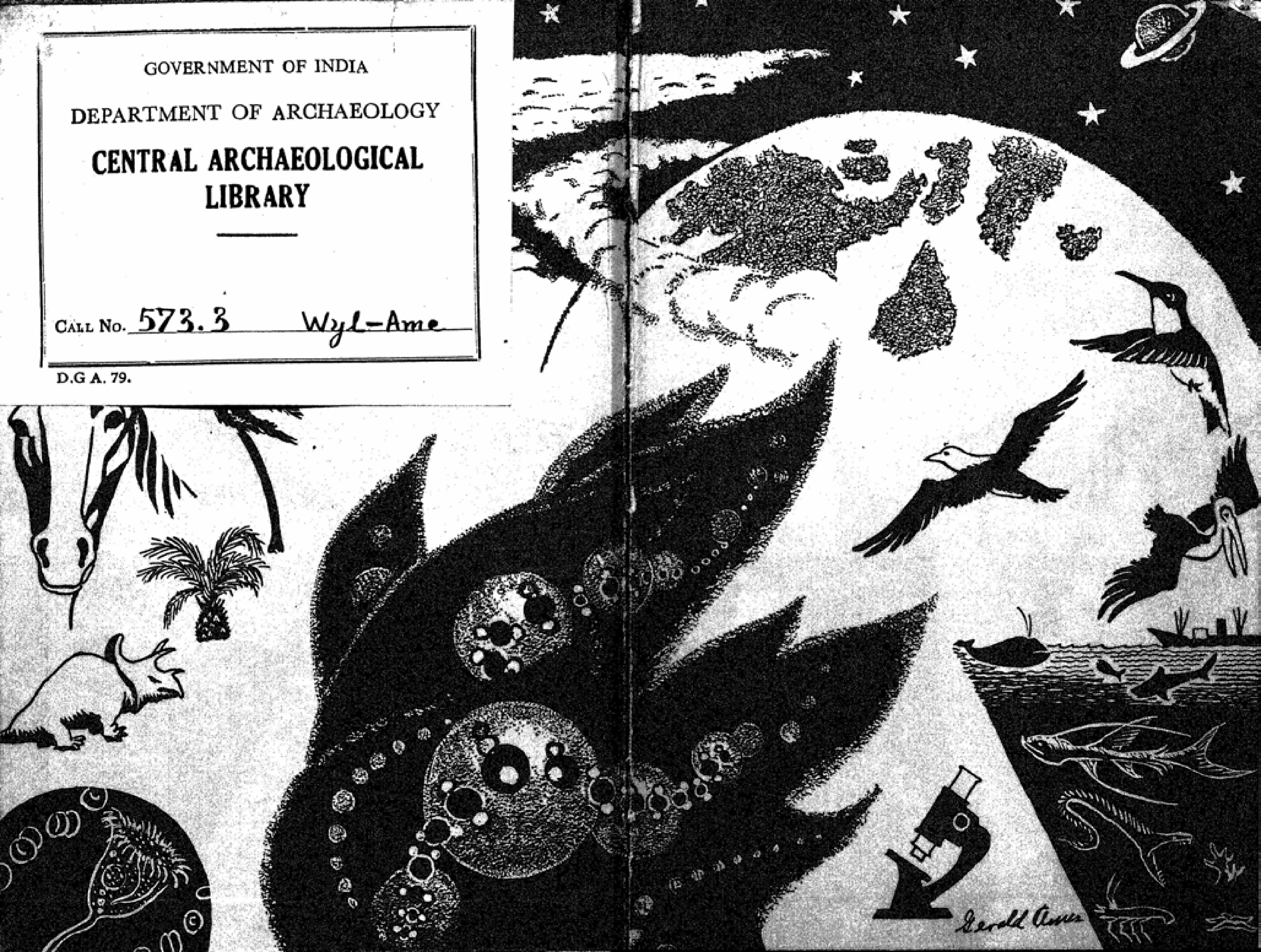
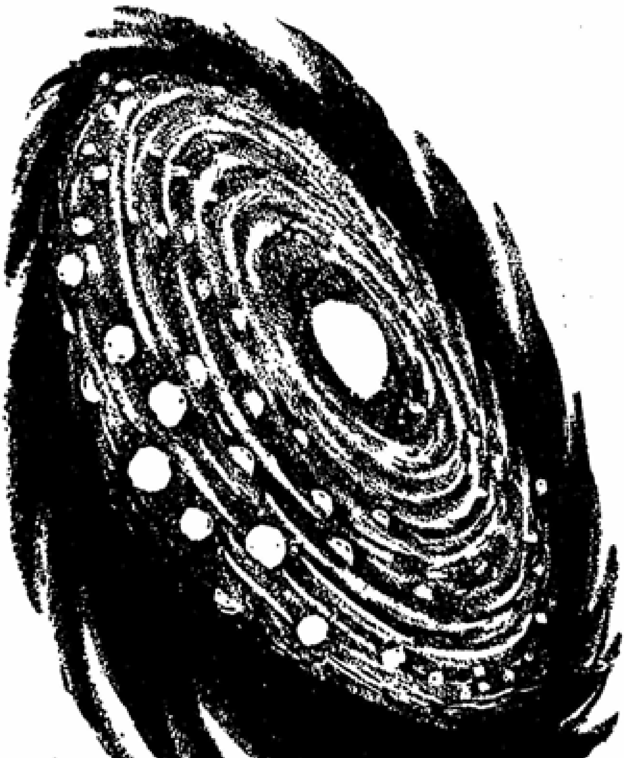

Gerald Ames

Life on the Earth



ILLUSTRATIONS BY GERALD AMES

LIFE ON THE EARTH

ROSE WYLER AND GERALD AMES

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FOREWORD

Several thousand years ago, before there were cities, people fed themselves by hunting and fishing and by gathering plants. They felt that their life was bound up closely with the life of the wild species they ate.

In later times, when people cultivated plants and bred animals, they wondered how the food species came into existence, and how all things live.

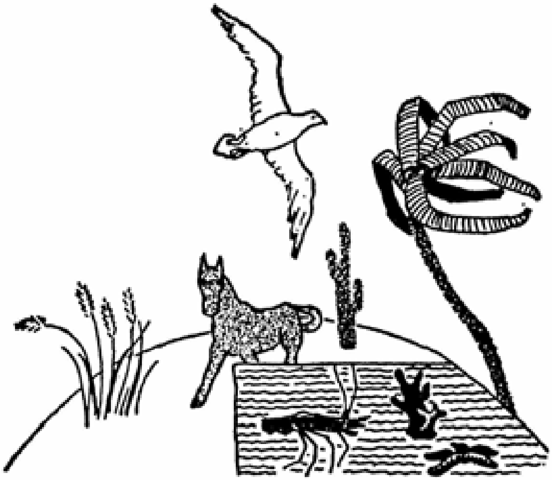
No real answers to these questions were found until the last few centuries, after scientists devised new methods of study and invented instruments with which to examine living bodies.

In this book we look into the discoveries of the modern "science of life"—biology. In our search we shall meet a number of interesting species, but we shall not be mere tourists among them. We are scientific-minded people. We wish to know as well as we can: In what ways are plants and animals and men alike? How do they keep alive? What is life? How did life begin?

Life
on
the
Earth

· CHAPTER *I*

LIVING THINGS AND THEIR · HOMES



All the living things known to us inhabit a thin film around the surface of the earth. The bottom of this zone of life is the ocean floor, where some creatures manage to exist at a depth of a few miles. Other plants and animals live on mountains almost as far above sea level as the ocean floor is beneath it. But the tallest peaks are forbidden places where no living things are known to dwell.

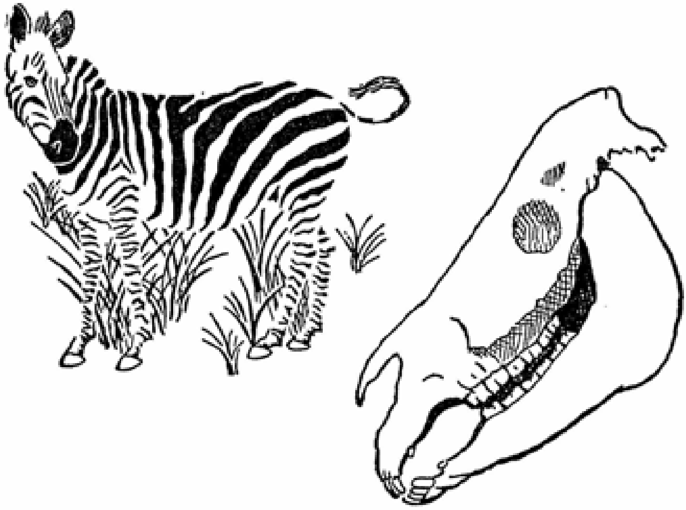
Men, with their planes, fly higher than the eagles. Mice have been shot in rockets to a height of forty miles and have parachuted to the ground unharmed. But mice and men can go that high and survive only because they are closed up in a capsule of breathable air. They cannot dwell at great heights. They invade the heights for a brief time and return to live on the surface of the planet that gave them birth.

• THE ZONE OF LIFE

Above sea level, some five miles of land and air are habitable, and the deepest ocean floor is six or seven miles beneath the surface of the sea. The combined height and depth of these layers make up only about twelve miles, a distance a person can walk, on level ground, in a morning.

Within this shallow film, a host of living things flourishes. Biologists have named almost a million species, and we do not know the number of unnamed plants and animals. Some living things are mere specks that can be seen only under the microscope. At the other end of the size scale is the North American redwood tree, which rises to the majestic height of three hundred feet. Size is not everything, however. The redwood is confined to such a small area that it could easily be wiped out by a change of climate or by fires. Microscopic plants of the sea, on the other hand, are quite secure for their home is the world-wide ocean.

A species can flourish if it is equipped to live in its environment and if the environment is suitable to the species. The zebra, for example, gets along very nicely on the grass-covered plains of South Africa. The climate of the veldt, as the plains are



called, is just right for grass—rather dry, but not too dry. The veldt has the grass; the zebra has a wonderful set of teeth for chewing grass, and his stomach and intestines work efficiently in drawing food material from it. The zebra is "fitted" or "adapted" to the veldt and the veldt is fitted to him.

• THE DESERT

An environment must have water, the first essential of life. The bodies of all plants and animals are more than half water. Our own bodies are about 63 per cent water by weight, and the percentage is higher in most other living things. Jellyfishes are as much as 98 per cent water. Plants and animals must obtain all their body fluid from the environment. If there is little water in an environment, there can be little life. Just a few kinds of living things can exist in dry regions.

If we consider the plants and animals that manage to live in deserts, we find they are especially adapted to get along on a short supply of water. Among plants, many species simply die during the driest periods, and leave behind them seeds incased in a tough capsule. Months or even years later, rain comes, the seeds grow into plants, the plants quickly flower and bear a new generation of seeds, then die in turn, leaving behind them their own seeds.

All plants, as they function, give off moisture. In most land plants, the moisture passes out through the surfaces of the leaves. The larger the green surface, the greater the loss of water. An oak in full leaf may lose many barrels of water a day.

No tree can exist in a desert for a tree uses up too much water. The problem of desert plants is to keep down the amount of surface from which water evaporates. Leaves therefore are few and small. Many cactuses have no leaves at all.

The barrel cactus, which grows in the desert regions of North America, is an expert at keeping down its amount of surface. It has no leaves; it does not spread out in wide, flat surfaces. It is thick and squatty and in this shape has a small surface area for its bulk. In addition, the surface is constructed in a way to conserve moisture. In the leaves of other plants, there are thousands of little pores that discharge moisture. In the cactus, the pores are fewer and they can close up tightly, thus holding down the loss of water.

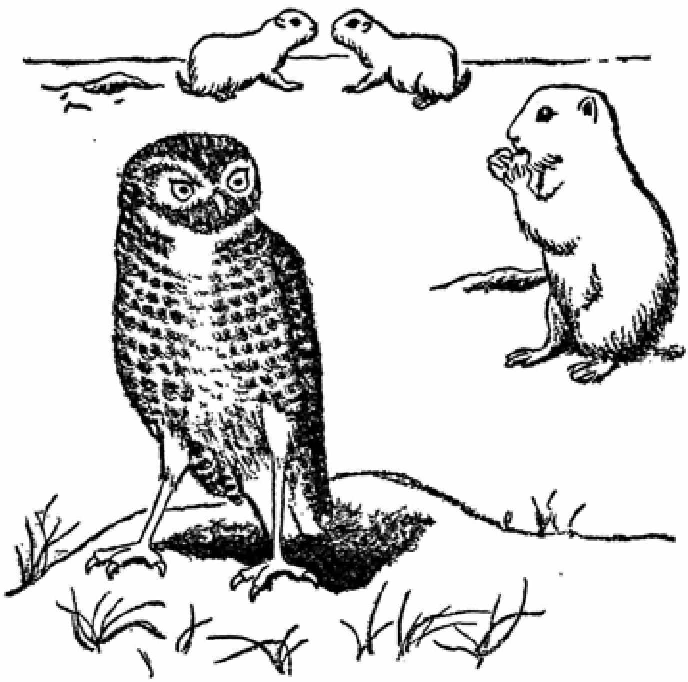
Outside, the barrel cactus may be as dry as dust, but, inside, it is a reservoir holding gallons of water, which the plant uses as needed. Thirsty animals tap the cactus for water, if they can. But unfortunately for them, the cactus guards itself with an array of sharp spines.

All these features of the cactus—its shape, its limited surface, its surface structure, its spines—are adaptations that fit the cactus to live in a desert.

Animals of the desert also have problems. They must be able to stand a pretty wide range of temperatures. By day the rocks may become hot enough to fry eggs. By night, the temperature may fall to the freezing point.

In other regions, temperatures are moderated by the presence of a considerable amount of water in the air and on the ground. Water can absorb a great deal of heat without getting hot, and can lose a great deal of heat without getting cold. In the daytime, moisture in the air helps keep it cool; by night the warmed-up moisture keeps the air warm. But in the desert there is not enough water to regulate temperatures in this way.

Animals cannot endure the severest heat of the



BURROWING OWL PRAIRIE DOGS

desert. During the day many hide from the sun. Since there are no trees and no shade, animals make their own shelters. The gophers, prairie dogs, and rabbits of North America dig burrows in which they spend the day underground. So do the xerus of South Africa, the piping hares of Mongolia, and the desert mice, rats, and ground squirrels of many lands.

Birds that fly can leave the desert when conditions are at their worst. Yet some birds do not choose to migrate. Instead they go underground, like the rest of the population. A few dig themselves a burrow but some others just take over an abandoned burrow or move in with some animal and become his tenant.

In a desert that has a brief season of rainfall, frogs, which begin their lives in water, manage to survive from one rain to the next. The desert frog of Australia scrapes through the long dry season by using water which it stores up during the short wet season. When the rains come, the frog soaks up water through its skin. The water passes into the blood, whence it is drained by the kidneys and stored in the bladder.

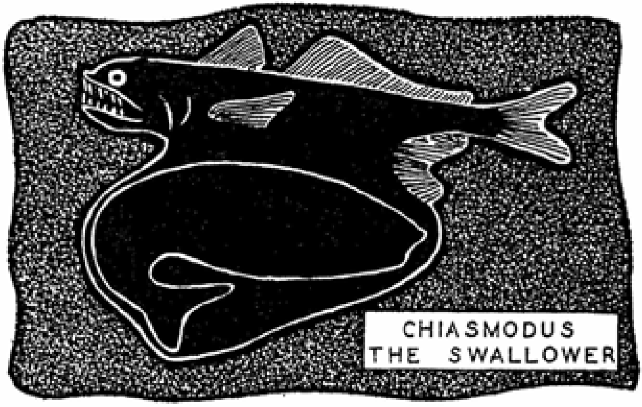
At the beginning of the drought, the water-swollen frog digs itself into the ground, safe from the drying air and the sun. It can stay buried for a year or more, drawing upon its water supply. The desert tribesfolk of Australia used to seek out this frog when the country dried up and drink its store of water.

In the desert, scarcity of water makes the sunlight unbearable to most living things. In another part of the earth's zone of life, water is so abundant that it soaks up the sunlight and causes darkness. This realm of darkness is the deep sea.

• THE DEEP SEA

Light, which seems to travel in radiating waves, passes through water as it passes through air. Some light waves go down a few hundred feet into the sea, until finally they are absorbed. No light waves reach the deep sea, which is darker than night.

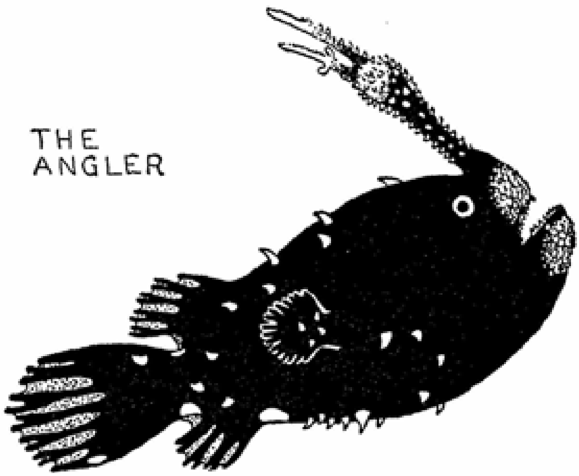
Since green plants cannot exist in darkness, none are found living in the depths of the sea. But some fishes and other animals have managed to



make themselves at home in this dark realm. They lead a special kind of existence there. The very size of the deep-sea creatures hints at their story. The fishes are small, measured in inches rather than feet. This suggests a scarcity of food. A number of skinny little species, the viper fish for example, have monstrous jaws and teeth. A fish with such jaws can seize a big bite of food when it is to be had. And to go with the jaws is a stomach that stretches out like a balloon, so that the fish can gulp down a chunk of food bigger than itself when it has the good fortune to find such a banquet. Meals are few and far between and each one has to last a long time.

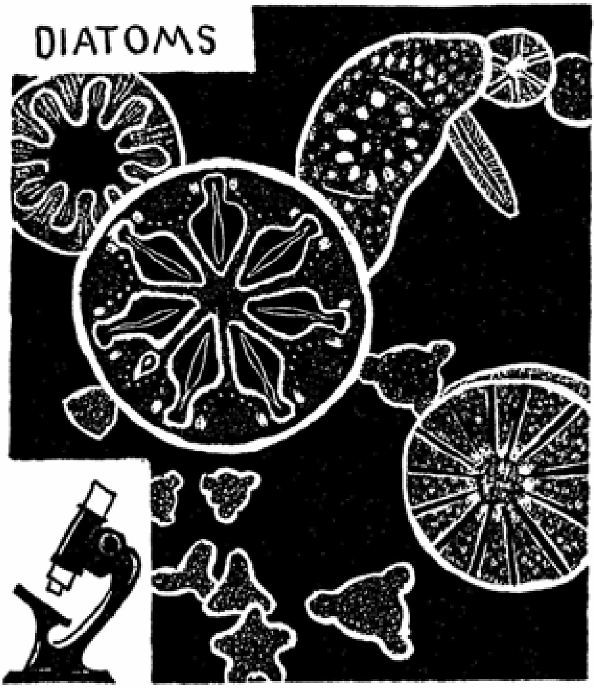
Part of the deep-sea animal's problem is to find food in the dark. For this purpose it may have long feelers with which it feels out its food. Or it may have a "searchlight." This is an organ or set of organs that generates enough light to illuminate a small area. Light-giving tissue sometimes grows in patches on the head or body or at the end of a long, delicate stem extending forward. The glowing tip of such a structure may serve as a lure with which the fish attracts some prey toward its jaws.

THE ANGLER



One animal species eats another, and that one eats another, and so on. But the deep-sea animals do not exist entirely by eating one another. If they did, they would all disappear. What else is there for deep-sea animals to eat? Not growing plants, for none exist in the dark deep sea. But there is another source of food—the corpses of dead plants and animals that sink from above. The deep-sea animals are like Lazarus at the rich man's table. They live on the crumbs that fall to them.

The surface of the sea is a floating meadow. Some of its plants are large enough to be seen from the deck of a ship, but most of them are very small—so small that they can be examined only under a microscope. Yet they grow in such multitudes that they color the surface of the sea green. Biologists



group nearly all water-dwelling plants together as algae. Most important of the algae are little shelled plants called diatoms. This name, meaning "cut in two," was adopted because diatoms are enclosed in a shell divided in the middle. One half fits down closely over the edge of the other, like the lid on a pill box. When we examine diatoms under the microscope we see that their shells have beautiful patterns of ridges and furrows, as if they were engraved.

