INTRODUCTION TO HUMAN ANATOMY
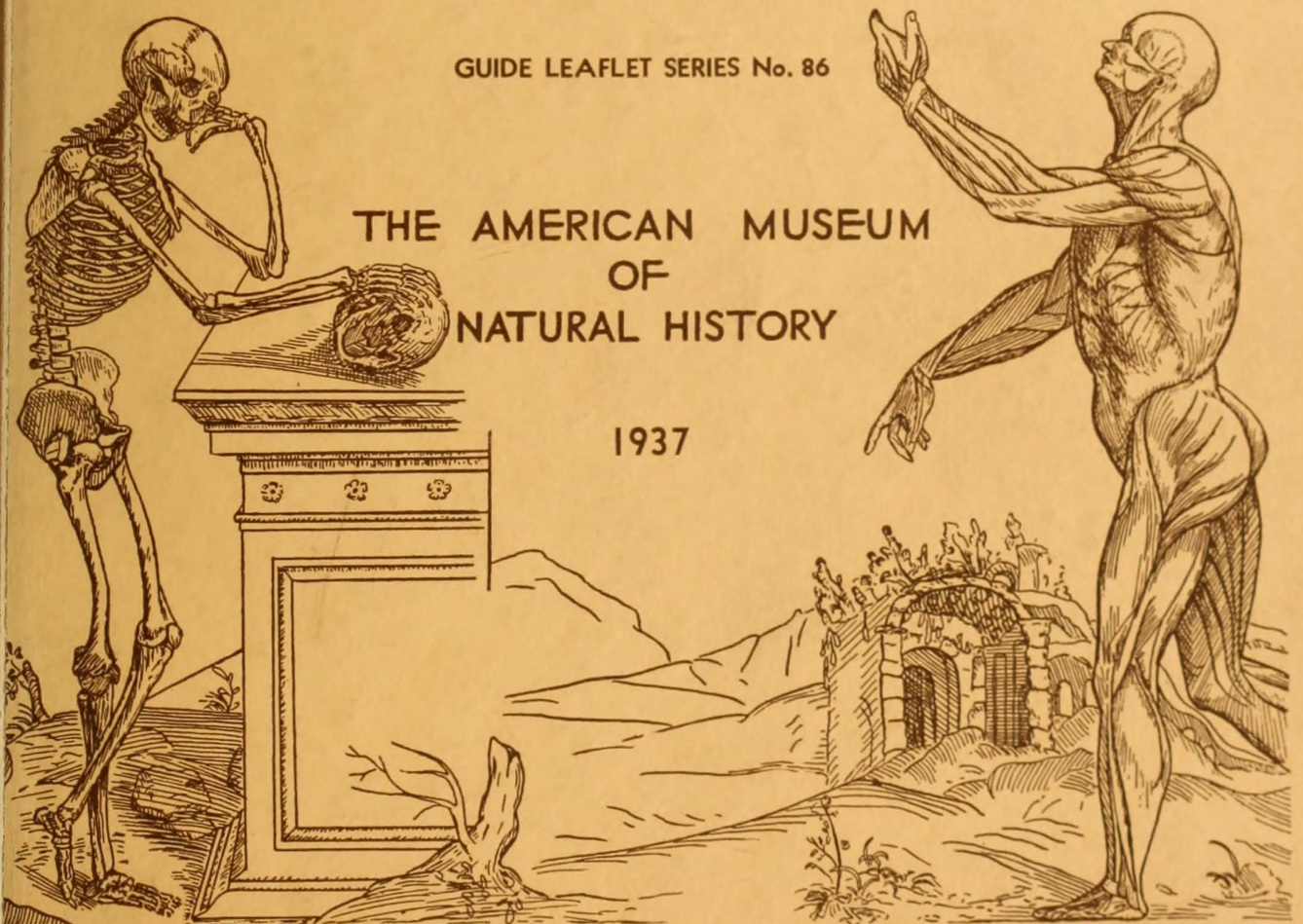
By

WILLIAM K. GREGORY

and

MARCELLE ROIGNEAU

GUIDE TO SECTION I OF THE HALL OF NATURAL HISTORY OF MAN

GUIDE LEAFLET SERIES No. 86

THE AMERICAN MUSEUM
OF
NATURAL HISTORY
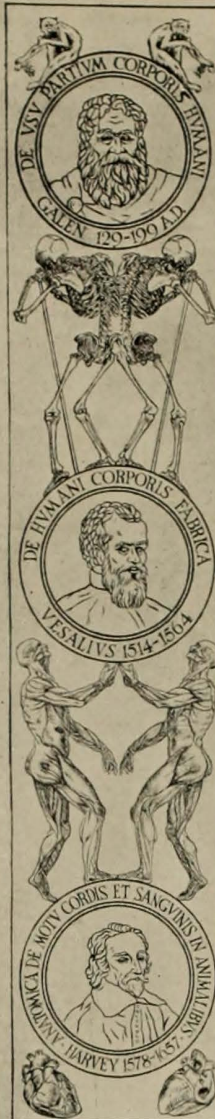
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<div align="right">Roy W. Miner, *Chairman*</div>

GUIDE TO SECTION I OF THE HALL

OF

THE NATURAL HISTORY
OF MAN

The EVOLUTION OF ANATOMY

THE SCIENCE OF ANATOMY SPRINGS FROM TWO MAIN SOURCES: FIRST, MAN'S SEARCH FOR THE CAUSES OF HIS BODILY PAIN; SECONDLY, FROM HIS CURIOSITY ABOUT HIMSELF. THE FIRST MOTIVE GIVES RISE TO SURGERY, OR APPLIED ANATOMY, AND MEDICINE; THE SECOND TO COMPARATIVE ANATOMY, OR, MORPHOLOGY. THIS DEALS WITH THE STAGES THROUGH WHICH A GIVEN ORGAN HAS PASSED DURING ITS EVOLUTION.

AMONG THE ANCIENTS ANATOMY WAS LARGELY MIXED UP WITH ASTROLOGY AND OTHER FORMS OF FORTUNE TELLING AND MADE COMPARATIVELY LITTLE PROGRESS UNTIL ARISTOTLE (BORN 384 B.C.) LAID THE FOUNDATIONS OF COMPARATIVE ANATOMY, AND GALEN (129-199 A.D.) FAIRLY OPENED UP THE SCIENCE OF ANATOMY, PARTLY ON THE BASIS OF HIS DISSECTIONS OF THE BARBARY APE.

AFTER A LONG ECLIPSE OF ANATOMY DURING THE DARK AGES (200 TO 1050 A.D.) THE SCIENCE WAS REVIVED AT BOLOGNA, PADUA AND OTHER UNIVERSITIES OF THE MIDDLE AGES.

THE GREAT ARTIST LEONARDO DA VINCI (1452-1519) LEFT BEHIND HIM A SERIES OF WONDERFUL DRAWINGS OF HUMAN ANATOMY. HE WAS FOLLOWED BY VESALIUS (1514-1564) THE FOUNDER OF MODERN ANATOMY.

AMONG THE GREATEST ADVANCES IN MODERN ANATOMICAL KNOWLEDGE MAY BE MENTIONED THE FOLLOWING:

(1) THE DISCOVERY OF THE CIRCULATION OF THE BLOOD BY WILLIAM HARVEY (1616).

(2) THE INVENTION AND DEVELOPMENT OF THE MICROSCOPE AND OF MICROSCOPIC ANATOMY, OR HISTOLOGY BY LEEUWENHOEK (1632-1723) AND HIS SUCCESSORS. THIS HAS MADE POSSIBLE THE MODERN SCIENCE OF EMBRYOLOGY, GENETICS, EXPERIMENTAL BIOLOGY, ENDOCRINOLOGY, ETC.

(3) THE FOUNDING OF MODERN COMPARATIVE ANATOMY AND PALAEONTOLOGY BY CUVIER.

(4) THE DISCOVERY OF THE "ECHELLE DES ETRES" OR SCALE OF LIFE AMONG RECENT FORMS, BY BUFFON, LAMARCK, DARWIN AND THEIR SUCCESSORS. THIS GAVE NEW LIFE AND MEANING TO COMPARATIVE AND HUMAN ANATOMY.

(5) THE DISPROOF OF THE DOCTRINE OF THE FIXITY OF SPECIES AND THE ACCUMULATION OF PROOF THAT DURING THE COURSE OF AGES THE HIGHER ANIMALS HAVE BEEN DERIVED FROM LOWER TYPES BY DESCENT WITH MODIFICATION, BY CHARLES DARWIN (1859) AND HIS SUCCESSORS.

THUS THE HISTORY OF THE STRUCTURE OF MAN BECOMES PART OF THE HISTORY OF THE VERTEBRATES IN GEOLOGIC TIME.

ANATOMIA PERSICA A.D. 1400

ANATOMIA ITALICA A.D. 1555

DE VSV PARTIVM CORPORIS HVMANI — GALEN 129-199 A.D.

DE HVMANI CORPORIS FABRICA — VESALIVS 1514-1564

ANATOMICA DE MOTV CORDIS ET SANGVINIS IN ANIMALIBVS — HARVEY 1578-1657

HISTORIA ANIMALIVM — ARISTOTLE 384-322 BC

LECONS D'ANATOMIE COMPAREE — CUVIER 1769-1832

THE DESCENT OF MAN — CHARLES DARWIN 1809-1882

HOMO ZODIACUS APUD ASTROLOGOS

ANATOMIA MVNDINI — MONDINO 1270-1326

LEONARDO DA VINCI 1452-1519

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IN

THE AMERICAN MUSEUM
OF NATURAL HISTORY

Second Edition, Revised
by W. K. Gregory and H. C. Raven

CONTENTS

PREFACE

The exhibits on the south side of the hall are designed to give an introduction to human anatomy, to show by simple examples how the machinery of the body works, and especially to trace the origin and rise of the principal systems of organs.

The synopsis of the exhibits is as follows:

How man, like other organisms, derives his life-energy from the sun and how he spends it (Case I).

The ground-plan of each of the main organ systems of man is present in such a primitive form as a shark (Case IIA).

The evolution of the motor system, from its simple beginnings in the fish to the upright-walking motor system of man (Cases IIB, III, IV, and VA).

Embryology, or development of the body before birth (Case VB).

The history and origin of the human face, the skull, jaws and teeth (Cases VI and VIIA).

Chief characters of the nervous system, including the organs of sensation and response (Cases VIIB and VIII).

The wall charts show man's place among the vertebrates.

This Hall, although not completed, was opened to the Public in August 1932, in connection with the Third International Congress of Eugenics.
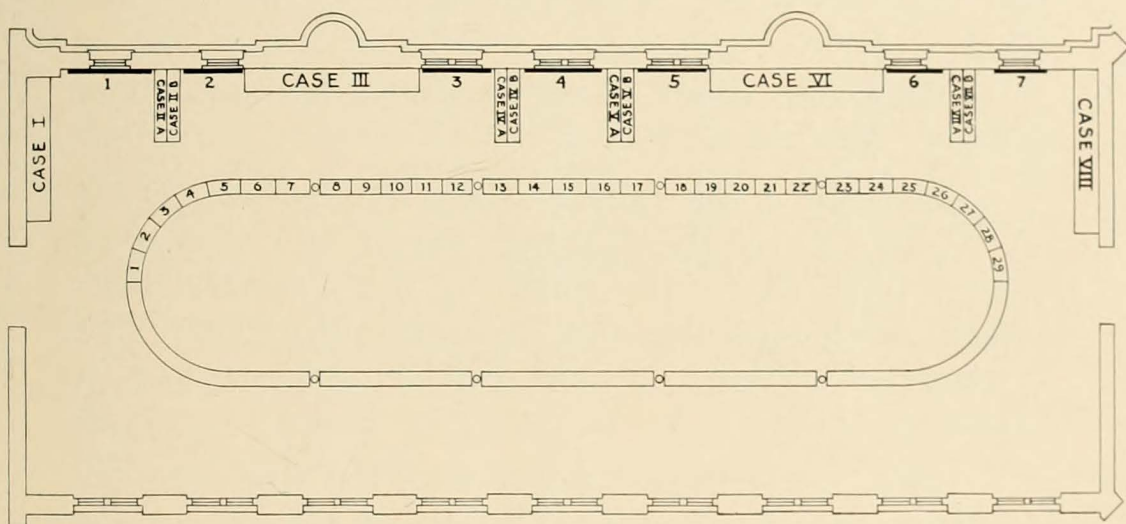
FLOOR PLAN OF THE HALL

The numbers are those which may be found marked on the cases.

3

THE SUN

Chief Source of Human Energy

Man, like other animals, draws his supply of energy from the sun.

The sun is the source of the energy stored up in plants. It is the leading factor in the forces which have made the earth fit for human habitation. Without the sun man could never have appeared; without it he could not survive a moment.

Man, however, cannot absorb the sun's energy directly, as the plants do; he must take it in his food, thus appropriating it from other animals and from plants.

The green coloring matter (chlorophyll) of plants has the power of absorbing some of the red, blue and violet rays of the sun, using them to transform raw materials into food for the plant's growth.

These raw materials are carbon dioxide, which the plant takes from the atmosphere, water, dissolved nitrates and other salts, which it draws up from the soil.

When the chlorophyll, with the aid of the sun's rays, breaks up these substances, the carbon is pulled out of the carbon dioxide and the hydrogen out of the water.

After a complex series of chemical reactions the finished products appear as sugar, starch and other carbohydrates, fats and proteins, which are the food-stuffs of both plants and animals.

Every animal is endowed with the power of locomotion so that he may either pursue the prize or flee from those who would wrest it from him. And when he has overtaken it he devours it, that it may sustain his life. But that he may know what to eat and what not to eat, when to run and when to fight, Nature has bestowed upon him a keen eye and an understanding brain.

Thus the energy of the sunlight, stored up in the substance of plants and animals, becomes a hidden treasure of great worth, to obtain which all animal life labors and struggles unceasingly.

THE LIVING CHEMICAL ENGINE

[Case I]

The human body is often compared to an automobile: the consumption of food recalls the combustion of the fuel; the contraction of the muscles is like the action of a piston on a shaft; also unless the products of combustion are thoroughly eliminated the machine becomes choked with its own waste. Such a comparison, however useful is quite inadequate, for the body, considered as a living organism dominated by its own control system, is infinitely more complex than a lifeless machine.

The body has also been likened to a whirlpool, which is constantly seizing upon new inert matter from the outside, whirling it around and then ejecting it. The body is also like the flame of a candle, which lives only as long as its food supply lasts and its wick holds out. But it is rather to be considered as a conscious flame that seeks out suitable fuel and makes its own wick.

By means of its cells the body as a whole has the properties of IRRITABILITY, MOTION, METABOLISM[1], GROWTH and REPRODUCTION, common to living organisms.

The body is first of all a commonwealth of active living cells that dwell in the midst of non-living substances which they have secreted; or they float in a watery fluid or lymph.

A cell is normally a mass of protoplasm containing a nucleus, or center of cell activities. Protoplasm itself in its most typical form is a colloidal or jelly-like substance permeated with globules. It contains much water, a little salt in solution and chiefly proteins, or nitrogenous compounds, in suspension and fat droplets in emulsion. The cells are separated by membranes or walls; these membranes permit varying concentrations of certain chemical compounds in the cell; they are also like filters in straining out insoluble substances; by OSMOSIS the membranes also permit the passage of fluids of different degrees of acidity in opposite directions. The motive force of all these movements, as well as the contractility of muscle cells, is to be found in the various electric charges of the different kinds of aggregates of molecules, especially of the very complex protein molecules.

All the activities of the body are dependent upon these and similar conditions.

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[1] The process of breaking down and building up organic substances.

aorta
(cut)

right auricle

right ventricle
(cut)

right lung

stomach
(cut)

liver
(cut)

gall bladder

inferior vena
cava

ascending
colon

cæcum

larynx

trachea

left pulmonary
artery

left auricle

left ventricle
(valves)

diaphragm

spleen

pancreas

duodenum

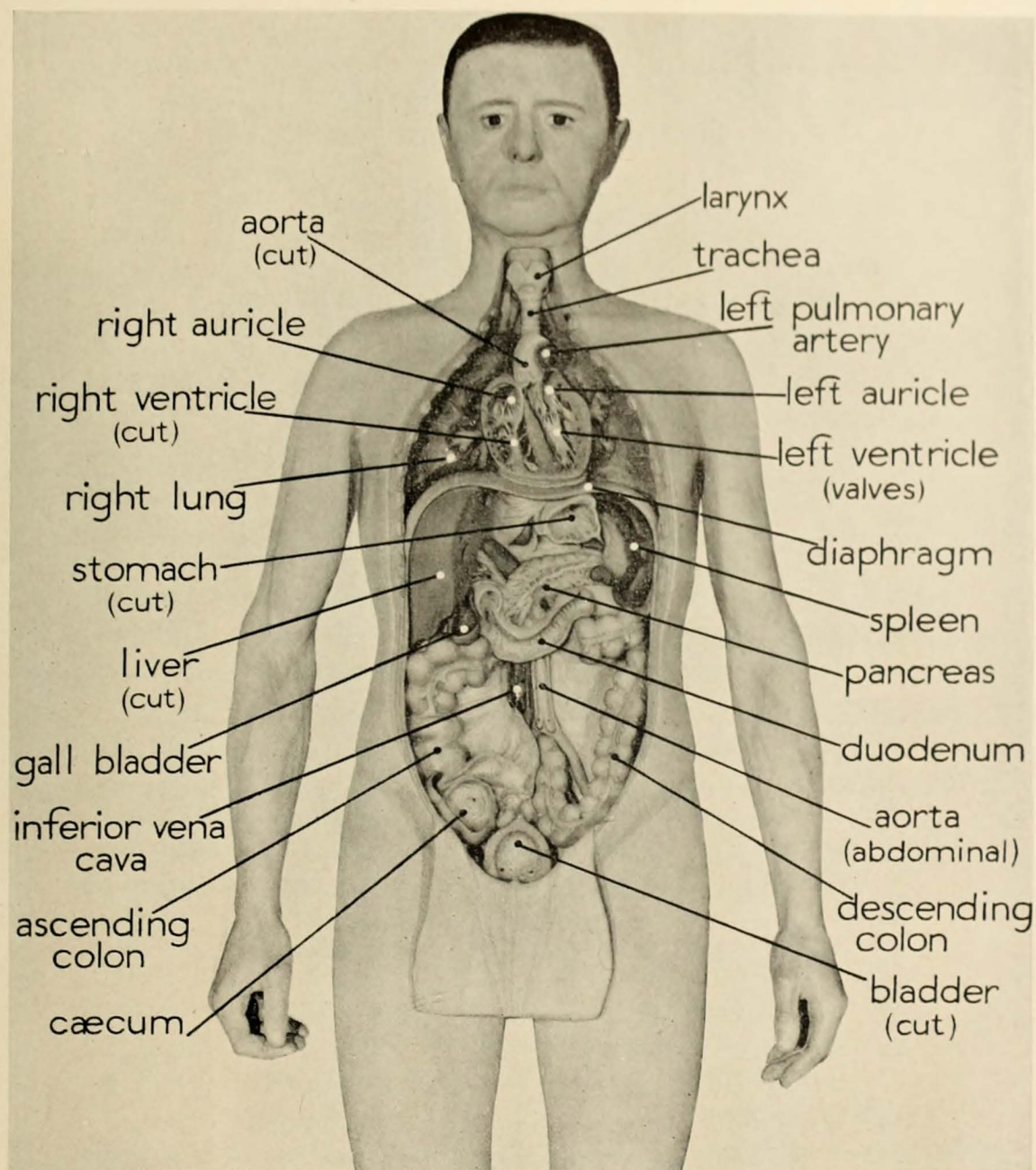aorta
(abdominal)

descending
colon

bladder
(cut)

Fig. 1. The hidden parts of the human engine

Model showing the interior of the chest and abdomen, after the removal of the stomach and other organs.

