As a prerequisite to sexual reproduction it is necessary that the individuals become sexually mature. It is important to remember, however, that sexual maturity is quite a different thing from structural maturity. It is true that in the great majority of animals after sexual maturity is reached structural development abruptly ceases, very shortly ceases, or proceeds at a much slackened pace. In certain butterflies, indeed, structural development ends six months or more before full sexual maturity is reached.

But this is not always true. Even larval stages may become sexually mature. Thus in one group of the ctenophores the larva develops sexual cells which mature during the summer and produce eggs which develop normally into larvæ which are, however, smaller than the larvæ produced by adults. After the production of eggs has continued for some days the larva loses the sexual cells, undergoes a complicated metamorphosis, and develops into an adult, when sexual cells again appear. Certain flukes also may produce eggs in their larval stages.

In nearly all animals on land the individuals are divided into males and females. But this is by no means always true. In many different kinds of animals both sexes are developed in every individual so that single individuals produce fertile eggs or young.

Both sexes equally developed and functioning at the same time so that a single individual alone produces young are found in a number of cœlenterates,



VARIOUS TYPES OF ANIMAL LIFE

FOR AN EXPLANATION OF THE FIGURES SEE P 231

including all the ctenophores, in the tapeworms, most flukes, most turbellarians, some nematodes, the arrow-worms or chætognaths, most polyzoans, possibly a few brachiopods, most barnacles, a few fishes, and an amphibian. In a number of fishes and some amphibians individuals occur casually in which both sexes are equally developed.

Both sexes are equally developed in earthworms, leeches and snails, but in these creatures the individuals are not capable of self-fertilization. In tadpoles both sexes are equally developed, but only one sex continues to develop to maturity.

In some animals, as for instance in the slime-eels and some nematodes, the individuals are at first male and later female, while in others, as in most tunicates, the individuals are at first female and later male.

In a number of different creatures, including some nematodes, some barnacles, and the ceratioid fishes, the males are wholly helpless parasites and live attached to, or within, the body of the female.

From this brief mention of some of the more important methods for assuring the continuity of life from one generation to the next and so on indefinitely it is clear that every conceivable expedient is to be found in some animal type or other. Furthermore, in every animal type that form of reproduction best fitted to produce the greatest number of young under the conditions which must be met is the one adopted.

These conditions differ very widely. In some cases the greatest number of young results from the actual production of relatively few which are cared for by the parents until almost the adult stage is reached, as in the mammals and most birds. In other cases the hazards of life are so very great that very many young must die for each one that survives.

In the common human tapeworm it has been shown that of the young produced only one in thirty-five millions has any chance of becoming an adult tapeworm.

In the case of the common eel of our ponds and streams an average female lays from five to ten million eggs, and large females lay from fifteen to twenty millions. Thus the chance that any given egg will hatch and the resulting young will grow into a mature eel which will succeed in returning to the spawning grounds is only one in about ten millions.

CHAPTER XVII

LIFE

TIME and again it has been shown that living things arise only as the children of other living things. This rule has no exceptions, and it is inconceivable that there should be exceptions. It is utterly impossible for any living thing to arise spontaneously. The continuity of life from parent to child is not doubted by any student of animals or plants at the present day. It is a basic axiom of biology.

Since all living things are derived from other living things, it naturally follows that the ancestral line of every living thing in the world at the present time has been continuous and unbroken, going back to the very earliest life upon the earth. No biologist today doubts the continuity of life from parent to child through all the ages that have passed since life's first beginnings, or the common origin of all forms of life.

Every living thing develops from a unit particle of living matter—a single germ cell—in which no trace of the adult form of that living thing is discernible. This is a second basic axiom of biology. Furthermore, the bodies of all living things are composed either of a single cell, as in the case of the single-celled animals or protozoans, or of vast numbers of cells of varied form and function grouped into the various organs of the body and forming either of themselves or as a result of their activity the diverse structural elements.

Since every animal, no matter what it is, originates as a single cell, and the body of every animal is composed of one or many cells which are always essentially the same in structure, we clearly see that all types of animal life must be explained in terms of a single cell.

Unbroken continuity of life from its very first appearance on the earth, and the fact that all animals begin as single cells and no matter what their size are always composed of a single cell or of a multitude of cells which in their broader features resemble the original single cells from which they are derived—these are the fundamentals out of which we must construct our picture of the interrelationships of animal forms.

Our first reaction to the plain statement of these fundamentals is that the problem is a simple one. Since all animals begin as a single cell, and since many animals are known whose entire body consists of a single cell, therefore these single celled animals must be the most primitive and all other animals must have been descended from them. So we are tempted to construct an evolutionary line from the single celled animals to those whose body is most complex in terms of cells, and then to arrange all animal types as best we may along this line. Such an assumed course of development of animal forms, from those whose body is composed of a single cell to the multitudes of multicellular types which we know today, is explained by what is called the theory of evolution.

Evolution as commonly understood assumes the gradual development step by step of all the widely varying forms of animal life from an original form of simple structure. But the developmental course which has been followed by animal life cannot be reduced to any such simple formula. In the first place, the study of animal life itself, whether the study of adult forms or of embryology, shows it to be wholly incapable of such simple interpretation. In the second place, this hypothesis is not in accord with the fossil history of animals as we know it. In the third place, it is not in accord with our interpretation of the geological processes and conditions in the very distant past.

Any acceptable theory of animal development must be in complete agreement with its setting. It must take into account the geological background and must be in accord with what we know, or believe, to have been the condition of the earth in the very distant past.

In tracing the history of animal life from its very first appearance to the infinite complexity which we see at the present day there are three entirely separate sets of facts to be considered, and any acceptable theory of the development of animal life must harmonize and correlate all three.

In the first place, within each of the so-called phyla or major groups of animals, as is well seen in the vertebrates, particularly in the mammals and the reptiles, there are many well marked, obvious, and undeniable evolutionary lines which, beginning with a relatively simple form of creature run by easy stages to a specialized and highly complex form.

In the second place, very few of these evolutionary lines are perfectly continuous. Practically all of them are more or less interrupted by gaps of various widths, and these gaps are often very broad. Especially is it true that these evolutionary lines tend to be separated from each other for their entire course, running parallel or more or less convergent right down to their very earliest beginnings, and not uniting in a common type of animal as we would expect. For instance, the whales and the seals are always whales and seals, and show little or no approach to any other type of mammal. Similarly, there are no intermediates between turtles and snakes, or between turtles and lizards, all of which are reptiles, or between squid (fig. 45, p. 97) and oysters, though both types are mollusks.

In the third place, no animals are known even from the very earliest rocks which cannot be at once assigned to their proper phylum or major group on the basis of the definition of that group as drawn up from a study of living animals alone. A backboned animal is always unmistakably a backboned animal, a starfish is always a starfish, and an insect is always an insect no matter whether we find it as a fossil or catch it alive at the present day. There can be only one interpretation of this entire lack of any intermediates between the major groups of animals, as for instance between the vertebrates, the echinoderms, the mollusks and the arthropods. If we are willing to accept the facts at their face value, which would seem to be the only thing to do, we must believe that there never were such intermediates, or in other words that these major groups from the very first bore the same relation to each other that they do at the present day. Is this creationism? Not at all. It simply means that life at its very first beginnings from the single cell developed simultaneously and at once in every possible direction. All of the phyla or major groups seem to be of simultaneous development—at least we have no evidence that it was otherwise. From each one of these a separate developmental line or tree arose, growing upward through the ages.

The numerous developmental lines are explained by the process of *evolution* as that term is commonly understood, and this descriptive word should be restricted to these developmental lines.

The gaps within these lines, and between related lines which run more or less parallel, are explained by an extension of the theory of *mutations*.

The complete absence of any intermediate forms between the major groups of animals, which is one of the most striking and most significant phenomena brought out by the study of zoology, has hitherto been overlooked, or at least ignored. This condition may readily be explained by an application of the facts gained through the study of embryology by a theory which may be called the theory of *eogenesis*.

Restriction or expansion of the meaning of a well known word results always in confusion. The term evolution is commonly used to cover the entire developmental history of animals. But evolution contemplates a gradual and continuous unfolding of animal life beginning with creatures consisting of a single cell and ending with man. A better understanding of the subject will result if we recognize the fact that this process includes three distinct but interrelated phases, first, *evolution* properly so called; second, *mutations*; and third, *eogenesis*.

If we regard the complete history of the development of animal life in this light we must, in order to avoid confusion, use for it an entirely new term. We may call it *zoogenesis*.

CHAPTER XVIII

DEVELOPMENTAL LINES AND TREES—EVOLUTION

THE first of the three sets of facts to be considered in connection with the development of animal forms has to do with the existence within each of the larger of the so-called phyla or major groups of animals of well marked, obvious and undeniable evolutionary lines which, having their origin in far distant geologic time in a relatively simple form of creature, run by easy stages to a specialized and highly complex form or group of forms.

Such lines of progressive bodily development are well marked in the backboned animals or vertebrates, particularly in the mammals and the reptiles. We may illustrate this point by a consideration of the history of the horses.

At present there are living on the earth about ten different kinds of horses all but one of which, the domestic horse, which is not found in a wild state, are confined to Asia and to Africa, most of them, the various kinds of zebras, living in Africa.

But in the Pleistocene or Ice Age many different kinds of horses roamed over all the continents except Australia. According to Dr. James W. Gidley there were a number of different kinds in North America where they ranged north to beyond the Arctic circle in Alaska.

These horses were all the modern type, with relatively long limbs and with a single toe and hoof on each foot. Their skulls were long-muzzled and their jaws were deep in order to accommodate the long and high-crowned teeth which are so characteristic of the modern horse. They ranged in size from little creatures no larger than the smallest Shetland pony to some that exceeded the largest draught horses.

As related by Dr. Gidley, these horses of the Ice Age were preceded by others of a still earlier geologic time. The fossils of the later portion of the so-called Tertiary period, known as the Miocene and Pliocene epochs, give abundant evidence of earlier groups of horses which were even more varied in types and more numerous in kinds than those of the Pleistocene.

The duration of this period was very long, being measured by hundreds of thousands or perhaps even millions of years, and the records show that horses were abundant from its beginning until its close. There were no very large horses at this time, and the general average size was notably smaller than that of the horses of the Pleistocene. They all resembled the modern horses in a general way, but most of them differed in several rather inconspicuous but very important features.

The limbs and feet of the horses of this period were much like those of modern horses, but in addition to the single rounded hoof most of them had on each foot a pair of extra toes, one on either side of the main toe. These extra toes varied in size from small ones, resembling the so-called dew-claws of the deer or elk, which did not reach the ground, to larger ones which reached the ground and must have borne some of the weight of the animal in walking. A very few of the horses of this period had feet like the modern horses—that is, entirely without the lateral toes—but their remains occur only in the later portion of the period. Most of the horses of the earlier phases of the period had longer and better developed lateral toes than those of the middle and later phases.

All horses with single toes, both modern and extinct, have on each foot a pair of long splint bones, one on either side of the main toe, which in life are covered by the skin. The upper ends of these bones are greatly expanded and have well developed articular facets for contact with the small bones of the wrists or ankles. This part of the foot is identical in structure in the one-toed and in the three-toed horses, but in the three-toed horses there are three additional terminal bones on the lateral toes which are absent in the one-toed horses.

In the horses of the Pliocene and Miocene the muzzle portion of the skull is usually relatively shorter than in the modern horse, and the jaws are not quite so deep, due to a difference in the relative height of the crowns of the cheek teeth. In the living horses and the horses of the Pleistocene or Ice Age all the cheek teeth when fully formed have long and nearly straight crowns from three to four inches or more in height. These are set deeply in the jaws and move outward as they are worn away by use. It is this type of tooth which, as remarked by Dr.

Gidley, gives the great depth to the jaws of modern horses. In most of the horses of the later Tertiary the cheek teeth are of this type, but the crowns are less heightened and are usually much more curved. Both of these features tend to decrease the depth of the jaws.

A few of the kinds of horses which lived in this period had teeth of a simpler type in which the crowns are low and are attached to the jaws by means of roots. For the most part these kinds are found in the earlier portions of the period. Of the kinds with high crowned teeth those with the least heightened crowns are also found in the earlier phases of this time period. This group of the earlier horses represents in a way a transition stage between those with low crowned and those with high crowned teeth, for the young or colts of the horses of this group had cheek teeth of the low crowned type which in adult life were replaced by teeth of the high crowned type.

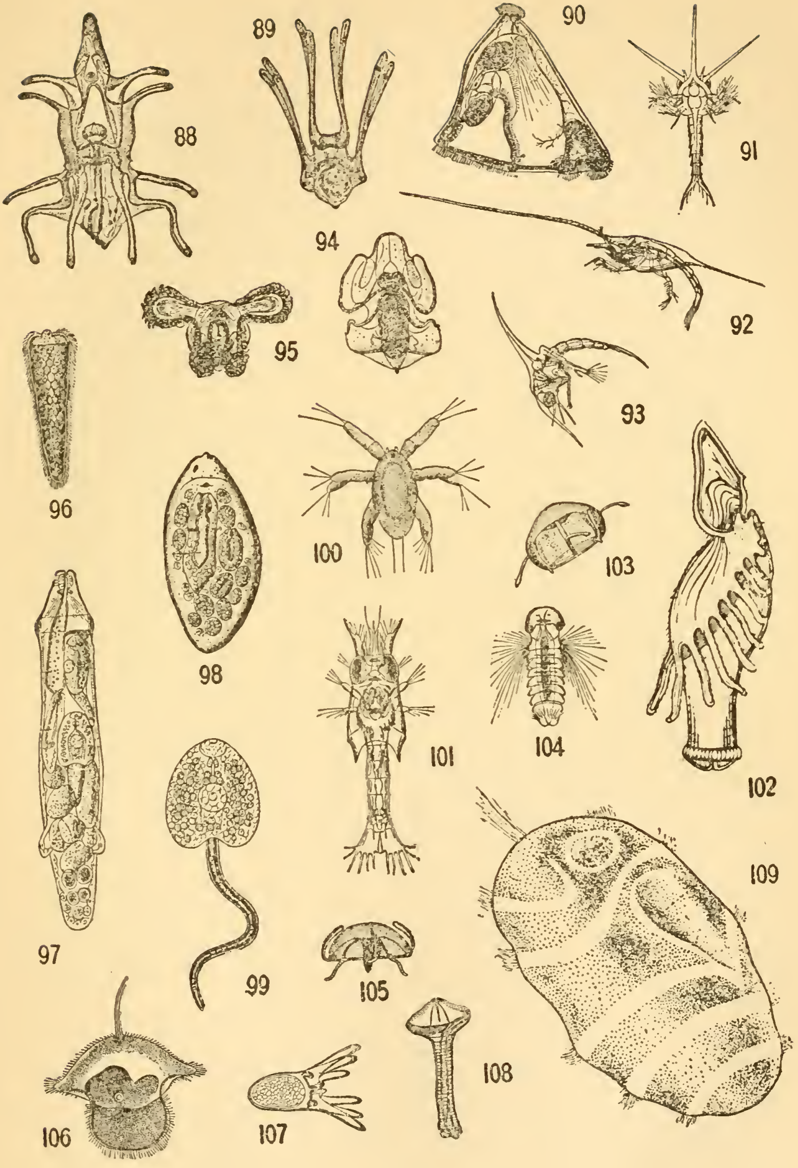
In the next older epoch of the Tertiary period, known as the Oligocene, still other kinds of horses inhabited America. These more ancient horses were on the average smaller than those just noted. Most of them were about the size of a shepherd dog or a little larger; a few were somewhat smaller. There were many different kinds of these little horses. All were three-toed types with the lateral toes reaching to the ground, and all had low crowned teeth, so except for their smaller size they must have resembled closely those of similar type belonging to the next later period (Miocene).

All through the sedimentary rocks of the earliest epoch of the Tertiary—the Eocene or "dawn time"—there are records of an abundance of little creatures much resembling those of the Oligocene but still more diminutive in size. They also had a main central toe with well developed lateral toes on each hind foot, but the fore feet were provided with four toes instead of three. The muzzle portion of the skull was relatively shorter in the little very early horses than in the larger later horses, so that the eyes were about midway between the ears and the tip of the nose instead of being nearer the ears as in the later horses.

The oldest member of the group of four-toed horses, which is also the oldest member of the great group to which belong all the horses, was a little creature no larger than a fox called *Eohippus* or the "dawn horse."

While no member of the horse family has five complete toes, some of the little four-toed ones have in the foot an extra small bone of splint-like shape which can only be interpreted as the representative of a fifth toe.

This account of the different types of horses, beginning with those of the present day and running back further and further through geologic time to the very earliest creature known which can be called a horse leads us by easy stages to an animal which is very different from any kind of horse we ever saw. Without a knowledge of the intermediate types we would never suspect that it had any affinity with horses. Now if we reverse the picture we shall get a good example of an evolutionary line.



Young Stages of Various Animals
FOR AN EXPLANATION OF THE FIGURES SEE P. 282

In the Eocene there lived a curious little creature no bigger than a fox called the "dawn horse"—*Eohippus*—which had four toes on the front and three on the hind feet and a relatively short head with the eyes about half way between the ears and the tip of the nose instead of nearer the ears than the tip of the nose as in the later horses. In the same epoch, though somewhat later, there was an abundance of very similar little creatures.

Following these there were a number of different kinds of horses all of which had three toes and, like the "dawn horse," low crowned teeth which were affixed to the jaw by means of roots.

Still later there were horses which as colts had low crowned teeth, but when fully grown had teeth with fairly high crowns. With these lived others in which the teeth had high crowns at all ages. These horses had shorter muzzles and rather less deep jaws than the modern horses, and while they had a single hoof, there was a toe on either side of it. These lateral toes varied from small ones which did not reach the ground to larger ones which reached the ground.

In the Pleistocene or Ice Age—in the epoch just before the present—there were very many different kinds of horses which were all of the modern type and inhabited all the continents with the exception of Australia.

So we see a well marked and distinct evolutionary line beginning with the little four-toed horses in the Eocene and culminating in the large single-toed horses of the present day.

While this series of horse types may broadly speaking be considered as representing a single line running from the little four-toed horses to the large single-toed horses, the actual conditions really are not quite so simple.

Several of the horse types after their first appearance branched out in various directions, and these diverse branches became more and more distinct from each other and themselves gave off branches in the same way, and again the process was repeated.

In the Pleistocene the modern type of horse, which was then of relatively recent appearance, had already branched out in many different directions. At the present time there exist a single sort of true wild horse in Asia, four kinds of wild donkeys, three in Asia and one in Abyssinia (Ethiopia), and several different kinds of zebras, all in Africa.

The development or evolution of the horse from its first beginnings in the Eocene to the present day may thus be most faithfully represented by a tree-like figure, the base of the tree-like figure being a creature more or less closely resembling *Eohippus*, and the present wild horses, wild asses and zebras being represented by a few of the topmost twigs.

The existence of many well marked developmental trees like that delineated by the fossil horses enables us to present a general picture of the evolutionary history of many different types of animal life.

Large sections of certain groups of animals may even be delineated in this way and their evolutionary history described on the analogy of a tree with a close approximation to the known facts.