Small though they are, the diatoms and other algae provide most of the food of marine animals. Every beast of the sea either eats algae or eats other animals that feed on algae. The algae form the beginning of the food chain—the chain of the eaten and the eaters. All the animal life of all the seas of the world, from the surface to the bottom, is built up from the bodies of these tiny floating plants.

Over the whole earth, on land as in the sea, the rule of life is the same. Plants supply the first food of animals, whether the animals eat plants directly or eat other animals that feed on plants. Animals can exist only because there are plants to supply them with food. Without plants, no fish, no insect, no mouse, no human being could live.

· CHAPTER 2

SUNKEN TREASURE

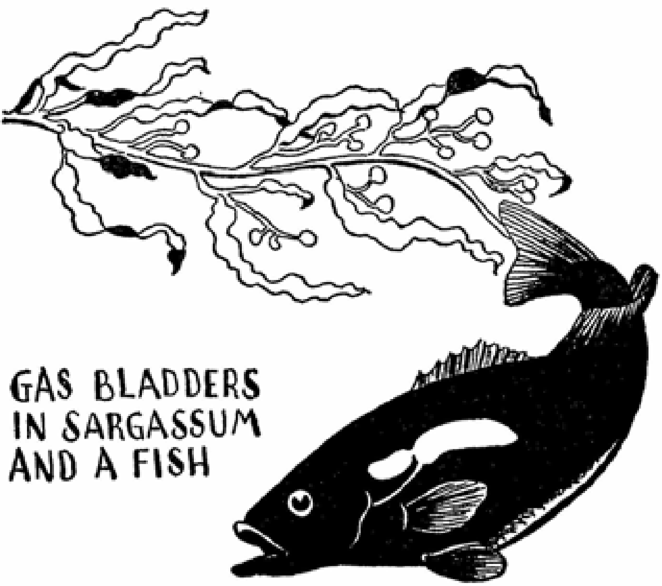
It is easy enough to see how a cactus is fitted to desert surroundings, or a zebra to grasslands. But how does a tiny alga "fit" in the vast ocean?

· THE ADVANTAGE OF BEING LITTLE

When we look into this question, we find that being little is one of the alga's greatest advantages. Its minute size benefits the alga in several ways. First of all, it helps the alga to keep afloat.

The substance of living things is just a little bit heavier than sea water. This means that they will sink unless they have some means of keeping afloat. A fish like the shark stays afloat by swimming mightily with its great tail and fins. But constant swimming tires the shark, so it must stop from time to time and lie down to rest on the sea bottom.

A great many fishes have a gas bladder that keeps them afloat without swimming, and permits them to nap right in the middle of the water. Plants like the rockweed and the sargassum also buoy themselves up by means of gas bladders.



The simplest of all aids in keeping afloat is smallness. We can get some hint of how this principle works if we use the microscope to investigate the behavior of small particles in water. The particles dart about as though they are jounced by something, and that is just what happens to them.

Water is made up of little units called molecules. They are too small to be seen under the most powerful microscope, but we know from the behavior of water that they exist. Molecules move: motion is their natural state of existence. The molecules of a liquid or a gas shove each other around and keep each other in motion. As a result, the whole crowd of molecules dashes about in all directions like a swarm of gnats.

Water molecules jounce the alga in the same way they jounce other small particles. The bombardment is not even. Sometimes more molecules hit the alga on one side than on other sides. When the bombardment is heavier on one side, it shoves the alga toward the other side. The alga is light enough so that even the force of molecules bombarding it works against gravity, helping the alga to keep afloat.

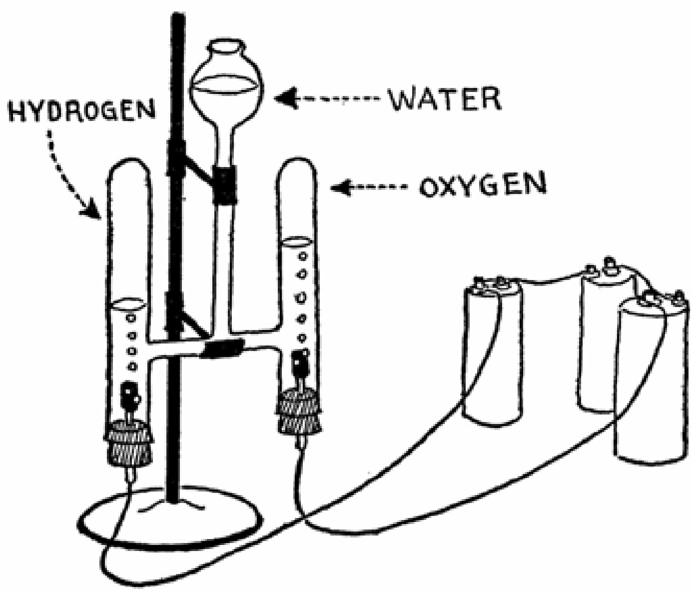
• THE TINY WONDER PLANT

Some of the molecules, when they bump the surface of the alga, bounce away from it. But not all of them hit a solid part of the surface. The alga is covered with a film having tiny openings through which water molecules and other small molecules can pass and enter the body of the alga. Such a film is called a membrane.

When the living tissue of a plant is analyzed, we find that about 95 per cent of its weight is made up of three substances: carbon, hydrogen, and oxygen. Each is an element—a substance which cannot be broken down into simpler chemicals.

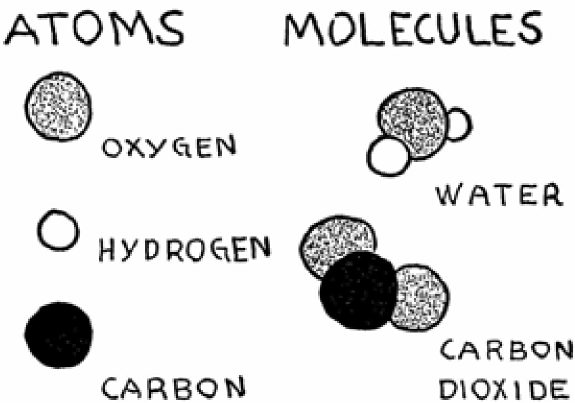
The three important elements, carbon, hydrogen, and oxygen, are quite plentiful on the surface of the earth. Carbon seldom is found pure but it forms the bulk of such substances as coal and mineral oil. Hydrogen and oxygen, in their pure form, are gases. Oxygen is abundant in the air but since it is odorless and colorless we are not aware of its presence.

Plants as a rule do not obtain their materials from pure elements but from substances which are combinations of elements. One of these combinations is ordinary water. We can easily find out what



water is by passing an electric current through it. The current breaks the water down into two colorless gases, hydrogen and oxygen. Pure hydrogen bubbles up around one wire of the circuit, and oxygen around the other wire.

Whether a substance is a pure element or a combination of elements, it is made up of a particular kind of molecule. The oxygen molecule, for example, has two particles bound together by electrical attraction. These particles are atoms of oxygen. The two atoms attract each other and thus form the molecule. We can diagram the oxygen molecule so as to keep in mind its atomic linkage. The water molecule, a combination or compound of different elements, is made up of one atom of oxygen linked with two atoms of hydrogen.

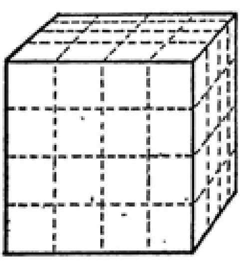


Plants get their hydrogen and oxygen from water. They obtain their carbon from another compound.

This is the colorless, odorless gas, carbon dioxide, which exists in the air mixed with the other gases. In the carbon dioxide molecule, one atom of carbon is linked with two atoms of oxygen.

A land plant takes its carbon dioxide directly from the air, but a sea plant is cut off from the air and therefore has to be supplied through the water. Some carbon dioxide dissolves in water at the surface. This is not an absolute dividing line between air and water; it is a boundary that can be crossed in both directions. Some water molecules are always evaporating into the air as water vapor. And molecules of gases from the air constantly cross the surface and dissolve in the water.

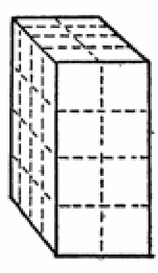
Since carbon dioxide and other nutrients must enter the alga through its surface membrane, the alga needs a surface large enough to take in the nutrients in sufficient quantity.



1. VOLUME
4 X 4 X 4 = 64.
SURFACE
4 X 4 = 16;
6 X 16 = 96.

2.

VOLUME
4 X 2 X 4 = 32.
(HALF THE VOLUME OF 1.)
SURFACE
4 X 2 = 8; 4 X 8 = 32   32
4 X 4 = 16; 2 X 16 = 32   32
(MORE THAN HALF THAT OF 1.)   64



It is a simple mathematical fact that the smaller a body, the greater its surface area in relation to its bulk. Thus, the tiny alga has a large surface for its volume. This is the alga's main adaptation to existence in the sea. The large surface enables the alga to touch a lot of water with its membrane, so that the membrane can gather in plenty of nutrients.

• FERTILE WATERS

We know that land plants depend on a supply of nutrients in the soil. When land is farmed continuously, some of these nutrients are used up and they have to be restored with fertilizers.

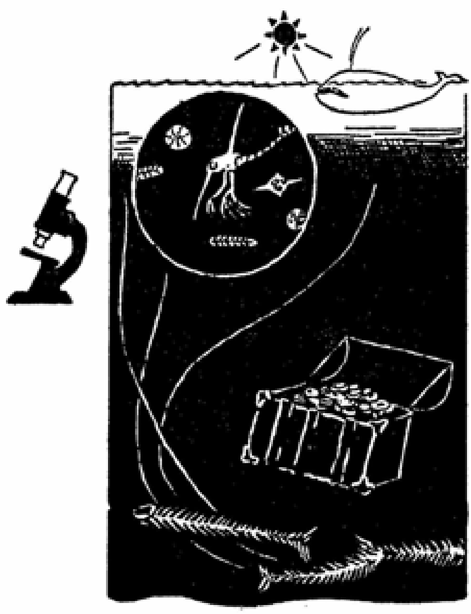
The meadows of the sea, like the meadows of the land, may become exhausted as plants use up their supply of nutrients. Even carbon dioxide may be scarce in the springtime when the algae burst into growth and crowd the sea with their trillions of little green bodies.

Some of the carbon dioxide used up by the algae is restored from the air. But carbon dioxide dissolves slowly. The small amount coming from the air would not be nearly enough for the needs of the vast population of plants that exists in the sea. Where does the rest of their carbon dioxide come from?

Animals help keep up the supply, for they breathe out carbon dioxide into the water. And as suppliers of carbon dioxide, animals are "worth more dead than alive." When decay takes apart the body of an animal—or the body of a plant, for that matter—one of the resulting products is carbon dioxide.

In the sea, since dead creatures sink, much of the carbon dioxide from their decay falls beyond the reach of plants. It is only in the shallows, where light penetrates all levels, that plants grow at the bottom, and can use the carbon dioxide from sunken corpses.

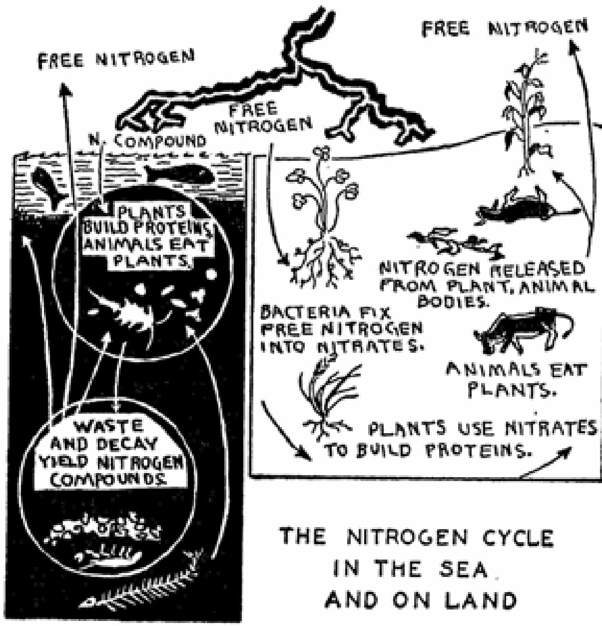
In the deep sea, the decay of organisms constantly adds to the store of buried carbon dioxide. Since no plants are there to use it up, the carbon dioxide goes on accumulating in the depths. The plants that live far above in the surface levels cannot get at the sunken treasure.



Besides carbon, hydrogen, and oxygen, several other elements are needed by plants, and algae have to get these elements from the surrounding water. Chief among them is nitrogen. The pure element nitrogen is a colorless, odorless gas that forms about three-fourths of the air. Though very plentiful, nitrogen in its pure form is useless to plants. It is too inert—it dissolves in slight amounts only, and it does not unite readily with other elements to form compounds. The plant therefore has to get its nitrogen in a more usable form. Compounds of nitrogen have been built up and accumulated on the earth's surface, and it is from these compounds, nitrates mainly, that the plant obtains its nitrogen atoms.

Pure nitrogen in the air has spectacular adventures before it is combined into a nitrate. One of these adventures requires a blast of energy, which is supplied by lightning. During electric storms, lightning forges together atoms of nitrogen and atoms of oxygen.

The compound of nitrogen and oxygen immediately reacts with water in the air, forming nitric acid, a compound of nitrogen, oxygen, and hydrogen. The nitric acid, dissolved in rain, falls on the land and into the sea. It promptly reacts with salts dissolved in sea water and soil water. In the reaction, the nitrogen-oxygen grouping combines with the metallic atom from a salt and forms a nitrate such as potassium nitrate or sodium nitrate. On land, certain kinds of bacteria take nitrogen from the air and fix great quantities of it in usable compounds.



THE NITROGEN CYCLE
IN THE SEA
AND ON LAND

Both on land and in the sea, plants get a large portion of their nitrates from the wastes and the decay products of living things. In the sea, where dead plant and animal bodies sink, much of the nitrogen from their decay, like the carbon, leaves the surface and is buried in the lower levels.

The story of carbon and nitrogen is repeated in the case of another element, phosphorus. Compounds of phosphorus make up a small but vital part of the nutrients of green plants. There is so little of these phosphates in sea water that plants may easily exhaust the supply in the surface levels, while phosphates accumulate in the deep sea.

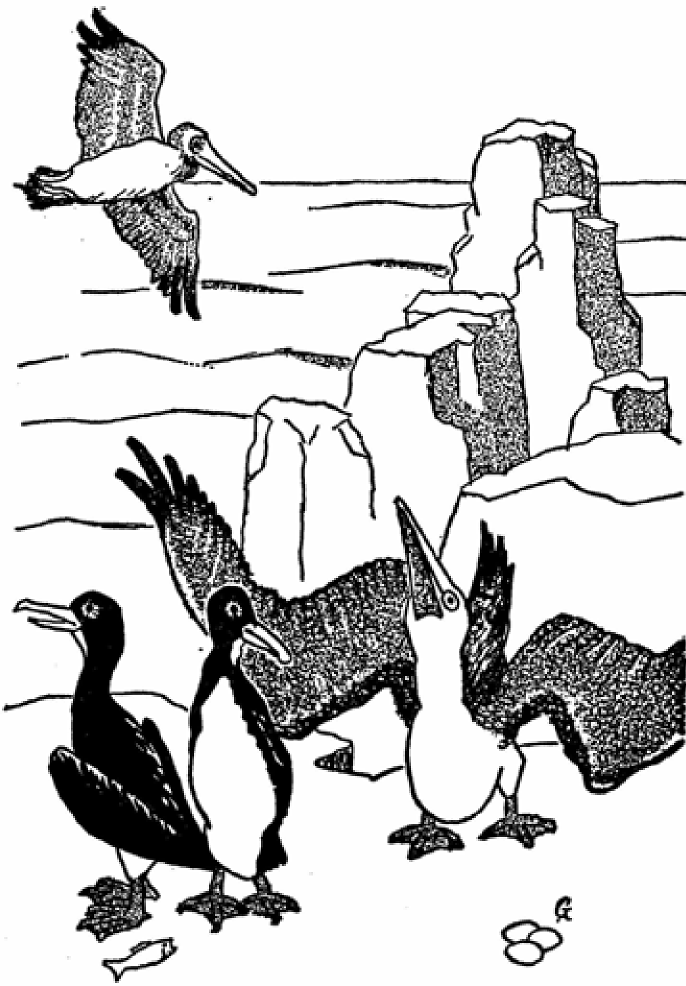
• PLOWING THE DEEP SEA

Clearly, plants of the sea need some great plow to dig up the riches of the deep. And fortunately for the plants, a mechanism exists to stir the oceans and bring up their buried store of nutrients. This mechanism is a great earth-wide system of currents.

Water masses are set into motion by differences in temperature. Colder water, a little denser and heavier than warmer water, sinks beneath it. In far northern and far southern zones, the cold winter air, by chilling the surface water, makes it heavier and causes it to sink. Room is left at the surface for other water to flow in. This space is taken up by warmer water drifting from the direction of the equator. Meanwhile, the cold water drifts along at lower levels toward the equator.

Drifting waters are speeded by the winds. The shapes of ocean beds and shore lines help to turn the drifting water into streams that course through the oceans for thousands of miles. Where these water masses pass each other, their differences in temperature start upward and downward movements.

Whatever its causes, an upwelling current raises the sunken treasures from the deep. Laden with compounds of carbon, nitrogen, phosphorus, and other essentials, the upwelling water spreads its riches through the surface levels, supplies the plants with nutrients, and turns the sea into a green meadow.



In the Humboldt Current, which flows northward in the Pacific off the coast of Chile and Peru, upwelling water nourishes a vast population of algae. Little animals feed on the algae, and plants and animals drift together and form a living mass that serves as the food of a multitude of small fishes. These in turn become the food of the big flesh-eating fishes.

The next creatures to benefit from the Humboldt Current are the birds. Finding abundant food in the waters of the Current, many species, among them pelicans, boobies, cormorants, terns, and gulls, flourish on the islands off the coast. Since this region has almost no rainfall, the bird droppings accumulate on the islands and form thick deposits—"guano." Rich in nitrates, the guano is mined and sent to many countries to be used as fertilizer. Thus, nitrates brought out of the sea by the birds serve to nourish plants of the land.

Both on land and in the sea animals depend on plants and plants depend on animals. Their bodies are temporary storehouses for the substances that make up living matter. Animals obtain these substances from plants. Plants recover them in simpler form from the bodies of dead animals and also from the corpses of plants. In the end, the materials in the bodies of all living things are used again to build up the bodies of new living things.

· CHAPTER 3

ENERGY FOR LIVING

Wood and other plant substances, when burned, release energy in the form of heat. Coal is made from plant bodies that long ago were packed into the ground. Mineral oil and natural gas also come from plant deposits.

What sort of things are these products that supply power for the lighting of cities and the operation of factories?

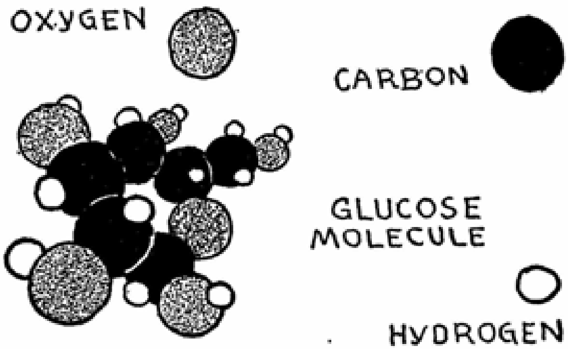
· MOLECULE BUILDING

The plant produces three classes of finished products: fats, carbohydrates, and proteins. Each kind of substance is built up in a number of stages. Atoms from the raw materials are first linked to form simple molecules; then these are joined to form larger, more complex molecules. The whole process is so swift that chemists have a hard time finding the compounds that are formed at middle points of the series. Both the intermediate products and the end products, since they are created by living organisms, are called "organic" compounds.

Each class of substance is built on its own special assembly line, we may say. What the final product will be depends on which direction the chemical building takes. If it goes through one particular series of actions, the final product is a fat. On another assembly line, the product is a carbohydrate; on the third line, the product is a protein.