Based chiefly on the plates in Spalteholz' Hand Atlas of Human Anatomy. Model by Christopher Marguglio.

All cells in the body have been derived by subdivision from the single zygote or combined male and female sex-cell; nevertheless they have become differentiated by regions into manifold tissues, with diverse chemical and physical properties.

WHAT THE BODY IS MADE OF

WATER	FATS
CARBOHYDRATES	INORGANIC SALTS
PROTEINS	VITAMINS

These chemicals make up the food we eat and are therefore what we ourselves are made of.

WATER heads the list, forming about 65 per cent of the body weight. Water circulates in all our arteries, veins and lymph vessels, carrying other substances in solution and in combination; it dissolves the food and is an indispensable element in digestion; it washes out injurious products through the kidneys; it forms a greater or lesser part of all the bodily tissues. Water comes into the body in all food and drink; it escapes as vapor from the lungs and skin and goes out as liquid in the urine and feces.

CARBOHYDRATES. The energy of the sun's rays, when passed through the green coloring matter of plants, builds up water and carbon dioxide (CO_2) into glucose and other forms of sugar, and into starches. These carbohydrates taken in as food must all be reduced, through the process of digestion, to glucose, a simple sugar, before being carried by the blood stream to the liver and the muscles. Most of the energy of the carbohydrates is used as fuel for the muscle engines.

PROTEINS. Proteins are very complex compounds of carbon, hydrogen, oxygen, and nitrogen; most of them also contain sulphur and some contain phosphorus. Albumen, or white of eggs, is a protein in a weak salt solution.

Plants draw up nitrates from the soil and combine their nitrogen with carbon dioxide and water to form amino-acids, which are in turn built up into different plant proteins.

The animals, including man, are not able to form amino-acids from such simple materials; herbivorous animals must obtain amino-acids in the form of "vegetable proteins"; carnivorous animals rely chiefly on "animal proteins"; omnivorous animals, including man, can use both.

In the course of digestion these proteins taken in as food are decom-

posed by a series of hydrolyses[1], into their respective amino-acids, which are then absorbed into the blood stream and carried first to the liver; then they are distributed from the liver to the various tissues of the body, where they are built up into the characteristic proteins of the particular tissues.

The wide geographic distribution of mankind is partly dependent upon man's ability to eat many kinds of food and to utilize them all either for work or for the storage of energy.

FATS. These are compounds of carbon, hydrogen and oxygen. By the action of the pancreatic juice and the bile the fats taken in as food are split into glycerol C_3H_5 $(OH)_3$ and fatty acids; these are then absorbed by the intestinal epithelium where they are recombined into neutral fats. Then instead of passing directly into the blood stream, they are taken up by the lymph vessels as chyle and are poured with the lymph into the blood from the thoracic lymph duct.

However, most of the fat stored in the body is the product of the synthesis of any excess of carbohydrates that may occur.

INORGANIC OR MINERAL SALTS. (Not sources of energy.)

Calcium. When bone is burned, lime (calcium oxide) is left in the ash along with other "earthy salts." Calcium phosphate $(Ca_3 (PO_4)_2)$ forms most of the hard parts of the skeleton. Also to a less extent calcium carbonate $(CaCO_3)$. Weak solutions of calcium chloride $(CaCl_2)$, sodium chloride $(NaCl_1)$ and potassium chloride (KCl) are essential for alternate contraction and relaxation, or tonus, of the heart muscles. That is, the rhythmic beating of the heart depends partly on the antagonistic action between these salts. Such antagonistic reactions between salts are probably requisite for the maintenance of the proper degree of permeability in cells. For example, calcium has a balancing or compensating effect on metabolism. Milk is especially rich in calcium; but many other foods contain small amounts of it.

Sodium chloride, or common salt, occurs in the blood plasma and other fluids of the body. **Potassium**, on the other hand, occurs most abundantly in the soft solid tissues, the corpuscles of the blood, the protoplasm of the muscles, also in certain secretions, e.g., milk. Most vegetables are rich in potassium.

A conspicuous function of the salts in the tissues is the maintenance of the normal osmotic pressure. The plasma, or clear fluid of the blood, consists of about 90 per cent water, 9 per cent proteins and .09 per cent

---

[1] *Hydrolysis:* from Greek *hydros*, water and *lysein*, to loose.

salts. Sodium chloride is excreted through the kidneys. Potash (potassium) salts tend to cause the loss of sodium and chlorine. The craving for common salt (sodium chloride), when one is eating vegetable food, especially potatoes, tends to correct undue loss of chlorine and sodium.

Phosphorus enters into the nucleo-proteins of the cell nuclei, which are very active in metabolism and growth. Phosphorus is an important element of the nerve cells, and particularly of the skeleton. Many foods contain phosphorous compounds, especially milk and egg yolks.

Chlorine is found both in the chlorides of the blood stream and in the hydrochloric acid of the stomach. This acid seems to be formed through the decomposing action of a certain protein on sodium chloride in the presence of carbon dioxide.

Iron is present in excessively small quantities in red blood corpuscles, where in combination with Carbon, Hydrogen, Nitrogen and Oxygen it forms hæmatin, which in turn is united with a protein, "globin," to form hæmoglobin. This extremely complex substance contains several thousands of atoms of carbon, hydrogen, nitrogen and oxygen to every one of iron. Hæmoglobin carries oxygen from the lungs to the tissues of the body. Iron is present in certain foods, especially in egg-yolk, barley, spinach and liver.

Iodine. This element is very important in the secretions of the thyroid gland.

VITAMINS ("accessory food-stuffs") are organic food materials, not in themselves significant sources of energy but essential, in some way not yet definitely known, to normal metabolism; e.g., children whose food lacks vitamin D develop rickets, while want of vitamin C causes scurvy.

DIGESTION AND ABSORPTION

In chemistry a substance is said to be "digested" when it is exposed to the action of hot liquid. Digestion is also defined as a process of HYDROLYSIS, the breaking-up or decomposition of a complex substance, some of whose parts unite with the hydrogen and oxygen of water. Water is therefore an absolute necessity for digestion.

The diagrams (Fig. 2A, B) indicate how the several divisions of the digestive tract pour certain reagents into the food-containing solution.

The complex carbohydrates, fats and proteins of the food are thus broken down into simpler substances, such as glucose, fatty acids, amino-acids, etc. These soak through the mucous membrane of the intestine and are reconverted into such forms of carbohydrates, fats and

proteins as can be assimilated by the body; after being absorbed by the walls of the capillary blood-vessels of the digestive tract, (except the fats which are first taken up by the lymph vessels) they are carried eventually to the heart, whence they are pumped to all parts of the body.

BLOOD CORPUSCLES

(The Currency of the Body)

The energy contained in the food-stuffs is carried to the billions of the body's cells by the circulating medium, including the blood and lymph streams. The blood stream also carries the oxygen from the lungs to all the tissues of the body. The principal units of the circulation are: the red blood corpuscles, the white blood corpuscles and the blood-platelets. All these float in the watery plasma of the blood.

The **red blood corpuscles** (erythrocytes) are extremely minute, there being about five million in one fifteen-thousandth of a cubic inch ($= 1$ cubic millimeter); also they are so numerous that a man weighing 154 pounds has in his blood about 30,000,000,000,000,000 of them, which if spread out side by side would cover about 4,400 square yards.

The red coloring matter, or hæmoglobin, consists of an iron-containing pigment combined with a protein. Hæmoglobin has the power of carrying oxygen from the lungs, of giving it up to the tissues and of receiving from them the waste gas, or carbon dioxide, which is again carried to the lungs to be given off into the outer air. The red blood corpuscles originate in the red marrow of certain limb bones.

In man, as in other mammals, the red corpuscles at first have a nucleus but later expel it.

The **white blood corpuscles** (leucocytes) are amœba-like cells which can pass through the walls of the capillary blood vessels to form the pus or matter of inflamed parts. There are several kinds of leucocytes. One kind, called microphages, derived from cells in the red bone-marrow, engulfs and devours foreign bacteria in the blood stream and thus protects the body against certain diseases. Others, called lymphocytes, are necessary in elaborating some of the food-products so that they can be taken up by the tissues. These originate in the lymph glands.

The **blood-platelets** are exceedingly minute. They have the important function of assisting in the clotting of the blood.
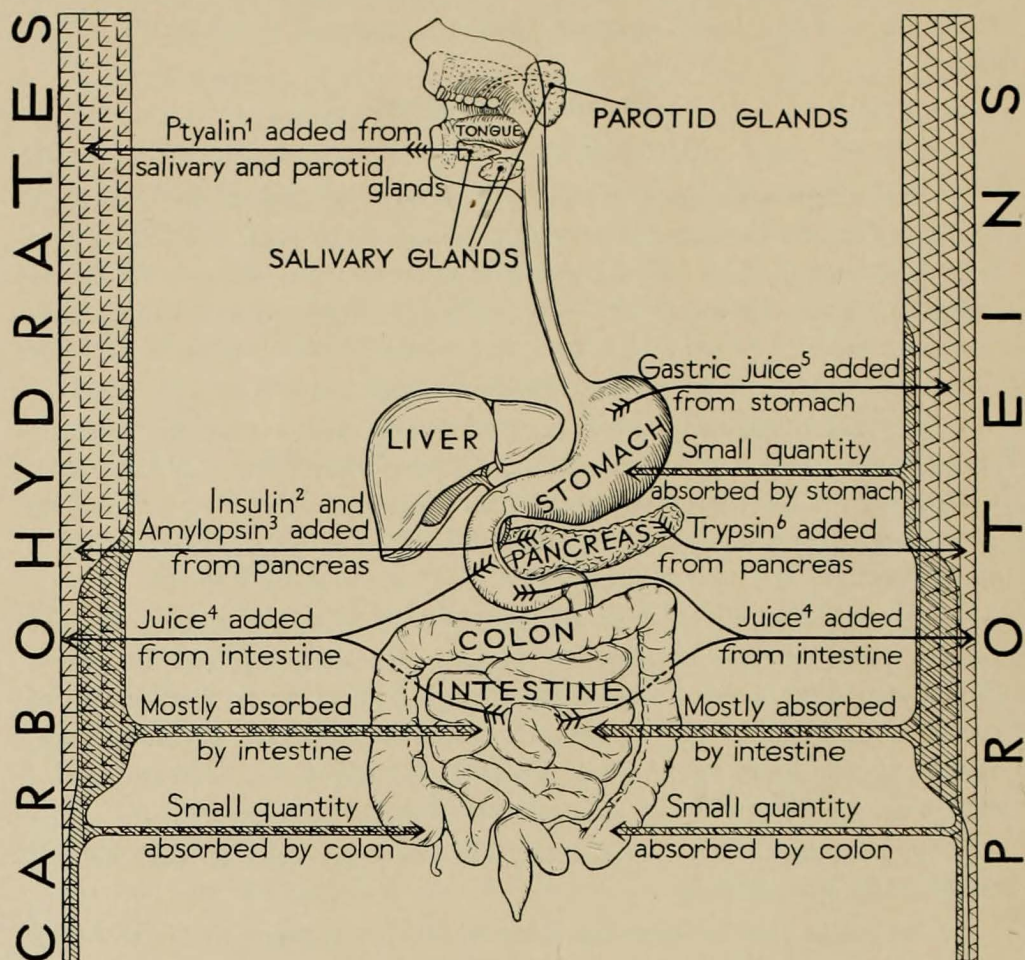
Fig. 2A.   Digestion and absorption of foods.

1. Ptyalin (salivary diastase) turns starch into soluble sugar (maltose).
2. "Islands of Langerhans" (in pancreas) give insulin, a hormone which enables tissues to take up sugar actively.
3. Amylopsin (pancreatic diastase) splits starches.
4. Intestinal juice continues digestion of carbohydrates and proteins.
5. Gastric juice = free hydrochloric acid + pepsin (from stomach) converts proteins to intermediate products.
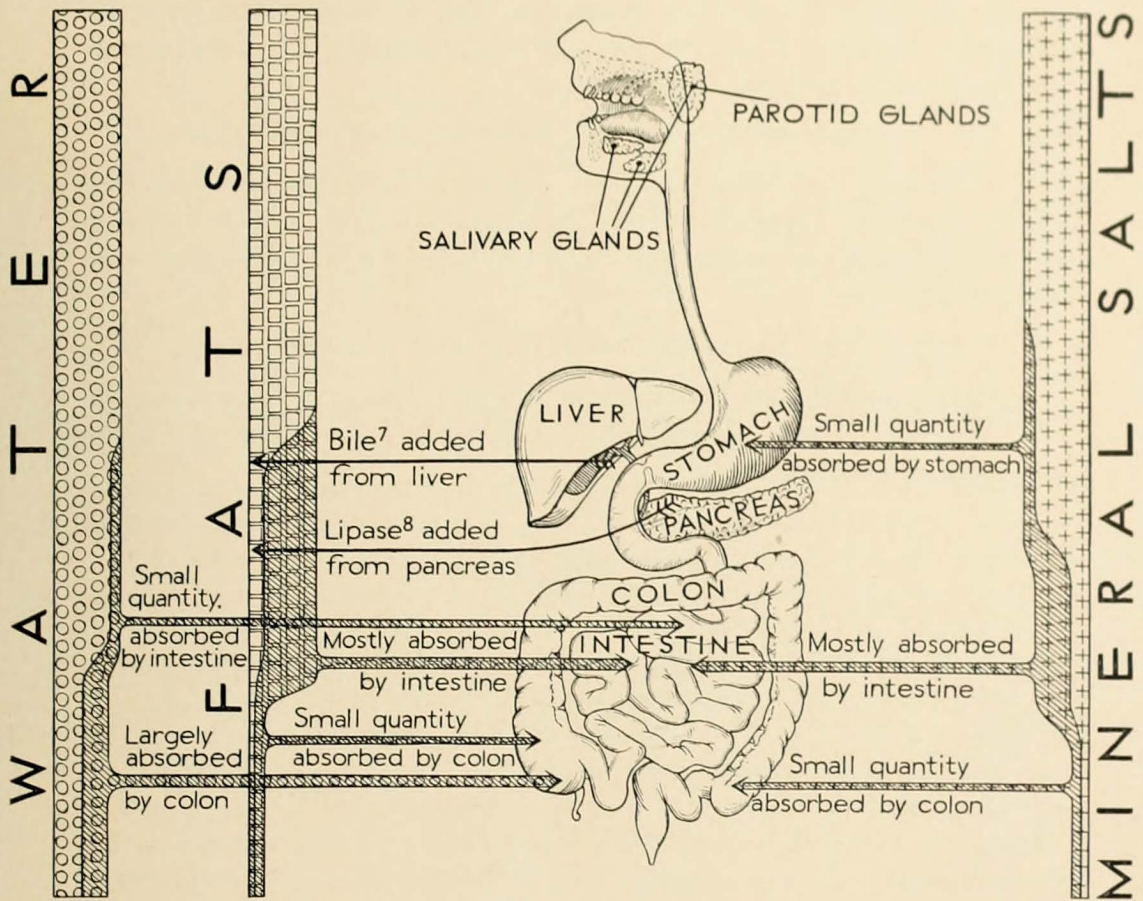6. Trypsin (pancreatic juice) splits proteins.

WATER

FATS

SALTS

MINERAL SALTS

PAROTID GLANDS

SALIVARY GLANDS

LIVER

STOMACH

PANCREAS

COLON

INTESTINE

Bile[7] added from liver

Lipase[8] added from pancreas

Small quantity.
absorbed by intestine

Largely absorbed by colon

Mostly absorbed by intestine

Small quantity absorbed by colon

Small quantity absorbed by stomach

Mostly absorbed by intestine

Small quantity absorbed by colon

Fig. 2B.   Digestion and absorption of foods (continued)

7.   Bile, or gall (from gall bladder in liver) greatly accelerates action of lipase in splitting fats.

8.   Lipase (pancreatic juice) splits fats, converting them to fatty acid and glycerol.

Diagrams based on the illustrations and data published in *Der Mensch* by Martin Vogel.

THE SOLAR ENERGY IS UTILIZED BY THE MUSCLES

The chlorophyll of the plant, as already shown, utilizes the energy of the sunlight to build up sugar and starch out of water and carbon dioxide. These carbohydrates taken in as food are turned into glucose by the digestive juices of the intestine. The blood stream carries the glucose to the liver, where it is converted into glycogen or animal starch (which is the anhydride of glucose).

The liver then stores up the glycogen for future use.

Indirectly, the combustion of glycogen furnishes the heat and energy necessary for the life of the higher animals, but the direct energy of the muscles is due to the breaking down of a creatine-phosphoric acid compound.

Creatine is an amino-acid which is present in muscle tissue.

Insulin, a hormone manufactured by the Islands of Langerhans in the pancreas, is also essential for the proper combustion of carbohydrates in the animal body.

HEAT REGULATION

The chemical processes involved in the capture and use of solar energy by the body all generate heat. Overheating of the body, which would finally cause heat-stroke, is normally prevented largely by the radiation of heat from the surface of the skin. Also when the body gets too hot the "temperature sense-organs" in the skin send messages up the afferent nerves to the "temperature center" in the brain stem; this in turn sends currents down the nerves to the muscular sheaths of the capillary blood vessels, causing them to become dilated and the sweat glands to pour out sweat. This, being a slightly salt solution, evaporates quickly and causes a rapid cooling of the heated blood in the skin. On the other hand, excessive loss of heat is checked in most mammals by the furry undercoat of the skin, and in man especially by the secretion of the adrenal glands; this secretion unites with the free oxygen in the blood, thus producing heat. Additional heat is generated also by shivering, but chiefly by muscular exercise.

Thus we see that man, like other mammals, possesses various mechanisms for maintaining a relatively high and stable temperature (about 98.4° Fahrenheit in man) in spite of wide variations in the temperature of the environment. The lower vertebrates (reptiles, amphibians), on the other hand, have a more variable body temperature and are more at the mercy of changes in the environment.

THE MAIN PUMP OF THE BODY

The heart is the motor that drives the blood through all the circulatory system and keeps it on its ceaseless round. It is an automatic double pump operated by involuntary muscles and by nervous reflexes. The minute muscular engines which contract and expand this double pump are built into its walls.