Thus the reptiles first appeared in that very ancient time known as the Carboniferous and gradually branched out, increasing in diversity and in maximum size. The largest land animals of which we have any knowledge are the largest of the dinosaurs, which flourished in the Jurassic and Cretaceous. At the end of the Cretaceous period most of the larger and more spectacular of the reptiles suddenly disappeared, but many reptilian types, for instance the turtles, lizards, snakes and crocodilians continued right through to the present day.

The mammals first appeared in the form of very small and insignificant creatures at the time (Jurassic) when the great reptiles were the dominating giants of the land and sea. After the sudden disappearance of the giant reptiles at the end of the Cretaceous, the mammals increased greatly in diversity and somewhat in size, though in the earlier portion of the epoch following (the Eocene) the largest mammal was not so large even as a sheep.

These mammals of the earlier portion of the "dawn period" (Eocene) soon disappeared, but as they disappeared their place was taken by other types which were more or less comparable to the sorts we know today. Gradually as time went on these mammals became more and more diversified. Various extraordinary types appeared, some of huge size and in aspect most bizarre, while together with these came others which we have no difficulty in recognizing as the direct predecessors of the types which we know at the present day.

In many other groups, especially in the mollusks, in the echinoderms, and in the jointed-legged animals or arthropods, similar and comparable evolutionary figures may be constructed on the basis of the facts available.

CHAPTER XIX

GAPS IN THE EVOLUTIONARY LINES—MUTATIONS

THE second of the three sets of facts to be considered in connection with the development of animal forms concerns the imperfections in the evolutionary picture as portrayed by a branching tree-like figure.

All the evolutionary lines are frequently interrupted by gaps of various widths, and these gaps are often very broad. Thus in the horses, as has been pointed out by Dr. James W. Gidley and by Professor W. D. Matthew, there is a considerable gap between the Eocene and the next following (Oligocene) types, and there are numerous other gaps, many of the types of horses being more or less, and sometimes rather widely, isolated from their nearest relatives.

In the horses, as stated by Professor Matthew, we "have in many cases a succession of collateral ancestors so nearly related to the direct genetic line as to afford, when critically studied with due recognition of their status, a clear record of the physical evolution of the race, sometimes in more general, sometimes in more detailed terms according to the nearness of their approximation to the direct ancestral line."

So we see that even in the horses the tree-like figure is after all only an approximation to the truth. The twigs of the tree do not actually join the branches, and the branches do not join the main trunk; and besides, the main trunk itself is not continuous. The gap between the very earliest horses that we know, the horses of the Eocene, and those of the next following period, the Oligocene, will undoubtedly be narrowed by future discoveries, but most of the gaps probably will not.

Especially is it true that evolutionary lines tend to be separated from each other for their entire course, the trunks of the evolutionary trees running parallel or more or less convergent right down to their very earliest beginnings and not coming together in a common type of animal as we would expect.

For instance, the whale line is always distinct from every other line of mammalian development, just as in the reptiles the corresponding ichthyosaurs always were distinct from every other line of reptiles. So also the seal line is always distinct. Just as whales were always whales, seals were always seals. No intergrades between the seals and other mammals are known, although the seals belong to the Carnivora and therefore must have had an ancestor common to them and to the terrestrial members of that great mammalian group.

Among the more familiar mammals, the cat and the dog lines are always separate. No forms intermediate between cats and their relatives and dogs and their relatives are known, even though both cats and dogs are collateral members, together with the seals, of the Carnivora.

But in the case of cats and dogs the very early types which are found in the Oligocene are less widely different from each other than are the cats and dogs of the present day. Professor Matthew says that "there is no serious gap in the line through which the dogs are traced back to the Lower Eocene *Miacis*, but the Lower Eocene ancestors of the Felidæ [cats] are represented only by a number of European genera imperfectly known and apparently not very close to the direct line of descent." Palæontologists, however, admit the distinctness of these three groups by placing the cats in one family (Felidæ), the dogs in another (Canidæ), and the Lower Eocene Carnivora to which they are most closely related in still a third (Miacidæ).

Among the other backboned animals or vertebrates there are no intermediates between turtles and snakes, or turtles and lizards, or snakes and lizards, all of which are reptiles, and in the fishes there are no intermediates between the cyclostomes (lampreys and hagfishes), or the teleosts or bony fishes, and any other types.

It should perhaps be emphasized that discontinuities in descent and in relationship are much less conspicuous and marked among the backboned animals or vertebrates than they are in the large invertebrate groups. In the vertebrates there are no such enormous gaps as those between the squid, octopus and nautilus, and the snail or oyster, all of which are mollusks, or between the starfishes, sea-urchins, sea-lilies and sea-cucumbers, all of which are echinoderms.

All the backboned animals taken together form a very homogeneous group in which the entire structural range from the tadpole or the leptocephalid to the highest mammal is scarcely greater than the structural range found in certain individual species of crustaceans or of insects at different stages in their development from newly hatched young to adults.

Thus while in many animal types we are able to trace, as in the horses, a gradual evolution from a form which is simple and generalized in structure to a group of forms all of which are highly specialized, this is by no means always true. Indeed, it is the exception rather than the rule. All lines are broken by gaps which may be small and insignificant, or broad and striking.

It is commonly assumed that these various gaps are due to our lack of adequate knowledge of the animals concerned, and especially of their fossil record. No doubt in many cases this is partly, or even perhaps largely, true, but in very many cases these gaps undoubtedly are real and never were bridged by so-called missing links.

In the light of our present knowledge it is not possible for us to doubt that all living things are the children of other living things, and that life has been continuous from parent to child from its earliest beginnings. How is it possible to harmonize this fact with the occurrence of broad and unbridged gaps in the evolutionary lines?

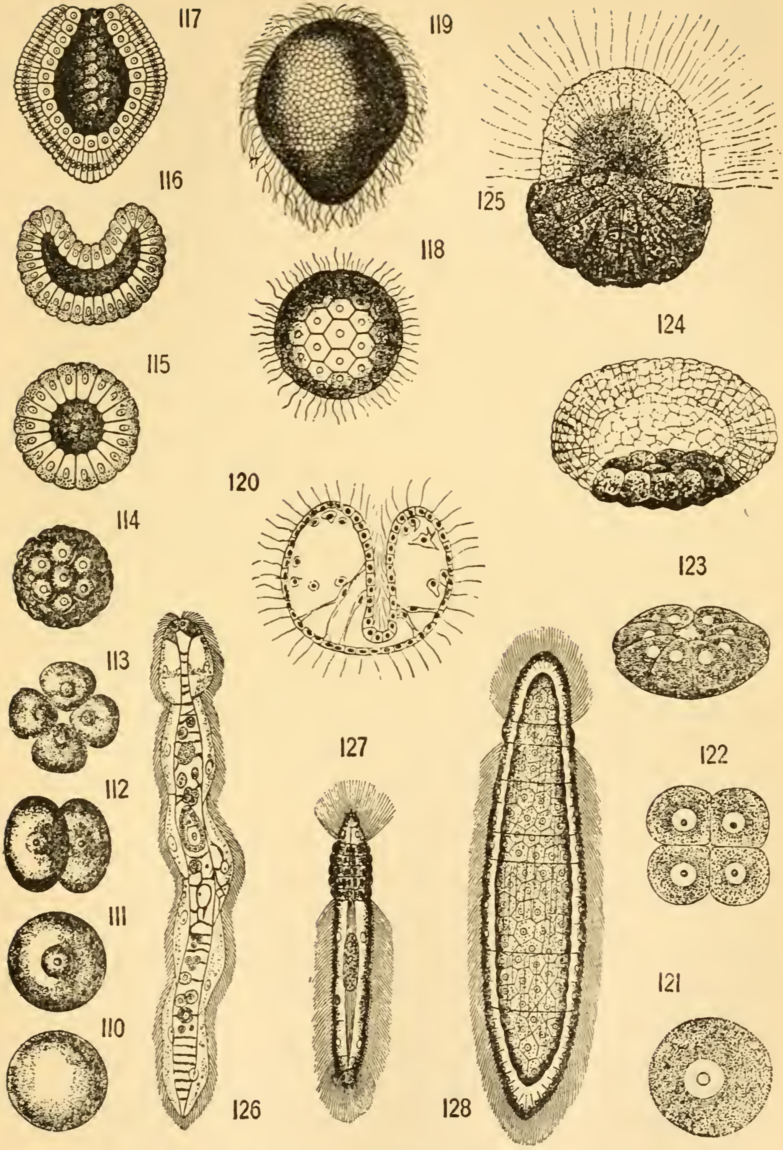
The answer is that continuity of life does not necessarily imply a similar continuity of the bodily form in which that life is manifested. In other words, children may be very different from their parents. As an illustration of continuity of life from parent to child coupled with abrupt and striking discontinuity in form, and also in mental traits, let us consider the dogs.

According to the best authorities, all of the nearly two hundred different breeds of domesticated dogs are descended from a single type of ancestor, which was a wolf or wolves closely resembling our native wolf but with slightly different teeth. The domestic dogs may be grouped, following Gibson, into wolf-dogs, greyhounds, spaniels, hounds, mastiffs and terriers.

Some of the wolf-dogs, as for instance the dogs of the Esquimaux and of the Kamchadales, show a more or less close resemblance to wolves and are said to interbreed with them, while others, as the collies, police-dogs, sheep-dogs, Newfoundlands and St. Bernards, are much less wolf-like. But the wolf-dogs may be arranged in a fairly continuous series from the most to the least wolf-like.

This series of dog forms is parallel to many of the evolutionary lines which are seen in the geological history of the mammals, as for instance in the horses, camels and hyænas. It is a series of types which differ only slightly from each other running, with many side branches and ramifications, between two extremes which are widely different.

Of the other breeds of dogs we may select the greyhounds, hounds, bull-dogs and pugs—the last two from the mastiff stock—as representative types known to everyone.



EARLY DEVELOPMENTAL STAGES, AND TWO CURIOUS ANIMAL TYPES

FOR AN EXPLANATION OF THE FIGURES SEE P. 283

It is not necessary here to describe the diverse bodily forms characteristic of these well known breeds of dogs. But their mental traits call for brief consideration. Viewed in relation to the structure of these dogs, they are extremely interesting.

The greyhounds, or as they are sometimes called the "gaze hounds," have deficient powers of scent, but unusually keen eyes and ears. They hunt entirely by sight. The hounds have poor sight, and hunt almost exclusively by scent. Bull-dogs are deficient both in sight and scent and are stupid and ferocious, displaying little affection. Pugs, which are much like bull-dogs and are equally stupid, differ markedly from them in being both timid and affectionate.

Now although the early history of the domestic dogs is involved in complete obscurity since the companionship of dogs and man runs back into the Stone Age, far beyond the first beginnings of history, it seems to be quite clear that certain types of dogs, at least, appeared as wide and abrupt departures from parents of a very different bodily form and with widely different mental traits.

We seem to be quite within the facts in stating that the bull-dogs, the pugs, and the strange hairless dogs appeared suddenly as anomalous types which, appealing to human fancy, have been perpetuated and their peculiarities accentuated, or at least preserved, by careful breeding.

The greyhounds existed in the typical form in the early days of ancient Egypt, and the modern hounds go back to the later days of the Roman empire, so we cannot make any really definite statement about their ancestry.

But regarding bull-dogs, pugs and hairless dogs we can say with reasonable certainty that they do not intergrade, and also that there are now no intergrades, and there never have been any intergrades, between these and any other types of dogs, or wolves.

They therefore furnish an excellent and obvious illustration of unbroken continuity of descent, from wolves through other types of dogs, which is coupled with abrupt change or discontinuity in bodily form and in mental attributes. So far as we know, the greyhounds, the hounds, and many other forms of dogs had a similarly abrupt and discontinuous origin.

The question naturally arises, is it permissible to use the domestic dogs to illustrate the course of animal evolution during geologic time?

It is generally agreed that the changes in animal life which took place from one geological epoch to another occurred as a response to changes in the environment of the animals concerned—in other words to changes in the conditions any given animal type was forced to meet. Varieties or forms which were best suited to meet the new conditions survived, and the rest died out. The successful varieties or forms, in the absence of competition, branched out into many different forms which became more and more distinct from each other until, with further geological changes, most or all of these died out.

Domestication means a change in the environment of all animals which are subjected to its influence.

Biologically considered, all changes in environment are strictly comparable whether they be brought about by geological processes affecting large areas, or by domestication affecting relatively small groups of individuals.

Furthermore, there is no tangible difference between the natural elimination, by the agency of enemies or through disease or other causes, of all the individuals of a certain type of wolf which are unfitted to cope with their environment, and the development of a special breed of domesticated dog through the elimination of all the individuals that do not come up to the standard set by the dog breeder.

To say that the evolutionary plan which is illustrated by the dogs is not comparable with the evolutionary trees evidenced by the fossil animals is to deny a similar effect as the result of similar causes. If, however, we admit the validity of the comparison, we at the same time admit the natural occurrence of broad and striking gaps or discontinuities in evolutionary lines.

Unbroken continuity of descent coupled with abrupt discontinuity or change in bodily form is a common, striking, and well known phenomenon in all types of animal life. It is far more striking among the invertebrates than it is among the vertebrates.

CHAPTER XX

THE ORIGIN OF THE EARLIEST ANIMALS—EOGENESIS

THE third of the three sets of facts to be considered in connection with the development of animal forms is perhaps the most puzzling and the most extraordinary. It has always been the chief obstacle in the way of the successful development of a theory of evolution which shall assign to every animal type a fixed, definite and logical position in relation to every other animal type.

No matter how far back we go in the fossil record of previous animal life upon the earth we find no trace of any animal forms which are intermediate between the various major groups or phyla.

This can only mean one thing. There can be only one interpretation of this entire lack of any intermediates between the major groups of animals—as for instance between the backboned animals or vertebrates, the echinoderms, the mollusks and the arthropods.

If we are willing to accept the facts we must believe that there never were such intermediates, or in other words that these major groups have from the very first borne the same relation to each other that they bear today.

Is this creationism? Not at all. All living things are derived from other living things. Furthermore, all types of animal life must be explained in terms of a primitive single cell. The seemingly simultaneous appearance of all the phyla or major groups of animals simply means that life at its very first beginnings developed at once and simultaneously from the primitive single cell in every possible direction, giving rise to some original form or forms in every phylum.

So at its very first appearance animal life assumed essentially the same form as that in which we know it now so far as the phyla or major groups of animals are concerned. That is, at the very beginning there appeared a representative or representatives of the arthropods (figs. 7–32, pp. 21, 33, 47 and 55), the jointed worms or annelids (fig. 85, p. 161), the mollusks (figs. 45–52, p. 97), the arrow-worms or chætognaths (fig. 62, p. 111), and so on. There is no evidence whatever that would lead us to believe otherwise.

As age succeeded age the forms within these major groups underwent constant and continual change. For instance, in the arthropods the trilobites (fig. 32, p. 55) and the eurypterids (fig. 31, p. 55) increased in diversity and then died out, giving place to a wealth of other types developed from other lines within the phylum. But the characteristic features of the phylum as a whole remained unchanged.

Thus the evolutionary picture that we get from a survey of the actual facts is that at the very first there were numerous basic forms from each of which a separate evolutionary tree arose growing upward through the ages. The topmost twigs of each of these evolutionary trees end in the numerous forms of animal life we know today.

What was the origin of these basic forms of life, and how did the original representative or representatives of each of the several phyla or major groups of animals come into existence?

All animals have the body composed either of a single cell, or of a multitude of cells all of which are essentially the same in structure. Furthermore, all animals in which the body is composed of numerous cells begin their independent life as a single cell, which divides into two, four, eight, sixteen, and so on, until the full number of cells is reached (figs. 110–117; 121–125, p. 185).

Since all animals, no matter what they are, begin life as a single cell, it is clear that all animal forms must be interpreted in terms of a primitive single cell.

A single cell cannot increase in size beyond a certain point without serious interference with the chemical and physical interchanges on which life depends. On reaching the maximum size permitted by the chemical and physical restrictions, the animal cell divides into two; later these two cells each divide into two, becoming four, these four become eight, these eight sixteen, these sixteen thirty-two, and so on indefinitely (figs. 110–117, p. 185).

In this process of division there are three paths that may be followed (fig. A, p. 238). As they divide the cells may separate from each other so that the individual animals always remain composed of a single cell. In other words, on the division of the original cell into two each of these halves may separate from the other and become a separate animal with half the bulk of the original. Further division would give rise to a corresponding number of entirely separate animals. The so-called single-celled animals or protozoans (fig. 87, p. 161) illustrate this process.

But after the division of the original cell into two, four, eight, sixteen, and so on, the cells resulting from division might remain in contact, eventually forming a body consisting of vast numbers of cells. Here there are two alternatives. The cells may adhere more or less irregularly (figs. 121–125, p. 185) so that a poorly differentiated mass of cells results, the mass as a whole being more or less distinctly radial in its symmetry. The result of such development is represented by the sponges.

On the other hand, the adhesion of the cells may take place in a regular geometrical fashion (figs. 110–117, p. 185) until a hollow ball of cells (called a blastula; figs. 114, 115, p. 185) is formed which, by collapsing like a rubber ball with one side pushed in, would form a two-layered cup (called a gastrula; figs. 116, 117, p. 185) with an axis passing through the center of the opening and of the opposite pole, and the walls the same in all the radii.

We know that all animals begin life as a single cell which divides into two, and these derivatives continue to divide in the same way. We see that this continued division of the cells takes three different lines. The cells resulting from the divisions may (1) separate completely, (2) adhere irregularly, or (3) adhere in regular geometrical fashion.

There is no reason for believing that these three paths of development were not followed simultaneously—that is, that animal life did not from the very first develop in three divergent ways (fig. A, p. 238). There is no logic in the assumption that the earliest animals were necessarily of the single-celled or protozoan type. All of the single celled animals that we know are quite as highly specialized as are any other animals, though they are specialized in a wholly different way.

While it is most reasonable to suppose that all three alternatives were realized from the very start, if any one of the three alternatives were to precede the others it would presumably be the development of a more or less formless sponge-like mass from which on the one hand single-celled creatures were derived through a complete separation of the cells after division, and on the other hand the structurally more complex animals were derived through the arrangement of the cells as they divided in regular geometrical fashion. The almost complete individuality of certain cells in sponges and especially the behavior of dissociated sponge cells would seem to support this view. But the most probable supposition is the simultaneous appearance of all three lines of development from the primitive single cell.

We have seen that regular adhesion of cells after division in geometrical fashion results in the formation of a two layered cup called a gastrula (figs. 116, 117, 119, p. 185), which is radially symmetrical about its only axis. If the gastrula should continue its development to the adult stage, following to its logical conclusion the preceding line of geometrical development, the result would be an animal radially symmetrical in form with the body composed of two layers of cells. Such an animal type we actually find in the sea-anemones, hydras and allied creatures —the so-called cœlenterates (figs. 3, 4, p. 5; figs. 78, 79, p. 143).

But during the development of the gastrula some irregularity might appear which would disturb the fundamental radial symmetry either partially or completely, leading to the development of animal types more or less elongated in form and with, instead of radial, bilateral symmetry—that is, with the two halves the same on either side of the central plane (see figs. B, C, D, pp. 240, 246, and 250).