On the carbohydrate line, one of the early substances to be formed is the simple sugar glucose. This compound has a molecule made up entirely of atoms of the big three—carbon, hydrogen, and oxygen. The carbon comes from carbon dioxide; the hydrogen and oxygen come from water. The number of each kind of atom in the glucose molecule is exact. There are six atoms of carbon, twelve of hydrogen, and six of oxygen. The chemist sums up these quantities in the formula, $C_6H_{12}O_6$.

The twenty-four atoms in the glucose molecule are not just thrown together like beans in a bag. Their arrangement, like their number, is definite. The carbon atom is a good joiner and unites readily with other atoms. In the glucose molecule, six carbon atoms link to form a chain. This chain is a sort of framework to which the hydrogen and oxygen atoms are attached. The whole chain curves around to form a closed loop.



The glucose chain in solution is a lively thing that easily goes through chemical transformations. It loops and unloops again, wiggling its ends around and hooking on to other chains like itself. Two glucose chains may link and form a molecule of fructose, the sugar that gives fruit its sweet flavor. In plants like the sugar beet and sugar cane, molecules of simple sugars are built up into sucrose, which is our ordinary table sugar.

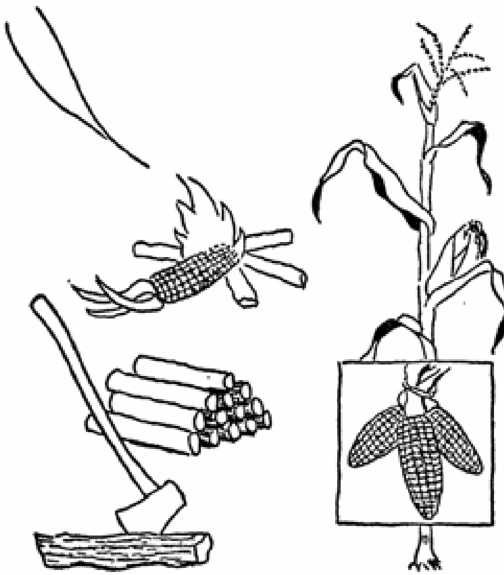
A great number of molecules of glucose and other sugars may join to form a starch molecule. This molecule is a giant in comparison with the glucose molecule, yet it is so small that it cannot be seen under an ordinary microscope. All sugars and starches are classed as carbohydrates because their molecules are made up of carbon, hydrogen, and oxygen, and there is a two-to-one ratio of hydrogen to oxygen, as there is in water (H_2O).

On the protein assembly line, carbon atoms are linked in another sort of chain, to which atoms of hydrogen, oxygen, and nitrogen are attached in special ways. On the assembly line for fat, a third type of carbon chain is built, with hydrogen and oxygen atoms linked to the carbon in a characteristic pattern.

• ENERGY AND THE FOOD MOLECULE

Food is chemical fuel—a source of energy that can be released through chemical actions. In order to understand how energy is obtained from food, we may compare the consumption of food with the burning of another chemical fuel, coal. Coal, like food, is built up around groupings of carbon atoms. The various compounds in coal have hydrogen linked to the carbon, but no oxygen. The compounds, under ordinary conditions, are stable and inactive and the carbon does not react with other elements. Yet a very powerful reaction with oxygen can be started by heat. The coal, when heated in the presence of oxygen, burns fiercely and may even explode. The combustion is a uniting of the carbon atoms with oxygen from the air. The carbon is "oxidized," and its quick uniting with oxygen yields energy in the form of heat.

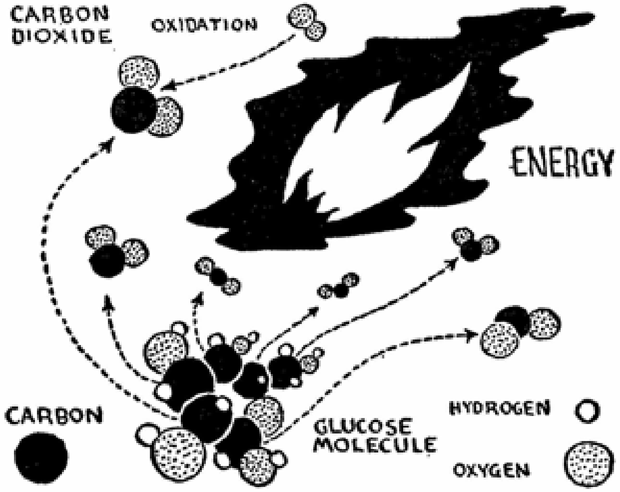
The consumption of a food like sugar in the plant or animal body is also a burning of carbon. And



just as coal needs heat to set it burning, so the burning of food needs something to start it off. The "starter" is a type of chemical called an enzyme, of which there are many in plant and animal bodies.

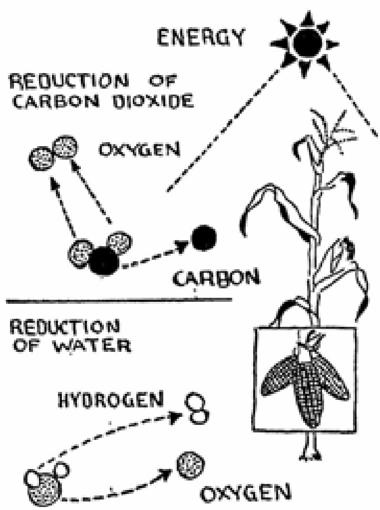
With the help of enzymes, the combustion of food gets under way. The process does not happen all at once, like an explosion. It goes on through several stages, each of which is helped along by a special kind of enzyme, or by several. In the burning of a carbohydrate, for example, the fuel with which the process begins may be a complex sugar. Step by step, the big carbon chain is unlinked, reversing the process by which it was built up. At each step, the chain is cut down to simpler sugar molecules, until finally the sugars are transformed back into glucose.

In the form of glucose again, the carbon chain now has six atoms of carbon that can unite with oxygen to form carbon dioxide. Enzymes speed the oxidation of the carbon, which releases energy.



Where does the energy come from? Is it something packed away in the carbon atom, like the jinni in Aladdin's lamp? In order to throw some light on this question, let us examine the process of food construction.

Before a carbon chain can be made, the plant has to take apart carbon dioxide molecules for their carbon. The carbon atoms are kept in the plant and the oxygen is voided into the surrounding water or air. This sort of action, the separation of oxygen from another element, is called reduction.



Another example of reduction is the smelting of iron ore, which is a compound of iron and oxygen. The iron and oxygen atoms cling so tightly in the molecule that it takes the heat of a blast furnace to rip them apart.

The plant too needs energy for the splitting of carbon dioxide. Where does the energy come from?

A simple experiment will show us the plant's source of energy. We cover some of the leaves of a plant with black paper to shut off the light but allow the rest of the plant to remain in sunlight. After a few days we test for starch and sugar, which we find present only in the leaves that were exposed to sunlight, but not in the darkened leaves. Their carbohydrates have been used up, and they have not been able to make any more.

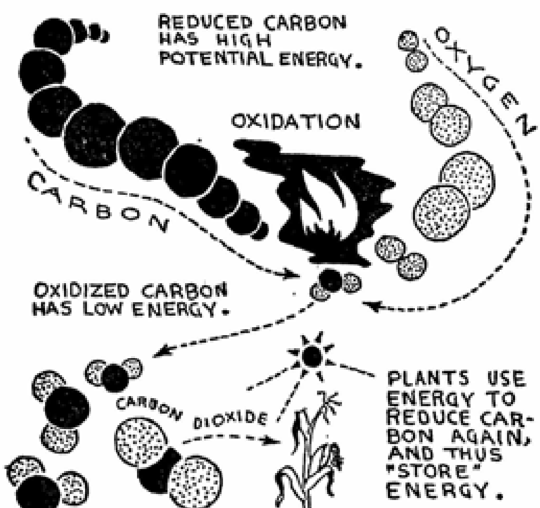
• SUNLIGHT CHEMISTRY

Clearly, the energy used for splitting carbon dioxide comes from sunlight. The whole process of construction in the plant therefore is called photosynthesis—"building with light." The work does not go on everywhere in the plant body. It takes place only where there is chlorophyll—"leaf-green."

The chlorophyll absorbs some of the waves of energy radiating from the sun as light. Any green surface, like a piece of cloth or paper, absorbs the same light waves, but the only effect is to warm the surface a little. The sun's energy in this case is "wasted." Energy can do work only when it is channeled in a definite direction. It has to pass through some kind of machine or system that channels it. A blast furnace is one kind of energy-channeling system. The plant is another. Heat energy applied through the blast furnace separates oxygen from iron. Light energy applied through the plant separates oxygen from carbon.

The energy spent in reducing iron oxide is not lost. We may say it is transferred to the iron and oxygen as stored energy, or potential energy. Of course, we do not mean the energy is some material packed into the two elements. We simply mean that energy can be obtained by reuniting the iron and oxygen. A way to prove this is to take some iron dust and set it afire. If enough oxygen is present, the iron dust will burn fiercely. The iron joins with oxygen again, and the reaction yields energy in the form of heat.

In the plant, similarly, the energy spent in reducing carbon dioxide is not lost. It is transformed into potential energy in the products of photosynthesis. These, we remember, are carbon compounds in which the carbon is in a "reduced" state. That is,



there are many carbon atoms, with very few oxygen atoms linked to them. It is this reduced state of the carbon that gives the compounds their high potential energy. In the presence of air, the reduced carbon easily is oxidized again and yields up its energy. This is the energy that was stored up, we may say, when the plant recovered carbon from carbon dioxide and built it into reduced compounds.

In times of darkness or cold, when plants cannot carry on photosynthesis, they oxidize some of their carbon products. The rest of the output accumulates as a reserve of chemical energy. The store of reduced carbon created by plants supplies the entire animal population of the earth with fuel for living.

· CHAPTER 4

DRAMA OF THE CELL

One way to investigate life processes is to put a small organism under the microscope and watch its behavior. Assume that we are going to examine some microscopic organism that lives in fresh-water ponds. Having taken water from a pond, we place a drop of it on a glass slide under the microscope. Then, looking through our instrument, we adjust the focus and examine different sections of the drop of water.

Soon we catch a glimpse of something that moves. Several hazy forms glide about in the water drop, like little transparent ghosts. If we hit one of them at the right angle with a beam of light we can make out its shape and watch how it behaves.

• SIMPLE LIVING THINGS

The first thing we examine may turn out to be a minnow-shaped creature that bunches up short, then stretches out long, as it moves through the water. At the forward end it has a fine thread which coils and uncoils and by its lashing movement pulls the creature along. From the presence of this thread, called a flagellum, or whip, we know that the creature belongs to the flagellates, the bearers of whips. It is one of a group named Euglena.

From the active way the euglena moves about, we are inclined to think it is an animal. But this creature is green. Looking right through its body, we see that the green is contained in little grains that float around in a fluid. The substance that makes up the grains is chlorophyll.

The green euglena will qualify as a plant since it makes food by the action of its chlorophyll in sunlight. But there are other euglenas that have no chlorophyll; these types live by soaking up ready-made organic materials from the water. Even green euglenas can be deprived of their chlorophyll. Then, unable to photosynthesize, they switch to the way of life of a colorless type, absorbing organic compounds as their source of energy. Is it correct, then, to call green euglenas plants and colorless ones animals? The little whip-bearers compel us to think differently than usual. We must be ready to consider the flagellates as animals or plants, or both, or neither.

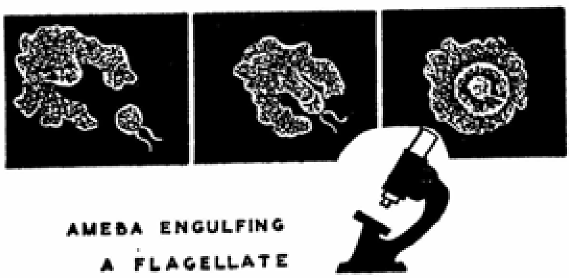
In the same drop of water we may find organisms that definitely are plants—algae resembling the algae of the sea. And we may find creatures that unquestionably are animals. Among these may be types of a group called Ameba. The one we hope to find is the interesting Ameba proteus. Actually, this species is not very common, though a favorite for study purposes. It has been rumored that the natural environment of Ameba proteus is the biological laboratory. In any case, we probably shall have to take a domesticated Ameba proteus that has been raised in a flask.

The family name of this creature, Ameba, comes from a Greek word for "changing." Its given name, proteus, is the name of the Greek god Proteus, famous for assuming any shape that he chose. Ameba proteus has earned both its names. When we catch it in a beam of light, the ameba looks like a little blob of whitish, transparent jelly. The blob does not keep one shape for long. It is by a constant changing of shape that Ameba proteus manages to function and move about.

The way it appears to us, the ameba bulges on one side, sending out an extension. This we call a "false foot," a pseudopod. The fluid substance of the ameba oozes into the false foot until all of it is there and the ameba now is where the false foot was. It has managed to shift to a new position next to its old one. Then the ameba starts out on another ooze.

Sometimes Ameba proteus moves in order to get away from harmful substance in the water, such as an acid. The ameba takes the avoiding action automatically, through a chemical response to the acid. Other actions, such as movement toward food, also are chemical responses.

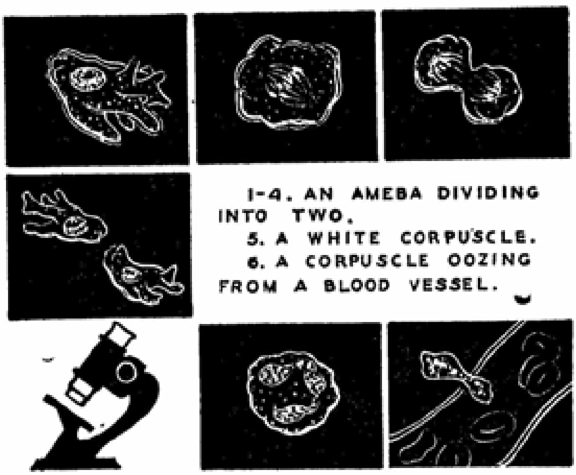
The little bag of jelly has no mouth, but manages to eat without one. The ameba simply oozes toward a food particle—an animal or a plant fragment of microscopic size—and flows around it. The particle



AMEBA ENGULFING
A FLAGELLATE

of food floats about inside the ameba in a droplet of water, called a food vacuole. For a while, we do not notice anything happening to the food in the vacuole. But as we watch, it gradually melts away and then disappears. The dissolution of the food particle can be explained only in one way. Chemicals from the ameba's body fluid seeped into the vacuole, acted upon the food and took it apart—digested it. We can see something like this when digestive fluids are drawn from an animal or human stomach and are placed in a flask with a piece of food, which they break up and liquefy before our eyes.

If we watch the ameba long enough, we may see it reproduce itself. Having eaten well and grown until it is about twice its original volume, the ameba begins a series of remarkable changes. First, a collection of particles appears in the middle of the body, in a disc formation. This structure, the nucleus, is present at all times, but ordinarily it is hard to see. The particles divide into two equal portions, which move to opposite locations in the body. Then the ameba pinches together in the middle, dividing itself into halves. Each half possesses its own nucleus. The halves separate, and behold, each half is a new ameba!



1-4. AN AMEBA DIVIDING INTO TWO.
5. A WHITE CORPUSCLE.
6. A CORPUSCLE OOZING FROM A BLOOD VESSEL.

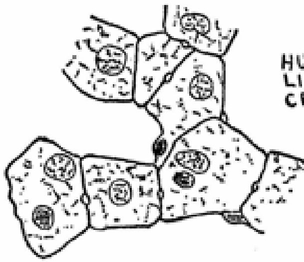
Wonderful as it is in its behavior, Ameba proteus is by no means unique. If we examine our own blood under the microscope, we find in it whitish objects which look and behave remarkably like

Ameba proteus. These are leucocytes—"white bodies."

A leucocyte moves in the manner of an ameba, putting out false feet and oozing into them, one after another. One type of leucocyte also eats in the amebic fashion. It flows around a food particle and envelops it. The usual foods of this kind of leucocyte, fortunately for us, are harmful germs that get into our blood and sometimes cause poisoning and disease. When the leucocyte comes within reach of bacteria, it engulfs and destroys them. Sometimes the leucocytes devour too many bacteria and they themselves are destroyed by their unwholesome meal. We see these dead leucocytes in an infected wound. It is their bodies that form most of the pus.

• THE CELL—WHY IT MUST BE SMALL

Tissues of a large plant or animal body are built of a multitude of tiny units—cells—which are separated from each other by membranes. Each kind of tissue is made of cells of a particular type. Yet all



HUMAN LIVER CELLS

types of cells resemble each other. Every cell has a covering membrane through which water can pass in both directions, carrying materials in solution into the cell and out of it. The cell uses some of these materials to build its own substance.

As the cell grows, a problem arises. This is the same problem that confronts the little alga in the sea. The alga needs a surface large enough to take in the required amount of nutrients. The alga therefore must be small so that its surface is large in relation to its volume.

How to grow and yet remain small? A microscopic organism like the ameba and the alga solves the problem by splitting in two. When it reaches a certain volume, the organism divides itself equally, and instead of one large organism there are two little ones. Each lives and grows as a complete individual.

In plant and animal tissues, each cell lives somewhat in the manner of an alga in the sea. It absorbs its foods from the liquid around it as the alga absorbs its nutrients from sea water. And since all the food of the cell comes through the surface membrane, the cell must have a surface large enough to take in an adequate supply.

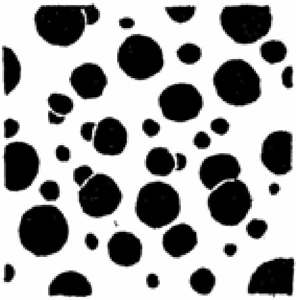
As the cell grows, its surface area becomes less, in proportion to its volume. Were the cell to grow indefinitely, the covering membrane would become too small to supply it with enough food. The cell solves the volume-surface problem in the manner of the ameba and the alga. It splits into two new cells of the proper size. This is the mechanism of all organic growth. In plants, animals, and man, tissues grow by the splitting and the multiplication of cells. A microscopic organism such as the ameba or the alga actually is a single cell living by itself.

• THE LIFE FLUID

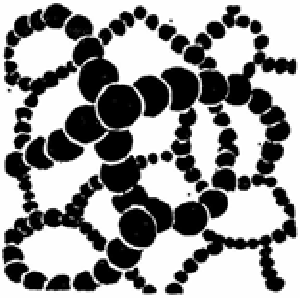
As we watch the functioning of cells and one-celled organisms, we wonder: what is this self-maintaining jelly? How does the bloblet carry on its ceaseless activity, its growth and change and renewal? How does it live?

The life-bearing fluid of the cell is called protoplasm—"first fluid." Though we speak of it as if protoplasm were the same in all plants and animals, actually there are as many protoplasms as there are kinds of cells. Protoplasms have different proportions of their substances and the kinds of proteins they contain are especially varied. Yet we are quite right in speaking of protoplasm in general, for all protoplasm is similar in make-up and behavior.

Ordinary gelatin or glue can help us understand the functioning of protoplasm. If we dissolve some dry gelatin or glue in warm water, the solution remains an ordinary liquid—a little syrupy, but still free-flowing. But make a simple change in conditions—a change in temperature will do. Cool the solution a little. For a while nothing happens. Then, all at once, the liquid turns into a jelly. Warm the jelly, and it turns into a free-flowing liquid again. The jelly stage of the solution is called a gel, and the liquid stage a sol. The balance between the two conditions may be very delicate. Small changes in pressure or salt content will make the solution go from one condition to the other. A mixture that acts in this way is called a colloid, which simply means "something like glue."



IN THE SOL STATE COLLOID PARTICLES ARE SEPARATED BY WATER. THE MIXTURE FLOWS EASILY.



IN THE GEL STATE PARTICLES STICK TOGETHER IN STRANDS. WATER IS HELD IN THE NETWORK. THE MIXTURE JELLS.

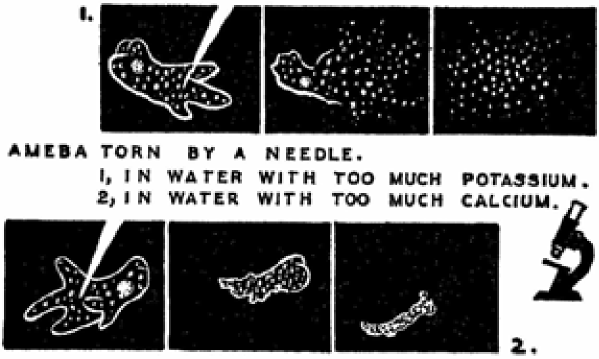
Milk is another colloidal system. We can use milk in a little demonstration to show how chemicals will change a colloidal solution from sol to gel and back again. If we add a little acid to milk—vinegar will do—the milk curdles to a gel. Then we stir in a little baking soda, sodium bicarbonate, and the curdled milk turns into a liquid again.