The two bag-like pumps, which work in unison, are placed side by side with a single muscular partition between them (Fig. 1). The left, or SYSTEMIC HEART, sends fresh arterial blood from the lungs to the body; the right, or RESPIRATORY HEART, receives venous blood from the body and sends it to be renewed, or oxygenated, in the lungs. Each half consists of an atrium (auricle) or thin-walled receiving chamber and of a ventricle, or thick-walled pumping chamber

Thus the four main divisions of the heart are as follows: (1) the LEFT AURICLE receives freshly oxygenated or arterial blood from the lungs through the right and left pairs of pulmonary veins; when the heart expands this blood is drawn through a one-way valve from the left auricle to the left ventricle; (2) the LEFT VENTRICLE then contracts, driving the blood through the aorta to the capillaries of the head and body. Here the blood loses its surplus oxygen and after absorbing the free carbon dioxide passes from the capillaries into the veins; these drain into the upper and lower venæ cavæ, which open into (3) the bag-like RIGHT AURICLE or atrium; the latter in turn passes the blood through another valve into (4) the RIGHT VENTRICLE, which pumps it through the right and left pulmonary arteries to the lungs.

Nerve fibers are diffused through the heart muscles. At each beat contraction begins in the "pace-maker," or sino-auricular node, and spreads thence to other parts of the heart.

While the rhythmical expansion and contraction of the heart is largely automatic, the beat is retarded by branches of the vagus nerve and accelerated by branches of the thoraco-lumbar nerves of the sympathetic system. The brain centers for regulating the heart beat are in the medulla.

The Living Bellows

Air is drawn into the chest cavity and forced out of it again by rhythmical movements of the ribs and diaphragm (Fig. 3). The scalenus and intercostal muscles pull the obliquely-set ribs upward and outward, the abdominal muscles pull them forward and downward. As they move upward they rotate slightly outward and thus increase the volume of the chest cavity; this reduces the air pressure in its interior and so draws fresh air into the lungs.

The diaphragm is a muscular and tendinous dome which, with the aid of the abdominal muscles, acts both as a bellows for the chest cavity and as a piston for the abdominal cavity. When it descends the abdomen expands; when it moves upward the abdomen contracts; thus it assists the circulation of the blood in the liver and digestive tract.

In the living bellows formed by the diaphragm, thorax and abdominal muscles, the great multitude of muscular engines are built into the wall of the bellows.

In the ascending series of vertebrates from fish to man the breathing muscles of the ribs have experienced a change of function, having arisen from the lateral muscles of the body-walls, which were originally locomotor muscles. The main muscle of the diaphragm represents a backward extension of one of the ventral neck muscles of the lower vertebrates; the diaphragm as a whole is a secondary partition, completed in the mammals, which separates the heart and lungs from the abdominal cavity.
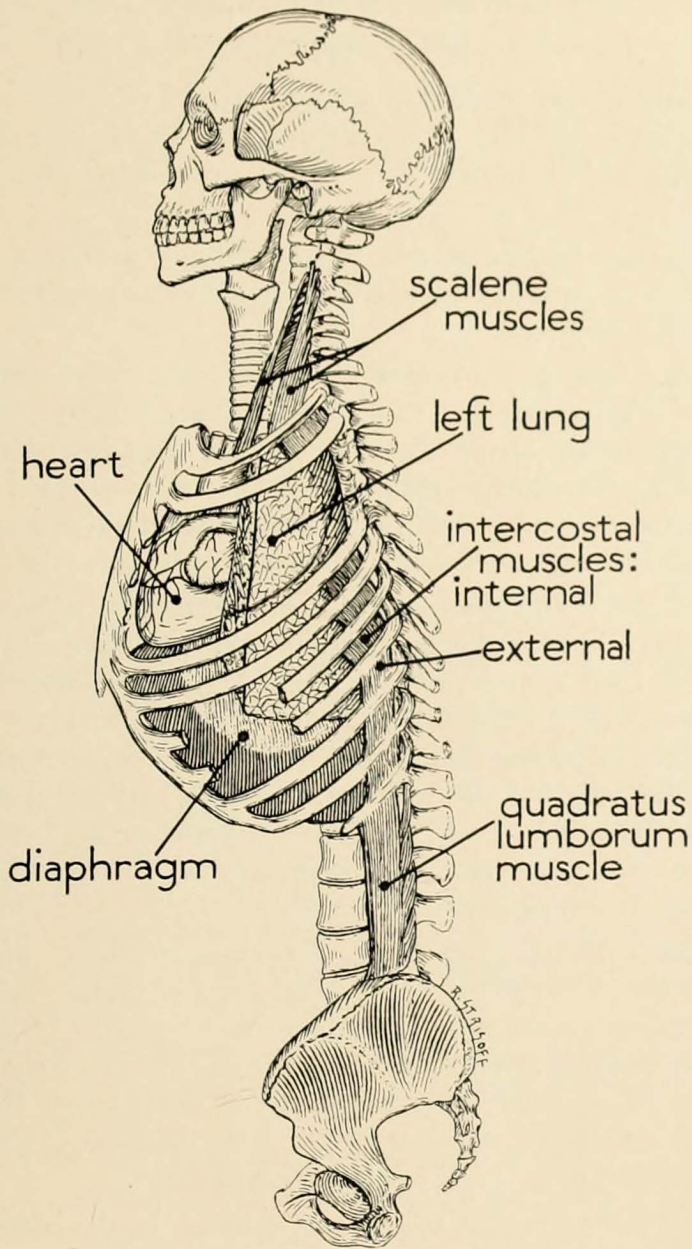
Fig. 3. The living bellows.
Sketch model showing the position of the muscles that cause the bellows-like action of the chest in breathing.
Based on data from Sir Arthur Keith's "Engines of the Human Body".

The Ductless or Endocrine Glands

(See also exhibit on opposite side of hall.)

The ductless or endocrine glands play an important part in metabolism (the breaking down and building up of the cell materials of the body), also in reproduction and in growth from infancy to old age.

The ductless glands secrete substances called hormones because they act as "chemical messengers," which are carried by the blood and activate other tissues.

PINEAL. This gland represents a stalk-like outgrowth from the roof of the third ventricle of the brain. In some of the lower vertebrates it is the stalk of the pineal eye, but in the mammals, including man, it has lost its eye and shriveled into a mere remnant. In young children with diseased pineal gland the sex glands develop at a very early age and there is a precocious abnormal growth of the long bones.

PITUITARY. This gland fits in the "sella turcica" or "Turkish saddle" in the middle of the base of the skull. It comprises three parts, the anterior, intermediate, and posterior lobes. The hormone of the anterior lobe, called TETHELIN, stimulates growth and the healing of wounds. Extracts of the middle and posterior lobes, containing PITUITRIN, produce a rise in blood pressure, increased activity of the kidneys and milk glands, and also stimulate contraction of the muscles of the uterus. On the other hand, pituitrin inhibits the secretions of the salivary glands, stomach and pancreas.

Deficiency in the secretion of the anterior lobe of the pituitary causes a child to become a diminutive dwarf. Early overactivity of the same gland makes him a "symmetrical" giant. If the activity begins after puberty, well rounded development is no longer possible, but the resulting overgrowth (acromegaly) takes place only in such parts of the body as are still susceptible to the influence of the hormone. The pituitary body is found in all the vertebrates.

The pituitary gland is of complex origin. In the human embryo the anterior lobe originates from a pouch-like projection of the outer layer of the embryonic mouth or stomodeum. The posterior lobe originates from the base of the mid-brain.

THYROID. Chemical analysis of the thyroid gland reveals the presence of compounds of carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, sodium, calcium, iodine and other elements.

Thyroxin, the most widely known derivative of the thyroid gland, is a crystalline body with a relatively high iodine content. Extremely

small quantities of thyroxin stimulate metabolic processes, while a deficiency of thyroxin is one of the causes of cretinism, myxoedema and other abnormal conditions.

"Hyperthyroid" persons have an excess of thyroid secretion and are extremely energetic. In "hypothyroid" persons the opposite symptoms appear.

PARATHYROIDS. These small glands, although closely associated with the thyroid, have a different function. They are indispensable for the assimilation of calcium. In rabbits from which the parathyroids have been removed the bones become soft and brittle and the teeth break easily, since they lack calcium. Complete removal of human parathyroids causes a tetany followed by death.

THYMUS. This "gland of childhood" is also highly necessary for the building of bone, especially the long bones of the limbs. The thymus shrinks when the sex-glands develop and becomes very small or vestigial in normal adults.

The thyroid, parathyroids and thymus are derived from different pockets of the embryonic gill structures.

SUPRARENALS. These glands are hat-like bodies, one on top of each kidney. The sponge-like medulla, or core, of the suprarenals forms adrenalin, or epinephrine. One part of adrenalin in four hundred million parts of water checks the action of the intestinal muscles, makes the heart beat faster, causes the liver to discharge its glycogen and prevents fatigue. The suprarenals have thus been called the "fighting glands." Adrenalin also inhibits the action of insulin from the pancreas. The cortex, or rind, of the suprarenals contains many delicate blood vessels, fat droplets, blood spaces and cells containing dark fatty pigments.

In Addison's disease the cortex of the suprarenals is affected so that an excess of dark brown pigment is deposited in the skin and the mucous membranes.

ISLANDS OF LANGERHANS. These very minute glands in the pancreas secrete insulin, a hormone indispensable for the "combustion" of glucose in the production of muscular energy.

SEX-GLANDS. The primary sex-glands (ovaries in females, testes in males) begin to appear at an early stage of embryonic development and to produce "hormones" which determine the subsequent development of either the female (egg-producing) or the male (sperm-producing) sex. In the males the secretions of the interstitial glands of the testes produce certain male characters. In the females the secretions of the yellow-bodies (corpora lutea) of the ovaries affect various changes in the uterus during menstruation and pregnancy.
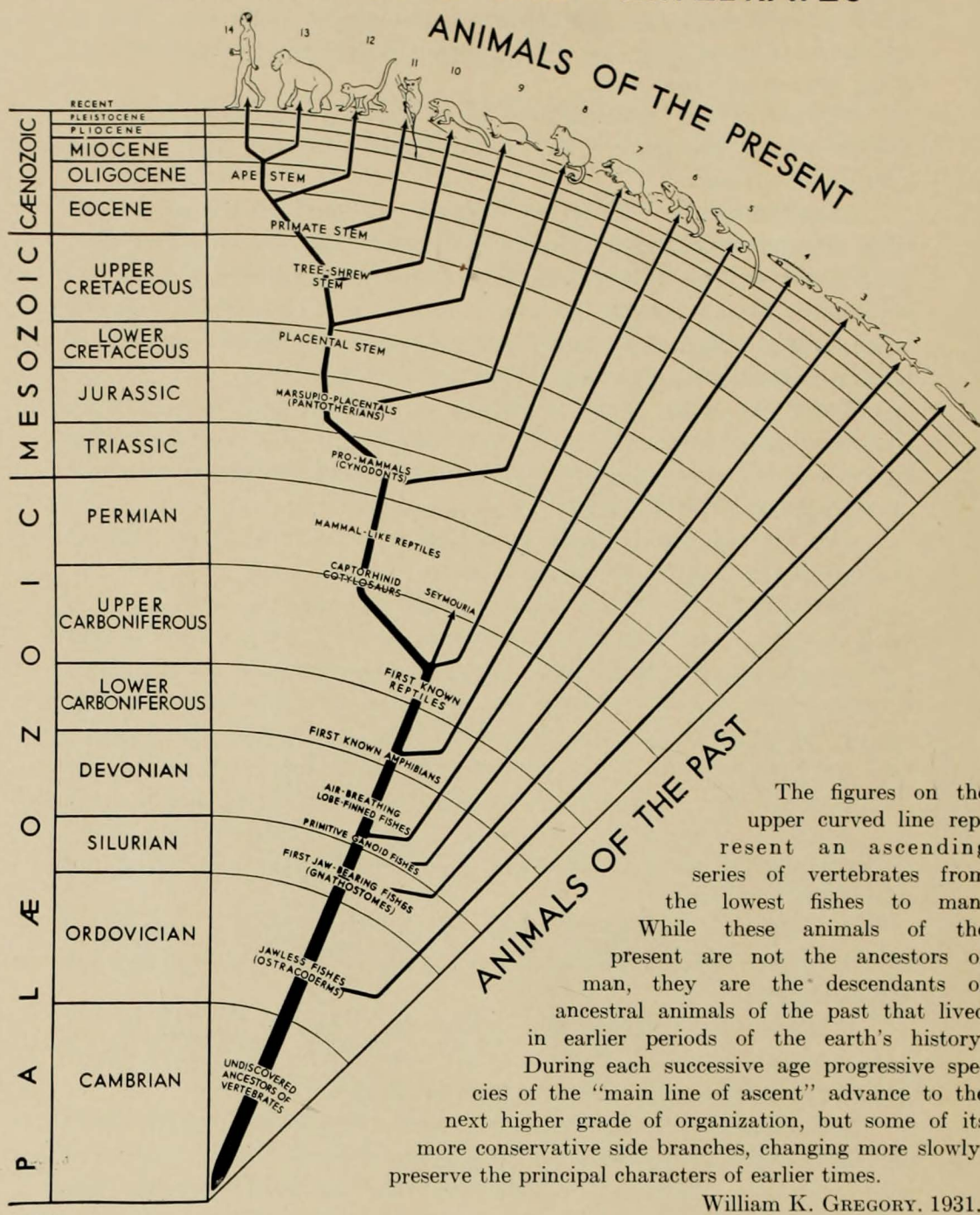
MAN AMONG THE VERTEBRATES

ANIMALS OF THE PRESENT

ANIMALS OF THE PAST

CÆNOZOIC — RECENT / PLEISTOCENE / PLIOCENE / MIOCENE / OLIGOCENE / EOCENE

MESOZOIC — UPPER CRETACEOUS / LOWER CRETACEOUS / JURASSIC / TRIASSIC

PALÆOZOIC — PERMIAN / UPPER CARBONIFEROUS / LOWER CARBONIFEROUS / DEVONIAN / SILURIAN / ORDOVICIAN / CAMBRIAN

APE STEM
PRIMATE STEM
TREE-SHREW STEM
PLACENTAL STEM
MARSUPIO-PLACENTALS (PANTOTHERIANS)
PRO-MAMMALS (CYNODONTS)
MAMMAL-LIKE REPTILES
CAPTORHINID COTYLOSAURS
SEYMOURIA
FIRST KNOWN REPTILES
FIRST KNOWN AMPHIBIANS
AIR-BREATHING LOBE-FINNED FISHES
PRIMITIVE GANOID FISHES
FIRST JAW-BEARING FISHES (GNATHOSTOMES)
JAWLESS FISHES (OSTRACODERMS)
UNDISCOVERED ANCESTORS OF VERTEBRATES

ARTHUR OHLMAN

The figures on the upper curved line represent an ascending series of vertebrates from the lowest fishes to man. While these animals of the present are not the ancestors of man, they are the descendants of ancestral animals of the past that lived in earlier periods of the earth's history. During each successive age progressive species of the "main line of ascent" advance to the next higher grade of organization, but some of its more conservative side branches, changing more slowly, preserve the principal characters of earlier times.

William K. Gregory. 1931.

Fig. 4.   Man among the vertebrates (Wall Chart 2).

1. Lamprey. 2. Shark. 3. Sturgeon. 4. *Polypterus*. 5. Newt. 6. *Sphenodon*. 7. Platypus. 8. Opossum. 9. Ground Shrew. 10. Tree Shrew. 11. *Tarsius*. 12. Monkey. 13. Anthropoid. 14. Man.

ORGAN SYSTEMS OF SHARK AND MAN

[Case IIA]

Man, like other animals, captures and utilizes the life-giving energy of the sunlight (contained in food) by means of a complex anatomical equipment, which includes the following systems:

(1) The Alimentary System
   (Mouth, jaws, teeth, tongue, digestive tract, salivary glands, liver, pancreas, etc.)

(2) The Blood-Stream System
   (Red corpuscles, white corpuscles, blood platelets manufactured in the spleen, marrow, and elsewhere)

(3) The Circulatory System
   (Heart, arteries, capillaries, veins, lymphatics)

(4) The Respiratory System
   (Lungs, windpipe, bronchial tubes, breathing muscles)

(5) The Motor System
   (Locomotor muscles, bones, joints, ligaments, etc.)

(6) The Excretory System
   (Kidneys, bladder, skin)

(7) The Heat-producing and regulating System
   (Temperature receptors in skin, sweat glands, etc.)

(8) The Endocrine or Ductless Gland System
   (Thymus, thyroids, parathyroids, pituitary, adrenals, etc.)

(9) The Receptor System
   (Sense organs, afferent nerves and nerve centers)

(10) The Autonomic Nervous System
   (Sympathetic and parasympathetic nerves, plexuses and their connections)

(11) The Central Control System
   (Spinal cord, brain, etc., controlling the motor system and coördinating all other systems)

(12) The Reproductive System
   (Ovaries, testes and associated parts)

DIGESTIVE SYSTEM. In both shark and man the digestion and absorption of food takes place in a long winding tube, the alimentary canal or gut; this is subdivided into œsophagus, stomach and intestine, and bears as appendages a liver and a pancreas. In both cases the stomach secretes an enzyme and a small quantity of hydrochloric acid. The other main divisions likewise secrete several enzymes or ferments, which split up the food into glucose, glycerol, fatty acids, amino-acids, etc., and thus prepare it for absorption by the capillary blood-vessels in the wall of the gut.

Although the shark's gut is thus an epitome of that of man, it also has certain peculiarities. Its stomach is subdivided into a swollen cardiac portion, separated by a valve from the tubular pyloric section; the intestine is filled with a great spiral fold, which greatly increases the absorptive area.

CIRCULATORY AND OXYGENATING SYSTEMS. The circulatory and oxygenating systems in both shark and man have the same functions, namely:

(1) to deliver to all parts of the body the energy-bearing food products from the digestive system;

(2) likewise to distribute everywhere the oxygen-bearing red blood corpuscles;

(3) to deliver the waste products to the excretory system.

In both shark and man the main muscular pump, or heart, drives the blood to the capillary vessels of the body, whence the veins return it to the heart, whence the heart sends it respectively to the gills or to the lungs. In the shark, however, the heart is a relatively simple pump, consisting of auricle, ventricle and conus arteriosus arranged in a fore-and-aft series; these drive the blood forward to the gills. In man, as in other mammals, a median partition divides the heart into a double or four-chambered pump, the right side sending venous blood to the lungs, the left, pure blood through the aorta to the body (See Case I). Intermediate conditions are found in lung-fish, amphibians, reptiles and in the embryonic stages of man.

In a human embryo 4 millimeters long the shark-like ground-plan of the human circulatory system is more evident than in the adult. In the shark the aortic arches give off vessels to the gills; in the human embryo gills are absent but the gill-pouches, which are still represented (See Case 18), are likewise supplied by aortic arches. The heart of the human embryo is also simpler, more shark-like, than in the adult.

COMPARATIVE ANATOMY OF THE HEART. The four-chambered heart of man is constructed on the same plan as that of other mammals, but in some of the lower vertebrates, especially the amphibians, the right and left halves are more or less incompletely divided from each other, so that the venous and arterial blood are mingled in the single ventricle. In the shark, representing primitive fishes, there is no median partition of the auricle and ventricle; in other words, the heart is single not double.