Excepting for the protozoans, the sponges, the cœlenterates, and the ctenophores, all animals are either completely bilaterally symmetrical, or the body is mainly bilaterally symmetrical with more or less marked traces of radial symmetry. Furthermore, during their development they all pass through a stage which is either a more or less typical gastrula (figs. 116, 117, p. 185), or may be interpreted as representing and derived from the gastrula. No matter how different they may be, the gastrula is common to them all. They all develop in comparable fashion as far as the gastrula, but from that point they all diverge, each in a different direction.

This divergence, however, is not haphazard, but on the contrary runs in certain very definite lines resulting in the production of a series of animal types each of which bears a definite relation to all the rest (figs. B, C, E, pp. 240, 246, and 254).

The key to this relationship is furnished by four curious groups of forms having a symmetry which is partly radial and partly bilateral (fig. E, p. 254).

These four groups are made up of:

1. Types which by continuous budding produce a linear colony;

2. Types in which the budding takes place internally within the original unit;

3. Types which are solitary, each individual representing a single dissociated cœlenterate unit; and

4. Types which are colonial, though the individuals are independent of each other.

Between each two of these types there is another type which combines the characters of both, but shows no trace of radial symmetry.

Thus between the types which by continuous budding produce a linear colony and the types in which the budding takes place internally we find a type which is segmented externally and also possesses internal (cœlomic) budding. Between the types in which the budding takes place internally within the original unit and the types which are solitary, each representing a single dissociated cœlenterate unit, we find a type which is solitary with internal budding but no segmentation, and so on.

On the basis of their fundamental characters all of the animal phyla or major groups may be arranged in five successive series of four each, the outermost four being the four partially radial types mentioned. The exact center of the figure is occupied by the vertebrates, which combine the characters of the four groups immediately surrounding them (cephalochordates, balanoglossids, cephalodiscids and tunicates) but are not more closely related to any one of these than they are to the other three (fig. E, p. 254).

Such a figure shows each phylum as related more or less equally to four others, and more distantly to all the rest. As we pass from the outer to the inner series we find that the phyla become more and more complex and, because of their increasing complexity, seemingly less and less widely differentiated from each other.

But how could such a curiously complicated interrelationship come into being? How could any single type of animal be related more or less equally to four others, and why should the more complexly organized types—the cephalodiscids, balanoglossids, cephalochordates, tunicates and vertebrates—be less widely different from each other than the more simply organized types?

The answer is a simple one. Since we have not the slightest evidence, either among the living or the fossil animals, of any intergrading types falling between the major groups it is a fair supposition that there never have been any such intergrading types.

We find twenty definite structural complexes which are apparently without any direct relation to each other. All, however, as well as the cœlenterates, are derived through a gastrula stage or its equivalent, which is the last stage common to them all.

Nothing exactly comparable to a gastrula exists as an adult animal. It is true that all the cœlenterates are essentially adult forms reducible to a gastrula, but all of them are developed very far beyond the gastrula. The cœlenterates are probably to be considered as having progressed quite as far beyond the gastrula as the bilaterally symmetrical animals, although they retain the original symmetry of the gastrula sometimes quite unmodified, but usually slightly modified (fig. B, p. 240).

In the cœlenterates the body symmetry always remains essentially that of the gastrula no matter how far development in other lines may go. But in all other types which are derived through a gastrula the body symmetry changes over from the radial symmetry of the gastrula to a different, usually a bilateral, symmetry during the course of the development from the gastrula to the adult.

In the bilaterally symmetrical animals during the course of the development from the gastrula to the adult profound modifications in the internal structure occur and these follow a different and divergent path in each of the seventeen major groups of animals concerned.

In none of these seventeen major groups of animals is there any indication of a cessation in the course of the development between the gastrula and the adult, except for the appearance in most cases of a special larval type which is almost always adapted to insure the wide distribution of the species. The unescapable inference is that the balance of the internal organs during this time is not of such a nature as to render possible the existence of such forms as adults.

Besides this, the fact that successful development from the gastrula to the structural complex characteristic of each major group always follows certain definite lines which, though they may be greatly shortened, are always undeviatingly the same, would seem to indicate that development outside of or between these lines would result in structural complexes which would be incapable of meeting successfully the conditions of existence. Many gastrulas develop in various abnormal ways, but these always die.

The picture that we get of the developmental history of animals through the study of comparative embryology is that there is not now, and there never has been at any time, any possibility of the existence of economically possible animal types anywhere along the line between a gastrula and the several structural complexes characteristic of the cœlenterates and the bilaterally symmetrical major groups.

The natural conclusion is that the original formation of the original members of these groups resulted from divergencies in early embryonic stages which followed simultaneously every separate line which could lead to an economically possible adult.

Such lines are limited in number, and for that reason we see the major groups curiously few when we consider the enormous multiplicity of minor types within these major groups in the larval as well as in the adult stages.

It is an interesting fact that the embryological development of the cephalochordates, balanoglossids, cephalodiscids, tunicates and vertebrates indicates a close relationship between these five groups, which are commonly referred to as the chordates and the protochordates.

This indicates that the increased structural complexities of these groups do not permit of much deviation from a general mean. It cannot be interpreted as indicating that these five groups were ever more closely related than they are now, or that any one of them was derived through or from any of the others. Each represents a separate and distinct path from the gastrula, though these paths are but little divergent.

According to this interpretation the various phyla of bilaterally symmetrical animals are in effect recombinations of features which are inherent in animals taken as a whole, or in other words recrystallizations of the fundamental features of animal organization, which occur at every focal point where an animal type capable of existence may be formed from the elements available in the general animal complex.

No appreciable time element is necessarily involved in such a process of recombination or recrystallization of fundamental animal features. Therefore at the very first appearance of life the animal world, so far as the phyla or major groups of animals are concerned, probably was quite the same as it is today.

The figure formed by this recombination of elemental structural features into the various phyla represents the basic picture of animal life—a flat picture with all its details of simultaneous appearance—in which all of the evolutionary trees are rooted and from which they rose, one from each phylum, upwards through successive ages.

The interpretation of the origin of the major groups or phyla as the result of recombinations—or varying combinations—of characters inherent in animals as a whole which took place in early embryonic stages supplies the key to the very sharp distinctions usually to be seen between the different classes in each phylum.

It has been mentioned that among the major groups the cephalochordates, balanoglossids, cephalodiscids, tunicates and vertebrates are rather more closely related to each other than are the remaining major groups.

These five phyla form an assemblage capable of definition as a unit—though a very heterogeneous unit—which to a certain extent is intermediate in character between a collection of five major groups and a single major group alone.

As a typical major group let us take the echinoderms. The echinoderms agree among themselves, and differ very markedly from all other animal types, in being cœlomate creatures with a fairly perfect radial and usually pentamerous symmetry, with a body wall containing calcareous plates and generally armed with spines, with the cœlome divided into two well marked portions, the perivisceral cavity and the water vascular system, and with the gonads not connected with the cœlome in the adults. The young larvæ of all echinoderms are always bilaterally symmetrical instead of radially symmetrical, and are almost always free-swimming.

The echinoderms are divided into five classes, the sea-urchins, holothurians or sea-cucumbers, starfishes, brittle-stars, and crinoids (sea-lilies and feather-stars) and their allies. These five classes are entirely and widely distinct from each other and do not intergrade. So far as we know there never have been any intergrades between them. From time to time various attempts have been made to construct evolutionary trees which shall account for the peculiarities of these several groups by reducing them to a hypothetical ancestor. But these attempts have simply served to emphasize the complete distinctness of the creatures.

The development of the feather-stars differs very considerably from that of the forms included in the other classes. The divergence begins with the complete formation of the gastrula, and rapidly increases. Almost immediately afterwards the embryonic stages of the other classes begin to diverge, and as development goes on they diverge more and more widely.

So in the echinoderms the only relationship between the five included classes is found in the embryonic stages immediately following the gastrula. As it is impossible to assume that these stages could ever have led an independent existence as adult animals, so it is impossible to assume that any adults ever existed which were intermediate between these five classes as we see them now and as they are represented in the early fossils.

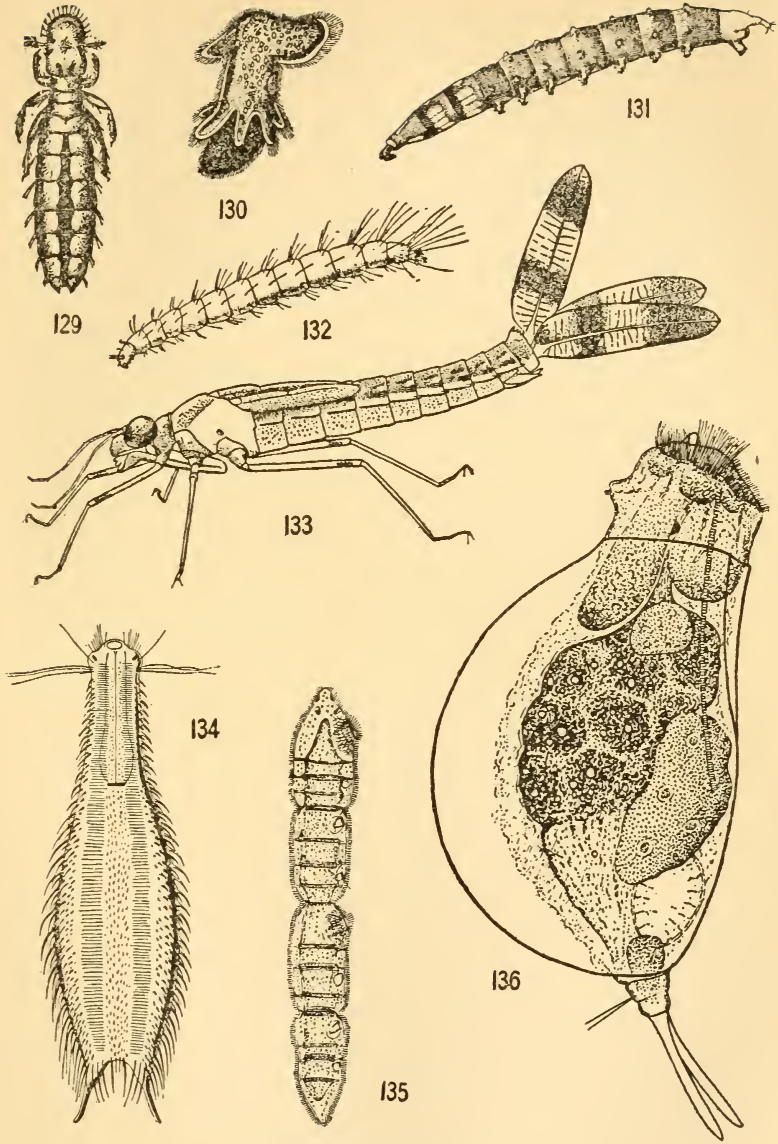
The principle of recombination of characters in the echinoderms as a whole, this recombination taking place at very early embryological stages, seems adequately to explain the sharp distinctions or very broad mutations between the starfishes, brittle-stars, sea-urchins, sea-cucumbers, and the crinoids and their allies.

In exactly the same way we may explain the sharp distinctions between the gastropods, bivalves, scaphopods, cuttle-fish and other types among the mollusks, and between the crustaceans, spiders, insects, centipedes and other forms in the arthropods.

Coming down to finer divisions, divergence in relatively late embryonic stages would serve to explain the curious isolation of the skippers (Hesperioidea) in the butterflies, and divergence in still later embryonic life the sharp difference between the megathymids and the other skippers.

If the conclusion be justified that each phylum or major group of animals represents the natural end product of a special type of cell division, and that all these special developmental lines leading from the single cell to the different phyla appeared concurrently, resulting in the simultaneous formation of some representative or other in all the major groups, there should be further indications pointing in the same direction.

We have traced a hypothetical course of development from the single cell to each of the various major



Various Types of Animal Life
For an explanation of the figures see p. 28

groups. Now let us see what may be ascertained by an analysis of animal forms.

From the study of the development of animal forms as they are preserved in successive geological deposits we learn that after a special line of development begins the types involved always increase in their degree of specialization. They divide into various subtypes each of which becomes more and more specialized, and these may again divide. Finally the end branches one after another, or sometimes simultaneously, come to an end and the type becomes extinct.

An excellent illustration of this is seen in the horses, the tree-like figure rising from the little *Eohippus* as a base and giving off a great number of increasingly specialized branches ending in still more specialized twigs about ten of which (the wild horse, the wild donkeys and the zebras) still are to be found in Africa and in Asia while the rest are all extinct.

At the base of every branching line of progressive specialization—or developmental tree—we find a type or form which in its structure includes all of the features found collectively in all the later types.

Specialization, or developmental progress, is a matter of subtraction and modification—never of addition. No structure lost ever is replaced.

Thus *Eohippus*, with four toes on the fore feet and three on the hind feet, was succeeded by other horses with three toes on all the feet. In still later horses the middle toe increased, while the lateral toes decreased in size. Finally we have the living horses with a single toe on all the feet.

The development of animal forms, as we learn from a study of the fossils, is not a reversible phenomenon. Once specialization has begun it always continues—by a process of progressive modification and subtraction—in the same general direction, becoming more and more extreme. There is never any retrogression.

Heretofore this principle has been applied only to more or less restricted groups of animals. But there is no reason to suppose that it is not applicable to animals as a whole.

If we attempt to apply it to animals as a whole—that is, to the various major groups or phyla—we at once discover some most interesting facts. Most important of these facts is that we find it wholly impossible to arrange the phyla in any sort of a line showing progressive subtraction and no addition—such a line as is so evident, for instance, in the horses.

Each phylum includes animals of a definite structural type of complex which is widely different from the structural type or complex characteristic of the animals in every other phylum. These structural complexes characteristic of the several phyla differ from each other by modification of fundamental structures, including the addition of some features and the subtraction of others.

Thus the echinoderms have acquired a radial symmetry apparently through the subtraction or loss of half of each segment of the body, and in addition have lost the nephridial system—at least in its usual form—and all trace of chitinous structures; the annelids or jointed worms have lost all traces of an internal calcareous skeleton, a structure very highly developed in the echinoderms; the mollusks are almost entirely without a trace of segmentation; while the arthropods are without a perivisceral cœlome or internal calcareous structures, and their endoderm and excretory organs are very much reduced.

There can therefore be no relationship whatever between the developmental figure represented by the horses from *Eohippus* to the modern type and the figure representing the interrelationships of the several phyla.

Since both addition and subtraction are involved in the differences between the phyla we must believe —if we are to be consistent—that all of the various phyla are on the same developmental plane, or in other words that they came into existence through derivation from a common ancestor or ancestral type which was possessed of the potentiality for producing each and all of them.

To express this in concrete terms, it is impossible to believe that the echinoderms, lacking half of each body segment and a nephridial system, the annelids, with no trace of an internal calcareous skeleton, the mollusks, without segmentation, or the arthropods, without a perivisceral cœlome or an internal calcareous skeleton, can represent steps along a developmental line running to the vertebrates in which the body segments are composed of two similar halves one on either side of the midline, in which there is always an elaborate nephridial system, in which there is an internal calcareous skeleton, and in which there is always a perivisceral cœlome.

Any assumption that the various invertebrate phyla represent steps in the development of the vertebrates must rest on the flat denial of the developmental truths which are so clearly evident within each of the larger phyla.

So through the application of a principle derived from the careful and detailed study of the past history of animal types within the phylum we reach the conclusion that the phyla themselves must have originated quite independently of each other from a common source. In other words, by the application of this principle we find indubitable indications of the origin of the various phyla through eogenesis.

CHAPTER XXI

SUMMARY

PREFACE.—The more we learn of the world in which we live the more clearly do we see that an orderly and definite plan underlies and dominates all the phenomena of nature. The living world of animals and plants is no exception. It is not chaotic. To picture it as chaotic is simply to confess our ignorance. What, then, is the plan upon which the living world is based? What is the relationship between the various types of living things?

Four different problems are involved in the answer to this question. *First*, how and in what form did animals first appear? *Second*, what has been the history of animal life from its first appearance to the present day? *Third*, how do animal forms give rise to other and different forms? *Fourth*, what is the relationship of man to the living world?

Before taking up these problems let us review the evidence which leads us to believe that these questions can be answered. We know that some definite relationship exists between the different types of animals because of two important facts.

In the first place, all living things arise only as the children of other living things. This rule has no exceptions, and it is inconceivable that there should be exceptions. Since all living things arise only from other living things, it naturally follows that all the present life upon the earth is descended from other life that flourished in the ages that are past, and that from still earlier life, and so on back to the time when life first appeared.

In the second place, all living things, no matter what they are, begin their life as a single cell in which no trace whatever of the adult form is discernible, and all germ cells no matter from what form of life they are produced are always strictly comparable. The bodies of all living things are composed either of a single cell or, more commonly, of vast numbers of cells which are all alike in their fundamental structure. No matter how many cells there may be in the body of an animal, and no matter how diversified they are, all of the cells in any individual arise through the division of the original germ cell.

So as the starting point for our search for order in the living world we have *first* the unbroken continuity of life from the very earliest times until the present day, and *second* the necessity of interpreting or explaining the origin of all forms of life in terms of the single cell.

These two important facts, the unbroken continuity of life and the necessity for explaining and interpreting all forms of life in terms of the single cell, must be considered in their relation to the further obvious fact that all living things must eat. The single cell in order to grow and to develop and to produce other cells must be supplied with food, and the continuity of life from one generation to the next indefinitely is dependent on a similarly unbroken continuity in the supply of the necessary food materials.

Therefore in a consideration of the living world it is essential to understand the origin of the food which supports the animals and plants and also the widely varying conditions under which that food is offered. For without a proper appreciation of the setting in which the development of animal forms took place any discussion of the subject becomes mere futile speculation.

Eogenesis.—From the air, the water and the rocks do all living things secure those substances which are necessary for their existence and their increase. Ever since life first appeared on earth rain has been falling on the land and the water, heat and cold have been weathering away the rocks, and from them liberating those substances necessary for the support of life in the same way that it is being done at the present time.

We cannot deny this without at the same time denying the validity of the comparisons between the geological processes of the present day and the geological processes of the past, comparisons which furnish the only clue to the interpretation of the latter.

Since the conditions on the earth, in so far as they affect the basic food requirements of plants and animals, to the best of our knowledge and belief have remained unchanged from the very earliest times at which we may assume that plants and animals existed, is it not reasonable to suppose that in its broader features the world of animals and plants has from the very first been essentially the same? The probabilities are in favor—overwhelmingly in favor—of the simultaneous development of some representative or representatives of all, or practically all, of the phyla or major groups of animals at the time of the very first appearance of life.

The only acceptable hypothesis is that in its broader features the development of animal forms took place by *concurrent evolution*.

All of the actual evidence we have supports this supposition. This evidence comes from the fossils that we find in the very earliest rocks wherein fossils are satisfactorily preserved. Practically all these fossils are more or less widely different from the corresponding animals we know today. But we recognize them for what they are because they fall within the definitions of their respective groups, and these definitions are drawn up from a study of their living representatives alone.

The recognition of these fossils as members of certain groups through the application of definitions based on living animals alone means that from the very earliest times of which we have a record the broader features of the animal life upon the earth have remained unchanged. So from all the tangible evidence that we have been able to discover we are forced to the conclusion that all the major groups of animals at the very first held just about the same relation to each other that they do today.

How may the simultaneous appearance of all the major groups of animals be harmonized with their common origin involving unbroken continuity of life from parent to child from a primitive single cell?