Now we can better appreciate the behavior of Ameba proteus when some acid touches it. What happens is that a portion of the ameba's fluid, on the side toward the acid, turns into a gel. The ameba cannot flow on that side and therefore when it oozes it must ooze from the other side, away from the acid.

The ameba's whole process of oozing takes place through a shifting of the cell fluid back and forth between the two conditions, sol and gel. The ameba moves when a part of its outside layer liquefies, allowing the protoplasm to flow out as a false foot. What if the flowing should go on and empty all of the ameba's protoplasm into the water, leaving an empty bag? This is prevented because the cell fluid, at the surface where it touches the water, turns to the gel state and forms an elastic membrane around the stream of protoplasm.

As the ameba flows into a new pseudopod, it draws its covering membrane along with it. This does not wrinkle and fold up like an emptied bag. The membrane, which is protoplasm in the gel state, turns to the sol state and melts into the fluid protoplasm.

The ameba's protoplasm is nicely adjusted to the water of its pond. The water is a dilute solution of a number of salts, including salts of potassium and calcium. These two elements affect protoplasm in opposite ways. Potassium favors the sol state. Using our microscope, we can see how potassium works by adding a little potassium salt to the water. Then we take a glass needle and make a cut in the ameba's membrane. The fluid streams out in what looks like a pseudopod, but its surface layer does not gel into a membrane. The fluid just pours out into the water until the ameba vanishes, entirely dissolved.



AMEBA TORN BY A NEEDLE.
1, IN WATER WITH TOO MUCH POTASSIUM.
2, IN WATER WITH TOO MUCH CALCIUM.

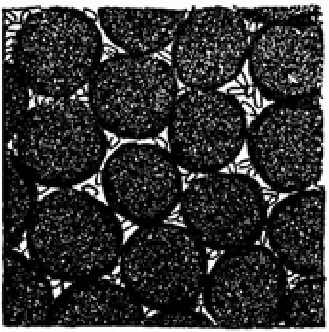
If we add a calcium salt instead of potassium and cut the ameba, the calcium seeps into the protoplasm and stiffens it into a gel. In this rigid, unmoving form the protoplasm cannot function, and the ameba shrivels up and dies.

It is the colloidal structure of protoplasm that enables all life to adjust so sensitively to its environment. In many-celled organisms, the environment of the cells is the fluid that bathes them—a dilute salt solution, like the water in which an alga or an ameba lives. Calcium and potassium salts are nicely balanced, with more potassium inside the cells to keep their protoplasm fluid, and more calcium outside the cells to keep their membranes a gel. With this delicate salt balance inside and outside the cells, the protoplasm can maintain itself as a colloidal system, trembling between the two conditions, sol and gel.

Inorganic substances also can form colloids, but such colloids act differently. Gold, for example, can be divided so finely that the particles will stay "suspended" in water. The bombardment of water molecules holds them up and spreads them out through the solution. The particles keep away from each other because all have the same electric charge and therefore repel each other. But when a substance of opposite charge is added, the colloidal suspension is destroyed. The particles lose their charges and come together, forming clumps larger than colloidal size. These clumps settle down as a deposit. In another type of action, particles with a negative charge and particles with a positive charge attract each other and fasten themselves in tight masses. That is, the particles coagulate into a solid. Either process destroys the colloidal system. All that remains is the solid and clear water.

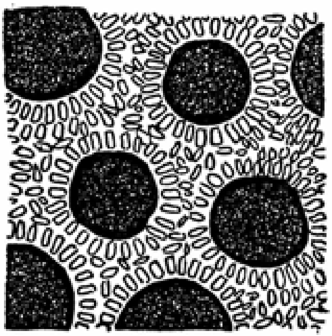
In organic colloids, something quite different happens. Particles of opposite charge draw toward each other but do not bunch tightly, coagulating into a solid. The particles stay a little bit away from each other so that they form only a half-solid, a gel.

Organic colloids behave in this way because their particles are "water-loving." Each particle attaches water molecules, which form a loose film around its surface. It is this film that holds particles of opposite charge a little bit away from each other. Therefore, instead of coagulating, the particles coacervate, as chemists say, meaning that they gather loosely and form a jelly-like blob.



COAGULATION

COACERVATION

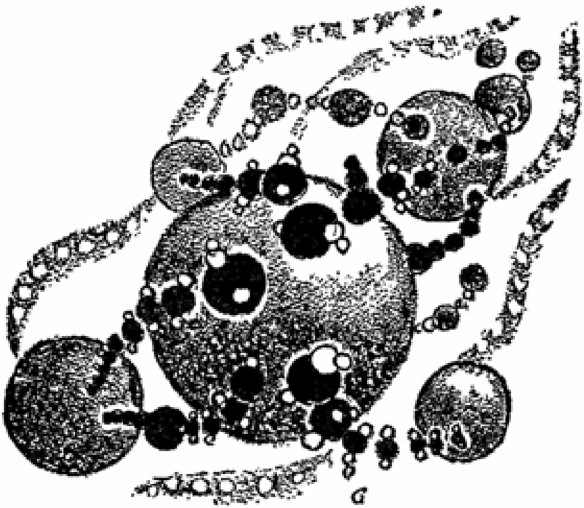


• THE CHEMISTRY OF PROTOPLASM

The colloidal suspension of particles is the key to the working of protoplasm. What it accomplishes is to hold molecules in an arrangement whereby they can touch and work on each other. The particles float in water, which carries to them the molecules of necessary chemicals and carries away by-products.

The colloidal particles themselves remain small enough so that they present a large surface to the water and to its stream of molecules. This is the old story of the relationship between volume and surface area: the less the volume, the greater the surface area. In this case, the volumes we speak of are of a different order of smallness than the cell. The cell can be seen under the ordinary microscope, but not the colloidal particles within the cell. The particles show their presence, however, when light is passed through the cell fluid. The colloidal bits are large enough to bend the light rays in different directions, which causes a glimmering effect.

In protoplasm in the sol state, the molecules move constantly. Big molecules or clumps of molecules are reached from all directions by the smaller molecules streaming about them. We may



think of the moving molecules as an assembly line, where smaller molecules join and build up the big carbohydrate, fat, and protein molecules.

The assembly line is reversible. It can go backward and take the big molecules apart again, to oxidize their carbon for energy. The whole cycle of building up and breaking down is called metabolism, which means "changing."

In the factory of the cell are special molecules that speed up each process of metabolism, whether it is the building or the dismembering of molecules. These specialists are the enzymes. In construction, the enzymes themselves are protein molecules. They are continually built up in protoplasm.

Since the biggest and most complex molecules in protoplasm are proteins, and since the enzymes which regulate cell chemistry also are proteins, we may wonder: are not proteins the very fabric of protoplasm?

Proteins, it is true, are the most complex structures in protoplasm, but since they are built on chains of reduced carbon, they too can be oxidized for energy, like any other carbon fuel. We know that an animal or a man can live for a long time without food, but the body shrinks. This is because the protoplasm burns up its own proteins, as well as stored fat.

The cells, deprived of new food, still must burn up carbon if they are to supply themselves with energy for living. So the cells consume their protein molecules. Through this burning, which is basically the oxidation of carbon, the cells release energy, and they eliminate waste products, chiefly carbon dioxide. The process can go on for quite a while, as long as enough water is supplied to the protoplasm to keep it fluid and to ferry its products through the organism.

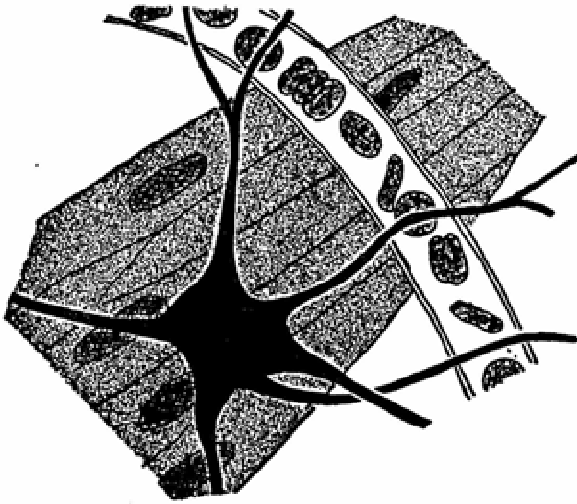
As the protein content dwindles, the yield of energy diminishes to the point where it can no longer operate the breathing system and other systems of the organism. The oxygen and water supply is cut off; wastes accumulate. The protoplasm has all but consumed itself in the struggle to live. Now, lacking the materials to carry on its activity, and poisoned by an accumulation of wastes, the protoplasm ceases functioning—dies.

An organism lives by dying piecemeal. The protoplasm constantly destroys itself in order to rebuild itself again. It breaks down its molecules, oxidizing their carbon for energy, and uses some of the energy to forge new molecules.

The energy system of the cell drives on continuously, forward and backward, building and destroying and building again. It is by this constant changing that protoplasm stays the same. It is by the eternal cycle of destruction and rebuilding that the colloidal fluid lives, that it gives life to cells and organisms. Truly we can say: Life is the chemistry of protoplasm.

CHAPTER 5

A CITY OF CELLS



How does a large organism supply its cells with food and oxygen? The human body is a vast city of cells, with a population of about seventy trillion—70,000,000,000,000. The problem of food and oxygen supply compels the cells to remain very small. How is it that the crowded trillions of cells, in their hunger for food and oxygen, do not struggle to soak up the supply, do not starve and suffocate each other? How do the cells in a large organism get the materials to keep alive?

Whether an organism has one cell or several trillion, all the materials exchanged between the cell fluid and the outside world must be in solution, so as to pass in and out of the protoplasm through membranes.

In some water-dwelling organisms, there may be thousands of cells, and yet the cells are arranged in such a way that each one remains in contact with the surrounding water and can exchange materials with it. The cells of such an organism hold together in a little, uncomplicated city, or "colony." All the cells of the colony are alike, or nearly so, and each one leads its own life, nourishing itself and functioning almost independently.

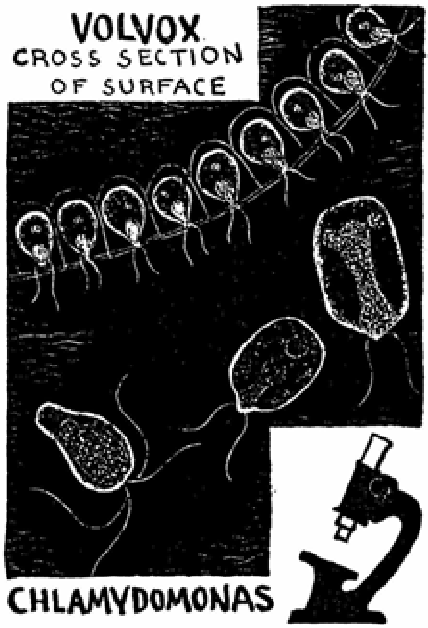
• THE COLONY AND THE CELL

Among such colony organisms is Volvox, which lives in fresh-water ponds. Under the microscope, a volvox colony appears as a ball, hollow and water-filled. The little globe rotates on a vertical axis, like a planet, and while rotating slowly moves through the water. If several are seen at once, they remind us of a planetary system in miniature.

The globe is made of a single layer of cells, a few hundred or thousand in number. The cells have grains of chlorophyll which color the whole globe green. From each cell two little threads—"whips" —poke out into the water. The outer surface of the globe is fringed with the tiny threads. They move in unison, and it is their lashing that spins and propels the globe.

This globe arrangement is very efficient. It keeps each cell in contact with the surrounding water and enables it to exchange materials directly with the water. The hollowness of the globe gives each cell another contact with water on the inside surface.

A volvox seems to be a collection of flagellate cells that might just as well live separately. A single



cell resembles a one-celled green flagellate that lives by itself. Biologists therefore have cut out cells from volvoxes in order to see if a single cell can live by itself as a complete individual.

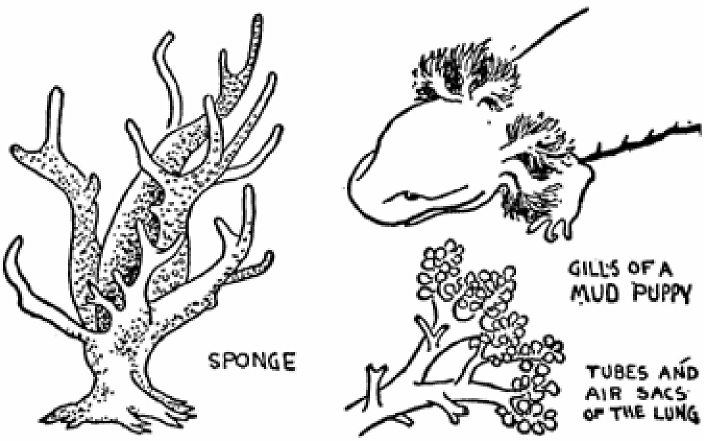
A separated cell swims off, fluttering its whips, as if it were a one-celled flagellate. Since the separated cell carries on by itself, we may be inclined to say, "This single cell is Volvox, and the globe is just a collection of them." But if we wait for the cell to divide and renew itself, it disappoints us. The cell dies without dividing and leaving successors. But the colony does reproduce itself, by developing little new globes within the old one. It takes the whole colony to accomplish this task of creating new cells and new globes. From this we conclude that a cell separated from Volvox is not a self-sufficient organism; the colony is the complete individual. Even at this very simple level, each cell depends on the colony as a whole.

• SUPPLY SYSTEMS

In colonial organisms, the arrangement of cells in flat layers, or in tubes or hollow globes, furnishes a large surface through which nutrients can enter the cells and wastes can leave them. Some colonies, like the sponges, can grow quite large because they have a structure of branching tubes. The sponge grows by extending its branching tubes, and the new branches provide new surfaces.

Even in some complex animals—the frog, for example—the skin functions as a membrane, exchanging oxygen and carbon dioxide with the surrounding water or air. The frog's skin must remain moist in order to absorb and discharge gases in solution. But the frog cannot exchange sufficient amounts of the two gases through its skin alone. It needs additional breathing surfaces. These are supplied by gills when it is a tadpole, and by lungs when it is grown up.

Gills are constructed either in flat layers or in branching tubes. In either form, they have a large surface for water to flow over. Lungs too are built on the branching tube plan, which gives a large surface through which gases can be exchanged.



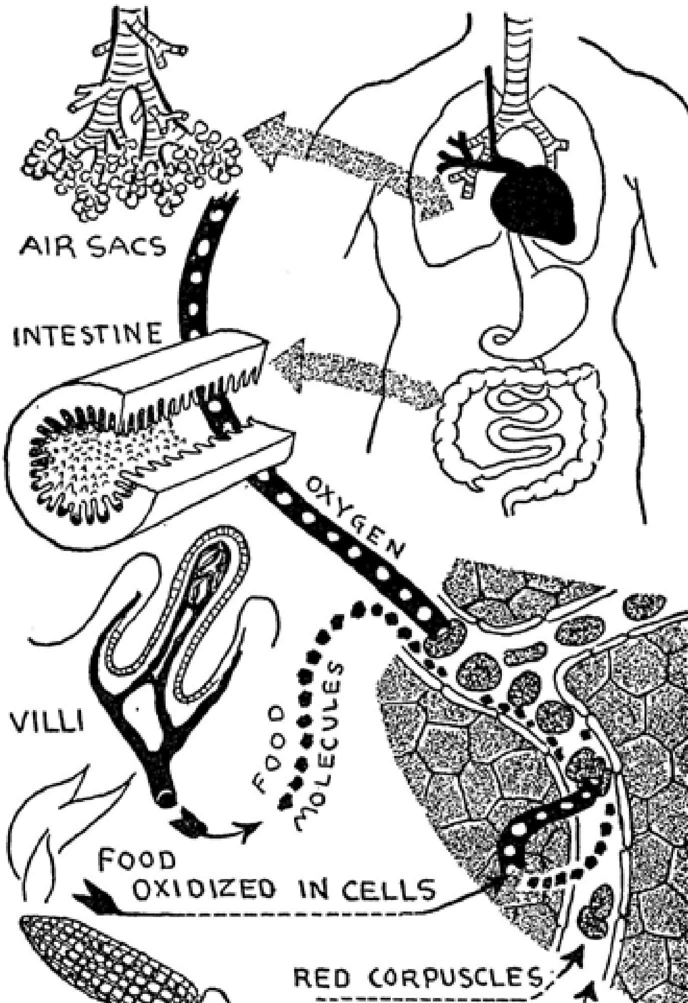
Food supply systems also have a structure determined by the need for large absorbing surfaces. In our own bodies, the food we eat has to be digested into small molecules that can pass through the membranes of the intestines and circulate to the tissues.

Our intestines have several features that increase their absorbing area. First of all, the gut is shaped as a long coiled tube—over twenty feet of it, an arrangement which in itself gives a fair amount of surface. The area is increased by having the inner lining folded into a series of accordion pleats. The folding adds area to the surface but it is still not enough. So the lining is provided with microscopic hair-like structures, the villi, which cover the lining as pile covers a rug. Fluids in the gut wash against the villi and pass through their membranes, carrying with them a cargo of food molecules for the whole organism.

The food molecules enter the blood, which ferries them through the blood vessels. A strong muscular pump, the heart, forces the blood through the vessels and keeps it circulating about the organism. In the tissues, the blood vessels branch into fine tubes, the capillaries. The food molecules leave the capillaries through their membranous walls, and enter the fluid that bathes the cells. The molecules pass into each cell through its membrane.

Thus the protoplasm receives its food, but the food would be useless without oxygen. Oxygen reaches the organism through another absorbing membrane, the lining of the lungs. Again a large surface is needed, for the lungs must take in oxygen for the whole city of cells. The lungs are made up of branching tubes with air sacs at their ends—a structure that gives the lining an area of about five hundred square feet.

Running through the lung lining are networks of capillaries. Blood courses through them, and in the blood floats a crowd of the little red corpuscles that give blood its color. The red stuff they contain,


AIR SACS
INTESTINE
OXYGEN
VILLI
FOOD
MOLECULES
FOOD
OXIDIZED IN CELLS
RED CORPUSCLES
CAPILLARY
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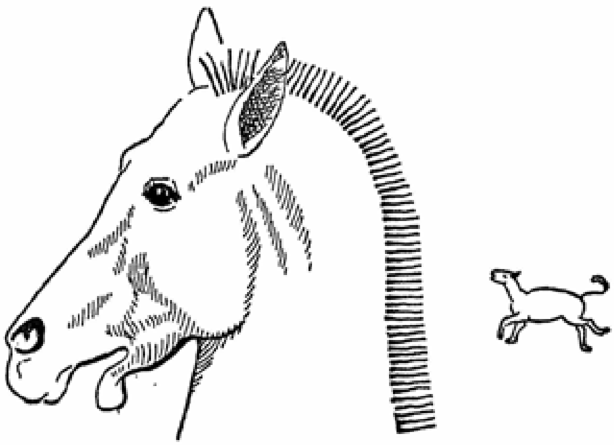
hemoglobin, does the important work of picking up oxygen molecules from the lung lining. Hemoglobin is a very special protein having some iron in its molecule. The iron enables it to attach and hold oxygen. The oxygen-bearing hemoglobin is carried in the blood stream to all tissues. In the tissues, the hemoglobin gives up its burden of oxygen to the fluid bathing the cells. From there the oxygen passes through the cell walls into the protoplasm, where it combines with the carbon fuels to produce energy.

Thus, through the joint working of the various systems of the body, the whole city of trillions of cells is well provided with food, and with oxygen to burn the food. In each cell the protoplasm, through the oxidation of its carbon fuels, obtains the energy to carry on its self-renewal.

· CHAPTER 6

NEW SPECIES FROM OLD



Living things resemble each other because their protoplasm is built from a common store of materials and has to function under generally similar conditions. But there is another reason for the resemblance of species: they are related to each other by common descent; their likeness therefore is a family likeness.

Before looking into the descent of species, let us be clear on just what a species is. It is something more than a collection of plants or animals that look alike and act alike. Of course, a species does have common traits by which we may be able to recognize it, but this is not the important thing. Dogs are pretty different in size and other features and yet all dogs can interbreed and have offspring, and this is what makes them a species.