The transition from the single to the double-chambered heart is seen in the developmental stages of the heart of man and other mammals.

URINOGENITAL SYSTEM. In *Amphioxus*, the most primitive known pre-vertebrate, the waste products of the blood are excreted through about ninety pairs of small nephridia, or bent tubes situated above the pharynx. The gonads (producing eggs or sperm respectively) are about twenty-six pairs of pouches arranged metamerically (in series) along the body wall. Thus the excretory and reproductive systems are separate in this very primitive type.

In the shark and higher vertebrates, however, the excretory tubules are united into a pair of organs, the kidneys, and the organs of excretion and of reproduction form a complex urino-genital system.

Each kidney consists of an immense number of coiled tubules, forming a "living high-pressure filter" that separates the clear blood plasma from the nitrogenous wastes, including urea, that have been received from the liver, etc., by way of the blood-stream. The kidneys also help to maintain the proper volume and composition of the blood partly by eliminating excess water, and rid the body of undesirable salts and foreign substances in the blood.

In the females of the lower vertebrates the ova, or eggs, after escaping from the ovaries are usually carried out by separate right and left oviducts. In the primates, including man, the lower parts of these ducts are united into a median thick-walled pouch, the uterus or womb, in which the fertilized egg develops into an embryo (Fig. 20).

In the males of many of the higher mammals, including man, the testes, containing the spermatozoa or male elements, descend during individual development (i.e., before or after birth) from the abdominal cavity into a pouch, or scrotum. Hence the ductus deferens through which the spermatozoa pass out, ascends from the testis, looping over the ureter or tube from the bladder and opening into the urethra. Thus in the higher mammals, including man, the male genital products and the urine pass out through a single tube, the urethra.
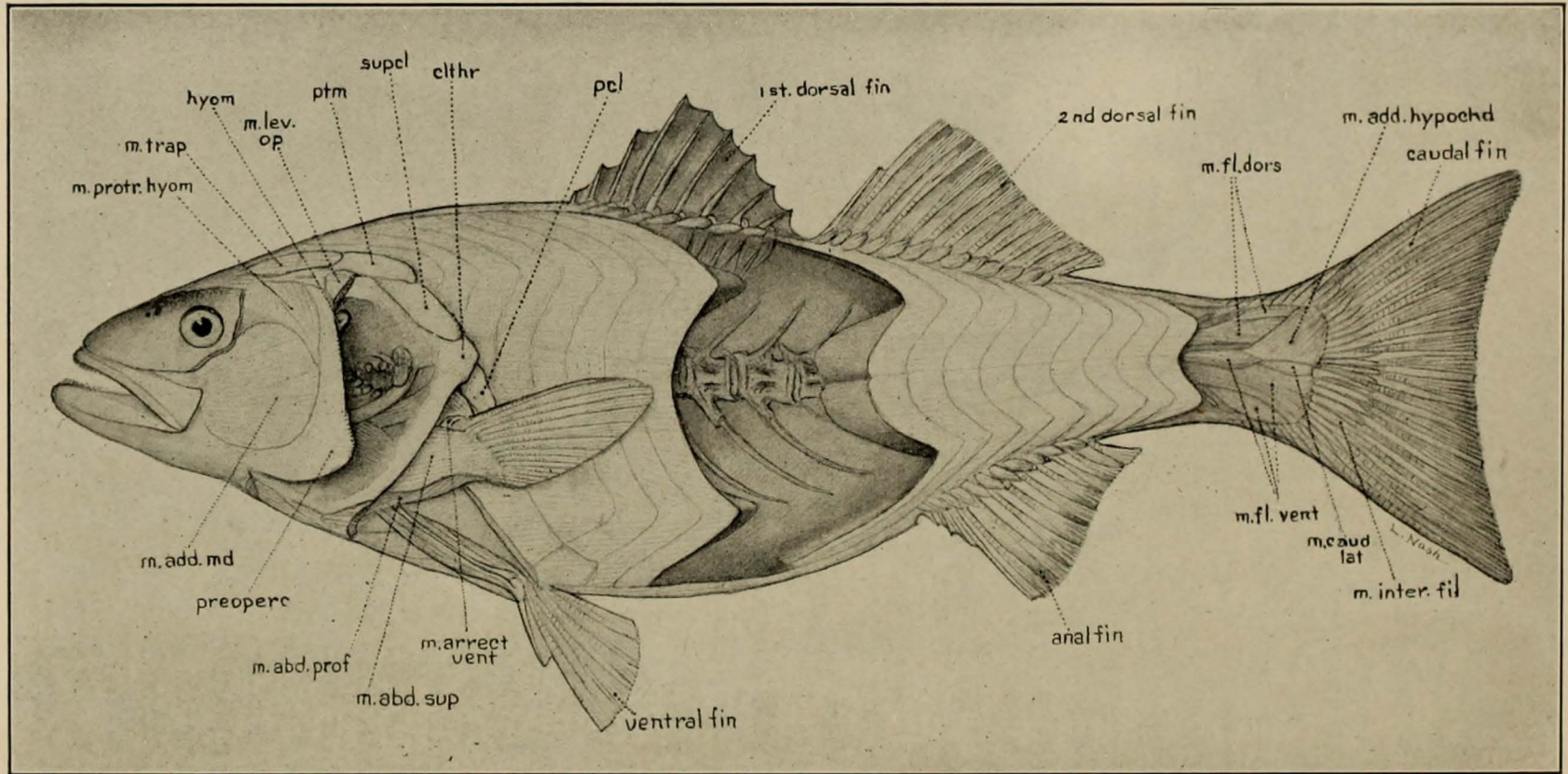
Fig. 5.   The locomotor apparatus of a typical fish (striped bass).

The myomeres or muscle segments are arranged in zigzags closely fitting one behind the other.   These are the main locomotor organs of the fish, the fins being of secondary importance.

Drawn from dissections by M. Roigneau.

ELEMENTS OF THE LOCOMOTOR SYSTEM

[Case IIB]

To explain how a man moves we begin with a fish. A fish moves through the water by turning his head first to one side, then to the other, and by sending one wave of contraction after the other along his tapering body. As these muscular waves flow backward they push against the water and drive the fish forward.

The body muscles of fish and other vertebrates are arranged in segments, one behind the other (Fig. 5). Immediately after the segment on one side contracts the nerves carry the message up to the spinal nerve cord and thence downward to the next segment on the same side; another set of nerves carries the message to the other side and starts a wave going on that side; and so on.

The human embryo passes through a stage in which the somites or segments are arranged in a fore-and-aft series, like the locomotor segments of a fish.

Although the muscle fibrils are so minute that the human body contains many billions of them, they are composed of molecules and atoms which are incomparably smaller still. When a muscle contracts it does so because its nerve fibres have discharged into it a current of some sort which suddenly upsets the equilibrium of the muscle's atoms and molecules. A chemical reaction takes place, the molecules shrink, causing contraction of the muscle, and lactic acid is set free in the tissues. Some of the oxygen carried by the red blood corpuscles is then used in restoring the muscle molecules and in oxidizing the waste products.

THE BACKBONE. The backbone arose as a flexible elastic rod (the notochord), which enabled the fish to thrust its undulating body forward through the water. As time went on the notochord became strengthened by bony rings or centra, which, being separated by elastic discs, enabled the backbone to bend. Bony arches were added to protect the spinal nerve cord.

In man the backbone, held at right angles to its original position, supports the skull, ribs and internal organs.

Vertebræ, or units of the backbone, are the essential and original core of the skeleton of vertebrates, or animals that are provided with a backbone, or vertebral column.

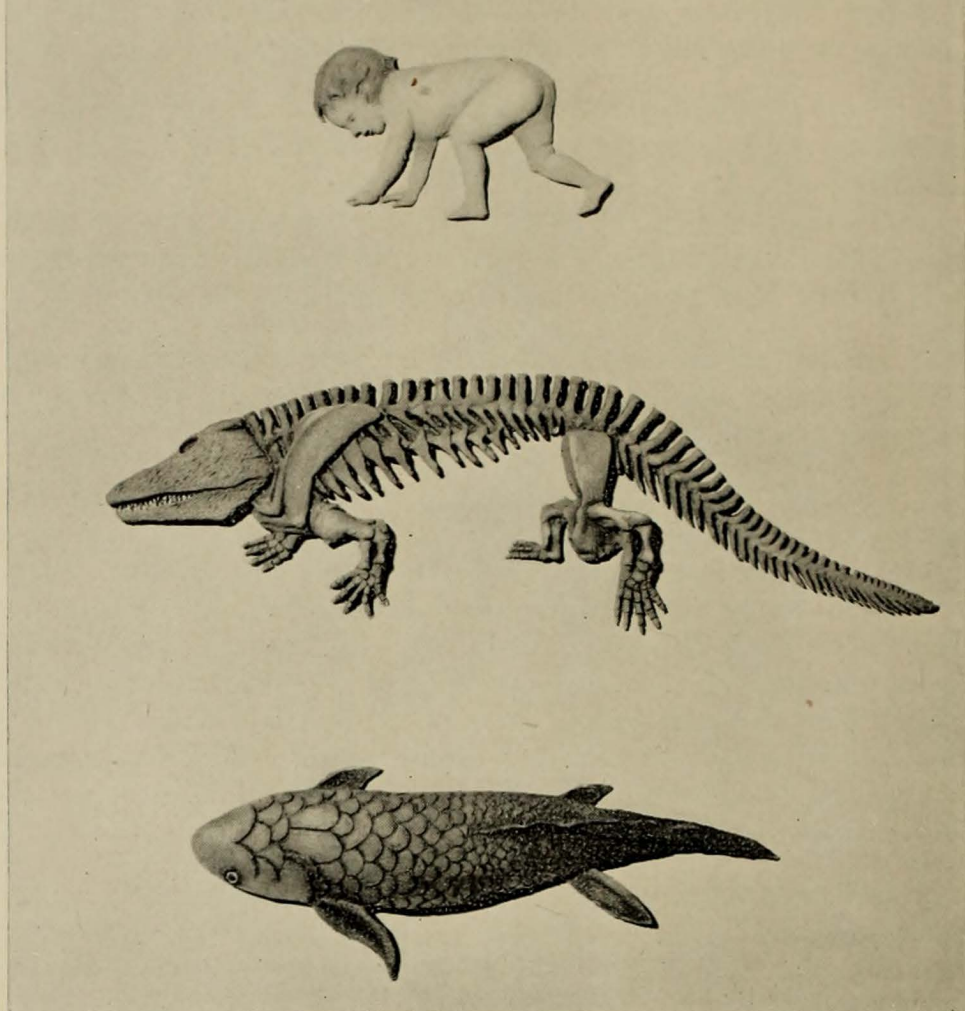## MAN'S HERITAGE
FROM QUADRUPEDAL ANCESTORS

Fig. 6.   Man's heritage from quadrupedal ancestors.
Below.   Air-breathing fish (*Ceratodus*) with paired paddles.   After Dean.
Center.   Fossil amphibian (*Eryops*) from the Permian of Texas.
Above.   Human infant running on all fours.   After Hrdlička.
Note the comparison between the paired paddles of the fish, the fore and hind limbs of the quadruped and the arms and legs of man.

STUDENTS IN NATURE'S
TRAINING SCHOOL

Neanderthal
cave-man

In the present and past ages of the earth Nature has kept a physical and mental training-school of many grades. Her examinations have always been practical ones, the prize of survival being awarded to the "fittest" in each successive grade.

In the primary school the lower grades were passed through under water. Here one learned to swim and steer in the currents, to lurk quietly, to strike successfully. A few grades further on the pupils were equipped with air-sacs, so that they could wriggle out on the banks and use their fore-and-hind paddles as limbs.

After acquiring the physique to withstand hardships of heat and cold, some of the more advanced candidates were admitted to the school of the forests and to the uncertainties of life in the trees, where a practical course in the care and feeding of infants was required of all mothers.

At last the most intelligent pupils ventured out into the open and went into training both for short sprints and

Miocene anthropoid

Early lemuroid
primate

Archaic mammal

Cynodont reptile

cross-country runs. In their manual training schools they learned the art of making flint implements and weapons and with these, before they retired to their dormitories at night, they prepared for themselves their simple meal of bear's meat.

Thus they were trained for the degree of H. S. (*Homo sapiens*), which was eventually won by their descendants.

W. K. GREGORY, 1931.
F. L. JAQUES, pinx.

Primitive terrestrial
reptile
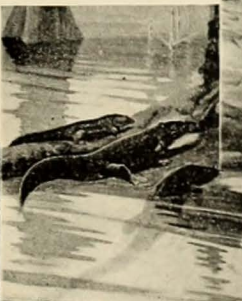
Generalized
amphibian

Lobe-finned fish

Primitive ganoid fish

Fig. 7. Students in Nature's training-school (Wall Chart 3)
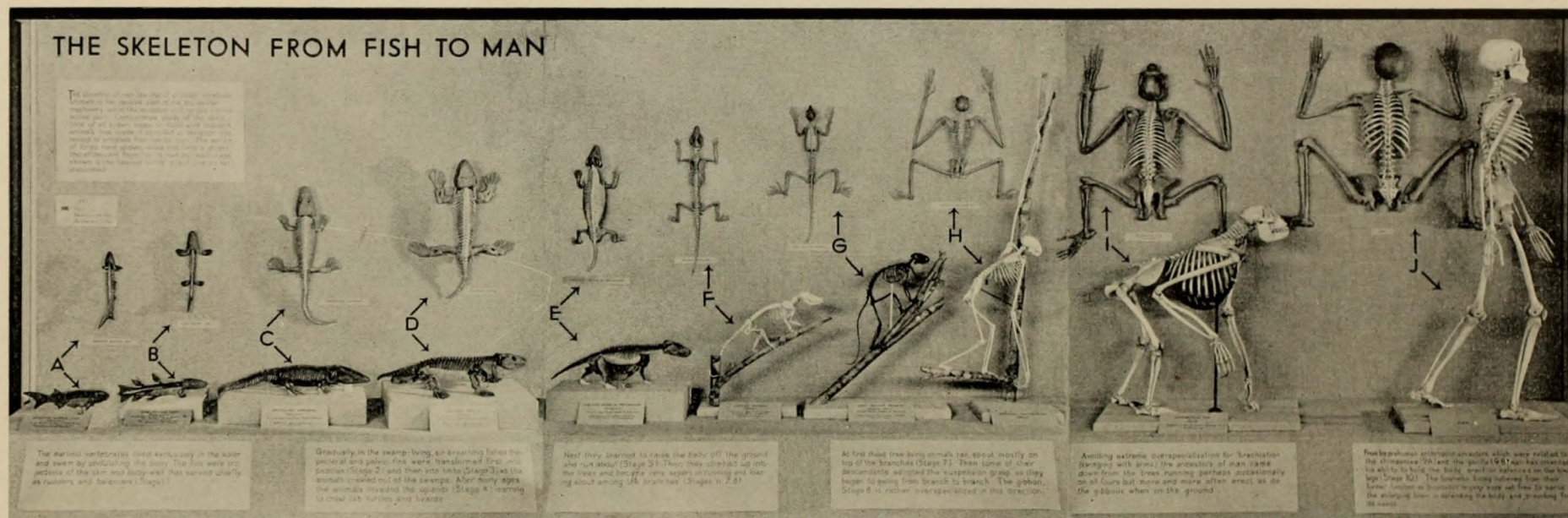
Fig. 8. The skeleton from fish to man

A. Primitive ganoid fish, *Cheirolepsis*, Old Red Sandstone (Devonian). Models based on fossils described by A. S. Woodward, D. M. S. Watson.

B. Lobe-finned fish, *Eusthenopteron*, Upper Devonian. Models based on fossils described by W. J. Bryant, D. M. S. Watson.

C. Generalized amphibian, *Diplovertebron*, Lower Carboniferous. Models based on fossils described by D. M. S. Watson.

D. Primitive reptile, *Seymouria*, Lower Permian, Texas. Models based on fossils described by S. W. Williston, F. Broili, D. M. S. Watson.

E. Cynodont reptile or pro-mammal, *Cynognathus*, Upper Triassic, South Africa. Models based on fossils described by H. G. Seeley, R. Broom, D. M. S. Watson and others.

F. Archaic mammal, Opossum, Recent, North America. Survivor of an Upper Cretaceous marsupial mammal described by W. D. Matthew.

G. Very ancient Primate, *Notharctus osborni*, Middle Eocene, Wyoming. Models based on fossils described by William K. Gregory.

H. Brachiating anthropoid, Gibbon, Recent. Specialized long-limbed derivative of primitive anthropoids.

I. Typical anthropoids, Chimpanzee (above) and female gorilla (below).

J. Man.

28

THE SKELETON FROM FISH TO MAN
[Case III]

The skeleton of man, like that of all other vertebrate animals, is the passive part of the locomotor machinery, while the muscles and nerves are the active part. Comparative study of the skeletons of all known types of fossil and modern animals has made it possible to decipher the record of progress from fish to man. The series of forms here shown (Fig. 8) does not form a DIRECT line of descent from fish to man but each stage shown is the nearest to the direct line so far discovered.

The earliest vertebrates lived exclusively in the water and swam by undulating the body. The fins were projections of the skin and body wall that served chiefly as rudders and balancers (Stage A). Gradually, in the swamp-living, air-breathing fishes the pectoral and pelvic fins were transformed first into paddles (Stage B) and then into limbs (Stage C) as the animals crawled out of the swamps. After many ages the animals invaded the uplands (Stage D), learning to crawl like turtles and lizards.

Next, they learned to raise the belly off the ground and run about (Stage E). Then they climbed up into the trees and became very expert in running and leaping about among the branches (Stages F, G, H).

At first these tree-living animals ran about mostly on top of the branches (Stage G). Then some of their descendants adopted the "suspension grasp," as they began to swing from branch to branch. The gibbon, Stage H, is rather overspecialized in this direction.

Avoiding extreme overspecialization for "brachiation" (swinging with arms) the ancestors of man came down from the trees, running perhaps occasionally on all fours but more and more often erect, as do the gibbons when on the ground.

From his prehuman anthropoid ancestors, which were related to the chimpanzee (I, upper) and the gorilla (I, lower), man has inherited his ability to hold the body erect or balanced on the hind legs (Stage J). The fore-limbs, being relieved from their former function as locomotor organs, were set free to serve the enlarging brain in defending the body and providing for its needs.

THE UPRIGHT POSTURE AND ITS MAINTENANCE
[Case IVA]

From fish to man there is still a chain of living forms, in spite of all the devastation and wholesale extinction of the present and past

ages. As the skeleton of man testifies to his derivation from lower forms of vertebrates (Fig. 8) so also does his muscular system; and through this orderly and intelligible series of stages we can follow the main changes of posture as our ancestors learned first to swim, then to crawl, to run, to climb and finally to walk erect.

In the swimming stages (see Fig. 8A, B) the segmental muscles of the backbone and ribs were dominant, the fin-muscles being subordinate extensions of the body. Then the paddles grew outward (C) and were eventually moulded into the new and highly organized limbs of land-living vertebrates (D-J).