Applying the knowledge that we have of the subject of embryology—of the earlier stages in the development of different types of animals—we may assume without the possibility of successful contradiction that all of the major groups of animals were formed at the same time as the result of following different developmental paths from the primitive single cell. No other reasonable conclusion can be drawn from the facts of embryology. There is no evidence of any kind which would lead us to suppose that any one of the major groups was derived through any of the others.

On the contrary there is strong circumstantial evidence which indicates that none of the major groups could have been derived through any of the others.

A study of the developmental lines of animals shows that developmental progress is always evidenced by increasing specialization along definite structural lines at the expense of other structural features. Organs may gradually become reduced and perhaps disappear, but nothing is ever added. Specialization is always a matter of subtraction from a well balanced whole. Such subtraction once started may continue, or it may cease, temporarily or permanently. But a structural feature that has once begun to lose importance and to dwindle never reverses the developmental path; it never recovers any of its lost significance.

All of the major groups of animals differ from each other both in the reduction of some of the bodily structures and in the very great development of others. Thus they differ from each other both by subtraction and by addition. To assume that any of the major groups are derived from any of the others is therefore to deny the general application of a well established principle.

Another factor which probably has a bearing on the question of the simultaneous development of the major animal groups is the necessity for the maintenance of a balance between the different forms of life. The necessary check on the excessive increase in the numbers of any type of animal is provided by predacious animals, by parasites, and by various types of animal feeding plants, principally bacteria and fungi. It is impossible to believe that such a check was not as essential at the time of the first appearance of life as it is today.

The process leading to and resulting in the first appearance of some representative or representatives of each of the major groups may be known as *eogenesis*.

Evolution.—We come now to the second question, what has been the history of animal life from its first appearance to the present day?

The various types of animals included in each single one of the larger major groups—for instance in the vertebrates or backboned animals, the mollusks or the arthropods—have varied very greatly in successive geologic ages. This is shown conclusively by a study of the fossils. If the broader aspects of the living world have from the first remained unchanged, why should we find such extraordinary changes in the details in successive ages?

The answer is a simple one. While all the food substances necessary for the support of animal life have been available from the first, the conditions under which these food substances were available have varied very greatly from one epoch to another. For instance, at one time the earth was largely cloud enveloped. The light was relatively dim, and the temperature was about the same almost everywhere. The winds were light, so that the seas were calm and quiet.

Living under these conditions were representatives of all the major groups we know today. But the representatives of the major groups which flourished at that time were quite different looking creatures from the types we know at the present day. The problems which they had to meet in securing food and in avoiding enemies—in the struggle for existence—were very different from the problems which must be met by their modern representatives. A cloud enshrouded world of about the same temperature everywhere with only light winds and with almost waveless seas is a very different thing from the world of the present day.

The changes in animal life from age to age for the most part took place according to a definite plan or system. A small and inconspicuous creature in one age was succeeded in the next by several more specialized and often larger creatures, and these were succeeded by many still more specialized, and so on, until the whole strain gradually or suddenly died out. In the larger major groups this process occurred at the same time, or at different times, in many different types.

Such a developmental or evolutionary process is well represented by a branching or tree-like figure in which each branch end represents a special line which has become extinct. An excellent example of this is seen in the developmental history of the horses.

This process of branching or tree-like development of many different animal forms from a single original type—as for instance the development of all the different kinds of dogs we know today from the original wolf—is commonly known as *evolution*.

Eogenesis and evolution.—What is the relation of evolution to eogenesis—the simultaneous formation through following different developmental paths from the primitive single cell of all the major types of animals?

Through eogenesis the ground is prepared for the growth of the evolutionary trees. Therefore the picture that we get shows a whole forest of evolutionary trees of widely different sizes each of which arose from a seed formed and planted by the process of eogenesis.

Broader aspect of the development of animal forms.—The evolutionary processes by which are formed the ultimate twigs of the various evolutionary trees are processes of specialization through the progressive suppression of certain features, leading secondarily to the emphasis of others. The more extreme the specialization in any animal type the more has it departed from a zoologically normal balance. The primitive types in all the major groups are those in which the most perfect balance between all the structural features is maintained.

The several major groups exhibit a great variety of conditions in the relation of their different structural features to each other; they show a very different balance in their various essential organs. In their embryonic stages the representatives of the various major groups show a close approximation to each other in the gastrula, but are wholly similar to each other only in the germ cell.

Thus the only fact of cosmic significance in the whole subject of evolution in its broadest sense is the appearance of the single cell. The single cell has inherent in itself the potentiality for development, through selective and progressive reduction in various directions and in various ways, into every form of life which at any time may be capable of existence and of self-perpetuation under the conditions obtaining at that time.

All animal types are therefore to be regarded, in their relation to cosmic evolution, simply as varied and varying manifestations of the inherent potentialities of the fundamental substance protoplasm. Such a concept contemplates the animal world as in reality but a single unit finding its expression in an infinity of equations all of which, no matter how complicated they may seem, reduce themselves to the same fundamental term.

If the animal world is fundamentally but a single unit, definite evidence of that fact should be available. We find the evidence in the ability of each and every type of animal, no matter what its structure or its form, to maintain itself equally well in the face of widely varying, though always ruthless, competition. Further evidence of the fundamental unity of animal life is seen in the recurrence of similar forms in creatures of widely different structure whenever because of a difference in size, or for other reasons, there is no direct competition, and also in the frequent occurrence in so-called abnormal or aberrant individuals of features normally characteristic of animals of a widely different type. More tangibly we find it in the recurrence of comparable and similar attributes in widely different types of life when they are faced with similar conditions. There is no other possible explanation for the reappearance of such striking similarities as those which are found in insects, in the small birds, in the rodents, and in man.

Mutations.—The third question to be answered is, how do animals change their form? The three factors immediately involved in the production of new animal species or types are; *first*, the production of variants or mutants; *second*, the hereditability of the characters possessed by these mutants; and *third*, the ability of such mutants as are able to establish themselves on an hereditary basis to maintain and to perpetuate themselves under the conditions they must meet.

Most mutations arise during the formation of the germ cells, and they are therefore already present in the germ plasm. An individual is marked as a mutant at the time when the body is composed of only a single cell. But sometimes mutations may appear during the course of development.

Mutants—individuals differing from the normal as a result of mutation—may show only a very slight departure from the usual form of the animal concerned, or they may depart so very widely that the individual is incapable of development beyond the earliest embryonic stages, or they may be of any intermediate degree.

The mutations with which we are familiar among the wild and domestic animals and in the laboratory are all relatively slight, showing no very wide departures from the normal form. How, then, is it possible to assume that mutation could account for such differences as those between flies, butterflies and bees, or between insects and crustaceans, or between the crustaceans and the mollusks?

The more specialized an animal type becomes the more inflexible and unchangeable does it become, the more closely dependent upon the maintenance of conditions as they are, and hence the more liable to extinction if conditions change.

The reason for this is that specialization is a function of progressive subtraction. The more an animal type has lost through this process of progressive subtraction, the less there remains for the production of mutants which will be capable of existence. For all mutants arise through the subtraction of something from the usual form. In a very highly specialized animal type subtraction has already progressed almost to the extreme limit compatible with existence so there remains very little that can be taken away without endangering the life of the individual. Naturally, therefore, the mutants with which we are familiar at the present day differ relativeiy little from the usual type. Yet rhinoceros mice, hairless dogs and horses, and many other unusual creatures, show how it is quite possible for new species and even genera to appear in such a fashion as to give but little indication of their immediate ancestry.

As we go further and further back in geological time we find ourselves among the ancestral forms from which the present highly specialized animals were descended. The ancestral form from which any assemblage of animals is descended combines the characters which are selectively distributed among the descendants. For instance, in the ancestral wolf there are combined all of the features which now are widely distributed among the various breeds of domestic dogs. Our different breeds of dogs differ from each other not in the appearance of any new characters, but in the selective suppression of characters through which one or more special features are made to stand out prominently.

The more well developed structural characters there are in any animal type—in other words the better and more complete the structural balance—the greater is the possibility for the appearance of many widely different economically successful mutants among its descendants.

So it is a reasonable assumption that, although those mutants capable of existence which appear among the young of the animals of the present day do not differ greatly from their parents, in the geological past successful mutants differing very widely from their parents would from time to time appear. And the further we went back into the geological past—the nearer we approached the bases of the evolutionary trees—the greater would be the possibility for the production of successful mutants varying widely from the parent type.

The primitive single cell, having within the potentiality for the production of all types of animals, might be assumed to be possessed of the ability to produce simultaneously mutants which would be widely different from each other, both by structural changes in the single cell and through development involving cell multiplication in various directions.

From this it is apparent that from what we know of mutants—especially as we see them in nature—and from what we know of the development of animal forms through progressively increasing specialization we arrive at the conclusion that from the primitive single cell there simultaneously appeared through mutation as many different types of animals as were capable of successful existence, while each of these several types through progressive mutation in each successive geological age branched out into every economically possible form.

In other words the study of the possibilities of mutation, combined with the study of progressive specialization, leads us directly to the original simultaneous appearance of the major groups through eogenesis and the subsequent development and refinement of each through evolution.

The flat picture of animal life presented as the result of eogenesis—which may be regarded as mutational development from the primitive single cell—shows many wholly distinct and separate major groups from each of which a phylogenetic, developmental or evolutionary tree rises upward through geologic time.

The larger phyla or major groups are divided into classes, and as a rule the classes within each major group are entirely distinct from each other and do not intergrade. Thus in the mollusks we find pelecypods or bivalves, scaphopods, solenogasters, gastropods or snail-like creatures, and cephalopods. In the echinoderms there are starfishes, brittle-stars, sea-urchins, sea-cucumbers, crinoids, cystids and blastoids. In the arthropods there are crustaceans, arachnids, myriopods and insects. In the vertebrates or backboned animals there are mammals, birds, reptiles, amphibians and fishes.

The distinctness of these classes each from the other is probably of the same nature as the much broader distinctions between the various phyla. That is, each class should be interpreted as a selective recombination through broad mutations in every economically possible form of the features inherent in and distinctive of the phylum. In other words, it is a fair assumption that the differences between the several classes within each phylum are differences arising in the early embryonic stages of the animal types concerned more or less immediately after the fixation of the structural complex characteristic of the phyla.

Within the classes the same phenomenon is again repeated in a less extreme form in the different orders, as is especially well seen in the insects, crustaceans, gastropods and brittle-stars.

Abrupt discontinuities, becoming progressively less and less pronounced, may be followed further into suborders, families, genera and species, as we saw (p. 133) among the butterflies.

Discontinuities of every sort, though often obvious and striking, are very much less conspicuous and marked within the phylum Vertebrata than they are in the large invertebrate phyla. In the Vertebrata even the classes are not always sharply distinguished from each other. Thus many fossils cannot with certainty be determined as reptiles or as amphibians. More or less intermediate between the birds and reptiles are two curious creatures from the Jurassic which figure together in text-books under the common name of *Archæopteryx*. Similarly intermediate between the mammals on the one hand and the reptiles and amphibians on the other are the strange egg-laying mammals or monotremes of Australia and New Guinea.

The relative homogeneity of the phylum Vertebrata is easily understood when it is realized that the vertebrates are the most highly specialized of all forms of animal life, and that the entire structural range in all the vertebrates taken together is scarcely greater than the structural range in certain single species of insects or of crustaceans at different stages in their life history. The vertebrates possess such a delicately balanced complexity of internal structure and, partly as a result of their large size, such a delicate adjustment to their environment, that changes brought about by a continuous series of slight alterations and progressive minor readjustments are more suited to them than the sudden wide and abrupt discontinuities so frequent in invertebrate types.

Because of their very high degree of specialization, well marked and reasonably continuous evolutionary lines are frequent among the vertebrates, and wide discontinuities are relatively rare, while the reverse is true in all the other phyla of comparable size.

That the gaps between the forms in individual species and the wide discontinuities between the several classes included in each of the larger phyla are fundamentally of the same nature and differ only in degree can scarcely be denied. The latter are to be interpreted as having resulted originally from mutations in creatures which were of a primitive nature and therefore capable of producing young very widely different from themselves yet able to meet the requirements of existence.

The relationships of man.—Since he possesses a backbone and associated structures, man belongs to the group of backboned animals or vertebrates, which group includes the fishes, amphibians, reptiles, birds and mammals. Within the vertebrates he is a member of the group of mammals. Within the mammals he presents the greatest similarity to the anthropoid or man-like apes of western Africa and southeastern Asia—the gorillas, the chimpanzees, the orangs and the gibbons.

Structurally and anatomically man is rather close to these man-like apes. This is a readily demonstrable fact which is quite beyond dispute. But it is also beyond dispute that there is a sharp, clean-cut, and very marked difference between man and the apes. Every bone in the body of a man is at once distinguishable from the corresponding bone in the body of any of the apes.

Man belongs to the same division of the mammals—the Primates—as the apes. But his similarity to the modern apes does not imply any direct relationship with them. Man is not an ape, and in spite of the similarity between them there is not the slightest evidence that man is descended from an ape.

The large anthropoid apes—the gorillas, the chimpanzees and the orang-outans—are all very highly specialized terminal twigs from the Primate stock. They are so very delicately adjusted to their environment that they all are very difficult to keep in captivity. They represent a vanishing group all the members of which are now restricted to very limited areas, the orang-outans to Borneo and Sumatra and the gorillas and chimpanzees to equatorial west Africa. They thus have almost the same distribution as those curious lemuroids called the lorises and pottos.

Man also is very highly specialized, though in quite a different way. He also has become very delicately adjusted to his environment. But in the case of man this has been an asset instead of a liability as it is with the great apes. Man has been able to overcome the increasingly delicate adjustment to his environment by artificially creating for himself a special environment in which he lives more or less completely independent of his natural environment. For the most part man grows his food and the materials to make his clothing and other necessities, and he controls the temperature in which he lives. Thus the Esquimaux actually exist in a tropical temperature no matter how low the temperature outside of their thick clothing and their heated igloos may be.

As man and the man-like apes are both very highly specialized, but are specialized in widely different directions, we cannot suppose that either descended from the other, or indeed that there really is any very close relationship between them. The truth of this is now very generally admitted by biologists.

Professor Henry Fairfield Osborn has pointed out that while nature may transform an organ through change of function, it can never restore a single lost part, whether it be a lost tooth, a lost digit, a lost ankle bone or rib, a lost tendon, or a lost nerve. The evolution of anatomical or structural organs is never reversible. By the application of this principle he pointed out that the human hand could never have reacquired the nerves, muscles, functions, freedom, flexibility and separate innervation lost in the highly specialized hand of the arboreal, or tree-living, apes.

The opposable human thumb could never have grown out of the partly atrophied ape thumb.

Many other structural features tell the same story. The more carefully we study the points of similarity between man and the apes the more clearly do we see and appreciate the importance of the differences between them. As Huxley truly said, the differences between man and the apes are broad and striking.

From time to time various "missing links" supposed to connect man with the apes have been described. But from what has just been said it is impossible to believe that such "missing links" ever actually existed.

In a recent article on "missing links" Mr. Gerrit S. Miller, Jr., the curator of mammals in the United States National Museum, reviewed in great detail the evidence and opinions regarding the "Java ape-man" or "Trinil man" (*Pithecanthropus erectus*) and the "Piltdown man" (*Eoanthropus dawsoni*) which are the only two finds that "can be seriously regarded as furnishing . . . direct evidence of man's blood relationship with animals resembling in some general manner the present day gorilla and chimpanzee." Mr. Miller concluded that while awaiting further discoveries "we should not hesitate to confess that in place of demonstrable links between man and the other mammals we now possess nothing more than some fossils so fragmentary that they are susceptible of being interpreted either as such links or as something else." So in the light of all the evidence available at the present time there is no justification in assuming that such a thing as a "missing link" ever existed, or indeed could ever have existed.

Yet since both man and the apes belong to the same division of the mammals—the Primates—and we cannot doubt the continuity of life from parent to child from the very first, man and the apes must have had at some time in the past a common ancestor.

Our knowledge of man goes back only to the end of the period—the Pliocene—just preceding the Pleistocene or Ice Age at the furthest, and many authorities believe that the earliest remains of man are not older than the earlier portion of the Pleistocene.

In the case of the Piltdown man all authors agree that the fragments of the brain case and the nearly complete nasal bones are human. Sir Arthur Keith wrote that the brain case of which the original fragments formed a part was essentially the same as that of modern man in both form and capacity, the capacity being about 1,400 cubic centimeters. Others have calculated the capacity as about 1,240, 1,100 or 1,170 cubic centimeters. In the case of the Trinil, Java, remains, all authors agree that the skull cap is strangely different from the corresponding part of other known mammals, living and fossil.

This is all the tangible evidence we have regarding early man. But the fragments of the brain case and the nasal bones of the Piltdown find are sufficient to indicate that man has been essentially the same since about the beginning of the Pleistocene, or in other words that the developmental histories of man and of the anthropoid apes have run parallel, and have remained wholly separate, as far back at the very least as the beginning of the Pleistocene.

This is important, for in the case of the horses the various types found in the Pleistocene, though numerous and varied, were all of the modern type, and the same is true in the case of other mammalian forms. So it is possible to assume that the developmental history of man has run parallel to the developmental history of other mammalian lines, as would naturally be expected.

What, then, was the connection between man and the other mammals, and when did man branch off from the Primate stock?

Professor Osborn has pointed out that the geological period in which the various lines of mammalian development separated and radiated from each other was the Eocene. "Even in Lower Eocene time all the existing families of hoofed mammals, such as the horses, tapirs, rhinoceroses and titanotheres (the last all now extinct) had widely separated from each other in tooth, limb, hand and foot structure. Before the close of Eocene time these branches were further subdivided into forest-loving and plateau-loving types; in every branch the forest-loving types were stationary or regressive. Similarly, by the close of Eocene time the mastodont and elephant families are found widely separated into five greater branches (in Oligocene time there were numerous sub-branches and in Miocene time eighteen distinct branches). In the succeeding Oligocene time we discover a sharp and world-wide division between plateau-loving and forest-loving types; in the forests remain all the backward conservative types; on the plateaus and uplands are found the alert, progressive, forward-looking types, including all the long-hind-limbed bipedal [two legged] animals adapted to rapid progression in an open or partly forested country. It is no exaggeration to say that at the dawn of Oligocene time all the plateau-loving animals are distinctly modernized both in habits and in bodily proportions."

Professor Osborn asks, "Is it likely that the Primates alone escaped this divorce between backward, forest-loving life and forward, plateau, savanna and upland life, especially as Eocene forest areas in every continent began to contract and upland open plains began to expand?"

It is difficult to see how anyone can take exception to this reasoning. There are no grounds for assuming that man offered an exception to the general truths which we learn through the study of the fossil history of the mammals as a whole. The conclusion that man was man as early as the Eocene—as early as the time of the little *Eohippus*—has far more in its favor than the assumption that man is directly connected with the modern apes.

Now *Eohippus* was a creature which was very different from the modern horses, or the donkeys, or the zebras. And besides, all of the Eocene representatives of the present mammals were very different from the present, or the Pleistocene types. So if the human line was distinct in Eocene time it necessarily follows that the man of that period was very different from what we know as man today. Similarly, the creatures representing the modern monkeys at that time must have been very different from them.