A species, in nature, is a population of animals or plants that interbreed and have progeny. The common traits of the population—their varieties of structure and ways of functioning—are handed down from parents to offspring. "Like begets like." But no two individuals are exactly alike. Offspring differ somewhat from their parents. They vary slightly in form, function, and habit.

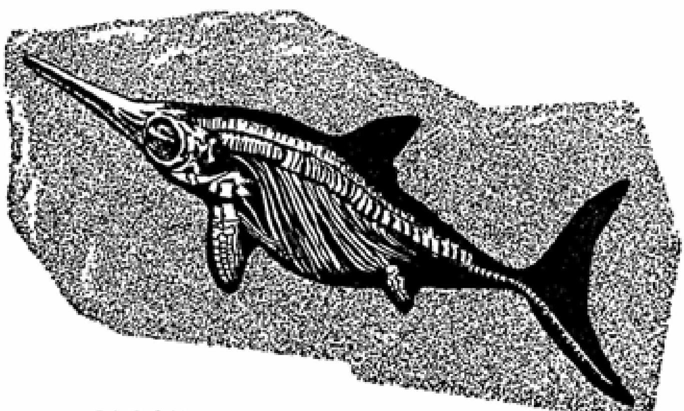
So long as the whole population remains fairly close together and its members can mate with each other, most variations become distributed through the whole population. The population changes, but changes as a whole; it remains one species.

Sometimes a population may become divided, as when groups migrate, or when land or water barriers cut them off from one another. Being isolated, the groups do not mate. And since they do not interbreed, they do not share new variations. Each group develops its own particular set of variations. When the ancestors of the horse split up into separate groups, a long time ago, some developed into the modern horses while others became zebras and asses.

In time, isolated groups become slightly different even in the make-up of their protoplasm. When this happens, it may be difficult or imposible for the groups to interbreed and have offspring. The groups then are separate species in the full sense of the word.

• STORY IN STONE

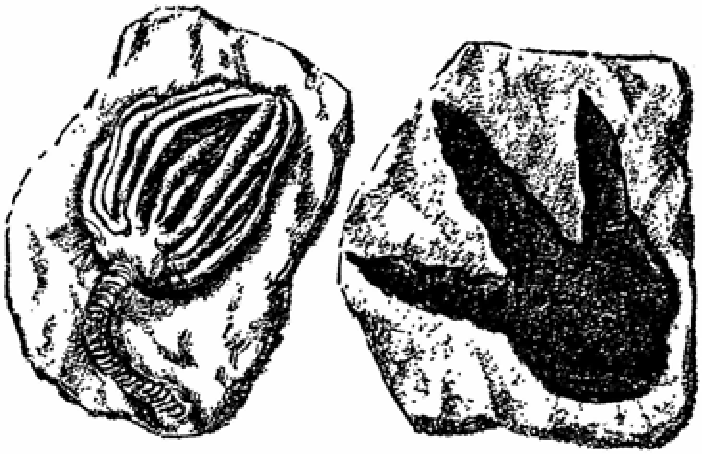
Species formation goes on so slowly that we would have to observe the process for a long time in order to witness and record any big changes. The span of time covered by written history is too short for this. Fortunately, however, the earth has made its own record of some chapters from the story of species. Certain rock beds hold the forms of plants and animals that succeeded each other for many million years.



FOSSIL
OF AN ICHTHYOSAUR, A FISHLIKE REPTILE

Fossil-bearing rocks are sedimentary—formed, as a rule, of water-borne grains of clay or sand which, when they reach still water, settle down on the bottom. The sediments pile up in layers from century to century. In time, pressure of the layers transforms the sediment into rock.

Sometimes, sedimentation buries organic remains whole and unharmed. Under favorable conditions, the remains become transformed into fossils. From the way fossils are embedded in the rocks, we can



A CRINOID OR SEA LILY FOOTPRINT OF A DINOSAUR

FOSSILS

often see just how they were formed. Once in a great while, a creature falls into mud and sinks in a place where bacteria of decay cannot get at it. In such a case, even the flesh may be fossilized. More usually, flesh and soft tissues quickly decay, and if anything at all is preserved it is the harder parts, the wood of plants and the shells, horn, and bone of animals.

A fossil may appear quite like a corpse, or a bit of a corpse. In most cases, however, the fossil actually is a cast of the corpse. In the first stage of fossilization, mud settles around the body and forms a mold. Meanwhile, the bones or other members enclosed in the mold decay. Minerals such as silica or calcium carbonate, dissolved in water, may seep into the mold. Gradually the minerals are deposited in the mold, replacing the organic material with a cast of rock. The mold also may remain intact. A mold, a cast, a footprint or other impression, a replica of dung or stomach contents—all are telltale traces of life, all are fossils.

Fossils lie in unknown numbers in the sedimentary rocks of the earth. Some are complete, or nearly complete, and give us a good idea of the structure of the plants and animals from which the fossils were made. In the case of trees, or creatures as big as the dinosaurs, the fossilized parts usally are separated and must be assembled carefully in order to give us some conception of the organism as a whole.

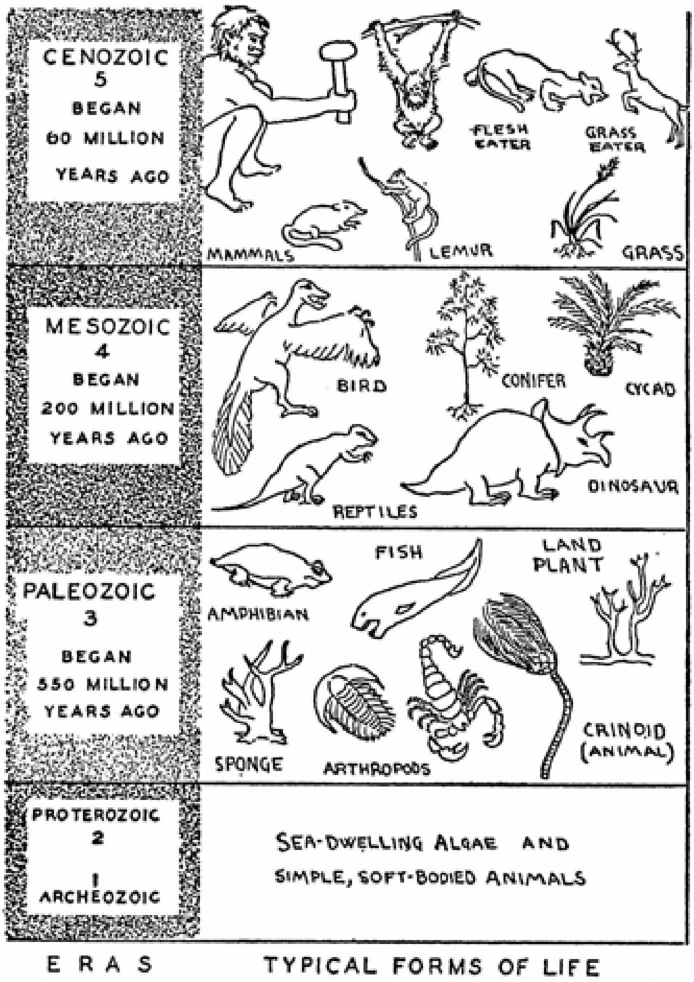
Some fossilized plants and animals look familiar to us—ferns and fish, for example. But most of the creatures we know best are lacking in older deposits. We see no bird of any kind and nothing that resembles a cat or dog or mouse or man. The majority of very ancient fossils are unfamiliar. Looking at them, we realize that a strange assemblage of creatures once inhabited the earth. We are bound to wonder what has happened to them.

Which living things came earlier and which later? In order to understand how the forms of life succeeded each other, it is necessary that we know the relative ages of the rocks in which they lie. Indeed, we must know the order in which all sedimentary rocks were laid down, over the whole earth. This is one of the tasks of geology, "earth science," which deals with the whole history of the earth, including the history of living things.

Geologists of many nations, by working together, have established the order in which most of the sedimentary rocks of the earth were deposited. The sequence of layers tells us the sequence of their fossils. The rocks become a book. The layers are pages in which we read the history of life.

In order to organize the record, geologists group a number of successive layers and give the series a name. The series stands for a period of geological time. Formerly there was no sure way of knowing whether a period lasted a million years or a hundred million. Now, however, the duration of periods is estimated with considerable accuracy, since it is possible to tell the approximate age of rocks from the extent to which uranium in them has decayed into lead.

We write the geological time scale from the bottom upward, and list succeeding periods one above another in the order in which the layers were deposited. The periods are grouped into larger divisions called eras. The earliest era from which there are abundant fossils has been named the



THE GEOLOGICAL TIME SCALE

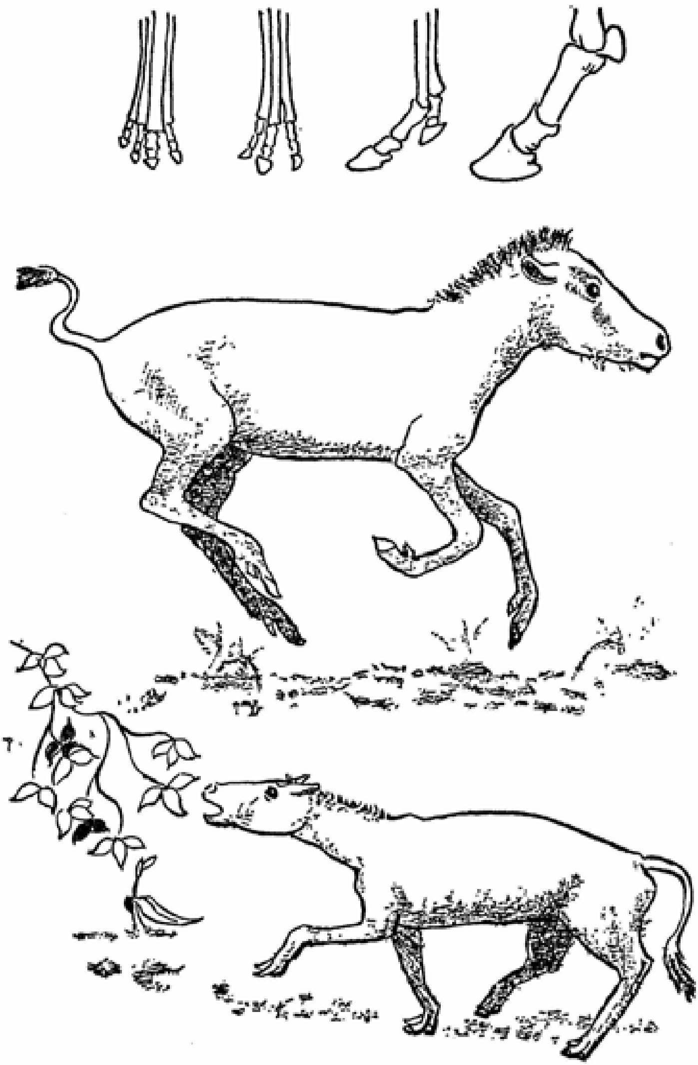
Paleozoic, which means "of ancient life"; next comes the Mesozoic era, "of middle life"; then comes the era in which we ourselves live, the Cenozoic, "of recent life." The time span from the beginning of the Paleozoic to the present, it has been estimated, is about 550 million years.

• THE MARCH OF SPECIES

By comparing the plant and animal fossils from Paleozoic times to the present, we gain a picture of the sequence of life forms. We can see that a few types appear early and continue through many periods. Sponges have existed from the beginning of the Paleozoic. Fishes appear somewhat later in the Paleozoic, and their descendants flourish through all succeeding periods.

Geologists reconstruct chapters from the story of life by tracing similar forms through succeeding rock layers. This procedure has led to some surprising discoveries. One episode reconstructed from fossil evidence is the story of the horse. A hundred years ago scientists noted that the leg bone of the horse has small structures fused into it on the sides. They concluded that these structures are remnants of toes and predicted that horse ancestors with several toes would be discovered.

This prediction came true when geologists, in exploring early Cenozoic rocks of North America, came upon the remains of a certain little beast about the size of a fox terrier. It had four toes on the front feet and three on the hind feet. Its teeth



were small and low-crowned, which showed that the creature lived by browsing on soft forest leaves.

In later layers, the geologists found a creature like the browser but bigger, about the size of a collie. Both the front and hind feet had three toes, the middle of which was considerably larger than the other two. In still later layers a creature turned up that resembled the others, but its middle toe was developed into a hoof, and the two side toes were small and useless remnants that did not even touch the ground. The teeth of this creature were large and high-crowned—strong enough to grind tough grasses as millstones grind wheat. The beast that used these teeth was unmistakably a grazer, a grass-eater. The teeth, feet, and whole skeleton revealed that the grazer was a horse.

From this series of forms, we see that the earliest one, the little browser, is a true ancestor of the horse. It is fittingly named Eohippus, "dawn horse."

At the time of the dawn horse, forests covered most of North America. Eohippus was a forest-dweller; it lived by browsing on soft leafage, as did many other animals of the region. Gradually, the climate of North America became drier. With the decrease of rainfall, trees and forest vegetation died out and there arose new types of plants that could thrive with less moisture. These were the grasses, which die down in a season of cold or drought, but with the return of warmth and moisture spring up again from their roots or from seeds.

As forests gave way to grasslands, animal species of the forest had to accommodate themselves to the new conditions, or migrate, or perish. In the changing environment, many browsers vanished, including the dawn horse. But among the descendants of the browsers were lines that adapted to conditions of the plains and became grazers like the modern horse.

If we keep the history of the horse in mind, we can imagine the process through which a species changes. Although the horses of each period were all more or less well fitted to their environment, individuals and lines varied, and among them were differences in degree of fitness. Some primitive horses still had teeth of the browsing type when grass was more plentiful than forest leafage and stronger teeth would have been more useful to crush the grass.

Among individuals and lines that are less well fitted than average, the life span is relatively short. This was true of the horse lines that kept their browsing teeth when food for such teeth was growing scarce. Because the members of these lines had a hard time getting along, and did not live as long as the members of other lines, they did not reproduce so plentifully. This meant that their variations, such as browsing teeth, gradually were eliminated from the species.

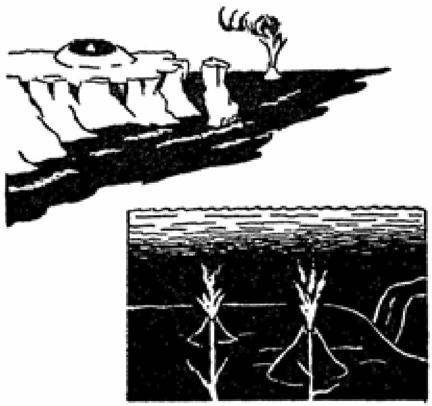
Among better adapted horses, the story was just the opposite. Suitable variations like grazing teeth enabled their possessors to live longer. And being long-lived, they could reproduce more plentifully and their variations were preserved. The net result was a sifting of variations in the species as a whole. Through the sifting, lines developed in a practical direction, became modern horses, and flourished.

Charles Darwin, the great biologist of the nineteenth century, called the sifting of variations "natural selection." He compared the process to the kind of selection practiced by cattle-breeders and plant-breeders, who develop new varieties by selecting the individuals they wish to breed. But in nature there is no breeder. Selection is brought about by natural forces—changes in climate, for example—which alter the environment. When the environment changes, the species must readapt itself if it is to survive there.

The whole process of development, through which species adapt themselves to live in a changing world, is called evolution. Over the course of hundreds of millions of years, a few simpler species evolved into many complex species, adapted in various ways to thrive in the different environments of the earth.

· CHAPTER 7

HOW DID LIFE BEGIN?



If we read the fossil record from the top down—from later to earlier layers—we see evolution in reverse, like a motion picture run backward. The deeper we dig, the simpler become the types of organisms. We would like to go back in time to the very beginning of the story; we would like to see fossils of the first organisms that lived on the earth.

But the story in the rocks does not begin at the beginning. The point at which the record becomes fairly clear, with good casts and molds and other fossils, is the opening of the Paleozoic era, about 550 million years ago. In layers from the preceding era, called the Proterozoic, there are limestones and marbles formed from the shells of living things, but no clear organic structures remain. The ancient rocks have gone through so much pressure and twisting during movements of the earth's crust that the fossils they contained have been transformed beyond recognition.

The Proterozoic era lasted 650 million years, longer than the entire span of time for which we have fossils. And yet the Proterozoic was only Era II of the drama of life. Before that was the Archeozoic era, which lasted 800 million years. In some of the deep, ancient rocks of the Archeozoic are deposits of carbon in the form of graphite. These deposits probably are remains of living things but no structures have been found to tell us what the organisms were like.

Altogether the five eras add up to 2,000 million (two billion) years. The 550 million years for which we have fossils make up only eleven per cent of the span—the latter part. The bulk of the story of life, 89 per cent, is "lost." Of what use can it be, then, to ask the question, "How did life begin?"

If there existed no evidence other than fossils, it would indeed be hopeless for us to try to understand how life began. But there is another kind of evidence; it comes from the science of biochemistry—"life chemistry." Workers in this field have examined the structure of protoplasm; they have artificially compounded a number of its products; and they have made up colloidal solutions which imitate, in a few details, the behavior of the life fluid. Through their work it is possible for us to imagine how life may have come into existence on the earth.

• THE EARTH'S SURFACE

Protoplasm builds up the most complex of molecules, but the raw materials it uses are elements quite common on the surface of the earth. When protoplasm is analyzed, we find it has carbon, hydrogen, oxygen, and nitrogen in about the following percentages by weight:

FOUR ELEMENTS IN PROTOPLASM

Element	Percentage by weight (average)
Carbon	10.5
Hydrogen	10
Oxygen	76
Nitrogen	2.5
	99

The remaining one per cent is made up of sulphur, phosphorus, potassium, iron, magnesium, calcium, and other elements.

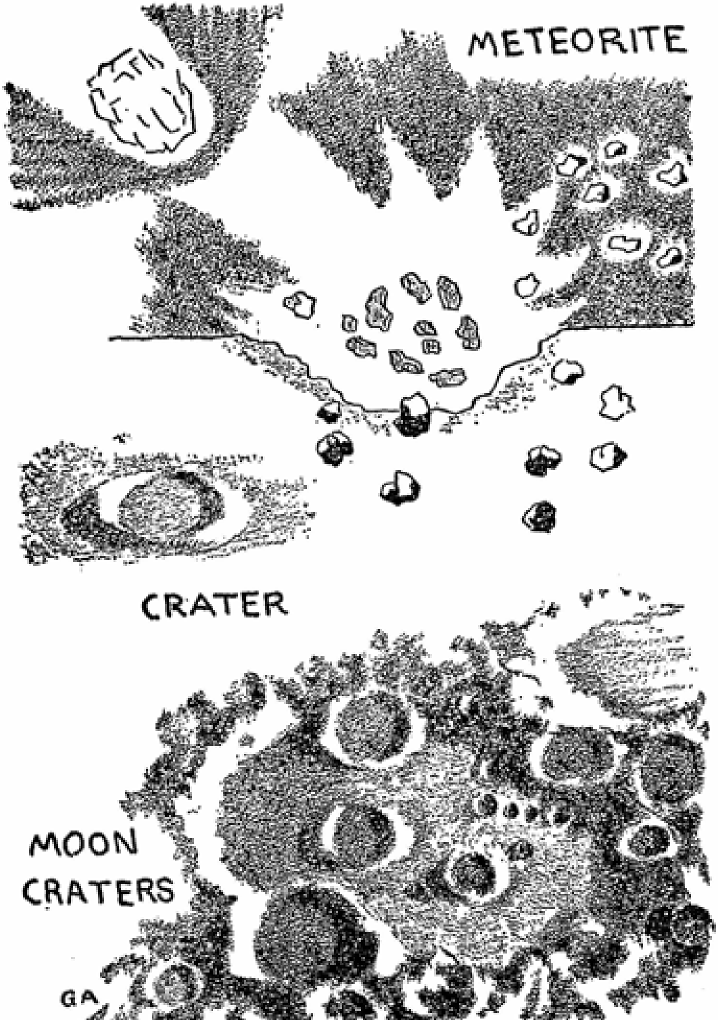
If we are really to begin at the beginning, we must account for the existence of the life-building elements on the surface of the earth. In other words, how did the earth begin? We shall not go very deeply into that dim story, but we do want to bear in mind some important facts about the background of our planet.