These limbs are compound levers with the muscles arranged on opposite sides of the pivots and acting in pairs as antagonists to produce extension or flexion, abduction or adduction, twisting and untwisting, etc. In walking and running each limb alternately pulls and pushes on the ground. When in early stages the limbs sprawled widely at the sides, the limb muscles were very thick. In the course of ages, as the feet were gradually brought in toward the midline and the body was raised off the ground, the limbs grew longer and more graceful.

THE SUPERFICIAL MUSCULATURE OF THE CHIMPANZEE. When running on the ground the chimpanzee usually goes on all fours, supporting the fore part of the body on the fingers, sharply bent at the middle joints. The muscular anatomy, however, is well adapted also for a semi-erect posture, as well as for sitting upright and for brachiating, or swinging with the arms (Fig. 9).

Among the more conspicuous differences from man are: the very short neck, the long arms and short legs, the long fingers, the short thumb and the inwardly-directed great toe. The loins (lumbar region) are extremely short and broad, the hip bones (ilia) long. The hind limb is habitually flexed at the hip and knee.

There are corresponding differences in the proportions of the muscles: for example, the limb muscles of the chimpanzee are more fleshy, with shorter tendons, than in man. A peroneus tertius muscle is usually lacking.

These and many other such differences between chimpanzee and man relate to the wide contrast in their PRESENT methods of locomotion; but in spite of these adaptive differences there is a remarkable unity in the plan and arrangement of the muscles in these two forms.

MAN. Man is a fully erect bipedal mammal whose entire weight is carried by his long hind limbs (Figs. 8J, 9). Consequently his
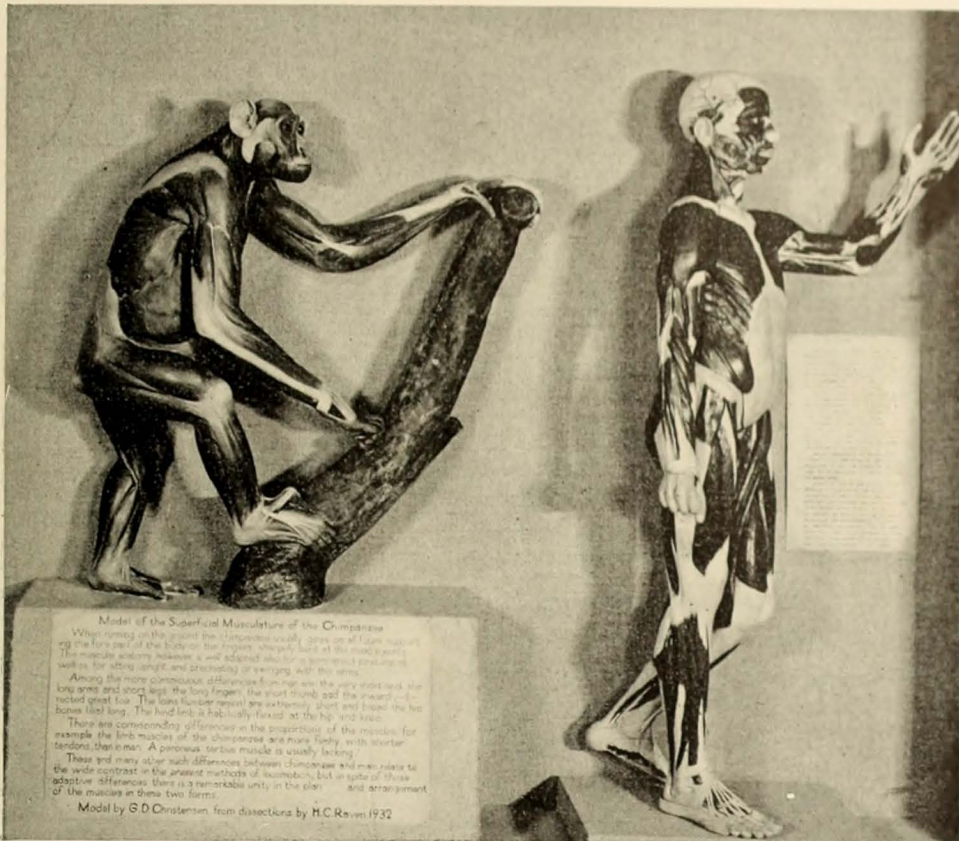
Fig. 9. Muscular anatomy of chimpanzee and man, showing principal muscles used in maintaining upright posture.

The model of the chimpanzee, by G. D. Christensen, was based on dissections by H. C. Raven.

superficial glutæal muscles are relatively enormous as compared with those of the chimpanzee, since they assist alternately in holding the body aloft on one side, while the opposite leg swings off the ground.

For similar reasons his erector spinæ muscles are much widened, especially at the lower end, his gastrocnemius muscle is very thick and short with a long tendon, and the biceps femoris muscle extends only a little way below the knee.

His long loins (lumbar region) form a flexible lever on which the whole weight of the upper part of the body is poised. In order to give better balance the back is curved in at the lumbar region and the hip bones are widened greatly.

Another consequence of the upright posture is that the fore limbs of man are completely suspended from the skull, the backbone and

the ribs, since they no longer serve as limbs but as levers for moving things.

In spite of these and many other special adaptations to the upright posture, man has inherited from his remote pre-human ancestors a great many characters which have also been retained in the existing anthropoid apes. For example, his shoulders are held far away from the neck by means of the long curved clavicle, his arms can be swung around in a complete circle, his hands can be freely turned up, or supinated; his thumb, however, has progressed beyond the grasping stage that is now represented in the ape's thumb.

THE PECTORAL AND PELVIC GIRDLES
[Case IVB]

A well-known dictionary defines the term girdle in the anatomical sense as "The ring-like arrangement of bones by which the limbs of a vertebrate animal are attached to the trunk." The pectoral and pelvic girdles might better be defined as originally U-shaped or V-shaped bony supports by which the trunk is suspended between the limbs (Fig. 12).

In the oldest and most primitive known fossil fishes the body moved forward through the water by waving from side to side by means of the contraction of successive muscle segments (Fig. 10). At that time the fins were merely keel-like projections from the body, which were stiffened internally by rod-like skeletal supports, and externally by spines formed in the skin. All the fins functioned as keels and rudders rather than as paddles. Between the pectoral and the pelvic fins in certain primitive fishes there were several other pairs of fins. Evidently the paired fins were similar both in origin and in construction to the median or unpaired fins.

The fins in ancient and modern sharks were supported by skeletal rods which were laid down in the membranes between adjacent muscle segments.

The anal, pelvic and pectoral fins of early fossil sharks (Fig. 10) exhibit progressive stages in the squeezing together of the basal rods into a U-shaped girdle.

The subsequent history of the shoulder girdle from fish to man is summarized in Figs. 11-13. In typical fish the pectoral girdle consisted of: (1) an outer or dermal series of bony plates (including the cleithra, clavicles, etc.) and (2) an inner or primary shoulder girdle, including the scapula and coracoid.
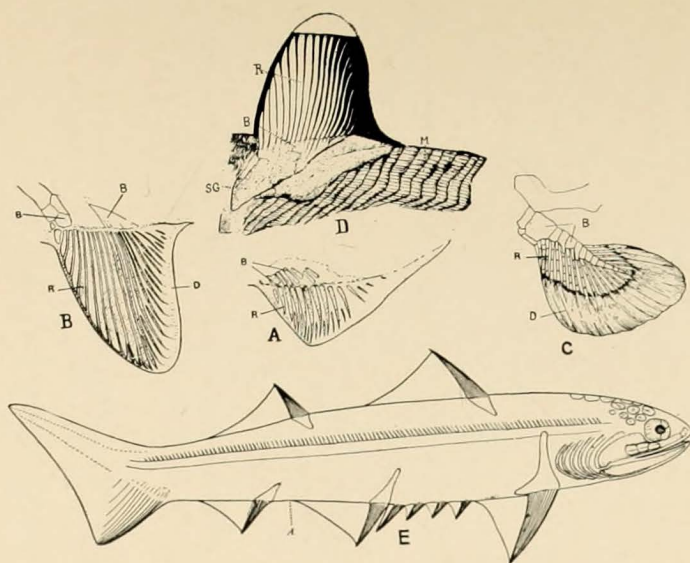
Fig. 10.   Earliest known stages in the origin of the fins and girdles.

A.   Ventral fins of Devonian shark (*Cladoselache*), showing separate rod-like supports of "fin-fold" fin.

B.   Pectoral fin of *Cladoselache*, showing pectoral girdle and basal pieces presumably derived from fusion of separate rods.

C.   Pectoral fin of Permian *Pleuracanthus*, showing fully developed paddle-like fin with jointed axis.

D.   Pectoral fin of *Cladoselache*, partly covered by preserved myomeres.

E.   Restoration of generalized acanthodian by Dean.
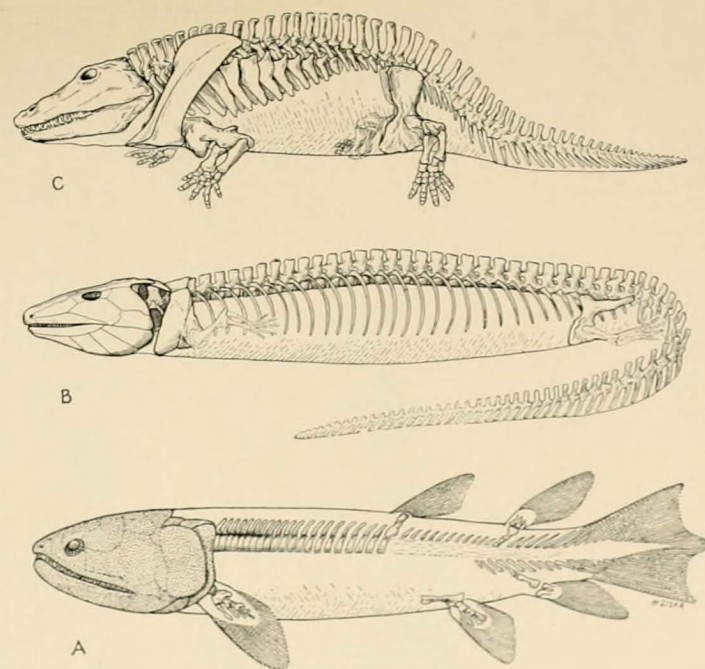
Fig. 11.   The shoulder girdle, originally attached to the skull by a bony link, becomes free from it in land animals.

A.   Reconstructed skeleton of *Eusthenopteron foordi*, based on the data of Bryant, Hussakof, Goodrich.

B.   *Eogyrinus*.   Reconstruction slightly modified from Watson.

C.   *Eryops megacephalus*.   Based chiefly on the mounted skeleton in the American Museum of Natural History.   Details of pectoral girdle and limb after Miner.

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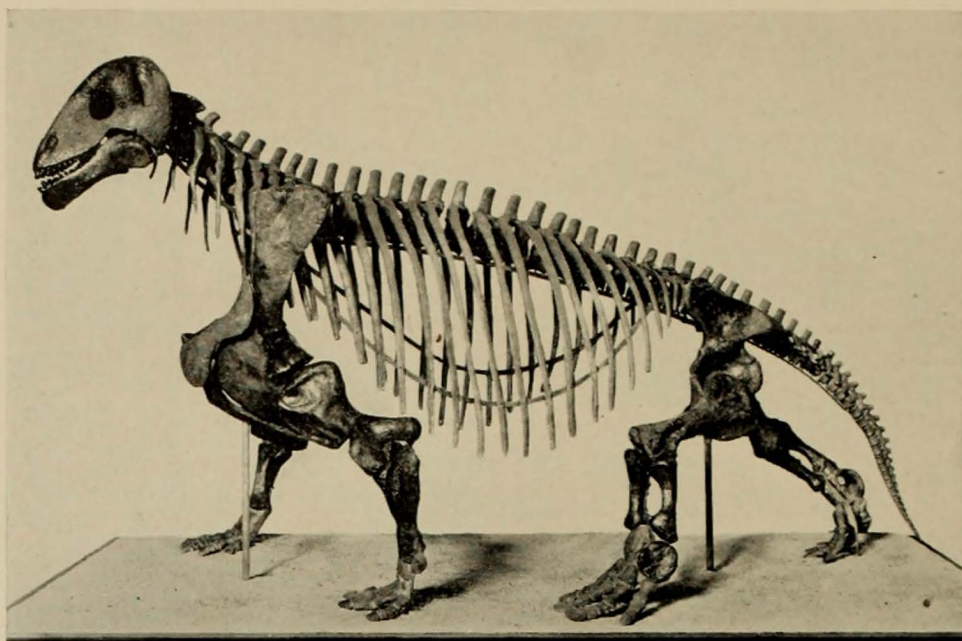
Fig. 12. Skeleton of *Moschops capensis* Broom.

In this fossil mammal-like reptile the shoulder girdle retained the cleithra (reduced), clavicles and interclavicles, representing the outer layer of the fish girdle, and the coracoids and scapulae (shoulder blades) of the inner layer of the fish girdle.
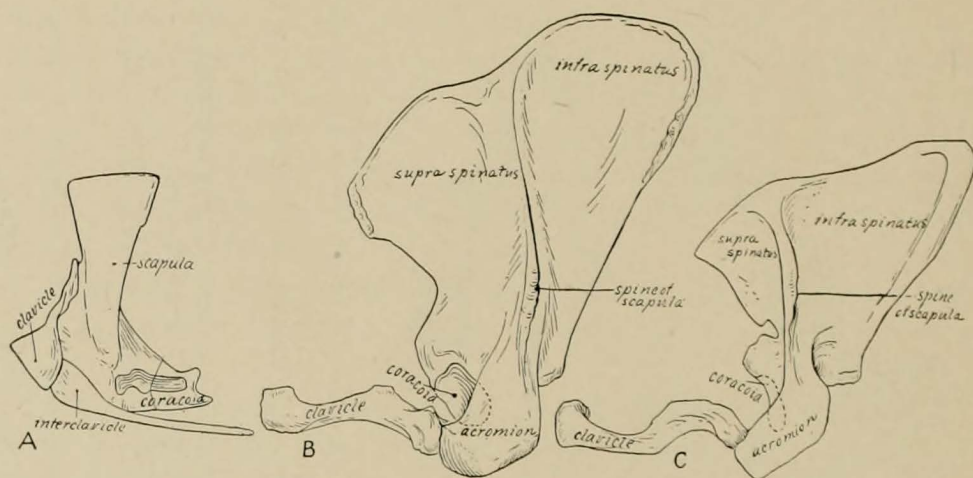
Fig. 13. In higher mammals the shoulder girdle consists on each side only of a shoulder blade (scapula) and a collar bone (clavicle), the remaining parts having been lost.

A. Typical early reptilian type, after the loss of the cleithrum.

B. Gorilla.   C. Man.
   The shoulder girdle of man is very like that of the gorilla.
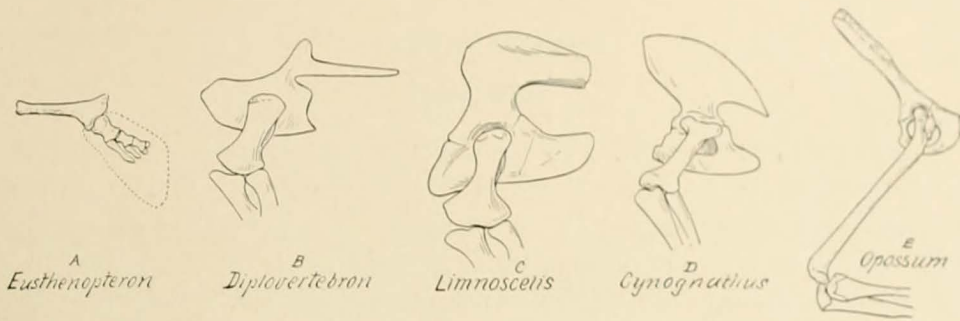
Fig. 14. Series of pelves and pelvic limbs, from lobe-finned fish to primitive mammal.

The pelvis (Figs. 14, 15) arose as a pair of bony rods on either side of the cloaca, or exit of the digestive and reproductive tubes. It supported the pelvic fins. After the lobe-finned fishes came out on land the iliac blades of the pelvis grew upward, becoming attached to the sacral ribs and thus to the vertebral column.

A. Lobe-finned ganoid (*Eusthenopteron*) of the Devonian period; B. *Diplovertebron*, early tetrapod; C. *Captorhinus*, primitive reptile; D. *Cynognathus*, advanced mammal-like reptile; E. Opossum, primitive mammal.
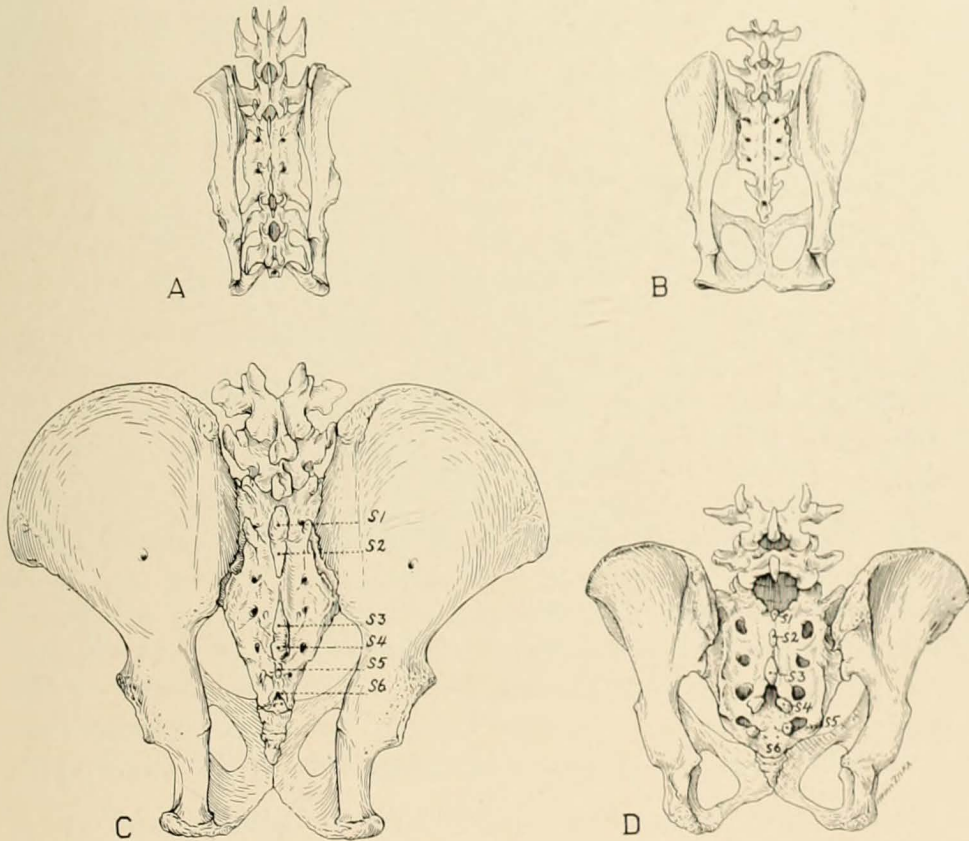
Fig. 15. Progressive widening of the pelvis and sacrum in primates.