Therefore the common ancestor of the Primates must have been a creature which we could not call either man or monkey on the basis of the accepted definitions of those terms, or of our current concepts of the animal world.

How it is possible for both man and the apes to be descended from a common ancestor not resembling either is made clear by the history of the greyhounds and the bull-dogs. These two types of dogs are very different from each other both in bodily form and in mentality, yet they are descended from the same ancestor, a wolf, which does not resemble either.

Unbroken continuity in descent from parent to child does not necessarily imply a similar continuity in bodily form or in mental attributes. This is well illustrated by the bull-dogs, which suddenly appeared as a rather broad mutation from another type of dog, and by the hairless dogs which had a similarly abrupt and sudden origin.

So while the general and broader features of human structure were inherited, in accordance with the unbroken continuity of descent from parent to child, from some as yet unknown ancestor common to all the Primates—but not from an ape as we understand that term—it is possible and indeed most reasonable to assume that man, like the bull-dogs and the hairless dogs, arose through a rather broad mutation and therefore that the details of man's structure and his mentality are, and always have been, man's alone.

Reflections.—The two chief features which distinguish man from all the other mammals are his extremely flexible and useful hand, and his unique family relationships. Human children follow each other so very closely that the second appears before the first is independent of the parents, the third follows the second in the same way, and so on. Other distinctive attributes are the use of fashioned or manufactured tools, the use of fire, the use of clothing and of ornaments, and the use of articulate speech, which enables man to accumulate knowledge in successive generations. Is there any relation between these several different types of attributes?

The flexible and adaptable hand of man lends itself naturally to the use, as implements or weapons, of various natural objects, such as sticks and stones. From this it is but a step to the manufacture and the use of tools.

The use of tools leads naturally to developments in three directions. In the first place, it is unlikely that any creature possessing the strength of man could use tools long without striking sparks and thus discovering the possibilities of fire. In the second place, the use of tools would lead to the manufacture and the use of clothing and of ornaments. In the third place, the use of tools permits the construction of a fixed abode or domicile wherein man would be safe from at least the majority of his four-footed enemies.

Such an abode would presumably become the abiding place of the female in which she would find protection and to which food would regularly be brought for joint consumption by the male. Man is the only vertebrate with slowly developing young born one at a time living continuously in an enclosed abode or domicile. Such a manner of life permits the rapid bearing of young, for with the mother protected and provided for she may devote herself entirely to the raising of her children. Animals kept in captivity—fed and protected—sometimes bear young before the preceding young are independent, although they are not known to do so under natural conditions, so there are some grounds for assuming that the human family of dependent young of different ages is associated with the fixed abode.

The development of a dependent family including young of many different ages would necessitate the interpretation by the parents of a great number of different sounds and thus might be assumed to lay the foundation for the beginnings of articulate human speech. The basic fundaments of language are already evident in all creatures with dependent young.

So we find that all the things that make man human may be traced back to the potentialities of the flexible human hand guided by a brain capable of developing those potentialities.

In the first chapter we saw that in the animal world taken as a whole there were very many instances of man-like attributes, especially among the insects and also among the smaller birds and rodents. We also saw that these man-like mental attributes were always coupled with some heavy liability, usually feeble and defenseless young.

We now are able to see further. The man-like attributes of the insects, birds and rodents, and a few other creatures, are correlated with the possession of jaws, beaks or other structures which are capable of being used more or less after the fashion of our hands. Wherever such occur the ability to make use of them enables their possessors successfully to meet and to overcome liabilities which otherwise would be insuperable. In other words, these structures permit the existence of liabilities without danger to the species; the liabilities themselves do not induce the appearance of man-like attributes.

In the complicated homes built by the ants, bees, wasps and termites are females which never leave them, constantly producing eggs, and hence an enormous serial family of dependent young. It is the elaborate home that makes this possible, and the deft and skillful jaws of the adults, coupled with their powers of defense, make the home possible.

So the lesson that we learn from the study of animal forms in the broadest sense is that it is the home and associated features that form the foundation of the human social structure; in the home originated, and from the home emanated, all our social progress.

APPENDIX A

The tracing of the details of the development of animal forms from the primitive single cell is a rather complicated process involving the use of various technical terms and the names of numerous types of animals which are quite unknown except to specialists in zoology.

So it has seemed advisable not to incorporate the discussion of eogenesis in the body of this work, but instead to consider this important subject separately in an appendix.

All animals living at the present time develop from a single cell. As this is true of every animal of which the development is known, we have no hesitation in assuming that it has always been true of every animal type. From this it naturally follows that all types of animal life must be explained in terms of an original single cell.

Since all types of animal life must be explained and interpreted in terms of a single cell, a path must be traced from the original and primitive single cell to the basic form or forms in every phylum.

Some animals possess bodies which are composed only of single cells. Such animals are always very small (fig. 87, p. 161). The bodies of other animals are composed of cells belonging to only two germ layers (fig. 117, p. 185), the ectoderm and endoderm. These animals are always radial, or fundamentally radial, in symmetry, more or less like a flower, and for the most part live firmly fixed to some support and grow after the fashion of a plant. Most of them are of medium size or small, like the sea-anemones or the hydroids, but a few, as certain jellyfishes, may be very large. Those which live, like jellyfishes, suspended freely in the water have only very feeble locomotor powers.

All creatures living on the land, and a very large proportion of those living in the sea and in fresh water, have their bodies formed of cells derived from three germ layers (fig. 120, p. 185). Such animals may be small, scarcely more than one one-hundredth of an inch in length, or very large, like elephants and whales, or of any intermediate size.

It is almost invariably assumed that the animals with bodies composed of a single cell represent the primitive animals from which all others are derived. They are commonly supposed to have preceded all other animal types in their appearance. There is not the slightest basis for this assumption beyond the circumstance that in arithmetic—which is not zoology—the number one precedes the other numbers.

Arithmetical simplicity in the broader features of animal structure does not by any means imply biological simplicity of functions and of reactions. In the animals with bodies composed of a single cell that single cell is so excessively complex in its physical and chemical makeup that it is able to perform of itself alone all of the vital and mechanical functions which in other creatures are distributed among a greater or lesser number of special organs, each of which is composed of more or less numerous cells fitted to perform a more or less limited range of functions.

Two animals each able with equal success to carry on all of the very numerous and complicated functions necessary for animal existence, and at the same time equally efficient in meeting the limitations and restrictions imposed by external forces, would seem to be on quite the same footing, and therefore of an equal degree of specialization. If this were not so—if on the other hand the arithmetically simpler creatures were biologically more simple than the arithmetically more complex—can anyone give any good reason why the former should not have disappeared as the latter appeared?

No reason can be given. All of the different major groups of animals existing at the present time are, in their respective spheres of action, equally efficient. If they were not, the more efficient would soon exterminate the less efficient. Among the various major groups of animals as we find them at the present day there is no possible question of simplicity or of complexity, of primitiveness or of specialization, from the strictly biological standpoint.

In size, and in everything correlated with size, the fish or the crustacean is vastly superior to the protozoan. In number of individuals, potentiality for rapid increase, and ability to survive adverse conditions, the protozoan is vastly superior to the crustacean or the fish. While so far as the existence of the *individuals* is concerned, the fish and the crustacean, because of their size, power, locomotor ability, and capacity for offense and defense, have a vast superiority over the protozoan, so far as concerns the existence of the *species* the protozoan, because of the immense number of individuals and their minute size, has an enormous advantage over the crustacean or the fish.

Biologically the protozoan, the fish and the crustacean are all on an equal footing, in spite of the apparent arithmetical advantage inherent in the multicellular structure of the body of the crustacean and the fish. Indeed, whatever advantage there may be rests with the protozoan, for very many different kinds of protozoans live as commensals and as parasites within the bodies of all fishes and crustaceans.

There is another way of looking at the matter. The bodies of all animals are at first composed of a single cell (figs. 110, 111, 121, p. 185). In the case of the protozoan the body always remains a single cell (fig. 87, p. 161), or at least special structures—which may be very complicated—are formed without the division of the cell as a whole.

In the case of the multicellular animals the original germ cell divides into two cells, these divide in the same way, and cell division keeps on until the final form and complexity is attained (figs. 110–117; 121–125, p. 185). The division of the original germ cell into two, however, adds nothing. The original potentiality of the germ cell is simply enclosed in two packages instead of a single one. Further cell division adds nothing. The original potentialities of the germ cell are simply being segregated and distributed in an increasingly large number of units. An adult multicellular animal may therefore be considered as merely the most effective form in which the fundamental attributes of the original germ cell can find expression.

It has been demonstrated by the study of genetics that mutations are localized in the so-called chromosomes, which represent a portion of the germ plasm, or contents of the germ cell. Thus in the germ cell even minor variations in the characters or features of any animal type are already present, although they will not become evident until the germ cell has become divided up into thousands or millions of cells.

Any individual animal, therefore, no matter how complicated its body may be, is simply the elaborated equivalent of its germ cell. As such, it is the equivalent of a single celled animal or protozoan. Assuming that a protozoan equals the number one,

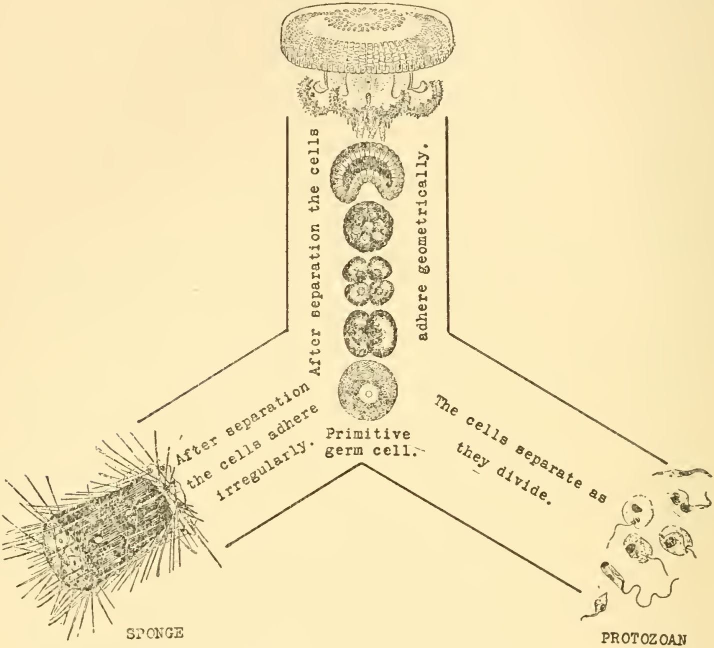


Fig. A.—Diagram illustrating the three simultaneous paths of development from the primitive single cell. Although both the protozoans and the sponges are enormous groups including great numbers of species, neither group ever gave rise to any other type. The geometrical line of development resulting in the radially symmetrical cœlenterate leads through the gastrula (see figs. 110–117, p. 185), an embryonic stage found in all the more complex animals. The cœlenterates and all other animals except the sponges and the protozoans must therefore be interpreted in terms of the gastrula (see figs. 115, 116, 120, p. 185).

any multicellular animal may be regarded as represented by a vast number of fractions grouped in various ways which, when added together, equal the number one, and which were all derived from an original number one.

Coming back to the single cell, there is no reason whatever for assuming that complete separation of dividing cells is a more primitive condition than adhesion of cells after division, or preceded adhesion. In fact, the great rarity of complete separation of cells after division in the animal world taken as a whole almost suggests that adhesion, not separation, is the primitive condition. Therefore the statement commonly made that the single celled animals or protozoans are the most primitive of the animals, and preceded in appearance the multicellular types, has nothing to support it. The only logical assumption is that the appearance of unicellular and multicellular animal types was simultaneous—perhaps even that the latter appeared first (fig. A, p. 238).

Cells which after division remain in contact may adhere irregularly, resulting in the formation of a more or less unorganized mass. Essentially such a condition is characteristic of the great group of sponges, in which creatures many of the constituent cells are almost wholly independent of each other and suggest masses of protozoans packed closely together.

Cells which after division remain in contact may adhere regularly, resulting in the appearance of a series of geometrical forms (figs. 110–117, p. 185). Regular division of cells followed by regular adhesion leads to the formation of a hollow ball of cells called a blastula (figs. 113, 114, p. 185). The blastula collapses, like a rubber ball with one side pushed in, into a cup with an outer and an inner layer of cells called a gastrula (figs. 116, 117, p. 185). The typical gastrula has an axis passing through the center of the opening and of the opposite pole, and the radii about this axis are everywhere the same—in other words the typical gastrula is radially symmetrical about its only axis.

If the radially symmetrical two-layered gastrula (figs. 116, 117, p. 185) should become adult, there would result a radially symmetrical animal composed of two layers of cells, which would be of quite the same nature as a hydra or a sea-anemone. The whole group of the Cœlenterata—hydras, corals, sea-anemones, sea-pens, hydroids, alcyonarians, gorgonians, antipatharians, jellyfishes, and numerous other types—represent animals which pos-

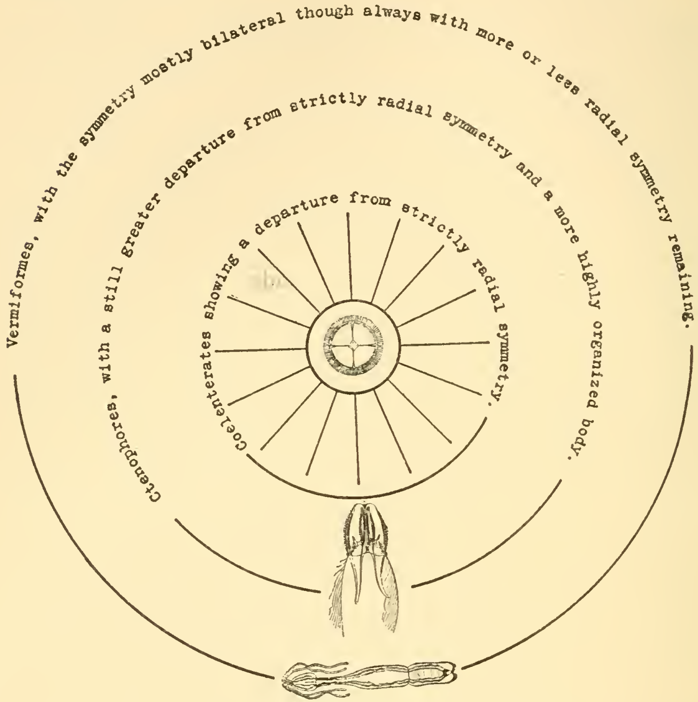


Fig. B.—Although all cœlenterates are developed geometrically through a gastrula or strictly comparable stage, few of them are perfectly radial in their symmetry. Many of them have a slit-like mouth instead of a circular mouth, with the two halves of the animal on either side of a plane passing through the long axis of the slit-like mouth alike. This condition is known as "biradiate" symmetry, and there are in the cœlenterates all transitions between truly radial and "biradiate" symmetry. But all cœlenterates are either radial or "biradiate," and all agree in having the body composed of only two germ layers, ectoderm and endoderm; there is no intermediate or mesodermal layer.

From this condition of radial, or approximately radial, symmetry and no mesoderm there are two lines of departure. Both lines of departure are accompanied by the appearance of mesoderm between the ectodermal and endodermal layers of the gastrula.

1. In the ctenophores the body is divided into two similar and equal halves by a plane passing through the long axis of the flattened stomach, and also into two similar halves by a plane at right angles to this which passes through the long axis of the so-called funnel into which the stomach leads. Thus either line in a right angled cross divides the ctenophore into two equal halves. This very distinctive symmetry is characteristic of, and is confined to, the ctenophores.

2. In the Vermiformes the body is divided into equal and similar halves by a plane passing through the long axis of the body dorsoventrally. But there is always a greater or lesser amount of radial symmetry evident in the nervous system, the digestive system, or the head structures. The Vermiformes are bilateral, though always showing a certain amount of radial symmetry.

sess radially symmetrical bodies composed of two layers of cells which arise from an original single cell through regular geometrical cell division.

As there is no reason for assuming that irregular adhesion of cells after division necessarily preceded regular geometrical adhesion of cells after division, there are no grounds for supposing that the cœlenterates are not as old as the sponges or the protozoans.

The single celled animals or protozoans, the sponges, and the two layered radially symmetrical animals each represent the logical end product of a special type of cell division and of cell behavior after division (fig. A, p. 238). There is not the slightest evidence that any one of these animal types preceded the other two in appearance.

We now come to those animals in which the body is made up of three layers of cells. The gastrula is formed as just described (figs. 110–117, p. 185), but a greater or lesser number of cells, arising in various ways, make their appearance within the hollow wall of the gastrula (compare figs. 116 and 117 with fig. 120, p. 185) and subsequently form the mesoderm.

In one group of animals with the body composed of three cell layers, the ctenophores (fig. 66, p. 111), the symmetry is quadrilateral; there are two axes, a long and a short, crossing each other in the middle at right angles, and the two halves on opposite sides of either axis are the same. These curious creatures (see fig. B, p. 240, fig. C, p. 246, and fig. D, 4, p. 250) may be regarded as on a par with the cœlenterates, though wholly different from them.

All other animals are always in some stage, and usually in the adult, bilaterally symmetrical with a more or less marked head end at which are the main nerve centers, the chief sense organs, and usually the mouth, if a mouth be present.

The bilaterally symmetrical animals segregate themselves in two rather well defined groups. The first group includes those types in which the symmetry is partly bilateral and partly radial, and there is no typical gastrula or cup stage in the development of the individuals. The second group includes the types in which the symmetry is wholly bilateral, and which in their development pass through a typical gastrula stage, or a stage easily recognized or interpreted as a modification of the gastrula.

The animals which are partly bilateral and partly radial in their symmetry form a most extraordinary assemblage of very widely diverse types. They are the cestodes or tapeworms, the acanthocephalids or spiny-headed worms, the trematodes or flukes, the turbellarians, the nematodes or thread-worms, the nematorpha or gordian worms (the "hair-snakes" of puddles and troughs), and a considerable number of curious small obscure worm-like things of uncertain relationships. Although the only features which these queer creatures share in common are the partially bilateral and partially radial symmetry, the absence of true cœlomic structures, and the absence of a true gastrula stage in the development of the individuals, there are indications that as a whole they represent a distinct zoological unit, although a remarkably heterogeneous unit.

There are forms which are intermediate between the tapeworms and the flukes, and others which are intermediate between the flukes and the turbellarians. Some authorities consider the spiny-headed worms to be related to the nematodes or threadworms, others believe them to be most nearly allied to the tapeworms, while still others regard them as wholly distinct from anything else. The gordian worms are usually considered to be related to the nematodes from which, however, they differ in practically every detail of their structure.

All of the tapeworms, spiny-headed worms, flukes and gordian worms are parasites, as are also many of the thread-worms and a few of the turbellarians. The tapeworms, spiny-headed worms, some of the nematodes, some of the turbellarians, and a few curious forms (such as *Rhopalura* [figs. 127, 128, p. 185], *Dicyema*, *Dicyemopsis* [fig. 126, p. 185], *Dicyemella*, and others) which are supposed to be allied to the trematodes or flukes have no mouth and no digestive system. A few of the small turbellarians without a digestive system are said to be able to live on inorganic material like a green plant through the medium of the green cells in their tissues.