Today we know that the earth is not unique in its chemical make-up. Scientists have an instrument, the spectroscope, with which they can detect various elements and compounds in the atmospheres of stars, and also, to some extent, on the surfaces of the planets. The spectroscope has revealed more than half the earth's elements in the atmosphere of the sun and on the planets. This shows that the sun and its planets are formed from one batch of material. Many of the elements of the solar system are detected in the stars also, indicating that the solar system is just a part of the same stock of matter that makes up the whole universe.

In order to explain fully the origin of the earth and its elements, we would have to explain the origin of the solar system, and, beyond that, the history of the universe. But instead of looking that far back into the unknown, let us just try to form a reasonable picture of the development of the earth.

It would be convenient if we had a series of "fossil worlds" to show us the evolution of the earth. We know of no such series, but fortunately there does exist, within the range of our vision, one "fossil world." This is the moon.

If we study the moon through an ordinary low-power telescope, we see that its surface is pockmarked with circular craters, each surrounded by a rim of rocks. The craters resemble the meteorite crater El Diablo, in Arizona, and the much larger


METEORITE
CRATER
MOON
CRATERS
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Chubb Crater in northern Quebec. From the appearance of the craters of the moon, we think they too were formed by meteorites.

Meteorites are lumps of stony and metallic stuff, part of the left-over material of our solar system. Swarms of them still travel around the sun. Meteorites no doubt have always bombarded the earth as they have bombarded the moon, and have pockmarked its surface with craters. But on the earth, moving air and water and other forces have worn away most of the craters. On the moon, however, where there is no air or water, a large number of craters remain as they were formed.

Another feature of the moon's landscape is a sort of broad plain called a "sea"—waterless, of course—which as a rule is roughly circular and surrounded by mountains. As we look at the moon's battered surface, it is easy to imagine that the seas of rock were produced by giant meteorites. When such a giant crashed into the moon, the impact generated enough heat, we think, to melt the rocky surface over thousands of square miles. When the disaster was over, the surface cooled and turned solid again, leaving a vast flattened area, a level sea of rock.

Before the planets and moons took shape, the solar system, many scientists believe, was a revolving cloud of matter. Particles—planetesimals, they are called—drew together in the cloud through electric and gravitational attraction, and formed lumps. Greater lumps (planetesimals) attracted and captured lesser ones. The most massive of the lumps became the kernels of planets. As the planet-kernels grew in mass and increased their gravitational pull, they picked up the remnants of the old cloud

of matter. Finally, not much matter remained outside the sun and planets. Most of the left-over material was condensed in the form of meteorites.

The planets now had enough mass and gravity to attract the meteorites. Each planet, and each moon also, no doubt, gathered in its share.

• RUNAWAY MOLECULES

While the planets were forming, gases in the original cloud of matter did not at once gather into atmospheres. In the gaseous form of matter, molecules dash about swiftly. It is possible to hold a quantity of gas in a closed vessel, but as soon as the vessel is opened the gas quickly spreads out in all directions. So it was in the cloud of matter.

A speeding gas molecule travels in a straight line, until it bumps another speeding molecule. The collision bounces each molecule off in a new direction. Collisions may speed up or slow down the molecules, but the whole collection of molecules in a gas keep up an average speed.

In the earth's atmosphere, a gas molecule acts like a bullet. It can shoot away from the earth, but the gravity of the earth pulls it back. In order to escape altogether from the pull of the earth, the molecule would have to travel at a very high speed. This speed, the escape velocity, is the same for all bodies, whether molecules or rockets. On the earth as it is today, the escape velocity is a little more than seven miles a second.

If the molecules of the gases in our atmosphere could pick up bursts of speed of more than seven miles a second, they might all eventually escape, beginning with those in the outer layer of the atmosphere. At last the earth, deprived of its atmosphere, would have no weather, and no life. It would be a fossil world like the moon.

Fortunately, few molecules in our outer atmosphere work up to the speed of escape. Their average speeds, at a temperature of 32 degrees, range from a quarter of a mile to a little over a mile a second. Heavier molecules, like those of oxygen, travel slower; lighter molecules, like those of hydrogen travel faster.

On a small planet having less gravity than the earth, a molecule can escape at a lower speed. On little worlds like Mercury and the moon, some gas molecules would escape even at a temperature as low as 32 degrees. But on both these little worlds, sunlight heats the lighted side to a temperature high enough to drive off all gases.

During a rain of giant planetesimals or meteorites, when the surfaces of the moons and planets were molten, temperatures became so hot that gas molecules moved at higher speeds. At such times the earth lost gas molecules faster than it gained them. Mercury and the moon were deprived entirely of atmosphere, and very little atmosphere remained on the earth.

At such periods, scientists believe, the surface of the earth became hot and half molten. The interior also was heated to melting, as a result of compression and other forces. As the surface cooled off, the slag on the outside formed a thin film of rock. The film broke and melted again at many points, and


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hot magma—liquid rock—pushed up from the cracks and flowed over the surface. The film re-formed, over and over again; in time it became a thicker and more stable outer shell.

While the surface of the earth remained hot, liquid water could not exist on it. Only gasified water, steam, drifted around the earth as an atmosphere. In the outer layers, clouds condensed and rain fell, but as it approached the hot surface the rain turned into steam again. Light from the sun was absorbed in the heavy shroud of vapor which left the earth's surface in darkness.

Since water is the carrier and the medium of life, it was a great event when the first liquid water rained down on the earth's surface and remained there. Warm puddles gathered in the hollows. The rains began to fill the great basins and form seas.

• HISTORY OF C, H, O, AND N

As water wore down the rocks, it dissolved certain of their compounds and carried them into the seas. Substances in solution worked on each other and formed a variety of new compounds. What were they? Did compounds of carbon, hydrogen, oxygen, and nitrogen—the big four—mix and form protoplasm?

We would be mistaken if we imagined that protoplasm could be formed all at once by a mixing of ready-made ingredients. If that could happen, chemists would be able to create life in the test tube.

To create protoplasm at one stroke would be like creating a horse or other higher organism at one stroke. We know that protoplasm is a complex, delicately balanced, self-maintaining system. Such a system does not come about by accident. Like the horse, it has a history. Biochemists have tried to reconstruct the story of the rise of protoplasm, and we shall tell the version that is most widely accepted.

The fuels of most living things, and their structural stuffs, are built around the element, carbon. The chemistry of life is the chemistry of carbon. Therefore the story of life must begin with the history of carbon on the earth. There is pure carbon in the atmosphere of the sun and compounds of carbon on the planets. Carbon compounds are found also in those remnants of the stuff of the solar system, the meteorites. When meteorites are analyzed, we find their carbon exists in a compound with iron, iron carbide, which forms at temperatures as high as the melting point of rocks.

These facts indicate that carbon must have been among the materials that made up the early kernel of our planet. At times when parts of the young planet became hot and molten, the carbon joined with iron to form iron carbide.

Flows of lava brought iron carbide to the surface. There the lava met an atmosphere of very hot steam. Chemists know from experiment what happens under such conditions. When iron carbide is treated with very hot steam, the hydrogen of the water vapor combines with the carbon and forms a hydrogen-carbon compound—a "hydrocarbon." In the hydrocarbon, we have a simple linking of two elements of the big four.

Another member of the big four, nitrogen, must have gone through a similar history. In the molten earth, nitrogen combined with iron and other metals to form nitrides. When the nitrides came into contact with hot water vapor, there was a reaction in which the nitrogen linked with hydrogen to form ordinary ammonia (NH_3).

What about the other member of the big four, oxygen? Some oxygen was produced in the outer atmosphere, where sunlight broke up water-vapor molecules into hydrogen and oxygen. But oxygen from this and other sources could not accumulate in any great quantity in the atmosphere. Iron in the surface rocks unites greedily with oxygen; it is always drawing oxygen from the air. The abundant oxygen supply of today is a recent product that must be attributed to plants, which liberate more oxygen than the rocks can grab.

• THE BROTH OF THE SEAS

On the earth as it is today organic substances cannot lie around for any length of time without being destroyed. Since they are reduced compounds having little oxygen, or none, the substances would be slowly oxidized in today's atmosphere. But before this can happen to them, organic compounds are devoured by bacteria and other micro-organisms, which oxidize them for their energy.

Different conditions prevailed at the time of the gathering seas. There was no free oxygen to oxidize organic substances, and there were no micro-organisms to decay them. The earth was as sterile as though it had been boiled in a sterilizer. Reduced carbon compounds therefore were able to accumulate in the water. In certain areas, they formed a richer and richer broth.

Organic substances in a water solution, if allowed to stand, react with each other and build new compounds. Some of these are the same as compounds formed in living cells. They are simple compounds, it is true, and the process of their formation is slow. But the building goes on—that is the important thing!

In the early seas, carbon chains linked and looped together, forming larger molecules. The chains unlinked, relinked, and made new combinations over and over again. More and more complex molecules were formed, including molecules with nitrogen. Certain of the nitrogen-containing molecules united into super molecules. These were proteins.

Much of the energy for this building, chemists believe, came from the step-by-step oxidation of carbon. Since there was no free oxygen in the atmosphere, the carbon at first had to take its oxygen from broken water molecules. There was no help from direct sunlight, in the early seas. The blanket of water vapor absorbed most of the sun's radiation and made the surface of the earth quite dark. This was beneficial, for if the ultraviolet rays of the sun had not been stopped, they would have destroyed any beginnings of life.

• FASTER CHEMISTRY— COLLOIDS

There came a time when the organic building process picked up speed and reactions worked faster. This happened when some of the proteins developed into enzymes. In the cell today, enzymes are the expediters of all activity. They increase the speed of reactions several hundred thousand times. The wonderfully efficient enzyme system was not fully developed until cells existed, but enzymes did begin their evolution in the broth of the early seas.

Organic molecules grew in volume, until some of them reached the size of colloid particles. Particles of opposite charge drew toward each other, but did not pull together tightly, coagulating to form a solid. The water film about them held the particles a little bit away from each other, so that they merely coacervated—formed a jelly-like bloblet.

In the laboratory, chemists have mixed up organic materials and formed colloids that show us what must have been the behavior of colloids in the early seas. Larger particles in the solution gather into little blobs—coacervate. A bloblet holds together, attaches molecules to its surface, reacts with them, and increases its volume.

In regions of the early seas where temperature and other conditions were favorable, molecules of colloidal size bunched together into bloblets. The surface of such a bloblet responded to calcium salts in the water and pulled together into a gel. In other words, the bloblet made itself a membrane. This was a help in holding it together.

Particles in a bloblet, because they were held close to each other, could freely react. In the process, they built up many new kinds of molecules. More efficient enzymes and enzyme systems developed. These enabled the bloblets to increase the speed of their functioning. When one of them

reached a certain volume, it would be broken up by outside forces, or by tensions pulling on its own surface. By splitting in two, a bloblet kept the relatively large surface it needed for exchanging materials with the sea.

Colloid bloblets multiplied in the seas until they became so numerous that they began to use up the organic substances. Up to this stage, all processes were on the level of chemistry. But now a biological process came into play—natural selection. As organic nutrients became scarcer, conditions favored types of bloblet that were able to use new fuels. Some types developed into the bacteria that get their energy by oxidizing pure nitrogen, or ammonia, or hydrogen sulphide gas. Other lines managed to derive energy from the fermentation of sugar. These bloblets developed into the group of simple organisms known as yeasts.

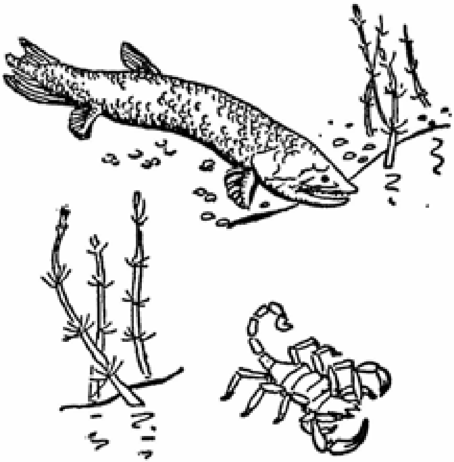
Meanwhile, the earth was changing. Sunlight now penetrated to the surface of the sea. The water and atmosphere were acquiring carbon dioxide from the process of fermentation. Certain lines of bloblet developed enzyme systems and structures that enabled them to benefit from the new conditions. The wonderful substance chlorophyll evolved, permitting plants to capture the energy of sunlight. This new way of gaining energy freed the green bloblet from dependence on ready-made organic compounds. It could salvage the ordinary waste product, carbon dioxide, formerly useless because its carbon was already oxidized, its energy spent. The green bloblet, using energy from the sun, could rip apart carbon dioxide molecules, get rid of their oxygen, and build for itself the reduced, high-energy carbon compounds that once had to be taken ready-made from the broth of the sea.

After a long course of evolution, lines of bloblets became cells. We do not know how the nucleus and other cell structures originated; but we can imagine, from biochemists' work with colloids, how matter on the earth crossed the gap from the nonliving to the living.

The fateful step was taken when organic molecules in the sea coacervated into bloblets. Before this, transformations of matter and energy were chemical transformations. But in the evolution of the colloid bloblet, transformations of matter and energy rose to the level of metabolizing, self-renewing protoplasm. This was the beginning of life on the earth.

· CHAPTER 8

FROM SEA TO LAND



All the plants and animals found in early Paleozoic rocks are sea-dwellers. Land plants appear only in later deposits, as do land animals, beginning with scorpions, centipedes, and millepedes.

It took hundreds of millions of years for living things to accommodate themselves to existence on land. It is a wonder they ever emerged from the sea at all, when we consider how unsuited they were to the land and the land to them.

Away from the sea margins, the continents were a desert of rock, bare and stark as landscapes of the moon. Rocks were worn down by weather changes and the action of streams, but the fragmented rock did not form soil. It lacked the decaying organic materials that plants need in order to grow. The rubble from the rocks was as barren as the rocks themselves.

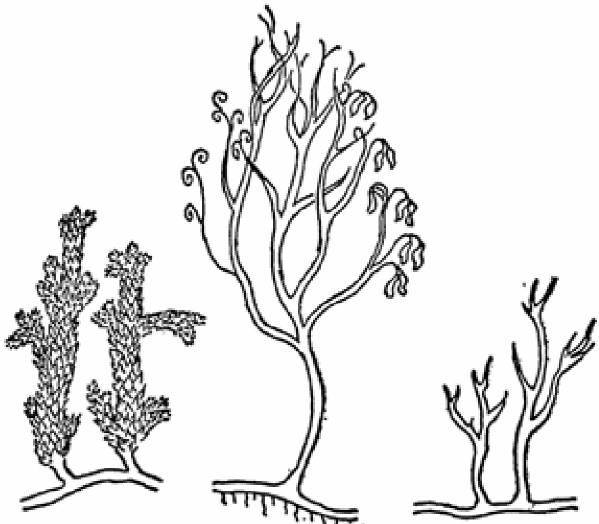
• STRANDED PLANTS

The off-shore waters abounded with life. In the shallows, up and down currents bring about a complete mixing of the water, from top to bottom. This distributes the nitrates, phosphates, and other plant nutrients that tend to accumulate in the depths. Algae are abundantly nourished. They thrive at all levels, for sunlight penetrates even to the bottom.

Seaweeds depend on water-borne nutrients which they take in through their whole body surface. This means that they have to be entirely covered with delicate membranes, to admit the dissolved nutrients. Such a covering is no protection in the air. When algae are cast up on land, their fluid evaporates through the membranes, and they dry up into empty wisps.

The first plants to survive in the air were not true land plants. They were plants that lived between the tides, half the time in water, and half the time out. Over a long span of time, some lines developed coverings that could protect the plant body from evaporation when exposed to the air.

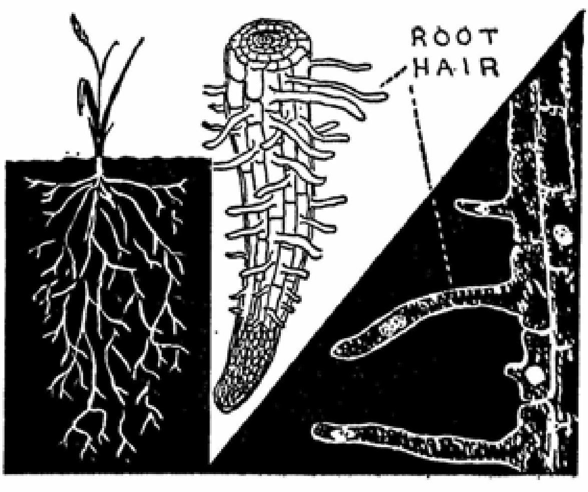
The first green plants of the land were simple little bodies like the mosses, perhaps, without division into leaves, stems, and roots. A later type of plant, as we know from its fossils, has an arrangement of branching stems without leaves. There is no root



system. Part of the stem lies underground and functions as a root. With only a crude makeshift for a root, or with none at all, the early plants had to cling to the tidal flats in order to absorb enough moisture. For ages, they went no farther inland. The continents, away from the green shores, remained desert.

In order to live on dry land, plants need, among other things, structures to hold them up in the light and air. In the sea, there is less need for supporting tissues. The water buoys up the plant body and holds it together. In the air, such support is lacking; a plant must make up for the loss of outside help by having strong cellulose fibers and woody stems to hold it together.

The main problem, in the forming of land plants, is to have surfaces capable of exchanging the necessary amounts of materials with the outside world. Leaves provide a surface to receive light, exchange gases, and make food. They are the fuel factories of the plant, and their working area must be large enough to supply all the tissues of the organism. The larger a plant, the greater must be the surface that its leaf system presents to the light and the air.



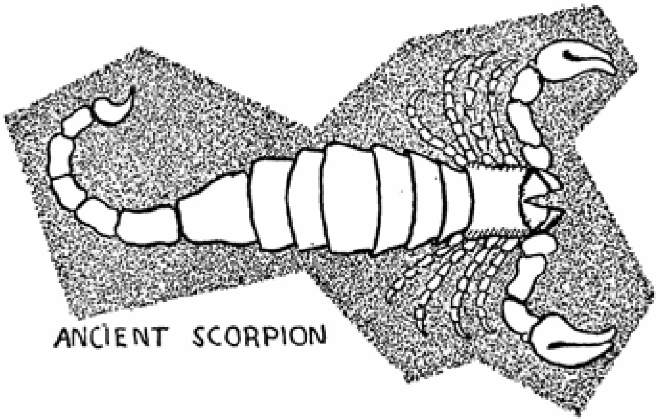
The volume-surface problem also determines the structure of root systems. The plant absorbs its water and dissolved nutrients through the roots. As the plant grows, the root surfaces must increase in order to supply the city of cells with water and nutrients.

The branching of roots increases their surface, but not sufficiently. Much more area is gained by having the root ends covered with tiny hair-like fibers, each an extension from a cell. Because of their slender shape and their great number, the root hairs provide an enormous absorbing area. In a plant of winter rye grown for study purposes, the roots measured a total length of about four hundred feet. Their surface amounted to 2,550 square feet.

• JOINT-FOOTED CASTAWAYS

Since animals depend ultimately on plants as the source of their fuel, they could not live on land until plants were established there, creating a food supply. Even then, animals had many problems to solve before they could become land-dwellers.

The first animals that managed to exist out of water were types of crawlers from the off-shore bottoms. They had jointed feet, and because of this we call them arthropods, "joint-footed." The crawlers had developed a structure valuable for survival on the bottom—a tough shell that protected them from the big fishes. The shell was divided into movable parts, with muscle attachments. Thus, it worked as an outside skeleton, which held the joint-foot together and enabled it to move about. The shell served another purpose. When the joint-foot was stranded out of water, the shell protected it against evaporation.



Today, descendants of the arthropods inhabit both the sea bottom and the land. Among the sea-dwellers are crustaceans like shrimps, crabs, and lobsters. The land-dwellers are the insects, spiders, scorpions, centipedes, and millepedes. In the long time they have been on land, the arthropods have evolved into a great number of species. Three-fourths of all animal species named and identified are insects.

The outside skeleton has served the insects pretty well, but it has serious disadvantages. The shell is not living tissue; it does not grow, and it must be shed if the animal is to grow. Crustaceans spend a good portion of their lives changing to larger sized shells. They have to put a lot of energy and material into the making of things that later are thrown away. Some insects too go through this wasted effort, and spend long inactive periods growing shells. The outside skeleton also limits the size of arthropods living on land, for beyond a certain size it becomes too heavy for them to drag about.