A. Lemur, with long narrow ilia adapted for leaping.
B. Gibbon. Incipient widening of the iliac blade.
C. Gorilla. D. Man.

Hands and Feet

[Case VA]

HANDS OF PRIMATES. The hands and feet of most mammals are provided with digits that are tipped with either claws or hoofs; but in the primates the digits usually bear nails. These nails appear to be relics of an ancient arboreal habitus, which, as the fossils show, had already been assumed by the early primates of the Eocene epoch. The most primitive existing primates are the lemurs of Madagascar, which have a strongly grasping type of hand with the fourth digit the longest and partly opposable to the thumb. In the most specialized of the lemurs, the potto of Africa, these characters are greatly emphasized, while the second finger has become vestigial. (Fig. 16.)

The hand of *Tarsius* retains the primitive five digits but the ends of the fingers bear large flattened discs like those of tree-frogs.

The New World monkeys, or platyrrhines, exhibit considerable skill in handling objects and their hands are more mobile and less clamp-like than those of lemurs. Most of these animals have five-fingered hands, but in the spider monkeys, which use the hands as hooks to swing with, the thumb is lost.

In most of the South American monkeys the nails are strongly folded; in the marmosets this tendency gives rise to false claws.

In the Old World monkeys, or catarrhines, the hands are intermediate between paws and true hands. In the species of *Colobus* monkeys the thumb is variously reduced, sometimes almost to the vanishing-point, doubtless in connection with the use of the hands as hooks.

In most of the anthropoid apes the hands have become elongate and specialized, with a more or less feeble thumb. These tendencies terminate in the orang-utan. In the gorilla the hands are very broad and massive, in keeping with the burly proportions of the body as a whole. In man the hand far surpasses those of other primates as an organ for picking up food and other things. The thumb is larger than in the anthropoids and is more easily opposable to the other digits.

However, the human hand inherits a generally anthropoid type of musculature and the thumb springs from the root of the hand as in the anthropoids, not from near the end of the metacarpals as in Old World monkeys.
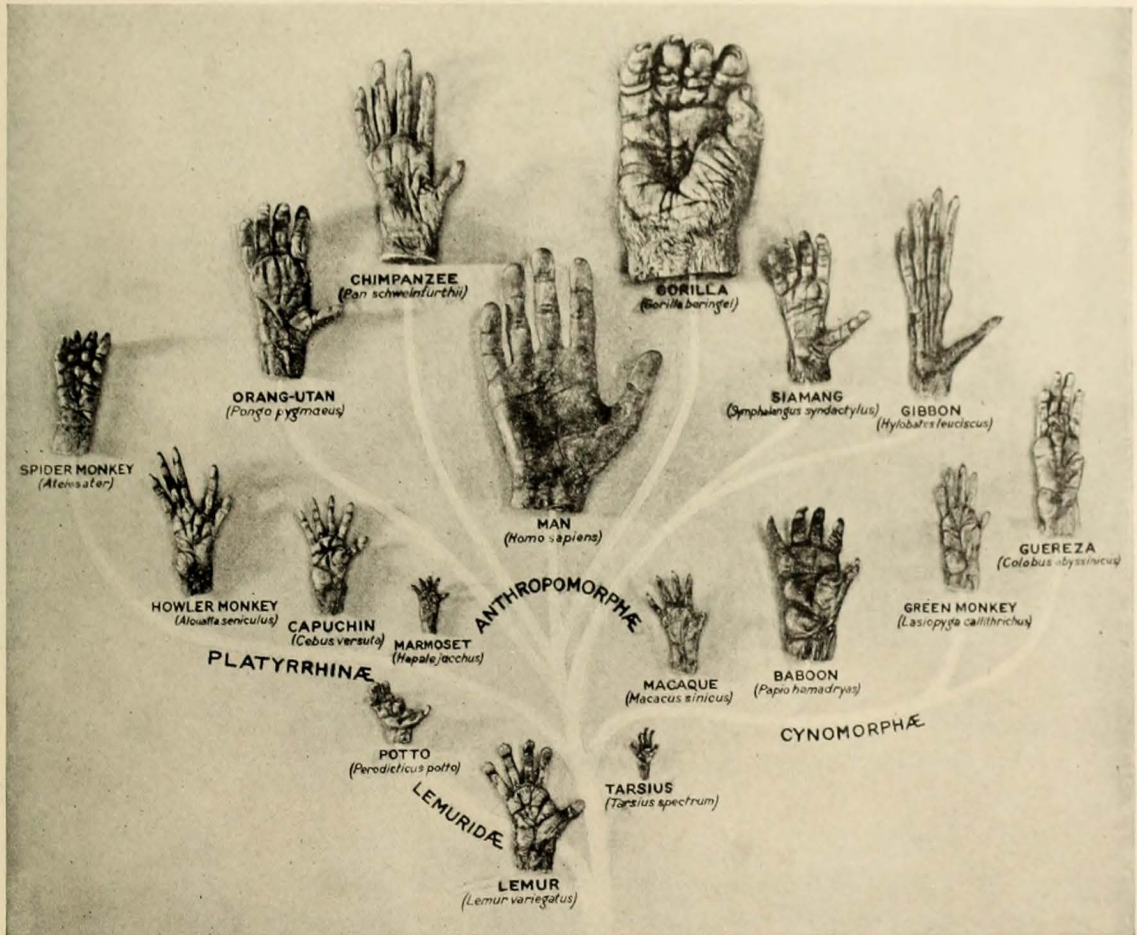
Fig. 16. Hands of Primates. Man inherits a five-rayed plan of the hands and feet, which has been specially modified so that the fore feet ordinarily have to do only with the handling of objects.
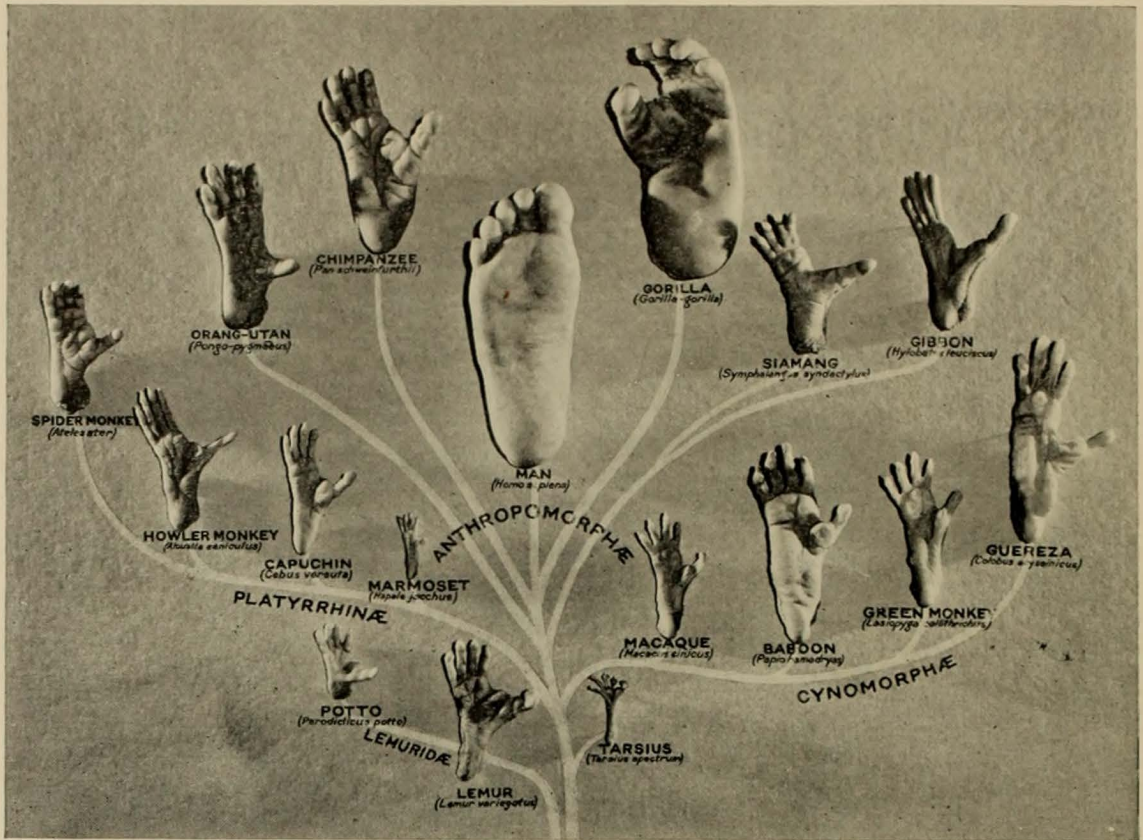
Fig. 17. Feet of Primates. Casts showing the sole of the foot. In the lower primates the big toe branches off at a sharp angle from the rest of the foot but in man it has been drawn forward so as to be nearly parallel with the other toes.

FEET OF PRIMATES. The five-toed feet of the lemurs have a large sharply-offset great toe tipped with a broad flat nail (Fig. 17). The clawed second digit is used for scratching the fur. The long fourth digit coöperates with the great toe in firmly clamping the branches. In the foot of the potto these grasping characters are further emphasized. In *Tarsius* the foot is spreading, with delicate digits, flattened discs and more or less clawlike nails.

In the New World monkeys the foot is more mobile, less clamplike than in the lemurs, and the same is true in the Old World monkeys, although all retain the divergent great toe.

In the anthropoid apes the foot is often used for suspension, especially in the orang-utan, in which the foot becomes extremely long and narrow. In the gorilla the toes have begun to shorten and the great
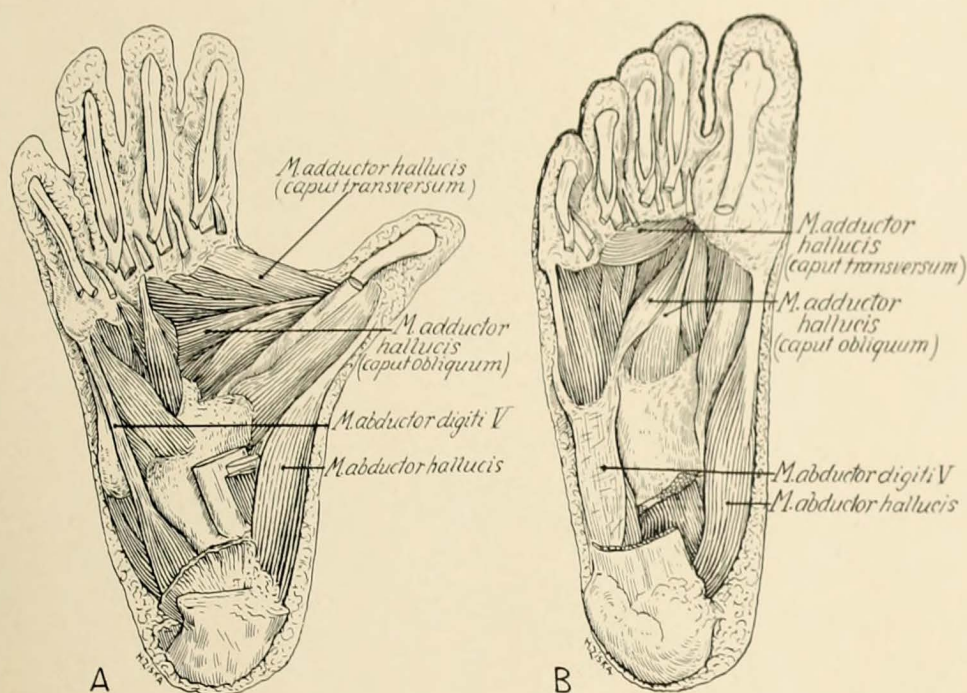
Fig. 18. Grasping muscles of the great toe and their opponents as seen on the sole of the foot in (A) Gorilla; (B) Man. After dissections by H. C. Raven.

In man the transverse adductor of the great toe is still present essentially in the anthropoid position though much reduced. The oblique adductors of the great toe are well developed in both man and anthropoids.

The abductor of the great toe is almost identical in man and anthropoids. The same is true of the abductor of the little toe.

toe begins to resemble that of man, except that it is still off-set from the other digits. In the orang, chimpanzee and gorilla the heel is placed on the ground in walking, as in man.

In man the great toe has become drawn in toward the other digits and the latter have become very short.

COMPARATIVE ANATOMY OF THE SOLE OF THE HUMAN FOOT. The superficially hand-like appearance of the feet of the chimpanzee and gorilla was viewed in earlier times as an important and fundamental point of difference from the foot of man, but dissections of the sole musculature show that the foot of the chimpanzee and the gorilla is operated by muscles which correspond, not to the muscles of the human hand, but to those of the human foot (Fig. 18). In brief, the musculature as well as the skeleton of the human foot is fundamentally of the biramous anthropoid type.
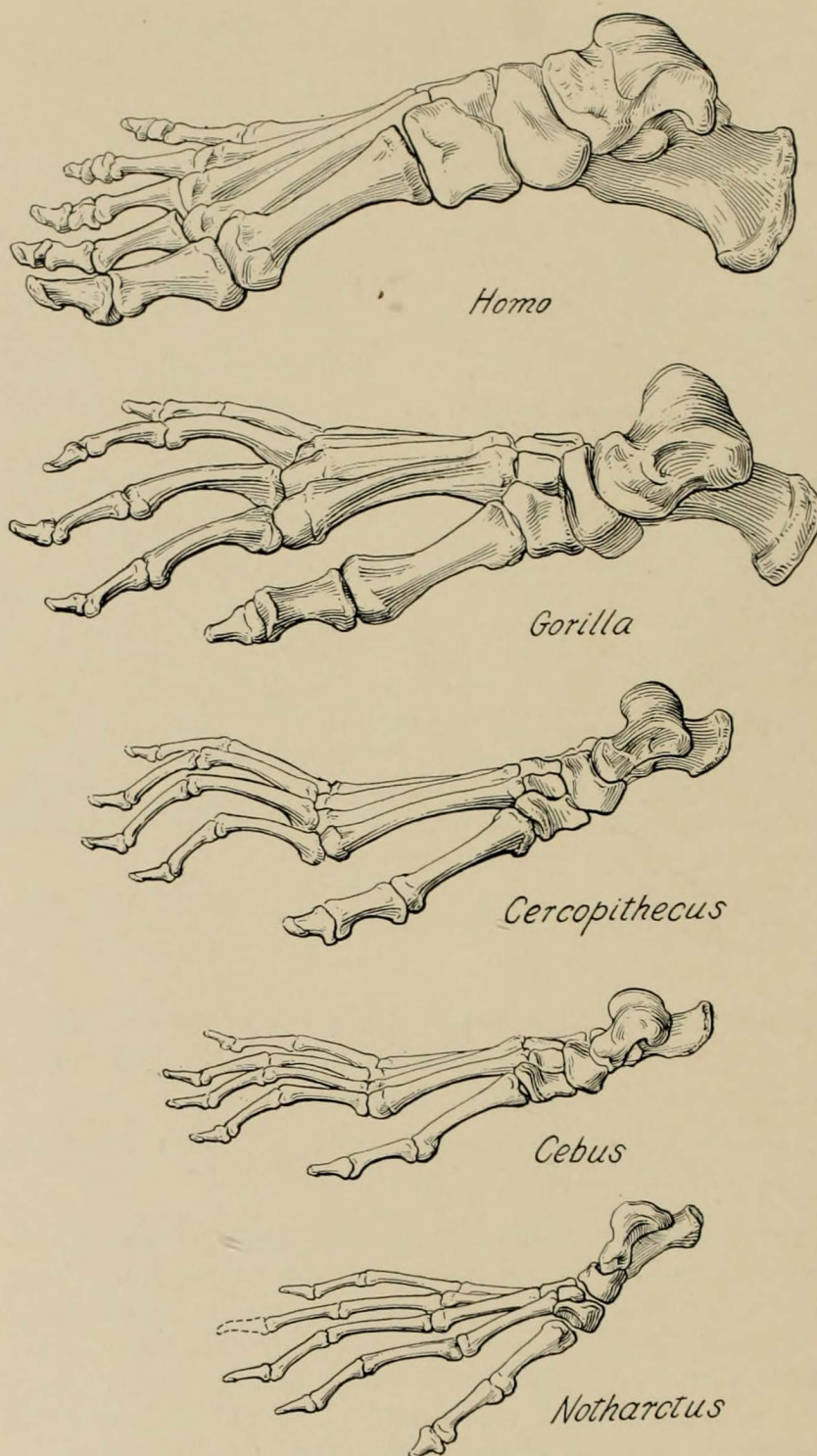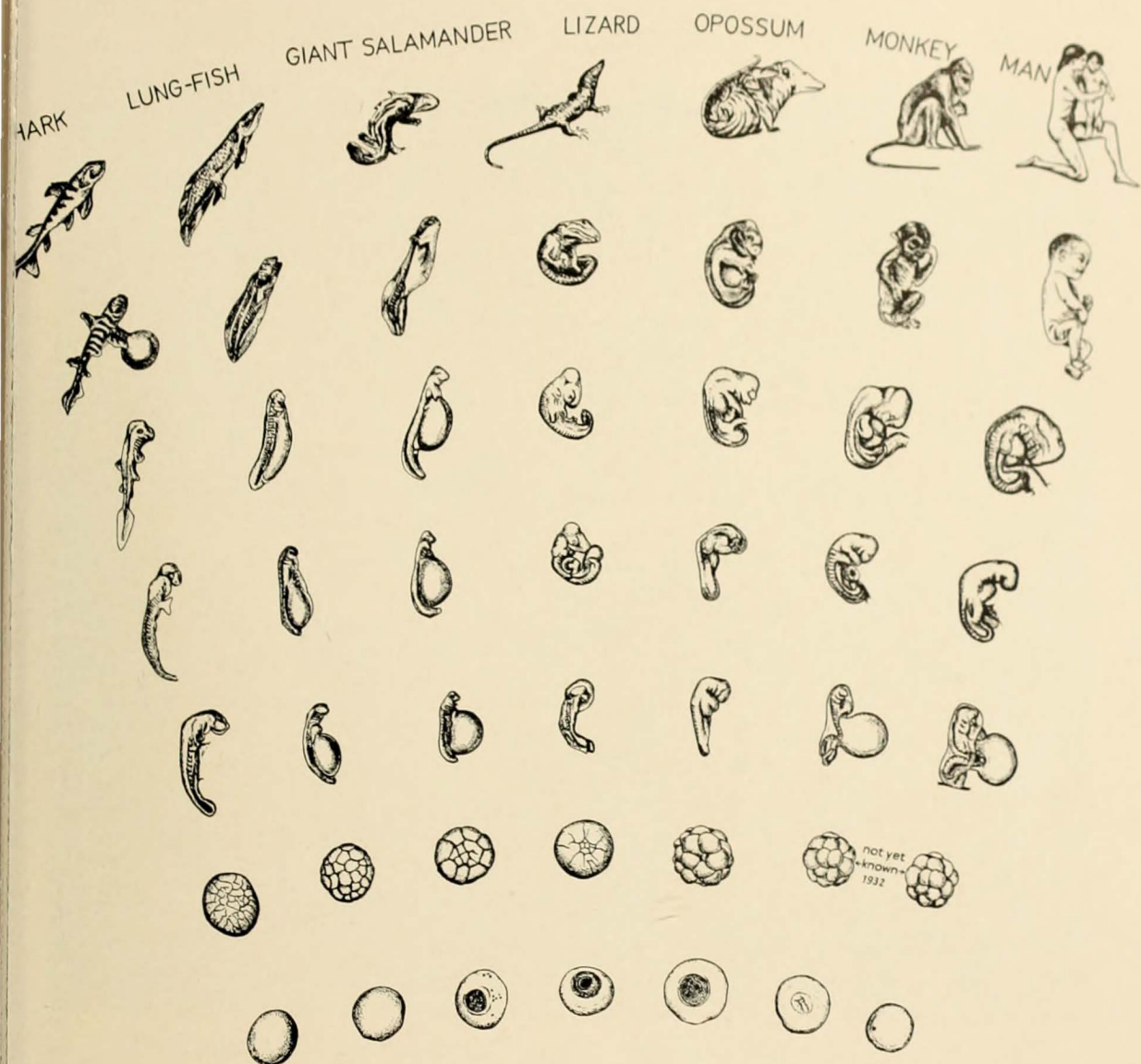
Fig. 19. A structural series of feet of primates from the Eocene
Notharctus to Man.