In the young stages of many of these creatures, especially in certain tapeworms and flukes and in a few turbellarians, asexual reproduction is carried to an extraordinary degree, recalling the conditions in the younger stages of many of the radially symmetrical cœlenterates. Other forms, especially among the turbellarians, possess the most remarkable powers of reparation and of regeneration, being able to reproduce an entire individual from a very small fragment. This also recalls the conditions in certain cœlenterates. On the other hand, in other forms there is simple sexual reproduction only, and the individuals possess little or no power of reparation. Such forms in these respects most nearly resemble the more complex forms of bilaterally symmetrical animals.

In some of these creatures both sexes occur in the same individual, while in others the sexes are separate. In a few, unfertilized eggs capable of developing are produced. Rarely, larval as well as adult forms produce eggs. Many develop directly from the egg to the adult, but others have one, two, three, or even four very distinct larval forms, some of which produce great numbers of the same, or different, larval forms through various types of asexual reproduction. Some of the larval forms are branched and plant-like, and in many cases the adults are practically colonial animals.

The number of different kinds of these animals is very great, and the part they play in the economy of nature, especially in preventing the too rapid increase of other kinds of animals, is most important.

It might be supposed that the fact that the great majority of these creatures are parasites indicates that they are simply anomalous forms the peculiar characteristics of which have been developed in accordance with and as a response to their parasitic habits.

Parasitic habits, however, cannot produce structures which are not already potentially present. Through parasitism certain structural *details* may be profoundly altered, or a parasite may lose various structural characters and through this loss become much altered in its general appearance. This is well illustrated by the various parasitic crustaceans and by the parasitic barnacles. But no *new structural complex* is ever formed.

Nature does not produce anomalies. To regard any creature as anomalous is simply to confess our inability to understand it. The living world is not chaotic—everything has its appointed place in the general plan.

The reason that the majority of these creatures are parasitic is that their curious structure renders them incapable of competing as free living forms with other types, while at the same time it lends itself with peculiar facility to the specialized requirements of a parasitic life.

None of these creatures can be assumed to be descended from the radially symmetrical cœlenterates, or to have given rise to, or to have been the ancestors of, any other forms of animal life. Yet all forms of animal life must have been derived from the same original ancestor or ancestral type. What, then, is their relation to other animals?

In their very earliest developmental stages—those immediately following the division of the germ cell—they resemble all other animal types. But they very soon diverge, both from the developmental line leading to the radially symmetrical cœlenterates and from each other. Their later embryonic stages are unique and very diverse. In some these recall in certain respects the cœlenterate planula, while in others they appear more like the early embryos of some of the more complex animals. How can this be reconciled with any developmental plan?

The fundamental difference between the single-celled animals or protozoans and all other animals is that the single cell of the protozoan divides into two cells which separate completely from each other, each half of the original cell becoming a separate animal with half the bulk of the parent. In all other creatures the original germ cell divides into two as in the case of the protozoans, but the two derivatives of the original germ cell remain connected.

So the difference between the protozoans and the other animals is chiefly and most obviously a difference in the behavior of the single cell which lies at the base of all animal structure.

The essential and most obvious difference between the sponges and the cœlenterates is that in the sponges the cells as they divide adhere in a more or less irregular mass in which many of them retain to a large extent their individuality, while in the cœlenterates the cell division takes place geometrically and results in the formation of a radially symmetrical body in which all of the cells —or practically all of them—have entirely lost their individuality through incorporation into various organs and structures.

Thus the difference between the sponges and the cœlenterates has its inception in the very early embryonic stages. But it would seem that the sponges and the cœlenterates are more closely related to each other than either group is to the protozoans in which there is no adhesion of cells—or at least no adhesion which impairs the complete individuality of the cells.

The curious assemblage of creatures with which we are at present concerned seems clearly to be less like the sponges than like the cœlenterates. But in their embryonic stages they depart very early from the regular geometrical line which leads to the adult cœlenterate. Their relation to the cœlenterates is of approximately the same nature as the relationship between the sponges and the cœlenterates, or as the relationship between the sponges and the cœlenterates taken together and the protozoans.

Any regular geometrical line of development would naturally be subject to every possible deviation and departure from the normal. Such of these deviating lines of development as would result in producing an adult animal—no matter how bizarre— which has an internal chemical and physical balance enabling it successfully to carry on the necessary vital processes, and at the same time was fortunate enough to find some niche in which it could maintain itself, could very easily produce an apparently wholly new type of animal.

Such new types of animals, coming into existence as the result of deviations from the regular developmental line originating at

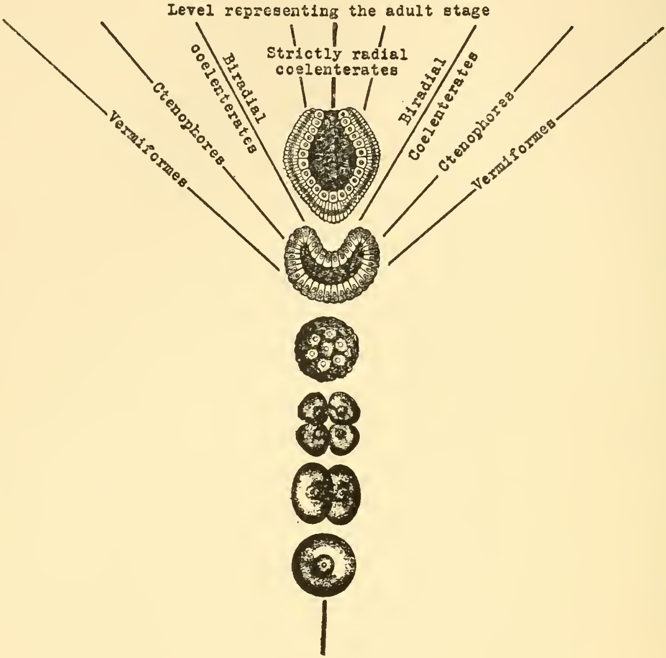


Fig. C.—In fig. B the animal types represented are considered as adults only. The outermost circle has no connection whatever with the next, nor the next with that within it. There are, however, numerous types connecting the innermost circle with the center. The origin of this condition is illustrated in this diagram. The radially symmetrical cœlenterates arise through regular geometrical division from the ovum or egg through the gastrula. Their development is represented by the line from the bottom to the top of the figure, the top being the small central circle in fig. B. The biradiate cœlenterates, the ctenophores and the Vermiformes arise through departures from this regular line of geometrical figures which take their origin at or about the early gastrula stage, or perhaps just before it.

a very early embryonic stage, would in the adult form give no certain indication of their origin. They would appear as isolated animal types with no close relatives.

Only in this way may the various types included in the Vermiformes be explained. They may be interpreted as having arisen simultaneously with the cœlenterates through deviations from the regular geometrical course of embryonic development leading to a radially symmetrical adult.

This deviation seems to have taken place at a slightly later stage in some than in others, and furthermore it seems to have been of several diverse types resulting in a curiously heterogeneous assemblage of forms relatively few of which are sufficiently well balanced to be capable of independent, that is, non-parasitic existence.

None of the Vermiformes can be assumed to have been the ancestors of anything else. As animal forms they are quite unique. But taken as a whole they furnish a most significant clue to the probable relationships of the other animal types.

No matter how different they may be—whether clam, bird, starfish, jointed worm, or other form of animal life—all of the more complexly organized animals in the course of their development pass through a gastrula or comparable stage. This gastrula stage is the last stage common to them all. Since they all pass through a gastrula stage they are all referable, as far as the gastrula, to a developmental line which, followed to its logical end, leads to a radially symmetrical animal (fig. A, p. 238).

Following—or usually during—the gastrula stage they all diverge in different directions. The radial symmetry of the gastrula is completely lost, and subsequent development leads in all cases to the formation of a bilaterally symmetrical creature.

All of the more complex animals agree in being bilaterally symmetrical, and also in having the body derived from three germ layers. Each major group, however, possesses characteristic and distinctive features which have their origin in the very varied behavior of the three germ layers—of themselves and in reference to the other two—in late gastrula and subsequent development.

Thus a mollusk is a mollusk, a vertebrate is a vertebrate, an echinoderm is an echinoderm, a jointed worm or annelid is an annelid, and so on, in the late gastrula, or at the furthest immediately subsequent, stage, and becomes more and more obviously so as the development progresses. Indeed, in some major groups the early gastrulas are characteristic and distinctive.

Such a condition is capable of but a single interpretation. The only possible conclusion is that there is not now, and there never has been at any time in the past, any linear relationship between the major groups of animals at any stage later than the gastrula. None of them can be assumed to have passed through a stage represented by any of the others in the adult form.

In all of them there are the same three germ layers—the ectoderm, representing and arising from the outer layer of cells in the gastrula cup, the endoderm, arising from the layer of cells lining the gastrula cup, and the mesoderm, arising in various ways within the hollow walls of the gastrula cup between the outer ectoderm and the inner endoderm.

Each of the three germ layers gives rise to definite sets of organs and of structures. Obviously, therefore, a slight modification of the relationships between them in early embryonic life will produce marked and profound differences in adult animals.

The relation between the various groups of the more complex animals can only be interpreted on the basis of embryological evidence—and no other evidence is available—as divergence from a common center, this common center being represented by the gastrula. There is no other possible point of common contact.

We may explain the matter in this fashion. A number of exactly similar hollow hemispheres of modeling clay may be taken and each modeled into a wholly different figure. In this way we could form an infinite series of clay figures which would not show the slightest similarity to each other. But each would be formed of the same clay, and each would have originated as a hollow hemisphere.

This is about what nature has done in the case of the more complex animal forms. Instead of hollow hemispheres of clay, however, nature's units were hollow hemispheres with an outer, an inner, and an intermediate layer of cells, the cells in each of these three groups or layers being capable of forming certain organs or structures only. And besides this, nature's remodeling of the original available materials—the three germ layers—had to produce as a result an animal form with a proper internal chemical and physical balance, and at the same time capable of securing suitable food in sufficient quantity and of defending itself against aggression.

The possible number of forms into which the materials available in the gastrula may be modeled so as to produce an animal type capable of successful existence is undoubtedly limited. Probably the major groups of animals as we know them represent the full total.

The reason for the assumption that the major groups of animals represent the entire range of structural possibilities is that they arrange themselves in a very definite order in relation to each other, and in this definite order there are no gaps. This order seems to correspond in the animal world to the periodic system of the chemical elements in the inorganic world. The key to this order is furnished by the group Vermiformes.

We have already pointed out that these creatures, which have a symmetry partly radial but chiefly bilateral, may be considered as having arisen from the line of geometrical development leading to the radially symmetrical cœlenterates as a result of the appearance of developmental irregularities in the early embryonic stages leading to the formation of a mainly bilateral adult.

The developmental figure represented by the radially symmetrical cœlenterates and the Vermiformes (fig. B, p. 240) would be a central spot, indicating the cœlenterates, surrounded by a circle of more or less detached spots each of which represents one of the several groups of "worms."

So far as the adults are concerned, there is no connection between the spots. But the same figure viewed from the aspect of the development of the individuals in each of these types of animals would show a vertical axis running from the primitive single cell upward through a series of geometrical embryonic stages—the two, four, eight, sixteen and thirty-two celled stage, etc., and the blastula and gastrula—to the adult cœlenterate. From various points in this vertical line, mostly at or near the early gastrula stage, lines would branch off and run diagonally upward and outward to each of the spots representing one of the flatworm or roundworm types (fig. C, p. 246).

In the circle of forms represented by the Vermiformes (fig. E, p. 254, outer circle) we see four distinct and widely different structural types, two or more of which, however, may occur in closely related animals. These four structural types are the following.

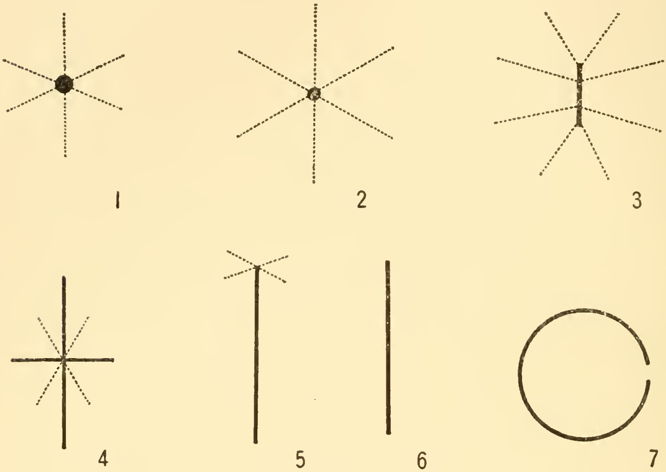


Fig. D.—The animal symmetries. 1.—The symmetry of the germ cells, which is also the fundamental symmetry of the protozoans; the dotted lines are assumed to radiate from the center of a sphere. 2.—Cœlenterate radial symmetry, viewed along the axis through the mouth and the opposite pole. 3.—Biradiate symmetry, a modification of the preceding (2), found in cœlenterates only. 4.—The cross symmetry of the ctenophores. 5.—The partly bilateral and partly radial symmetry of a tapeworm in which the head or scolex is four sided. 6.—Bilateral symmetry, with a single axis. 7.—The pseudoradial symmetry of an echinoderm—really bilateral symmetry with the axis curved in a circle, half of the five segments of the body failing to develop in the adult.

1. The jointed tapeworms. From a head end, or "scolex," which is commonly radially symmetrical and often four-sided (figs. 5, p. 5; 82, 83, p. 161), a series of units is continually budded off which, as they are shoved further and further from the scolex by the budding off of new units, become more and more developed. These units—the proglottides—are usually strongly flattened and have a more or less well marked dorsal and ventral surface. The proglottides usually differ more or less on either side of the plane passing through the center of the so-called dorsal and ventral surfaces.

In these jointed tapeworms we see a rather close approach to the type of development characteristic of various jellyfishes—for instance the common *Aurellia*. In these jellyfishes the egg gives rise to a little creature shaped like an inverted bell attached by the handle. From the margin of this bell two tentacles arise opposite each other in quick succession, so that at the two tentacle stage the little creature is bilaterally symmetrical—or rather biradial. After this, other tentacles appear. Subsequent to the formation of the complete circle of tentacles, the larva undergoes more or less extensive reproduction by the formation of buds which separate off and grow into new and independent animals, and also by division into two or more parts, each part after separation becoming a new animal. In this connection it may be mentioned that in certain tapeworms the larval form may in somewhat comparable fashion produce from its internal walls one or two generations of secondary vesicles which project into it, the cestode heads originating in special small brood capsules on these secondary vesicles. In these cases the number of separate tapeworms which arise from a single embryo is enormous. In the little bell-shaped jellyfish larva, after reproduction by budding and by fission have proceeded for some time the body begins to divide transversely, and the tentacles disappear. The body now elongates, and little plate-like or saucer-shaped bodies with four pairs of marginal lobes are detached one by one from the outer end. These float away and grow into jellyfishes. The distal proglottides of the jointed tapeworms are also detached, one by one or in groups, but in the case of the tapeworm the proglottides are fully developed before detachment. It may be remarked that not all of the tapeworms are jointed, some being single units.

2. The flukes, in which the budding off of young, which are different from the adult, takes place within the larval form. In the flukes the first larva, a miracidium (fig. 96, p. 175), generally becomes a sporocyst (fig. 98, p. 175), which is a hollow sack with excretory canals in its walls containing in its interior cavity a number of germ cells. The germ cells within the sporocyst usually develop into rediæ (fig. 97, p. 175), which resemble sporocysts except in having a mouth and intestine, and two lateral processes near the hind end. The germ cells within the rediæ usually produce cercariæ (fig. 99, p. 175), which are essentially young flukes with a slender and very mobile tail. Later the tail is lost, and the young fluke grows into the adult (fig. 55, p. 97).

If we are to maintain that the animal world has an underlying plan or system—that it is not chaotic—there must be some significance in the extraordinary developmental history of the flukes. To say that it is a response to, or was developed because of, their parasitic habits is simply to beg the question. If parasitic creatures are to be considered as derived from other forms of animal life, then every peculiarity of a parasite must be explained by, and may itself explain, other features found in other animals. In other words, no parasites can add anything to their fundamental structural equipment or to their ontogeny that does not exist in related types.

What structural peculiarities in the more complex animals may be explained by the development of the flukes? The very extensive asexual reproduction in the young stages of the flukes recalls similarly extensive asexual reproduction in the young, and often also later, stages in the cœlenterates. Many cœlenterates as they grow produce a large colony of interconnected animals of more or less plant-like form. In various cœlenterates the individual animals in these colonies are not all alike, but are divided into three types. These three types are: *First*, the nutritive or sack-like individuals, which do the eating for the entire colony; *second*, the reproductive individuals, which produce the eggs; and *third*, the "defensive" individuals, which serve to protect the colony by means of structures the chief feature of which is a poisonous secretion.

In the more complex animals there is developed, typically by budding from the enteron—the digestive cavity primarily derived from the endoderm—a structure or organ of the greatest importance called the cœlom. The cœlom has three divisions. These three divisions are: *First*, the perivisceral, which forms the body cavity in which the heart and other viscera lie; *second*, the gonadial, or reproductive portion, from the walls of which the reproductive cells arise; and *third*, the nephridial, the walls of which secrete the nitrogenous waste.

It is impossible not to see in the three divisions of the cœlom a correspondence with the three distinct types of polyps produced by many of the colonial cœlenterates. It is likewise impossible not to see in the extensive asexual reproduction by budding in the flukes the same phenomenon as the extensive asexual reproduction in the cœlenterates. In the cœlenterates the buds which grow into the new individuals—polyps—are always external, while in the flukes they are always produced *within* the original unit.

It is quite conceivable that the cœlom may have arisen from the budding internally as in the flukes instead of externally as in the cœlenterates of a sack-like, a reproductive, and an excretory unit corresponding to each one of the three types of polyps characteristic of many colonial cœlenterates. Such an explanation of the origin of the cœlom is at least plausible on the basis of the evidence, and no other explanation which does not involve the creation of a new structure out of nothing is possible.

3. The solitary flatworms and roundworms, wholly independent of each other, each individual developing directly, or through a larval form, from an egg without any asexual reproduction. In this group fall the thread-worms or nematodes (fig. 81, p. 161), most turbellarians (fig. 54, p. 97), and some other types.

4. Flatworms which are independent of each other, but form colonies of similar perfect individuals through asexual reproduction, as in the case of *Microstomum* (fig. 135, p. 203).

Thus we find in the Vermiformes four main structural types. These four chief structural types are:

1. Mainly bilateral animals taking the form of a linear and more or less unified colony.

2. Mainly bilateral animals in which colony formation is inverted, the budding off of the new elements taking place within the original unit.