Insects are still more restricted by their breathing system. They breathe through air tubes that carry oxygen directly into the body tissues and carry carbon dioxide directly out of them. Such a system would not work in a large animal, for it could not provide enough surface to absorb the needed amount of oxygen and to discharge the carbon dioxide. Insects, for all their variety and their success on land, are quite severely limited.

• FISHES OUT OF WATER

During the middle of the Paleozoic era, fishes became the most highly developed of animals. The main asset that enabled them to dominate the sea was the internal skeleton. This structure did not come into existence all at once. It first arose in little worm-like creatures which developed a rod of cartilage running through the center of the body, stiffening it, and supporting the central nerve cord.

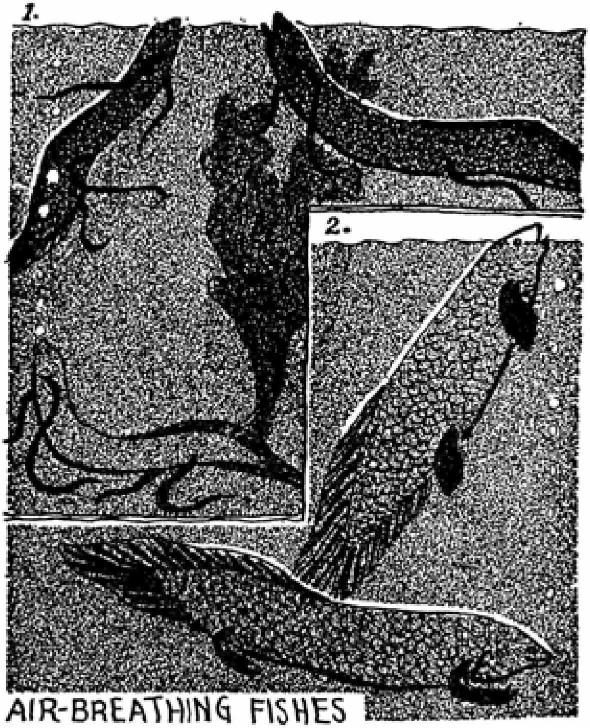
In fishes, the central rod was replaced by a spinal column made of movable parts, the vertebrae. From this structure we derive the group name of the fishes and all backboned animals, the "vertebrates." The muscles of the fish are attached to the flexible backbone and easily move it, working together in beautiful co-ordination to speed the fish through the water.

Fishes did not emerge from the sea so readily as the arthropods. They were too much at home there. They had no legs and they lacked a covering to protect them against evaporation. How to breathe air was a problem, too, but certain fish species developed lungs and breathed air before they possessed a suitable skin for living on land. Lungfishes were numerous in the middle of the Paleozoic era. They left descendants, the lungfishes of today. Studying their habits we see how vertebrates may have first developed the ability to live out of water.

Fishes with lungs live in the Amazon River system in South America; others inhabit the rivers of Queensland, Australia; and some are found in the lakes and rivers of central Africa. The African lungfish Protopterus does only a little breathing through its gills, which are too small to supply enough oxygen. The fish has to rise to the surface every now and then and gulp down a lungful of air.

Air-breathing fishes can live in environments that are dangerous for water-breathers. In central Australia and central Africa, streams and lakes dry up during the droughts, leaving only a few stagnant pools. The water in these pools is deprived of oxygen because most of the plants that supply this gas die off during the drought. Some of the products of their decay are poisonous. Fishes suffocate in such water unless they are able to breathe air.

When the African lungfish is trapped in a shrinking pool, it burrows into the mud. The mud dries up around its body, and it seems the fish has taken



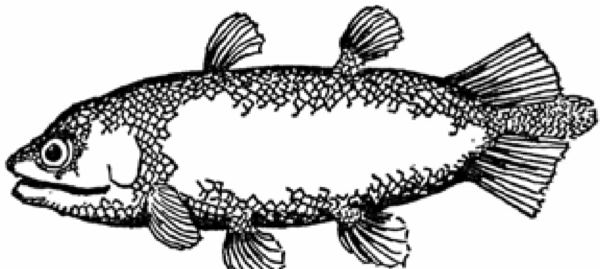
AIR-BREATHING FISHES
1. AFRICAN LUNGFISH PROTOPTERUS
2. AUSTRALIAN LUNGFISH NEOCERATODUS

the first step toward becoming a fossil. But it may escape such a fate. The fish is covered at all times with a mucous secreted through the skin. As the fish lies buried in the mud, the mucous dries and forms a capsule that encloses the whole body and protects it from drying. The fish may remain in its capsule of mucous and dried mud for several months, breathing air and nourished by the fat stored in its body. When rain comes and water again fills the bottoms, Protopterus is liberated; it swims off and lives as a fish again.

• THE DOUBLE LIFE

In the Paleozoic era, as today, existence in swamps was dangerous for water-breathing creatures. Evaporation and organic decay threatened to suffocate them. For millions of years, fishes stranded in such environments perished. But in time some lines developed lungs that enabled them to breathe air and survive in a region of stagnant pools.

Certain lines of air-breathing fishes varied in another way. They developed strong, paddle-like fins



with which they were able to wriggle from a dried up pool and push their way toward water. Such fishes of the Paleozoic era, as their fossils show, had two pairs of paddles on their sides, corresponding to legs. The fin part of the paddle is carried at the end of a "lobe," a short muscular organ attached to the skeleton. It has bones corresponding to the leg bones of a land animal.

In the middle of the Paleozoic, lines of air-breathing fishes evolved into "amphibians." This

name means "leading a double life," and refers to the fact that amphibians spend part of their life in the water and part on land. The early amphibian was just a fish on legs. In the water, the legs worked as paddles; on land, they enabled the amphibian to drag and push itself along, but since they were on the side of the body instead of beneath it, they could not raise the amphibian's belly off the ground.

The early amphibian kept to the water of necessity. A flesh-eater, like the fishes from which it evolved, the amphibian had to feed in the water, for on land there was no meat for it except the insects and their small fellow arthropods. The amphibian also needed water to keep its skin wet, for it breathed through its skin as well as through its lungs.

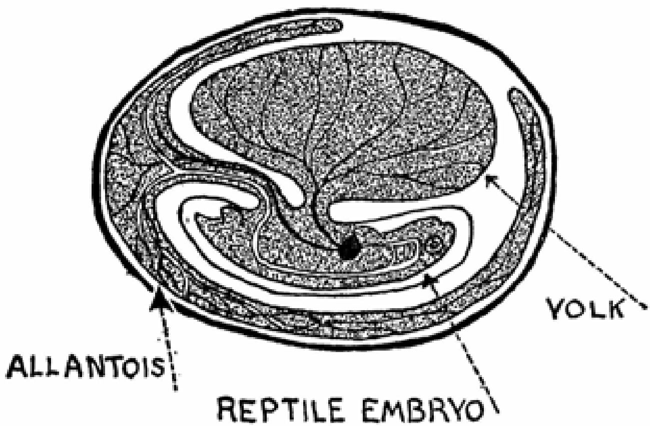
If we think that legs developed so the half-fish could live on land, we are mistaken. Legs developed so that the amphibian could escape from the land. In time of drought, a stranded amphibian used its legs to crawl toward water, its true home.

The early amphibians, like their descendants the modern salamanders, frogs, and toads, laid their eggs in water. An amphibian egg is covered with membranes through which oxygen from the water passes in to the unhatched young, the embryo, and carbon dioxide passes out from the embryo to the water. The young amphibian hatches in the water, and breathes water in the manner of a fish.

• THE REPTILES' TRIUMPH

During the close of the Paleozoic era, climates became cooler and drier. In many regions, the swamps dried up. Changing environments sifted out the amphibians. The lines that managed to exist and propagate their kind of drying regions were those that became fit to live away from the water. They developed better lungs and evaporation-proof skins. And their egg evolved in such a way that it could be laid on land and would function when surrounded by air rather than water. These various changes, and especially the new type of egg, freed the progressive lines of amphibians from the water, and they developed into reptiles.

The reptile egg has a shell dense enough to protect it from evaporation yet porous enough to admit air. As the embryo develops, a special breathing tis-



sue, the allantois, grows from the embryo and flattens out against the shell membrane. The allantois functions as a sort of lung, drawing oxygen from the air and discharging carbon dioxide.

The reptile egg is equipped with a large yolk, the food supply for the embryo. At first, the embryo is just a speck attached to the yolk. Gradually it absorbs the yolk. The food supply is sufficient for the embryo to stay in the egg longer and develop further than the young amphibian before hatching. The reptile embryo goes through the fish stage while still living in the water of the egg. By the

time it hatches, it is able to breathe air, beginning life at a stage which the amphibian does not reach until it is an adult.

Once they were liberated from water, the reptiles began their fantastic history. Many lines developed, branching out in different directions. From some lines evolved the dinosaurs, the "terrible lizards." In time, certain lines returned to the sea and became fish-like. Others developed wings, and some line of flying reptiles evolved into birds.

The heyday of the reptiles lasted from the close of the Paleozoic through the Mesozoic era—a span of about 140 million years. During their long triumph, the reptiles spread over all continents; they completely dominated animal life on the land. But the Mesozoic closed with tragedy for most lines. The dinosaurs died out completely. Today only the lesser reptiles remain—the lizards, turtles, crocodiles, and snakes. The causes of the extermination of the dinosaurs are not known for certain. Climate changes, both regional and world-wide, most likely were severe enough either to destroy the dinosaurs or to destroy their food sources.

· CHAPTER 9

LIVING AT HIGH SPEED

A serious disadvantage of the land, for living things, is its range of temperature, which today is more than four times as great as the temperature range of the sea. The sea, by comparison, is very evenly heated, both from region to region and from season to season.

When arthropods and amphibians first emerged on land, conditions were not severe, or such creatures would not have been able to survive. The climate of the earth as a whole, in the early and middle Paleozoic, was warm. Great marshes bordered the seas, lakes, and rivers. Tropical plants flourished in zones that today are cold, and rushes and ferns grew to the size of trees.

When climate changed, either regionally or on a world scale, land-dwellers either had to adapt to the change or migrate. When the earth as a whole became cooler and drier, at the close of the Paleozoic and again at the close of the Mesozoic, there was no escape from the new conditions.

• THE HALF-DEATH

We know how cold affects arthropods. A house-fly can barely move on a cold day in autumn. It becomes so helpless that we can pick it up easily. An insect in the cold is only half alive, and it dies when exposed to frost. Those that survive temperatures below freezing do so by very special means. They dig into some shelter and pass the winter in an inactive state, a sort of half-death that we call hibernation—"wintering." Amphibians and reptiles too must hibernate, in a zone of freezing winters. Frogs, toads, land turtles, and snakes go underground to avoid frost, just as animals of the desert go underground to avoid heat.

Given sufficient warmth, arthropods, amphibians, and reptiles become active and even lively. In tropical South America there are basilisk lizards that run upright on their hind legs, like miniatures of the two-legged dinosaurs.

A reptile or insect becomes lively in warm weather and sluggish in cold because its body metabolism changes speed when temperature changes.

Generally chemical reactions, whether in living things or in the non-living world, go on slowly at

lower temperatures and faster at higher temperatures. We understand the reason for this. Chemical reactions are movements of molecules and atoms, and heat is both the cause and result of such movement. In fact, heat *is* molecular movement. The speedier the chemical reaction, the greater the heat; the greater the heat, the speedier the chemical reaction. In plants as in animals every cell produces some heat as a by-product of its metabolism.

Reptiles and arthropods become sluggish in the cold because their cell chemistry yields only enough heat and mechanical energy to keep alive, but not enough to carry on other activity.

During regional and world-wide cooling, at the close of the Mesozoic era, the land-dwelling species that survived and propagated their kind were those that became fitted for life in the new temperatures. Among the reptiles, some lines managed to survive merely by changing their habits. These were the small creatures that could creep into some shelter when the cold of winter began to slow them down.

But "half-death" is a poor solution, for in every species of hibernators a great many individuals slow down too much, and before summer comes to revive them they are dead.

• THE EVEN-HEATING SYSTEM

A better kind of adaptation was developed in two branches of the reptiles. One of these was the offshoot that gave rise to the birds; the other, the branch that evolved into the mammals, the hair-covered beasts. These two branches met the problem of cooling climates by developing a climate of their own, inside their bodies. They did better than change their habits and their covering. They changed the very chemistry of their cells.

In a bird or mammal, the chemical system of the cell works faster than in a fish, amphibian, or reptile. We say that the bird and mammal systems have a high combustion rate, which means they oxidize fuels more speedily. Swifter metabolism gives the bird and mammal more energy. Some of this energy is spent in mechanical work like running, swimming, or flying; some is used to operate the organ systems of the body; and the rest is released in the form of heat.

We call birds and mammals "warm-blooded." This expression is not accurate, since a reptile, amphibian, or fish becomes equally "warm-blooded" when the surroundings are warm enough. A little fish living in the warm springs of Ceylon, which have a temperature of 122 degrees, is much "warmer-blooded" than any mammal or bird. Even when the environmental temperature is cold, a fish, amphibian, or reptile generates enough heat to be several degrees warmer than its surroundings.

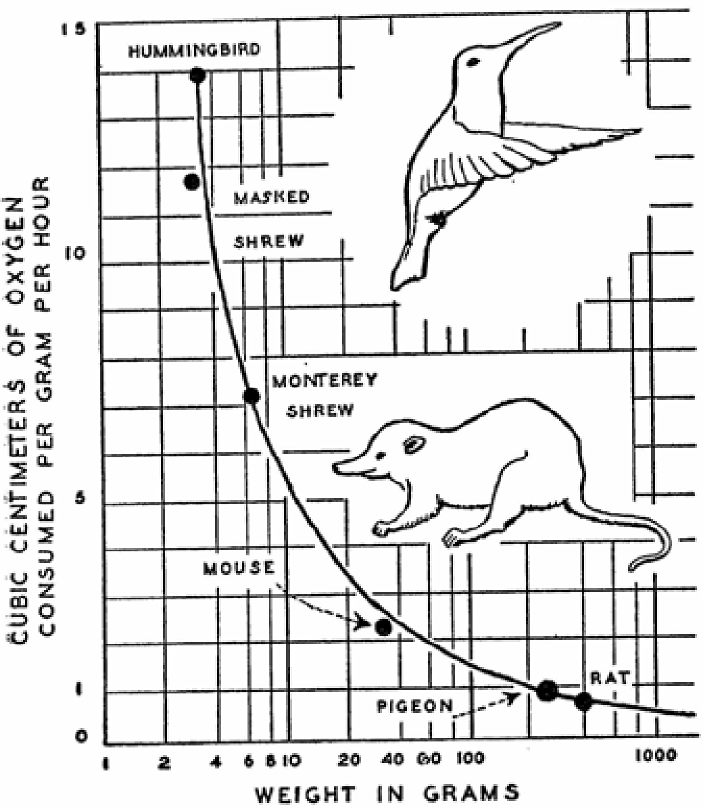
But the "cold-blooded" animal does not produce enough heat to stay warm when the environment is quite cold. As the surrounding air or water cools, the animal becomes nearly, if not quite, as cold. Still we should not call the animal "cold-blooded," for it has a heating system, even though an inefficient one that cannot keep the organism evenly heated in severe temperatures. The animal really should be called, not "cold-blooded," but "unevenly-heated."

In birds and mammals, the rate of metabolism is controlled at a point high enough to warm the animal even when the surroundings are quite cold. The bird and mammal are not just "warm-blooded"; they are "even-heated," since their body temperature remains about the same, in spite of changes outside it. The benefit of even-heating is that the organism can function in the cold and does not slow down and go through a dangerous half-death.

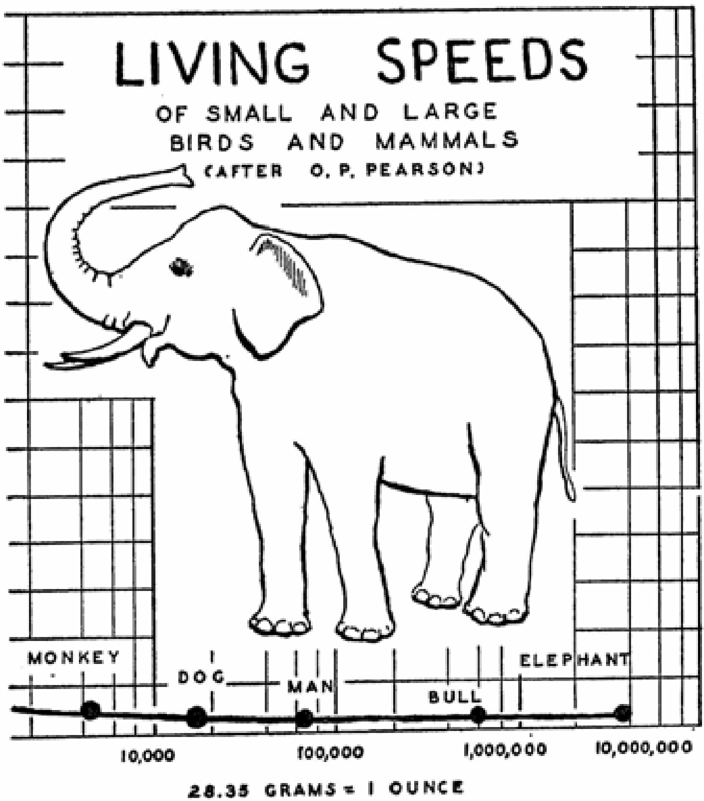
In the bird and mammal, metabolism speeds up or slows down readily, according to energy needs. Some energy must be produced at all times, even when the animal is at rest, in order to maintain cell functioning and to carry on breathing and the circulation of the blood. This metabolism of the resting state is called the basal metabolism. The rate of metabolism can be measured by the amount of heat produced in a given time, or by the amount of oxygen consumed and carbon dioxide given off. When energy is needed for muscular activity, the rate of metabolism increases. When the need is for more heat, the animal shivers or otherwise works its muscles, and in this way speeds up its metabolism and produces more heat.

All the heat produced eventually passes into the surrounding air or water. Heat therefore is energy thrown away, in the sense that it does no work. Yet such "waste" is necessary for the functioning of the bird and mammal body. The way the even-heated system is organized, all the cells have to metabolize—transform energy—at the basal rate at least. The cells cannot slow down much below this rate and keep alive. Even when the outside temperature is as high as the normal body temperature of the species, or higher, the cells must go on working at the basal rate. As they do so, they produce heat.

When the air is as hot as 98½ degrees, which is the normal temperature of the human body, a man need not produce any heat to maintain his temperature. Every bit of heat he does produce is useless and dangerous. It has to escape promptly, or the body would reach an intolerable temperature and the man would die of a heat stroke. Under these conditions, emergency mechanisms start to work. They cause the man to sweat plentifully, and evaporation of the sweat cools him.



The metabolic rate of a bird or a mammal depends on its size. A mouse lives much faster than an elephant. The mouse eats more food for its weight, and produces more energy. In a given time the mouse uses twenty-five times as much oxygen and generates twelve times as much heat as the elephant, per gram of body weight. In order to keep up this higher rate of metabolism, a mouse has to have cells smaller than those of an elephant. With metabolism going on



faster within the cells, the cells must have a greater relative surface in order that a greater quantity of materials can pass into and out of them.

But why does the mouse metabolize faster than the elephant? One reason is that the mouse radiates a relatively greater amount of heat into the air. In fact, the mouse loses a hundred times more heat per square inch of its surface than it would lose if it were the size of an elephant. The cause of this greater heat loss is the volume-surface relationship. Heat radiates from the body surface, and also escapes from the lungs during breathing. The mouse, smaller than the elephant, has a much greater proportion of surface to radiate heat. And since the mouse must breathe faster to supply oxygen for its fast metabolism, it also loses relatively more heat in breathing.

A hummingbird is very much smaller than a mouse, and it lives about seven times as fast. That is, it burns seven times as much oxygen as a mouse, per gram of body weight. It uses over a hundred times as much oxygen per gram as an elephant.