SHARK LUNG-FISH GIANT SALAMANDER LIZARD OPOSSUM MONKEY MAN

not yet known 1932

Dept. of Comparative and Human Anatomy 1932

Fig. 20. Comparative embryology from fish to man (Wall Chart 5).

Man, like other vertebrates, develops from a zygote or fertilized egg, which divides and subdivides as it grows until it eventually gives rise to the millions of cells in the adult body.

In order to facilitate comparison the corresponding stages in the different lines of development have been enlarged to about the same size, regardless of 'scale.' Thus the human egg, which measures only about 1/250 of an inch in diameter, is here shown nearly as big as the egg of the Port Jackson shark, which measures about two inches (bottom row).

The picture shows seven out of the innumerable stages of development.

The second row illustrates late cleavage stages. In the third row note the beginning of somites (body segments); in the fourth row gill slits and the beginning of the fore limbs are indicated; the fifth row shows late embryos with fore and hind limb buds; sixth row, late foetal, newly hatched, or new-born stages; top row, adults.

41

THE FACE FROM FISH TO MAN
[Case VI]

A comparative series of models, including living and extinct forms and showing a general progress from fish to man (Fig. 21).

These forms do not lie in the direct line of descent to man but are the nearest to the direct line yet discovered.

The lower forms contrast with man in the following characters:

	LOWER FORMS	MAN
Normal position of backbone	Horizontal	Vertical
Position of eyes	On side of head	In front
Direction of eyes	Outward, forward and upward	Forward and slightly downward
Position of mouth	Largely in front of eyes	Largely beneath eyes
Direction of mouth	Somewhat downward	Horizontal
Muzzle	Large	Much reduced
Nose	Not lifted above muzzle	Prominent, narrow
Nostrils	More or less separated	Close together
Upper lip	Separated by nose	Continuous beneath nose

Intermediate stages in the shifting and development of the parts of the face are seen in the monkeys and apes.

Taken as a whole, the series indicates that in the earlier forms the braincase was low; the forehead first begins to be lifted up in the monkeys but it is not until man himself appears that the brain swells up to produce an almost vertical forehead.

The eyes first appear on the side of the head and gradually shift around to the front, so that by the stage of the anthropoid ape they can both be focussed at once on an object held in the hand or near the face.

The nostrils also are originally wide apart and come together into a true nose only in the anthropoid stage. The nose is at first not differentiated from the projecting muzzle, but in the anthropoids it becomes separated from the mouth by the broad upper lip and begins to take on its human character.

The mouth is at first only the opening to a sort of fish-trap set with sharp teeth, but in the anthropoids it becomes adapted for a diet chiefly of tender shoots and herbs. In man the mouth finally becomes relatively very small and delicate.

Fig. 21. A comparative series of casts and models including living and extinct forms and showing a general progress from fish to man.

Thus the face has undergone great changes in adaptation to successively different modes of life; but, from first to last, the mouth, which is the gateway to the stomach, has been assisted by the nose, the eyes, and the ears. And as our brains have improved, our eyes and ears have told us more and more about the world of nature and of men.

THE FACIAL MUSCLES FROM FISH TO MAN
[Case VI]

The human face owes to its facial muscles the ability to smile or to frown and to express such emotions as joy, fear, dislike and their opposites. The facial muscles also take part in other movements of the lips, mouth, nostrils, ears and scalp. In mammals, including man,
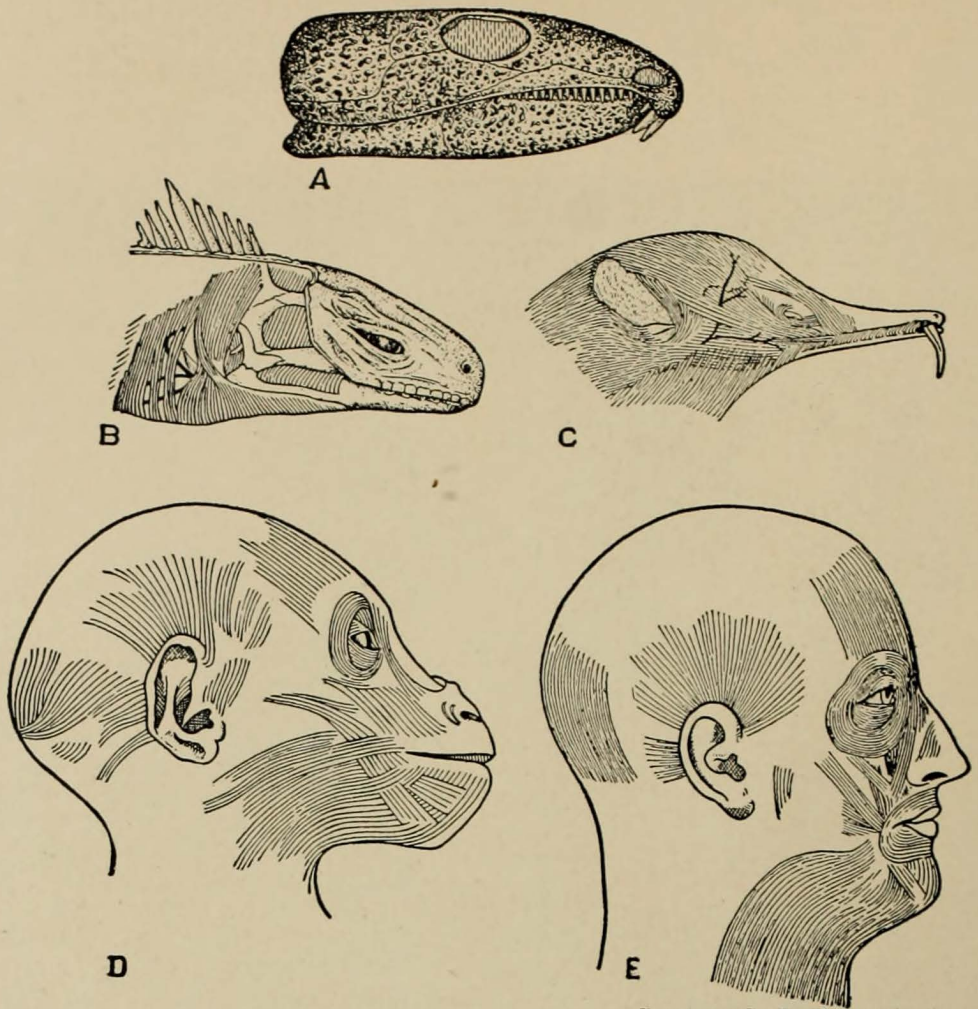
Fig. 22.   Origin of the Facial Muscles of Man.

A.   Primitive reptile with continuous bony mask covering skull. The mask was
    covered with thick skin without muscles, as in the alligator.   (After Willis-
    ton.)
B.   Modern reptile with an open or fenestrated skull covered with thick, non-
    muscular skin. (From Fürbringer, modified from Ruge.)
C.   Primitive mammal in which the sphincter colli system has grown forward over
    the face.
D.   Gorilla.   E.   Man.   (C, D and E after Ruge.)

they extend over the face and around the scalp, ears and neck; but in
the vertebrates below the mammals they are confined to the neck
and throat.

The present series of models in low relief illustrates some of the
steps by which the complex conditions in mammals are believed to
have arisen out of the more simple conditions in man's less progressive
relatives. The models (except No. 3) are based on a few of the numer-
ous dissections and illustrations prepared by the late Professor Ernst
Huber of Johns Hopkins University and described by him in his book
on "The Evolution of Facial Musculature and Facial Expression"
(1931).

44

Evolution of the Human Skull
[Cases **VI**, **VIIA** and 20]

During the evolution of the skull from that of a primitive lobe-finned fish to that of man (Fig. 24), many changes have taken place in the number, proportions and relations of the bones.

In the skull of the primitive Devonian fish, *Eusthenopteron*, there are about 145 bones, while in man (Fig. 23) the number is reduced to 27 or fewer. In the living codfish the skull is made up of 68 bones, not including the hyoid and branchial arches.

This reduction in number, as well as the striking great increase in the size of the brain-case and the reduction in the size of the jaws, well illustrates the principle recognized by Stromer and Williston, that as we pass from primitive to specialized vertebrates the number of primary skull elements is reduced, while those that remain become more highly differentiated.
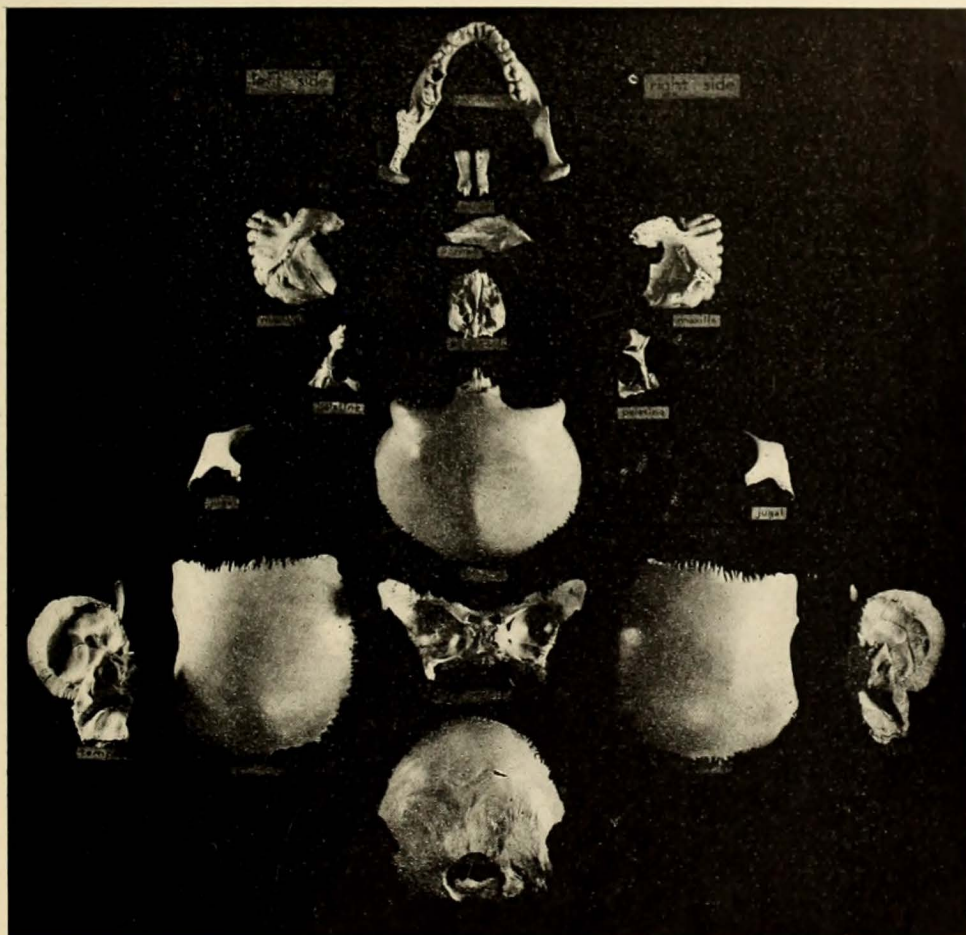
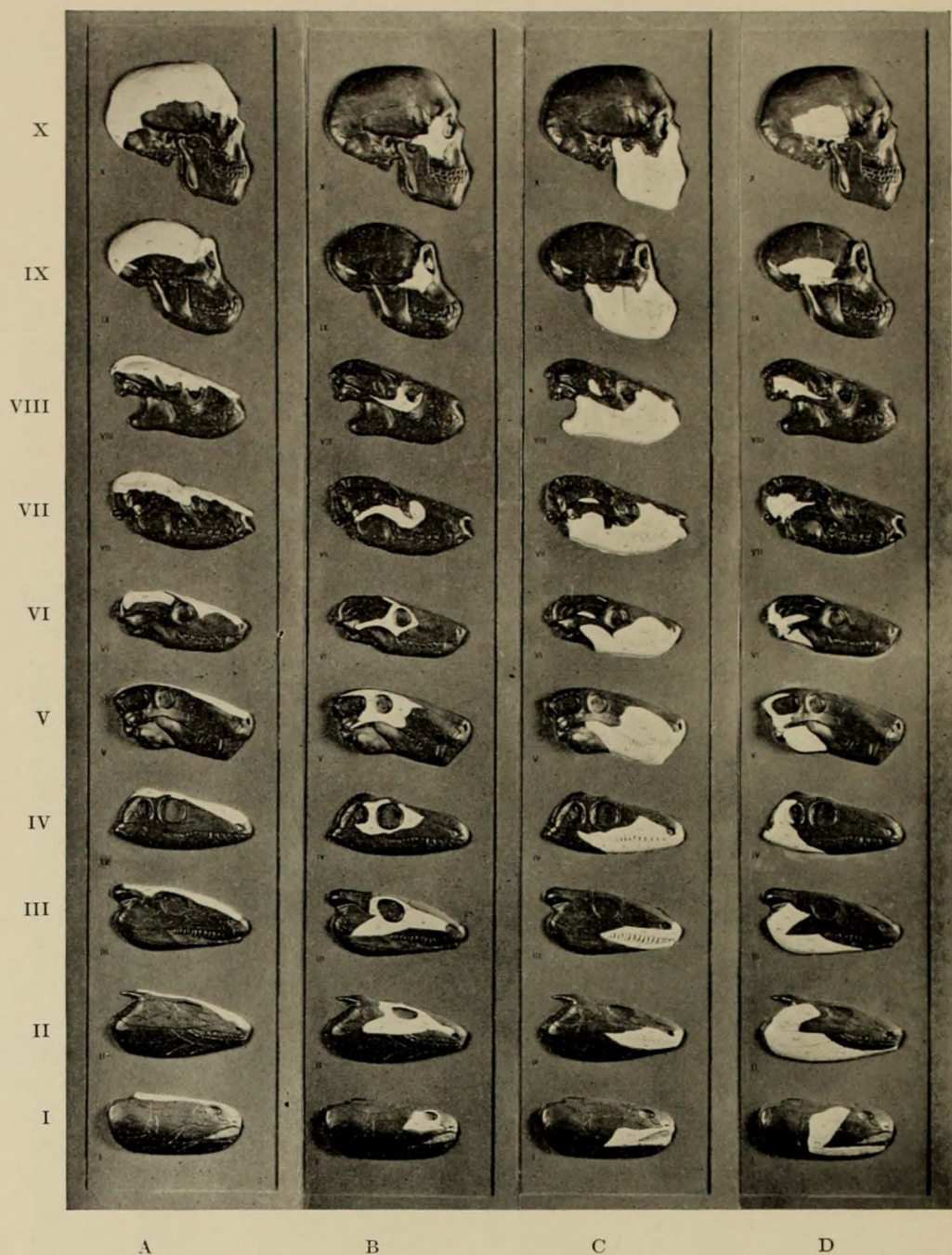Fig. 23. Disarticulated human skull, exclusive of hyoid and laryngeal elements.

Fig. 24.   Evolution of the human skull.

This exhibit is designed to show ten structural stages in the evolution of the skull from fish to man, represented by known fossil and recent specimens.

    I.   Devonian crossopterygian fish, *Rhizodopsis*.
   II.   Carboniferous amphibian, *Eogyrinus*.
 III.   Permo-Carboniferous reptile, *Seymouria*.
 IV.   Permo-Carboniferous theromorph reptile, *Mycterosaurus*.
   V.   Permian reptile, *Scymnognathus*.
 VI.   Triassic cynodont reptile, *Ictidopsis*.
VII.   Recent opossum representing Upper Cretaceous marsupials.
VIII.   Eocene primate, *Notharctus*.
 IX.   Recent anthropoid, chimpanzee.
   X.   Man.

EVOLUTION OF JAW MUSCLES. The temporal and masseter muscles of man are homologous with similarly situated muscles in lower animals (Fig. 25). The temporal muscle arises on the side of the skull, passes down beneath the cheek arch and is inserted into the upper part of the mandible. The masseter arises from the lower border of the cheek arch and is inserted into the outer, rear part of the mandible.

In the shark (I) the temporal and masseter are represented by part of the adductor mandibulæ mass, which in turn is in series with the deep flexor muscles of the gill arches.

The temporal muscle has played a prominent part in the perforation of the bony shell behind the eyes to form the temporal opening and cheek arch (see "Evolution of the Skull").

The two pterygoid muscles (external and internal) although usually small in the mammals are of great importance in the opening and closing of the jaw. They also counterbalance the pull of the masseter, which might tear the jaws apart at the symphysis.

The digastric muscle of mammals is a compound muscle and it, together with one of the muscles of the throat region, represents part of the second constrictor of the fishes.

Fig. 24—(Continued)

Column A.—Evolution of the skull roof. The paired nasal, frontal and parietal bones of the primitive vertebrates (I–V) are passed on by heredity to the lower mammals (VII, VIII) and finally to man (X). In man (top) the upgrowth of the brain is reflected in the dome-like cranium.

Column B.—Evolution of the bones around the eye. In lower vertebrates (I–V) there was a series of five bones around the orbits or eye-sockets. In the mammals (VII–X) only two of these bones (the malar and the lacrymal) remain. In the lower forms the eyes are on the sides of the muzzle behind the upper jaw, and they look sideways. In anthropoids and man they are above the upper jaw and are directed forward.

Column C.—Evolution of the jaws. In adult man the upper jaw on each side is composed of two fused bones, the premaxilla (intermaxillary) and the maxilla. The lower jaw on each side is composed of a single bone, the dentary. These bones are present in the lower vertebrates. As we pass from fish to man the maxilla and the dentary become larger and the dentary at Stage VII effects a new contact (the temporo-mandibular joint) with the skull. In the anthropoid and man the jaws become deepened and shortened in front beneath the eyes.