3. Mainly bilateral independent animals which do not form colonies and which show no asexual reproduction.

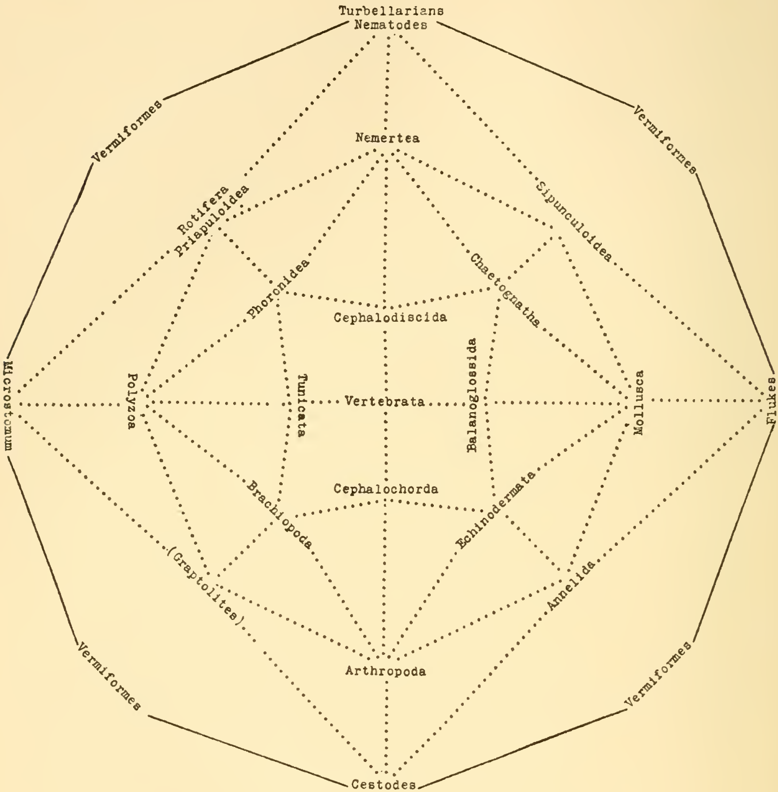


FIG. E.—Illustrating the relative positions in reference to each other of the bilaterally symmetrical animals. The outer circle (compare fig. B) represents the Vermiformes, a very highly diversified group including four distinct structural types showing features which are combined in four other types of more complicated animals not directly related to them. Similar recombinations of structural features account for all the other animal types, the Vertebrata occupying the center of the figure as the most complex of all animals. These different groups arose as a result of following different developmental lines from (approximately) the gastrula onward. The ancestral line of each radiates from the gastrula, and the groups were therefore never connected by intermediate types of adult animals, nor was any one derived through any of the others. The appearance of all was probably simultaneous or nearly so, and also simultaneous with that of the types not shown in this figure (see figs. A-C).

4. Mainly bilateral animals which, although remaining practically independent of each other, form colonies through asexual reproduction by transverse fission.

If we place these four structural types, represented by (1) jointed tapeworms, (2) flukes, (3) nematodes and most turbellarians, and (4) *Microstomum*, at equal intervals on the circumference of a circle (fig. E, p. 254) we find that there are four other groups of animal forms which structurally may be interpreted as intermediate between them, or rather which combine in a single type the characteristic features of the forms on either side. The animal types included in this second series of four have no trace whatever of radial symmetry, so they may be arranged on a circle within the circle on which the Vermiformes are placed. These types present the following characters:

1. Animals which are sharply segmented or jointed, like the jointed tapeworms, and also in their growth develop internal buds more or less after the fashion of the flukes, leading to the development of a cœlom. The animals which answer to these specifications are the annelids or jointed worms.

2. Animals which are unsegmented, like the nematodes and turbellarians, but possess an internally budded cœlom, thus in this respect corresponding to the flukes. These animals are the sipunculids.

3. Animals which are solitary and unsegmented without a cœlom, like the turbellarians and nematodes, but show abundant asexual reproduction like *Microstomum*. These animals are the rotifers. Possibly the priapulids belong here.

4. Animals which are segmented but without a cœlom, like the jointed tapeworms, but less completely unified and not subject to a continual loss of the units, as in *Microstomum*. Probably the graptolites belong here.

None of the animal types in this second series of four can be assumed to have any direct connection with any of the flatworms or roundworms, nor can it be shown that they have any connection with each other. Their development, however, where it is known, shows that the very early stages resemble the corresponding stages of the cœlenterates, but that they branch off from the regular geometrical line in such a way as to lead to the formation of completely bilateral larvæ and subsequently adults in which the broader structural features may be interpreted as combining those of two separate groups of Vermiformes.

As they depart from the cœlenterate line of development in very early larval stages, their origin was presumably simultaneous with that of the cœlenterates and the Vermiformes and had its inception in the different behavior of the gastrula. For instance, while the very young jointed tapeworm embryo develops in such a way as to produce a sharply jointed and semicolonial animal, and the fluke embryo during its growth undergoes extensive internal budding, the young embryo of the jointed worms or annelids in its development combines both external segmentation and internal budding.

Within this second series of four animal types there is another series of four which bears the same relation to the second series that the second series does to the first.

The third series of four animal types includes:

1. The polyzoans, which are colonial, or at least primarily colonial, and not at all, or only very imperfectly cœlomate, falling between the rotifers and the graptolites.

2. The arthropods, with a segmented body like that of the annelids, but divided into two or three units showing division of labor (in the insects one, the head, controlling and directing, another, the thorax, bearing the legs and wings and therefore locomotor, and the third, the abdomen, containing the digestive, reproductive and other organs) after the graptolite or polyzoan fashion, with a poorly developed cœlom, with abundant traces of asexual reproduction (polyembryony, parthenogenesis, fragmentation of larvæ, etc.), with a marked tendency to form (as in the ants) polyzoan-like colonies with division of labor among the (independent) units, and sometimes (as in *Thompsonia*) even forming dendritic colonies.

3. The mollusks, always solitary, like the sipunculids, with

a highly developed cœlom, and with traces of segmentation suggesting the annelids.

4. The fourth group should be composed of solitary animals with an indication of colonial structure and a cœlom, but without segmentation. It is possible to place the nemerteans here by assuming that their imperfect segmentation is of the *Microstomum* and not of the tapeworm type.

Within this third series of animal types there is a fourth series bearing the same relation to the third series that the third does to the second. This fourth series of animal types includes the following:

1. The echinoderms, combining a reduced body consisting in the adults of five half segments more or less of the arthropod type with a highly developed cœlom as in the mollusks.

2. The arrow-worms or chætognaths, suggesting a relationship with the mollusks, and also with the nemerteans.

3. The phoronids, suggesting a relationship with the polyzoans but with a well developed cœlom and with the colonial habit reduced to the budding off of new individuals.

4. The brachiopods or lamp-shells, suggesting both the polyzoans and the barnacle-like arthropods.

In this fourth series of animal types the features characteristic of each of the four groups of types in the first series all occur in varying proportions. A fifth series of four, bearing the same relation to the fourth that the fourth does to the third, would therefore be composed of types which would be structurally very much alike.

We appear to find such a series in:

1. The tunicates, which seem to be in line with the polyzoans, while they also suggest both the brachiopods and the phoronids.

2. The cephalochordates, which clearly stand in the cestode-arthropod line and at the same time show indubitable affinities with the echinoderms.

3. The balanoglossids, with no trace of asexual reproduction, which may be considered in line with the flukes and mollusks and between the chætognaths and the echinoderms.

4. The cephalodiscids, which seem to fall between the chætognaths and the phoronids.

These four very distinctive, but structurally closely related, types all show marked affinities with the vertebrates. It is possible to interpret the vertebrates as combining the features found in all of them and therefore as occupying, as the most highly perfected of all animal types, the center of the figure.

In the vertebrates we are able to recognize the segmentation of the cestodes, annelids and cephalochordates, combined with the cœlomic structure first indicated in the flukes, both enclosed in the undivided body of the turbellarians and nematodes. If the vertebrate limbs may be compared to budded units recalling certain highly reduced and specialized units in tunicates or polyzoans, the comparison is complete.

In these various recombinations of structural features leading to greater and greater structural complexity, numerous secondary features, such as visual and other sense organs, appendages of different kinds, diverticula and other outgrowths from the enteric canal, chitinous and calcareous skeletons, and others, became enormously developed and specialized in correlation with the increasing bodily efficiency resulting from the progressive improvement in the structural balance.

In this exposition of the development of the fundamental animal forms—of the original type representing each of the major groups or phyla—no claim is made that the last word has been spoken in regard to the placing of each phylum in relation to the others. But it is believed that the diagrammatic representation here given is in all essential features correct.

There can be no talk of any direct relationship between the adult forms in one phylum and the adult forms in any other. There is not now, and we have no evidence that there ever was, any intergradation between the phyla as represented by post-embryonic forms.

All of the evidence points to the origin of the phyla through modifications of the regular geometrical developmental course which took place in the gastrula, or approximately at the gastrula, stage, each departure from the regular course resulting in a different bilateral animal form.

This means that all animal types arose through various recombinations of features which are already present in the gastrula, and further that the animal types differ from each other not by the addition of certain features but, on the contrary, by the subtraction or repression of a varying number of the features which are inherent in, or an integral part of, the perfect gastrula, this subtraction or repression of certain features causing others to stand out with special prominence.

According to this hypothesis the most highly perfected animal types are the protozoans, the cœlenterates, and the vertebrates.

In the radially symmetrical cœlenterates the gastrula passes with the least possible change into an adult form. As the adult cœlenterate represents a gastrula which is only slightly modified and has lost relatively little of its inherent plasticity, we naturally see in the cœlenterates as a group such features as asexual reproduction by budding and by fission, colony formation, diversification of polyps in a colony, reparation, sexual reproduction by larvæ, and variation in individual and colonial form developed to an extent far beyond anything seen elsewhere in the animal world. The persistence of features inherent in the gastrula seems to be the only reasonable explanation for the extraordinary diversity so characteristic of this enormous and important group of animals.

In the vertebrates all of the features inherent in the gastrula are again present, but they are present in a very highly modified and static form as a result of the extensive and intricate changes which have taken place during the development of the individuals. The vertebrates therefore are so very delicately balanced, both in respect to their internal mechanism and reactions and in regard to their external contacts, that they have retained none of the plasticity characteristic of the gastrula, or of the cœlenterates. They are incapable of asexual reproduction, of colony formation, of extensive reparation of lost parts, or of assuming any great variety of form.

Structurally the least perfect animal types are those included in the Vermiformes, because each of these types lacks the maximum number of the features inherent in the gastrula. But the sum total of the features found widely distributed in the Vermiformes as we know them would be essentially the equivalent of the features found in the cœlenterates.

Such a concept of the development of animal life may be illustrated by comparing the primitive gastrula to a rosebud. As the rosebud opens the petals unfold and grow out to their full size. Each petal may be taken to represent a separate developmental line running from the gastrula to one of the major groups, which itself would be represented by the petal's outer edge.

All the available facts lead to the conclusion that the major groups of animals appeared simultaneously, or nearly so, in essentially the same form as that in which we know them now by a process of *concurrent evolution*. Furthermore, the animal world, taken as a whole, forms a closely unified entity, and the more we study animals the more clearly do we realize that this is true.

APPENDIX B

THE MAJOR GROUPS OF ANIMALS

Vertebrata—*the backboned animals.*—This very large group includes the mammals, birds, reptiles, amphibians and fishes which together are represented by about fifty thousand different species. The structure is very complex, and the size ranges from a length of 110 feet in the great blue whale as found in the Antarctic down to about three-quarters of an inch in the smallest adult fish. But all vertebrates are relatively large, and the average size is far larger than in any other group. Vertebrates are found everywhere, in every region and from the highest mountain tops down to the ocean floor. The animal from the greatest depth in the sea at which animals have been found (19,806 feet) is a fish. Most vertebrates live on land. The fishes, however, live chiefly in the sea; also living and breeding in the sea are the whales, except for a few fresh water dolphins in South America and Asia, and the sea-snakes. (Fig. 2, p. 5.)

Cephalochorda—*Amphioxus* (*Branchiostoma*) *and its allies.*—This is a very small group including only a few species which look like small colorless semitransparent fishes headless and pointed at each end. They live partially buried in sand. They are found only in the sea in shallow water and at moderate depths, and are widely distributed, though very local.

Balanoglossida.—A small group confined to the sea wherein they are very widely distributed. Like sponges, they have a disagreeable and usually strong smell which sometimes imparts a flavor to the fishes that feed on them. (Fig. 94, p. 175, young.)

Cephalodiscida.—A very small group including a very few species of two quite different types (*Cephalodiscus* [fig. 61, p. 111] and *Rhabdopleura* [fig. 63, p. 111]). They are found only in the sea in shallow water and in water of moderate depth and are widely distributed, though apparently very local.

Tunicata—*the sea-squirts, sea-peaches, pyrosomas and their relatives.*—This is a large and highly diversified group entirely confined to the sea. The various species are found in all seas at all depths, but most of them live in shallow water. Some live attached to the bottom, while others float freely in the water.

Many are colonial, forming incrustations on rocks or long chains or hollow cylinders which float about suspended in the water. Some of the bottom living types are raised on a long slender stalk. In many the tough outer covering is largely composed of cellulose, a substance especially characteristic of plants. Many are very brilliantly phosphorescent. (Figs. 56–59, p. 111.)

Phoronidea.—A very small group including less than ten species, found only in the sea where they are widely distributed, but very local. (Fig. 102, p. 175, young.)

Sipunculoidea.—A small group, entirely marine, but very widely distributed.

Mollusca—*the mollusks.*—A very large and much diversified group including the snails, slugs, clams, oysters, shipworms, sea-butterflies, squid, octopus, nautilus, and many other types, which are represented by a total of about fifty thousand species. Most mollusks live in the sea where they are especially characteristic of shallow water; but a few are found in very deep water and some in fresh water and on land, occurring even above the snow line in the Himalayas. A number are parasitic, a few in the larval stage only; others as adults are internal parasites, lacking a shell and a digestive system. (Figs. 33, 34, p. 55; 45–52, p. 97; 74, p. 127; 95, p. 175.)

Annelida—*the jointed worms.*—A large and much diversified group including the earthworms, sea-worms, etc. Most of the jointed worms live in the sea, but the earthworms and the onychophores (*Peripatus* and its allies) live on land, and quite a number, mostly allied to the earthworms, live in fresh water. Some are free swimming, others live in mud or sand or in holes in rocks or coral heads, and many construct limy or horny and quill-like tubes. Many live in the cavities of sponges, and one of these is branched, with a head on the end of every branch. A few marine forms are parasitic, some being internal parasites, chiefly in echinoderms. (Figs. 65, p. 111; 84, 85, p. 161; 104, 108, p. 175.)

Brachiopoda—*the lamp-shells.*—A small group including about 170 species all of which live in the sea mostly in shallow water or in water of moderate depth; but a few live in very deep water. (Fig. 60, p. 111.)

Arthropoda—*the jointed-legged* (literally, *footed*) *animals.*—This group includes the insects, spiders, scorpions, mites, crustaceans (crabs, shrimps, lobsters, barnacles, sow-bugs, beach-fleas, water-fleas, etc.), and various other types. The number of included species—roughly six hundred thousand of which about twenty thousand are crustaceans—is vastly greater than the number included in all the other animal groups taken together. But in spite of this the uniformity in the general structure is so very great that the members of the group are always readily recognizable, usually throughout their lives, or at least in the adult or first stages. Arthropods are found everywhere on land and in fresh water, and down to the greatest depths in the oceans. Most of them are free-living, but very many are parasitic, usually on other arthropods, but also on vertebrates and other creatures, both on land and in the sea. Some of the so-called parasitic barnacles can be recognized as arthropods only in the early stages, the adults becoming almost or quite structureless. (Figs. 1, p. 5; 7–16, p. 21; 17–23, p. 33; 24–30, p. 47; 31, 32, p. 55; 64, p. 111; 91–93, p. 175; 100, 101, p. 175; 129, 131–133, p. 203.)

Echinodermata.—This large group includes the starfishes, brittle-stars, sea-urchins, holothurians or sea-cucumbers, crinoids or sea-lilies and feather-stars, and the extinct blastoids and cystideans. Echinoderms are found only in the sea, where they are represented from between tide marks down to the greatest depths. They are especially characteristic of deep water. (Figs. 6, p. 5; 35–38, p. 55; 41, 42, p. 71; 43, 44, p. 87; 88, 89, 109, p. 175; 120, p. 185.)

Nemertea.—A moderate sized group including species which are found mostly in the sea, though a few live in fresh water and some on land. In the sea they live chiefly on the bottom, in mud and especially under stones or other objects lying on mud. But some live exposed, and a few others are free floating. Most of them have the most extraordinary power of elongating and contracting the body. Some break to pieces with the greatest facility, each piece later developing into a complete individual. They are all carnivorous. (Fig. 106, p. 175, young.)

Chætognatha—*arrow-worms*.—A small group living wholly in the sea, found everywhere in shallow or moderately deep water. They are transparent in life, appearing like small thin glassy fishes. They live freely suspended in the water. (Fig. 62, p. 111.)

Priapuloidea.—A very small group wholly confined to the sea, wherein it is widely distributed.

Rotifera—*rotifers or wheel-animalcules*.—A large group of universal occurrence in fresh water, but represented by only a few species in the sea. Many of them are able effectively to protect themselves when the pools and ponds dry up, and many can survive heat almost as high as the boiling point. With the drying up of water the encapsuled rotifers and their eggs are blown about and very widely scattered. Because of the great facility with which they are distributed by winds, rotifers are always to be found in water which has collected in sagging gutters, in the axils of epiphytic plants on telephone wires or high up in the trees—in fact anywhere that water collects and stands for a few days. Many kinds of rotifers may be obtained by letting marsh hay or even bark from trees in moist localities soak in water for a week or so. Even bark from logs that have been stored for some time in a cellar will sometimes yield rotifers. They always appear in aquaria, and usually in goldfish bowls. A few rotifers are parasitic, living in the intestines of earthworms, in the canals of fresh water jellyfishes, in the body cavity of sea-cucumbers, on crustaceans, and elsewhere. (Figs. 134, 136, p. 203.)

Polyzoa—*moss animalcules*.—A large group almost entirely marine, occurring from between tide marks down to the deepest portions of the sea, though most abundantly represented in shallow water and in water of moderate depth. One section of the group, and a few species in another section, live in fresh water. Most polyzoans form moss-like, leaf-like, fan-like, vine-like, or simply encrusting colonies; but a very few species are solitary. The most conspicuous fresh water type forms large jelly-like masses, usually in late summer, about sticks or other supports. In one fresh water type the colony as a whole crawls about like a worm. (Figs. 67, 68, p. 111; 90, p. 175.)

Vermiformes.—A very large and exceedingly diversified group including the tapeworms, flukes, turbellarians, spiny-headed worms, nematodes or thread-worms, gordian worms or "hair-snakes," and various other types. Most of the species are internal parasites in other animals, a few are external parasites, some live in plants, and some are free living, these last occurring in the sea, in fresh water, and in moist earth. Some are parasitic at one stage and free living at another, and many are parasitic in one type of animal in the young stages and in a wholly different type of animal as adults. They may develop directly from the egg, or they may pass through one, two, or several larval forms. The most familiar examples are the tapeworms, the hook-worms, various "worms" affecting children, dogs, cats, cattle, etc., the "vinegar-eels," the "wafers" of oysters, and the "hair-snakes" seen wriggling in pools and troughs in summer, which in the young stages are parasites in insects. (Figs. 5, p. 5; 54, 55, p. 97; 81–83, p. 161; 96–99, p. 175; 126–128, p. 185; 130, p. 203; 135, p. 203.)