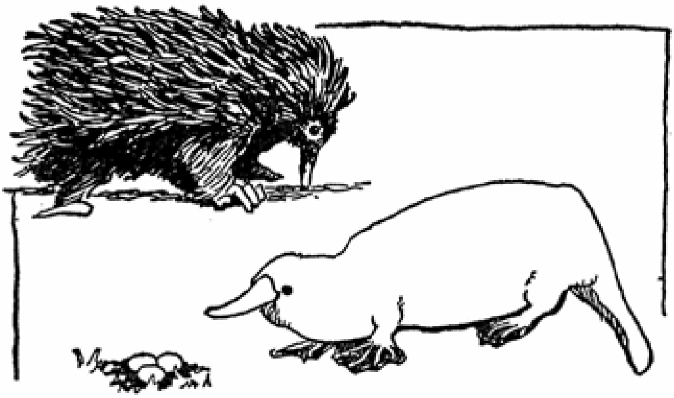
The hummingbird must eat almost continuously during the day, in order to maintain its high rate of metabolism. If it lived at such a speed at night also, the hummingbird would have to eat all night long, or starve. But it does neither. Instead, the hummingbird "hibernates." It slows down its metabolism to one fifteenth the daytime rate, and its temperature cools down to that of the air. The little bird remains chilled and torpid until morning. Then it quickly speeds up to its daytime rate of functioning, and busily sips nectar, the fuel for its rapid living.

• WARMTH FOR THE UNBORN

In cold climates, small animals have a hard time keeping alive. The cold sifts them out rigorously, and in order to survive they must develop good means of protection. During cooling periods of the Mesozoic era, the reptiles that most urgently needed even-heating were the small ones. And it was they—the little types—that developed even-heating and became mammals and birds. The fossil record shows that the early mammals were small, about the size of rats.

As bird and mammal lines became even-heated, there rose the problem of how the young were to come into the world. The young have to develop at about the normal metabolic rate and temperature of the species. Among the early even-heated animals, the practice of leaving the eggs and embryos to shift for themselves was no longer safe. The embryos would not develop if left in the cold. In cooling climates, the lines that survived were those in which the adults learned to take care of their eggs. The birds of today show us that egg-layers can prosper by brooding their eggs to keep the embryos warm. This method doubtless was adopted also by the early mammals, which probably resembled the two egg-laying mammals of today, the duckbill and the spiny ant-eater of Australia.

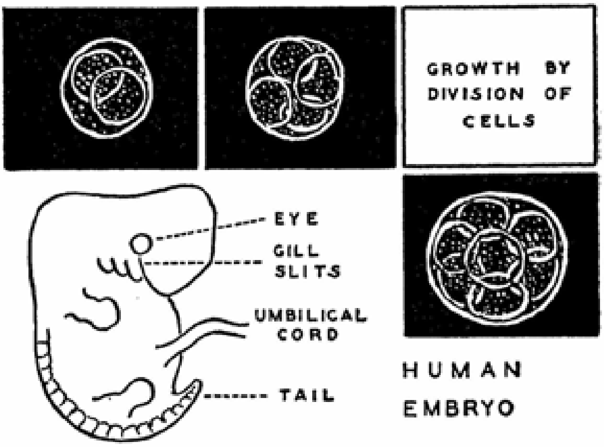
As their next forward step, mammals stopped



laying eggs, and brooded the embryo right inside the female's body. This arrangement solves many problems. The embryo is sheltered, snug and warm, at the temperature of the species. Not long after its birth, the young mammal is able to maintain its own temperature, so that it can exist in the world as an even-heated creature.

Before birth, the young mammal speeds through the evolutionary stages of its ancestors. The embryo begins life as a single cell; it grows by cell division into a colony of cells; it develops a fish-like form and even gill-slits; finally it becomes a little mammal.

But even at birth the young mammal is not complete. Before it can make its own way in the world it has to go through further development of the body. And not only that; it has to develop its intelligence, for it possesses a brain capable of a fair amount of learning.

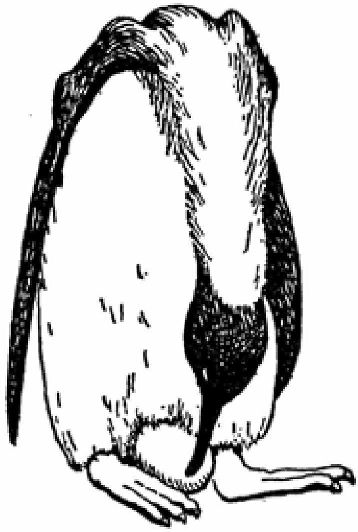


The young mammal has something else that young reptiles and amphibians lack—a mother. The female continues to nourish the young after it is born, while it goes on developing its body and its intelligence. The mother feeds the young from her special milk glands, the *mammae,* from which we derive the term "mammal."

• VICTORY OVER COLD

Since small animals lose a great deal of heat in cold weather, it is hard for them to live in very low temperatures. Small mammals and birds do not penetrate so far toward the poles as do larger ones. The farther north we go in the Arctic, the fewer small mammals we find. Some of these must hibernate in order to live through the winter. During hibernation they slow down their breathing and heart-beat, just as reptiles do. Sometimes their body temperature falls so low that they become almost as "cold-blooded" as a reptile, amphibian, or fish.

Only a few of the mammals must hibernate in order to live through cold winters. The great majority need not go through the half-death, even in polar regions. From the point of view of a reptile, this is truly a miracle—that animals can live at a normal rate of metabolism in the frozen wastes of the earth today.



A PENGUIN TUCKING AWAY ITS EGG.
THE EMPEROR PENGUIN LAYS A SINGLE EGG ON SEA ICE AND ROLLS IT ON HER FEET TO BROOD IT.
ANY MALE OR FEMALE WILL EAGERLY SHELTER THE EGG. THE CHICK BEGINS LIFE IN THE SAME SHELTER.

The even-heating system did not originate with the mammals and the birds; it did not come out of nowhere. It is just a higher development of the balancing and controlling mechanisms that regulate the chemistry of all cells. In a plant, or in a one-celled organism, or in man, the activity of protoplasm is governed by those wonderful self-renewing proteins, the enzymes.

In the mammal, the system of enzyme control has reached a very high degree of refinement. Enzymes specialized for various tasks are always ready to act, whether to slow down or speed up cell chemistry. The signal for a general quickening travels along the wire service of the nerves. It goes to a special center of the brain which controls temperature, and from there a message is sent out to the glands. Secretions called hormones pour out of the thyroid and adrenal glands into the blood stream, circulate to the tissues, and start a chain reaction in the cells. In each cell, the enzymes go to work and regulate metabolism according to the needs of the organism.

The regulating system of mammals is superior to anything possessed by the reptiles and their ancestors. It is not just from prejudice, as mammals, that we say this. There is a perfectly objective measure of progress in evolution. This measure is the degree of independence from conditions of the environment. Reptiles in their day achieved freedom from the water-living stage of the amphibians, and this freedom enabled them to populate most lands. But they could not survive in regions that became cold. To this day, reptiles and amphibians are confined to the hot and the temperate zones. Mammals, however, with their even-heating system, have gained a greater freedom from conditions of temperature, and through this freedom they have mastered new climates and new regions of the earth.

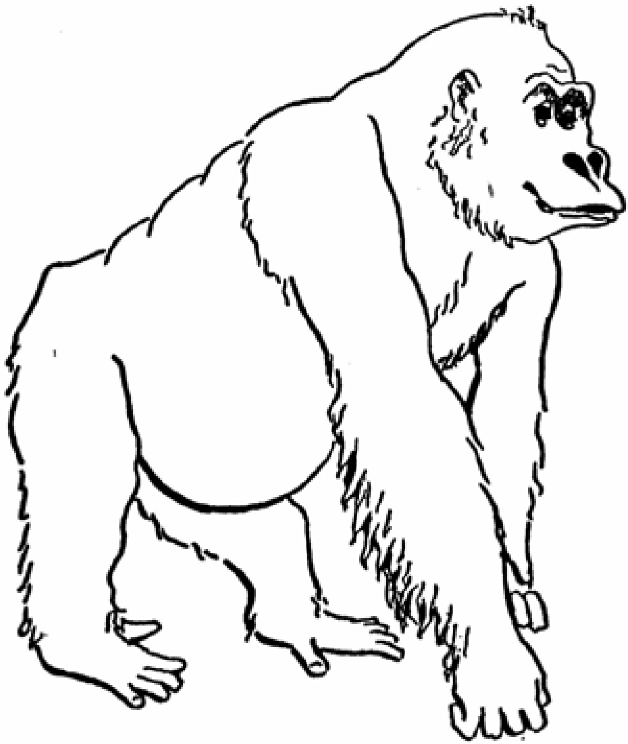
· CHAPTER *10*

THE AGE OF MAN

Man is a latecomer among the creatures of the earth. Human remains so far discovered date only from the last million years. Yet man, like the horse, did not come from nowhere, but descended from a long line of ancestors.

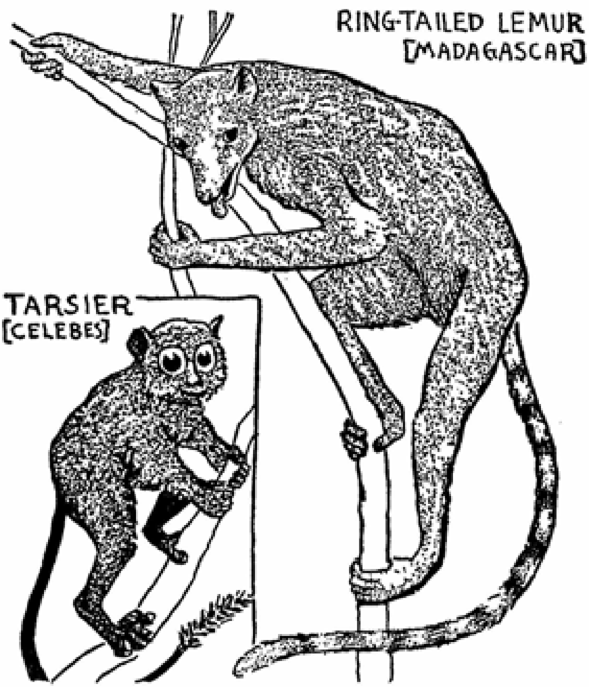
Man's closest living relatives, as we can tell at a glance, are the three great apes—the orangutan, the gorilla, and the chimpanzee. They come nearest to man in body form and in brain development and intelligence. Apes, men, and monkeys belong to the group called the primates. All the primates have the same general structure. For example, the forepaw of every primate is a hand, and the hind paw too is like a hand, in most species. This is true even of such simple primates as the tarsiers of southeastern Asia and the lemurs of tropical Asia and Africa. The tarsiers are little tree-dwelling creatures about the size of a small rat. The lemurs are larger, with a sharp, fox-like snout.

Primate structure evolved as an adaptation to a special habit of existence—living in trees. The hand, a tool for grasping branches, has fingers especially shaped and arranged for that function. Four



fingers, lined up side by side, work together, bending and closing in the same plane. The thumb is different. Bend your own thumb and fingertips and see what happens. The thumb bends in the opposite direction from the fingers, meeting them and closing with them. The thumb, we say, is opposable to the fingers.

A lemur, stepping delicately along the top of a



branch, grips it by curving the four fingers around one side, and the thumb around the other side. The apes use their hand in a different way. They hang from a branch by their arms, and get about by swinging from branch to branch—a method of movement we call brachiation. The ape, when hanging from a branch, grips it by curving his four fingers over it. With the hand in this position, the thumb is beneath the branch, where it is of no practical use.

YOUNG ORANG-OUTAN

Millions of years of brachiating have had their effect on the hand of the apes. The fingers are long and strong, but the thumb is small and weak. It is very feeble, compared to the thumb of a lemur or a man.

The thumb is a sign of the different paths taken by the ancestors of today's apes and the ancestors of man. The two branches of primates separated from each other several million years ago. The pre-human line perhaps were not such expert brachiators as the other line. In any case, they became quite at home on the ground.

• MAN MAKES HIMSELF

What caused the pre-human line to take to the ground after millions of years in the trees? The simplest explanation is that the trees died out in the regions inhabited by this line. The apes did not abandon the trees; the trees abandoned them.

Twenty million years ago, central Asia was a warm forest land, inhabited by apes and other forest species. The picture slowly changed; it was an age of mountain-making, and the Himalayas were rising. As their summits lifted higher and higher, the mountains forced the southerly sea winds to rise, chilled them, and caused them to give up their moisture, which fell in the mountains as rain and snow. The air moving northward across the mountains became too dry to nurture forest growth. The forests gradually died away and were replaced by grasslands, the steppes.

Animal species of the forest had to adapt themselves to the changing environment if they were to survive. Among the forest species were browsers which, like the horse in North America, shifted to a diet of grass. Thriving on the grasses of the steppe, they developed into large grazers such as the bison, antelope, goat, and camel. And because the grazers flourished, tigers and other large flesh-eaters were able to develop.

Among the apes, the lines that were very highly specialized for tree-top life either died out or migrated. Other lines developed in such a way that they were able to exist on the ground. Their legs grew longer, and their foot improved as an organ for walking and running. This freed the hands of the ground apes for other uses than locomotion. Their type of hand, since it possessed a strong thumb, could easily grasp a weapon or manipulate a tool. The prehuman apes probably could not have survived on the

ground without making use of weapons. As the fruits and nuts of the forest disappeared, the apes had to go grubbing along the ground for their food, and while on their expeditions they needed some defense against the flesh-eaters.

The hand of the ground apes, good organ though it was, would have counted for little if it had been used only by individuals isolated from others. The ground apes made the most of their hands by using them co-operatively. It was a talent for working together that gave these beings a future on the earth.

In order to co-operate, it is necessary to communicate. The ground apes inherited an instrument of

communication—the muscles of the larynx. Need for co-operation gave the apes something to say to one another. They put their tongue and larynx to use by calling signals as they foraged and hunted.

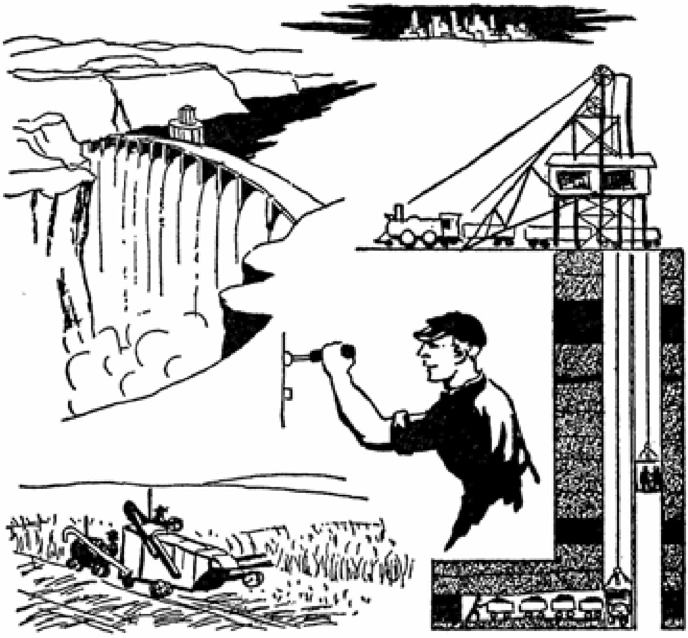
Higher brain structures developed as speech developed. With the greater nervous and mental growth they had to go through, the young took a longer time maturing. At birth, a pre-human or human was about one-fifth head. He spent many years of immaturity learning and developing under the care of his elders. It takes years of effort to make a man.

Among the pre-human lines, the poor co-operators died out; the good co-operators lived. Struggling jointly to master their world, the co-operators became men.

• MAN, MASTER OF LIFE

Man is very much like other animals in the way his body functions. It is not better metabolism or a better skeleton or muscles that make man a new and higher type of living thing. It is his intelligent co-operation. He speaks with his fellows; together they work, teach, and learn; by their co-operation they create things that no one man could create alone.

Men, through co-operation, have cultivated plants instead of gathering them, and have bred animals instead of hunting them. They have created systems of agriculture rich enough to support large populations and great cities.



Men have gained control over vast sources of energy. They have mined the carbon that plants extracted from the air over a period of millions of years. Men have harnessed rivers for their power; they have tapped the wells of oil in the earth. They have transformed the energy from these sources into electricity that lights up cities and drives the machinery of civilization. They have begun to master the energy that comes from the making and unmaking of atoms.

All through history men have used energy to increase the amount of life on the earth—plant and animal life, and human life. Peoples have improved their well-being. Human existence has become more secure. Work is so productive, or can be so productive, that men and women gain the leisure to learn and to become complete and creative human beings.

This is the heritage of man.

But mankind has not yet become completely human. In this age, a portion of the materials and energy controlled by men still is used, not to foster life, but to destroy life through war.

A small minority of the human species is willing to waste the heritage of man—to use energy to destroy life instead of conserving it. But the majority of mankind will not consent to destruction, but will follow the human path. The peoples of the earth will choose to live.

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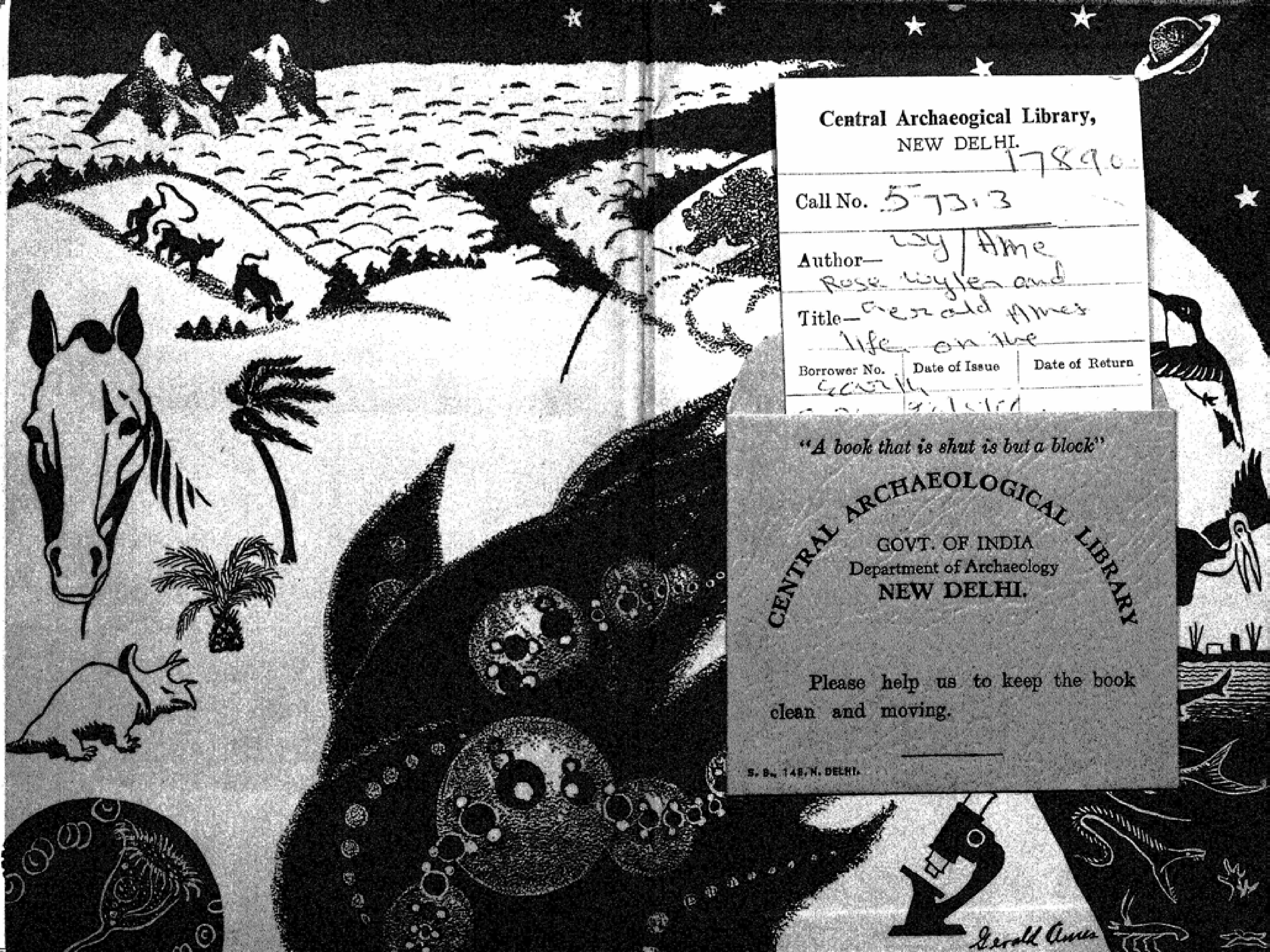
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