Ctenophora—*sea-walnuts, the Venus' girdle, etc.*—A fairly large group found only in the sea, more especially in the warmer waters. The ctenophores are nearly all free-swimming and are most abundant below the surface zone, but occasionally appear in great numbers at the surface. A few of them are elongated, flattened and worm-like and creep about on objects on or growing from the sea floor. Most of them are transparent and as clear as glass, the vibratile plates showing a beautiful play of iridescent colors. A few are more or less deeply colored, usually pink or red. (Fig. 66, p. 111.)

Cœlenterata.—A very large and very highly diversified group including the sea-anemones or animal-flowers, the hydras, the hydroids, the sea-pens, the sea-fans, the corals, the millepores, the gorgonians, the antipatharians, the alcyonarians, the jelly-fishes, the ctenophores, and various other types. Most of the cœlenterates are marine, living in shallow water or in water of moderate depth, but many are found in very deep water and a few in fresh water, the best known of these last being the hydras and the little fresh water jellyfishes which are so curiously erratic in their occurrence. Many cœlenterates are solitary, like the hydras and the sea-anemones, but most of them form bush-like, tree-like, wand-like, fan-like, mushroom-like, feather-like, en-crusting, or solid and massive colonies. Many form semi-transparent or beautifully and delicately colored free-floating colonies, of which the Portuguese man-of-war is an example. Some kinds are only found in association with other animals, particularly crabs (fig. 27, p. 47) and annelids, while a few are parasitic on other cœlenterates, on fish-eggs, etc. (Figs. 3, 4, p. 5; 69–73, p. 127; 75–80, p. 143; 103, 105, 107, p. 175; 110–119, p. 185.)

Porifera—*sponges.*—A large and much diversified group with the body mass encrusting, cushion-shaped, cup-shaped, saucer-shaped, globular, tubular, rod-shaped, leaf-like, trumpet-shaped, fan-shaped, mushroom-shaped, lobed, branched or digitate, sessile or raised on a long stalk, etc. Almost all sponges contain a supporting skeleton which may be limy, or silicious, or horny, or silicious and horny, and is usually exceedingly complex. Nearly all sponges are marine, living at all depths. Some types are especially characteristic of deep water. But a few kinds of sponges live in fresh water. All sponges when alive possess a strong and disagreeable odor. The common bath sponge is the cleaned skeleton of one of the horny sponges, and the "Venus' flower basket" is the cleaned skeleton of one of the silicious sponges. (Figs. 121–124, p. 185, development.)

PROTOZOA—*the single-celled animals.*—Very small, usually microscopic, animals, forming an enormous group, which is the most highly diversified of all the groups in the animal kingdom. More or less familiar examples are the foraminifera, to which we owe the great chalk deposits, the radiolarians, the infusorians, the gregarines, the sporozoans, etc. They are found everywhere in the sea and in fresh water, more or less throughout the bodies of all other creatures, and everywhere on land. In a special drought-resisting resting stage, many kinds are blown about over the land and lodge in quantities even on the topmost twigs of the tallest trees. If bits of bark or hay or dead leaves be placed in water they will appear in a day or two, and soon the water is swarming with them. Some of those that can be secured from the bark of fire logs are large enough to be seen with the naked eye, and many may be seen with a low power lens. Very many live upon or within the bodies of other creatures. Crustaceans are sometimes almost completely covered with a veritable forest of stalked forms, while others wander about over the surface of sea-urchins and other sea animals. Our bodies always contain many thousands of various harmless kinds. But very many are dangerous parasites, causing malaria and other diseases in man, Texas fever in cattle, etc. On the other hand, some are indispensable. Thus in the case of the termites or white-ants the cellulose swallowed is broken up not by the digestive processes of the insects, but by the intervention of various protozoans in their intestinal canal, and the termites digest the substances thus made available for them. Reproduction in the protozoans is commonly by division of the body into two equal parts, but in some by the formation of buds which become detached, by the breaking up of the body into "spores," or by other means; there is, however, never any reproduction through the formation of special sexual cells as in all other animal types. (Figs. 53, p. 97; 87, p. 161.)

The broader features of the interrelationships between the major groups may be appreciated by a study of the following key, bearing in mind that very many important structural characters are not mentioned in the key.

Key to the Major Groups of Animals

a^1 Body composed of a vast number of cells
b^1 body with definite organs and structures
c^1 symmetry completely, or almost completely bilateral; body with a dorsal and ventral surface, and the two halves on either side of a plane passing through the mid-line alike
d^1 no trace of radial symmetry
e^1 with a vascular system
f^1 with a body cavity; no protrusible proboscis the sheath of which runs the whole length of the body
g^1 no water vascular system
h^1 body never completely ensheathed in a tough or hard segmented external skeleton; jaws never formed of modified legs
i^1 body not enclosed between a dorsal and ventral shell; if enclosed between shells (as in some mollusks) these are left and right
j^1 with a notochord, a hollow dorsally placed nervous system, and a pharynx opening to the exterior by lateral passages
k^1 notochord extending practically the full length of the body; body segmented
l^1 dorsal nerve cord extending for some distance in front of the notochord, and expanded at its anterior end into a brain; anterior portion of the axial skeleton forming a skull enclosing the brain VERTEBRATA

*l*² notochord extending forward in front of the nerve cord; no skull; no true brain

CEPHALOCHORDA

*k*² notochord not extending the full length of the body; body not segmented

*l*¹ notochord confined to the anterior portion of the body; body with three divisions, the proboscis, the collar and the trunk

*m*¹ elongated and worm-like; collar not produced; alimentary canal a straight tube; without asexual reproduction; free living, inhabiting burrows in sand or mud

BALANOGLOSSIDA

*m*² body not worm-like; collar region produced into one or more pairs of tentaculiferous arms; alimentary canal U-shaped; reproducing asexually by budding; inhabiting tubes secreted by the animals themselves

CEPHALODISCIDA

*l*² notochord confined to the hinder portion of the body, and usually absent in adults

TUNICATA

*j*² no true notochord; nervous system ventral, and not hollow; no lateral openings from the pharynx to the exterior

*k*¹ unsegmented; no chitinous bristles or setæ on the body

*l*¹ no ventral foot, mantle-fold or shell; mouth associated with a series of hollow ciliated tentacles arranged in a circle, horseshoe, double horseshoe or double spiral; no special sense organs; elongated and worm-like

*m*¹ perivisceral cavity divided into three intercommunicating chambers; no horny structures on anterior portion of body; inhabiting tubes secreted by themselves and covered with foreign materials

PHORONIDEA

*m*² body cavity very large and undivided; anterior protrusible portion of body often covered with rows of horny hooks or with small imbricating scale-like papillæ

SIPUNCULOIDEA

*l*² with a ventral foot, and usually a mantle-fold, and a univalve or bivalve shell; no hollow ciliated tentacles about the mouth, which is commonly provided with very numerous teeth set in a radula, or a beak; various special sense organs present; very rarely elongated and worm-like

MOLLUSCA

*k*² body divided into numerous segments and usually much elongated; ventral nerve cord almost invariably with a swelling or ganglion in each segment; almost invariably with chitinous setæ or bristles embedded in and secreted by pits in the skin

ANNELIDA

*i*² body enclosed within a pair of shells, one of which is dorsal and the other ventral

BRACHIOPODA

*h*² body completely enclosed in a usually tough or hard segmented external skeleton; with jointed legs, and usually other jointed appendages, in the young or adult, or in all stages; jaws formed of modified legs

ARTHROPODA

*g*² a complicated water-vascular system, derived from the cœlom, present; body in the adult more or less perfectly radial, usually in five divisions, but bilateral in the younger stages; body wall with abundant calcareous deposits usually forming plates which generally bear spines

ECHINODERMATA

*f*² no body cavity; a protrusible proboscis lying in a sheath running the whole length of the animal on the dorsal side of the intestinal canal

NEMERTEA

*e*² without a vascular system

*f*¹ mouth armed with chitinous teeth or stout bristles; size moderate; no asexual reproduction of any kind

*g*¹ body fish-like, with fins, divided internally into three segments; cœlom highly developed, with three pairs of chambers separated by transverse septa; both sexes in the same individual; pelagic

CHÆTOGNATHA

g^2 body worm-like, unsegmented, with a spacious undivided body cavity not connected with the excretory or generative organs; living on the bottom in sand or mud; sexes separate

PRIAPULOIDEA

f^2 with a complicated generally retractile ciliated apparatus in connection with the mouth, used in the gathering of food; size very small; abundant asexual reproduction

g^1 ciliated apparatus consisting of cilia about the mouth in the form of a ring, or in lobes or various patterns; asexual reproduction by unfertilized eggs only; sexes separate and usually very different; solitary, though sometimes social

ROTIFERA

g^2 ciliated apparatus consisting of a circular or horseshoe-shaped crown of ciliated tentacles with the mouth in the middle; always with asexual reproduction by budding, sometimes also by the formation of "statoblasts" or by fragmentation of the larvæ; usually both sexes in the same individual; almost always colonial, forming plant-like colonies

POLYZOA

d^2 with definite traces of radial symmetry (superposed upon the bilateral) in the nervous system, the digestive system, or the anterior end

VERMIFORMES

c^2 individual animals entirely, or almost completely, radially symmetrical, like a flower, with tentacles or other processes about the edge of the large central cavity, which is bounded by solid walls

d^1 body divided into quadrants, with two axes, a long and a short, at right angles to each other; eight rows of vibratile plates formed of fused cilia; two tentacles or none; no stinging cells; never colonial; no asexual reproduction; mesoderm present

CTENOPHORA

d^2 body radially symmetrical about the central axis only; if the body is in fours, the crossed axes are of the same length and the quadrants are alike; no vibratile plates; four or more tentacles, lobes, or other processes present; stinging cells always present; always with asexual reproduction, at least in the young stages; no mesoderm

Cœlenterata

b^2 no definite organs or structures; body a solid mass of very varied form pierced by innumerable small holes which lead into a system of canals running together and eventually leading into the exterior by one or several large openings

Porifera

a^2 Body composed of a single cell, or the equivalent of a single cell

Protozoa

The relationships between the different animal types are of two sorts, differences and resemblances, and the successful division of the animal types into phyla is dependent upon the proper appreciation of the relative importance of the differences and the resemblances.

The potentialities of an animal form as an effective mechanism are largely dependent upon the basic symmetry of the form. The basic animal symmetries therefore should be regarded as the dominating factors in animal morphology to which all other factors are subordinated.

In the animal world there are five distinct types of symmetry (fig. D, p. 250). These five types of symmetry are characteristic of (1) all germ cells and all protozoans at some stage in their life history; (2) the Cœlenterata; (3) the Ctenophora; (4) the Vermiformes; and (5) all other types of animal life.

The symmetry of the single celled animals or protozoans is based primarily on the symmetry of the sphere—that is, a symmetry radiating equally in all directions from a central point. But this ideal symmetry is maintained, or closely approached, in only a very few types most conspicuous of which are certain heliozoans and radiolarians.

The symmetry of the sponges is based upon a mass production of cells which do not become segregated into definite organs.

Sponges, therefore, cannot develop any very definite symmetry, or a head end. Having no possibility of developing organs of locomotion or for the prehension of prey they must remain throughout their lives attached and are forced to find their support through the development of an efficient mechanism for straining minute organisms from the water. No other type of existence is possible for them. When viewed at right angles to the plane of attachment sponges are always more or less circular—or rather irregularly circular.

The symmetry of the cœlenterates is always a modification of a hemisphere—a sphere with one side pushed in forming a double-walled hemisphere. The cœlenterates are therefore radially symmetrical. This radial symmetry renders them incapable of effective locomotion in any definite line, since their sense organs and nervous system are arranged in a circle lying in a plane at right angles to the central axis and at some distance from it—that is, about the periphery of the open pole of the hemisphere. But this circular arrangement of the sense organs and nerves rendering every sector of the animal as alert and as efficient as every other sector peculiarly fits the cœlenterates for remaining fixed in one place and reaching out and capturing the organisms in the water about them. Most of them feed upon other animals of considerable size. They are by far the most successful and the most numerous of the fixed animals. They are also fairly successful as free-swimming animals. Not a few of them are very large. Some of the attached gorgonians reach a height of fifteen feet, and one of the common jellyfishes of northern seas reaches a width of seven and a half feet across the bell, from which depend tentacles more than one hundred and twenty feet in length.

The ctenophores are commonly regarded as representing a section of the Cœlenterata. They were separated from the Cœlenterata as a distinct phylum by the present author in 1921. They differ markedly from the cœlenterates in various significant ways, especially in their symmetry, in the presence of mesoderm, in the entire absence of asexual reproduction and therefore of colony formation, and in the absence of stinging cells. The ctenophores have two body axes, one long and one short, crossing each other in the middle at right angles. The two halves of the body on either side of these two axes are alike. The body is thus divided into quadrants, the quadrants diagonally opposite each other being alike, and reversed or mirror images of the two with which they are paired. This cross symmetry permits the development of a greatly elongated body, such as we see in the Venus' girdle (*Cestus*) and to a lesser degree in the creeping forms. But no matter what the form of the body may be, the center of the animal is always the axis passing through the intersection of the crossed planes, and all the radii are always alike on either side of this axis. So the elongated ctenophores are always double ended with the head, so to speak, in the center of the body. This cross symmetry is not adaptable to the requirements of a fixed existence, so the ctenophores are all free swimming or creeping creatures. But their locomotor powers are limited because of the similarity of the two sides of the body on either side of the median plane. Because of the mechanical limitations imposed by their unique symmetry the ctenophores are much less numerous in species than the cœlenterates, sponges or protozoans.

The several animal types here grouped under the Vermiformes are usually distributed among several different phyla because of the great differences in bodily structure that they show. There is no denying the fact that these differences are important. At the same time there is no denying the equally obvious fact that all these creatures agree among themselves and differ from all other animals in possessing a symmetry which is in part radial and in part—generally for the most part—bilateral. Thus in the tapeworms the head or scolex is commonly (though not always) radially symmetrical with four equal sectors. In the spiny-headed worms (Acanthocephala) which have by some authors been associated with the tapeworms, by others associated with the nematodes, and by still others regarded as quite without close relatives, the anterior end is radially symmetrical. In the turbellarians the mouth is on the ventral surface at, in front of, or behind the middle, and the digestive cavities commonly radiate from the base of the pharynx. Various transition forms unite the turbellarians with the wholly parasitic flukes or trematodes. In the trematodes the mouth is always at the anterior end and usually leads into a forked intestine. The nervous system, however, is radially arranged, consisting of six longitudinal cords, two ventral, two dorsal and two lateral, all of which are connected by transverse anastomoses. There are various types which intergrade between the trematodes and the tapeworms. As the spiny-headed worms are now considered to be more or less closely related to the tapeworms, it is evident that the union of the tapeworms, spiny-headed worms, flukes and turbellarians in a single phylum is a logical disposition of these groups. The nematodes or thread-worms, however, seem at first sight to have very little in common with any one of these groups. They have been generally associated with the spiny-headed worms and the gordian worms in the phylum Nemathelminthes. The nervous system of the nematodes consists of a ring about the gullet from which six anterior and six posterior trunks arise. There are also other suggestions of radial symmetry. These traces of radial symmetry are the only features which definitely align the nematodes with anything else. The nematodes entirely lack ciliated tissue, all of them molt, at least in the young stages, most of them possess a spinneret, many are more or less sharply and distinctly segmented externally, and some have segmented appendages as in the arthropods and some rotifers. But the differences between the nematodes, the arthropods and the rotifers are much greater than the resemblances. The characteristic nematode features seem in a most extraordinary way to supplement the features found in the tapeworms, flukes, etc., thus indicating that the Vermiformes as here understood is really a natural group.

The gordian worms or "hair-snakes" which have essentially the body form of nematodes but are otherwise very different, are radially symmetrical at the anterior end in the larval stage. We may regard the tapeworms, spiny-headed worms, flukes, turbellarians, nematodes and gordian worms as wholly anomalous and without any affinities to each other or to anything else—each as a sort of zoological accident—or we may regard the occurrence in all of them of traces of radial symmetry as significant and as showing that they differ equally from the radially symmetrical animals on the one hand and from the bilateral animals on the other. We cannot adopt the former alternative without implying a lack of order in the animal world, which is an inconceivable assumption. The only reasonable course is to accept the latter alternative and to consider all these creatures collectively as representing a rather heterogeneous phylum intermediate between the radially symmetrical cœlenterates and the more complex bilaterally symmetrical animals.

Except for those just mentioned, all the animal phyla include only forms which are bilaterally symmetrical. The echinoderms appear to be radially symmetrical, but the radial symmetry is far from perfect, and they are always bilateral in the young stages.

In the preceding key the characters used in separating the various phyla of bilaterally symmetrical animals are the most obvious or the most easily understood, but not necessarily the most important.

It is generally agreed that the supporting rod known as the notochord is a very important structural feature, so that the use of its presence or absence in separating the Vertebrata, Cephalochorda, Balanoglossida, Cephalodiscida and Tunicata from all the other phyla can scarcely be questioned.

The Vertebrata differ from the other four groups in having a definite skull (they are therefore often called the Craniata), in having the notochord surrounded by a stiff sheath and almost invariably divided up into segments which correspond with those of the embryonic muscular system, forming the "backbone," and in almost invariably possessing a movable jaw and two pairs of limbs.

In the key they are paired with the Cephalochorda solely because the latter in their general appearance resemble fishes far more than they do anything else. But the Cephalochorda are undoubtedly more closely related to the Tunicata, Balanoglossida and Cephalodiscida—especially to the first named—than they are to the Vertebrata.

Regarding the groups from the Phoronidea to the Polyzoa inclusive there is no agreement among zoologists as to what the most important structural features are, or as to what the actual interrelationships between the groups may be.

EXPLANATION OF THE FIGURES

Illustrations of Animal Symmetries (Page 5)

Fig. 1.—A bilaterally symmetrical animal, with the two sides—right and left—of a plane passing through the middle of the body alike. The European spurge hawk-moth (*Deilephila euphorbiæ*).

Fig. 2.—A bilaterally symmetrical animal. A curious fish (*Halieutella lappa*). From Gill, after Goode and Bean.

Fig. 3.—A radially symmetrical animal—eight similar sectors surround the central axis. A jellyfish (*Discomedusa philippina*) from the Philippines. From Mayor.

Fig. 4—An animal with "biradiate" symmetry—that is, with radial symmetry modified by the elongation of the central mouth into a slit. A sea-anemone (*Polysiphonia tuberosa*) dredged from a depth of 3,390 feet. From the *Challenger* reports.

Fig. 5.—A jointed or segmented tapeworm (*Tænia macrocystis*) from a wild-cat. The head, or "scolex," is radially symmetrical (four sided) but the body is bilaterally symmetrical. From Hall.

Fig. 6.—Pseudoradial symmetry. The body is divided into five almost precisely similar parts, but the internal organs are not all radially symmetrical, and the young are bilaterally symmetrical. A sea-lily or crinoid (*Ptilocrinus pinnatus*) from a depth of 9,528 feet, originally described by the author.

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Fig. 10.—The cotton-boll weevil (*Anthonomus grandis*) with wings extended. Courtesy of the Department of Agriculture.

Fig. 11.—The grape leaf-hopper (*Typhlocyba comes*). Courtesy of the Department of Agriculture.

Fig. 12.—A whip-cracker butterfly (*Ageronia fumosa*).

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Sans Tache

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Sans Tache

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