Column D.—Evolution of the temporo-mandibular bones. In the fish (I) the cheek plates cover the jaw muscles and are continuous below with the infra-dentary bones. In the reptiles this series is represented especially by the squamosal and angular bones. In mammals (VII–X) only the squamosal remains visible, to form the squamous portion of the temporal bone.
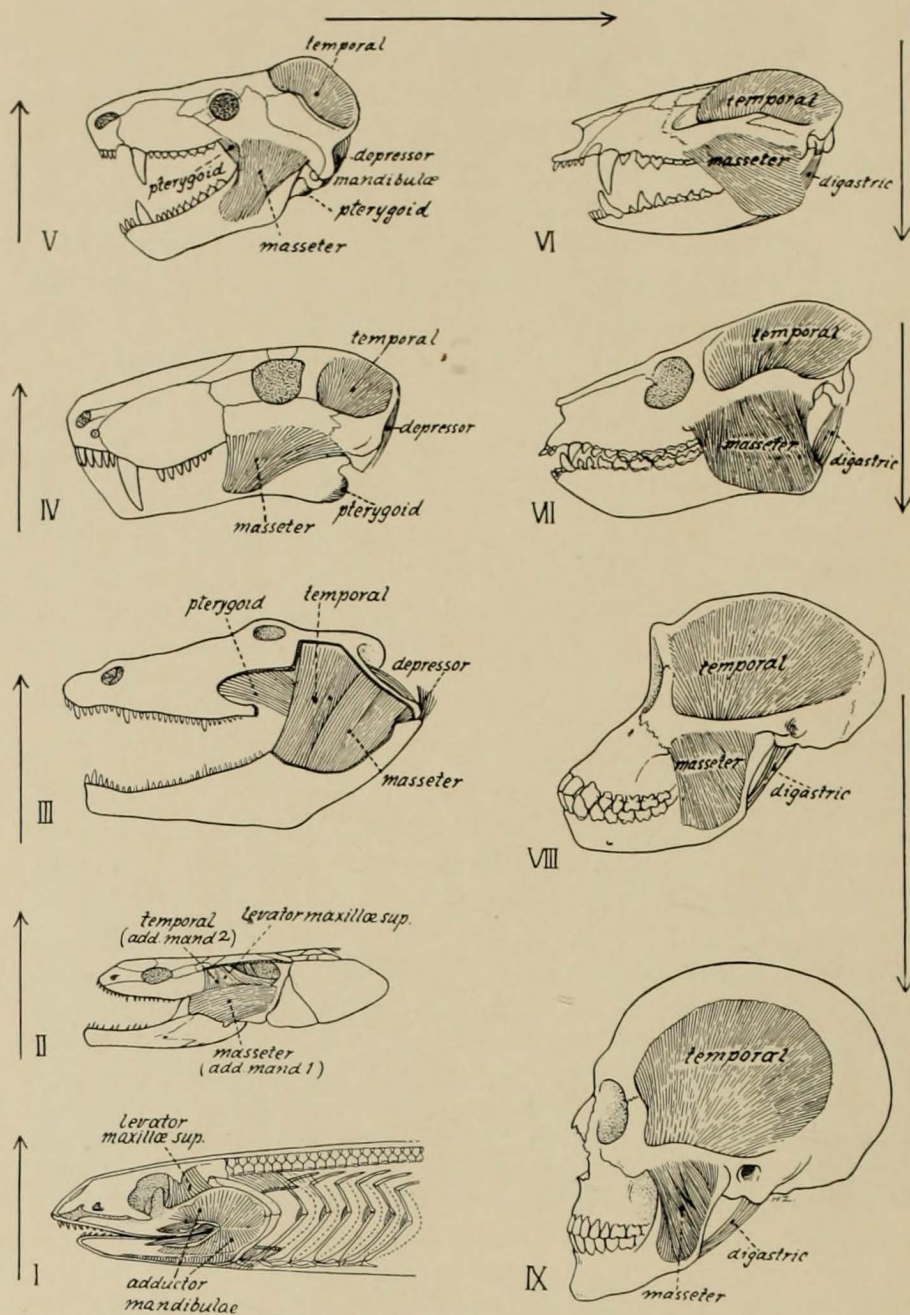
Fig. 25.   Evolution of the jaw muscles.

I.	Shark (*Chlamydoselachus*).	VI.	Opossum.
II.	Lobe-finned ganoid (*Polypterus*).	VII.	Primitive primate
III.	Primitive amphibian (*Eryops*).		(*Notharctus.*)
IV.	Primitive mammal-like reptile (*Scymnognathus*).	VIII.	Chimpanzee.
V.	Advanced mammal-like reptile (*Cynognathus*).	IX.	Modern Man.
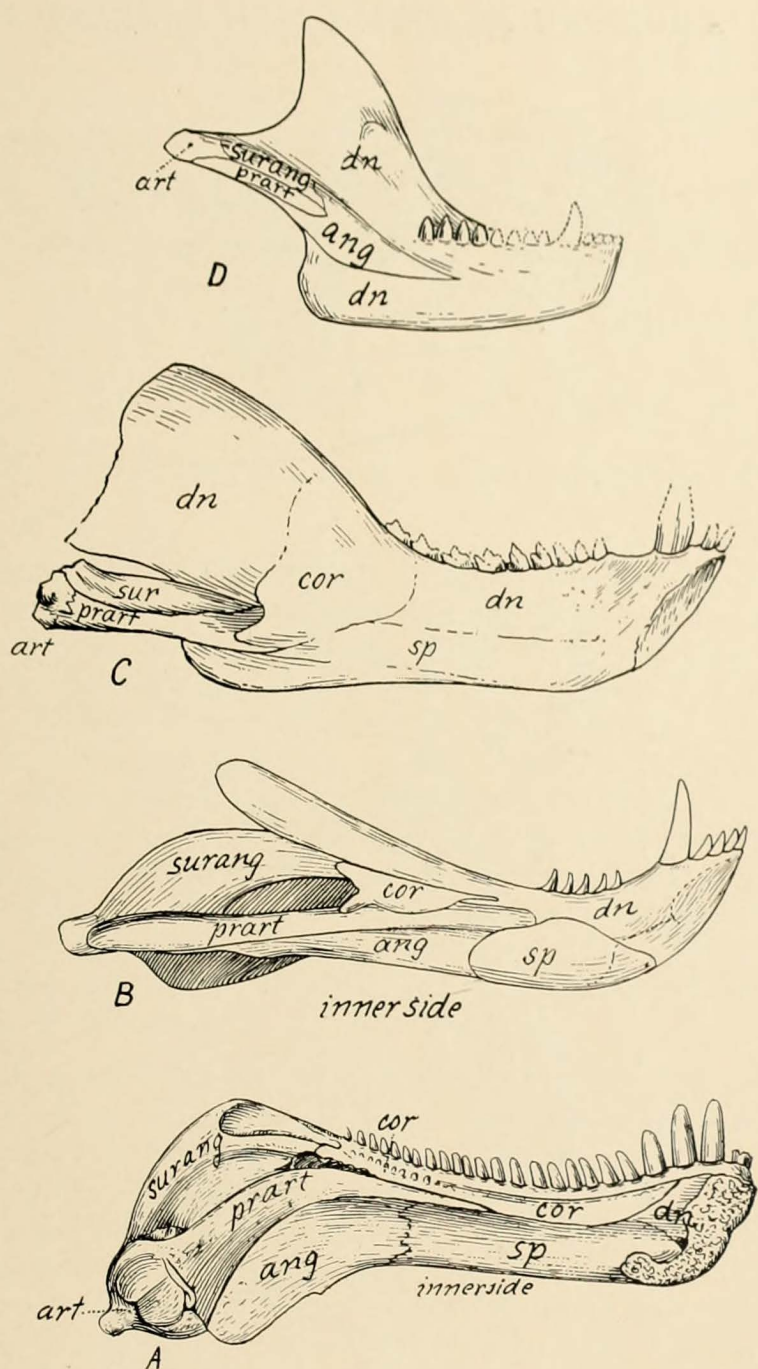
Fig. 26. Progressive increase of the dentary (*dn*) and reduction of the elements behind the dentary, leading to the mammalian jaw, which has formed a new articulation with the skull (see Fig. 27).

Inner side of left half of mandible.

    A. Primitive theromorph reptile, *Dimetrodon*. After Williston.
    B. Primitive gorgonopsian, *Cynarioides*. After Broom.
    C. Progressive cynodont, *Cynognathus*. Partly after Watson.
    D. Ictidosaurian. After Broom.
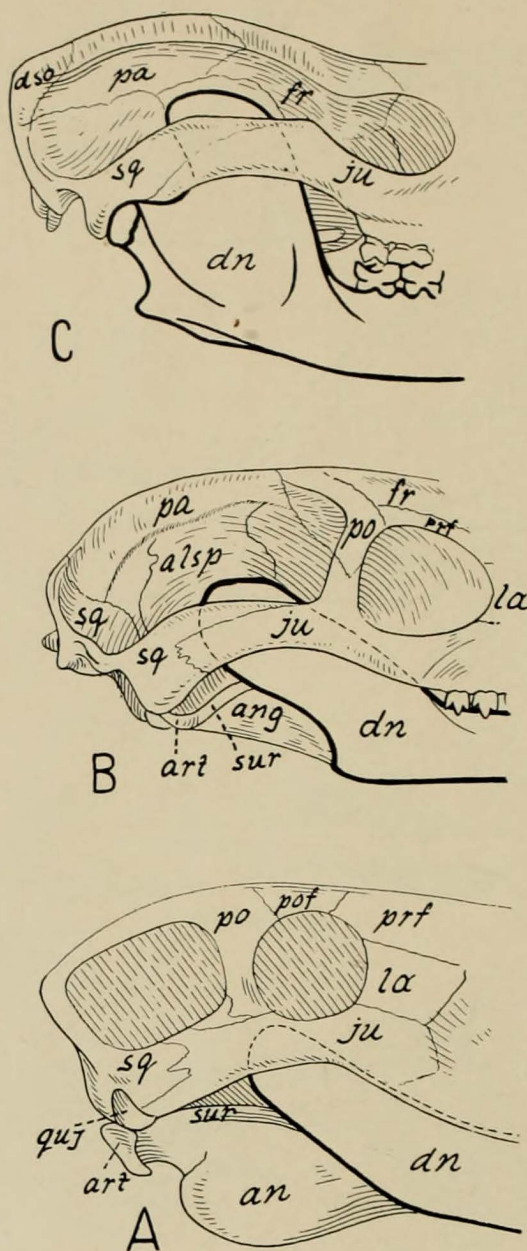
Fig. 27.   Progressive upgrowth (A, B) of the ascending branch of the dentary bone of the lower jaw, which eventually, in the early mammals (C), effected a contact with the skull, thus forming a new joint.   Meanwhile the old joint (at the back of A) dwindled away.

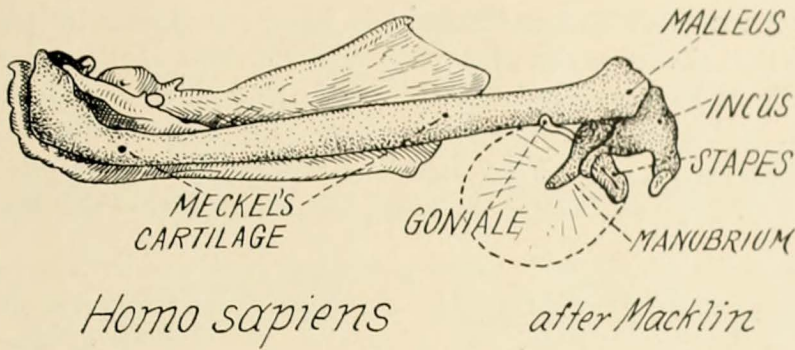A. Primitive mammal-like reptile; B. Advanced mammal-like reptile; C. Primitive mammal.

MALLEUS

INCUS

STAPES

MECKEL'S CARTILAGE

GONIALE

MANUBRIUM

Homo sapiens   *after Macklin*

Fig. 28.   Auditory ossicles of foetal stage formed from jaw elements behind the dentary.

EVOLUTION OF THE AUDITORY OSSICLES [Case 25].   The auditory ossicles of man, like those of mammals, are derived in the course of embryonic development from parts of the "visceral arches" corresponding to the cartilaginous jaws, hyoid arch and branchial arches of the fish.   Thus in the human embryo the future incus (anvil) is represented by a little cartilage that has the precise position and spatial relations of the quadrate bone of the lower vertebrates; the malleus (hammer) is a part of the Meckel's cartilage, or core of the lower jaw; while the stapes represents the upper part of the hyoid arch (Fig. 28). This interpretation of the origin of the mammalian ossicles was first put forward by the embryologist C. Reichert in 1837, but it has been greatly extended and confirmed by modern investigators, especially E. Gaupp of Fribourg.

In the series of fossil vertebrates from fish to man, the cynodonts, or pro-mammals of the Triassic age of South Africa, show a critical stage in the evolution of the auditory ossicles, immediately preceding the mammalian condition (Fig. 26 C, D).   The dentary bone of the lower jaw has increased in size and the bones behind it have become much smaller.   As in modern reptiles, the tympanum, or ear-drum, was very probably connected by ligaments with the back part of the lower jaw.   Hence in these animals the articular, quadrate and columella auris had already begun to function respectively as the malleus, incus and stapes.

This amazing but now fully documented transformation of jaw elements into auditory ossicles affords an excellent example of the principle of the "change of function."

For the relations of the auditory ossicles to other parts of the organ of hearing, see Fig. 33 and page 64.

EVOLUTION OF MOLAR TEETH. It has been shown by palæont-ologists that the more complex forms of the crowns of the molar teeth of mammals have evolved from a simple triangular or tritubercular pattern. This was the most important part of the "Cope-Osborn Theory of Trituberculy," developed by the American palæontologists Edward D. Cope and Henry Fairfield Osborn between 1883 and 1907.

The series of enlarged models of teeth of fossil and living mammals (Fig. 29) represents eight stages of advancement from the Jurassic period to the present time.

The series as a whole shows the transformation of the upper molars from an irregular cutting and piercing triangle to a rounded, four-cusped grinding tooth.

In the lower molars the progress is from small cutting triangles with very small posterior heels to large oval grinders with low conical cusps and a large central basin.

Noteworthy details of this transformation are as follows:

In the second stage (B) the tip of the upper premolars is repre-sented in the molars by a large conical cusp (solid black) called the amphicone. In the later stages the amphicone divides into two cusps (paracone and metacone), which move apart as the hypoconid of the lower molars comes to fit between them.

The "protocone" of Osborn is apparently not the oldest cusp of the upper molars but arises as a swelling or bud on the inner side of the base of the crown.

In the earlier stages the outer part of the crown, called the cingulum, is very large, but after the fourth stage (from the bottom) it disappears, leaving the paracone and metacone on the outer border of the crown.

In the fifth stage a new cusp, the hypocone, grows up, filling the space between the upper molars and changing a triangular into a roundly quadrangular crown.

In the lower molars we observe that in the earlier stages the talon-ids or heels are small, but finally they become larger than the trigonids (or lower triangles). As this happens, the protocones of the upper teeth enlarge to fit into the expanded talonid basins. The paraconids, or anterointernal cusps of the lower molars, disappear at the fifth stage, while the hypocones of the upper molars become enlarged.
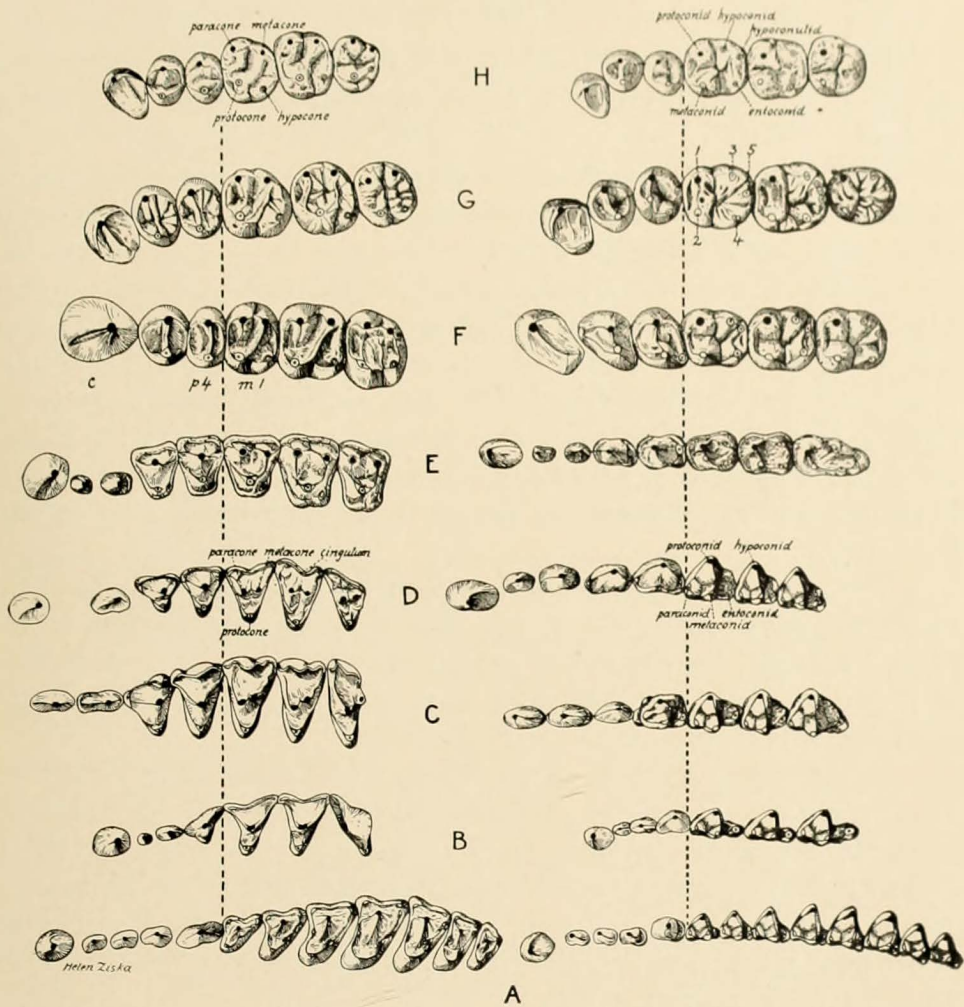
Fig. 29. Evolution of molar teeth illustrated by fossil and recent mammals. Upper teeth left, lower teeth right half of picture.

A. Pantotherian.
B. *Deltatheridium.*
C. *Potamogale.*
D. *Didelphodus.*
E. *Pronycticebus.*
F. *Dryopithecus.*
G. Le Moustier.
H. Man (modern White).

THE NERVOUS SYSTEM AND ITS FUNCTIONS

ELEMENTS OF THE NERVOUS SYSTEM

[Case VIIB]

Man, like other organisms, is a living solar engine, run by the energy of the sunlight that is stored in plant and animal food (See Case I).

This stolen energy may easily drive its user to destruction unless quick adjustments are constantly being made against dangerous forces both inside and outside the body.

The nervous system makes these adjustments possible; it also determines which one of several alternatives shall be followed when competing interests are at stake. In very simple animals a good adjustment is presumably rewarded by a sense of well-being or pleasure, while a bad adjustment gives rise to a sense of pain. In the higher animals the immediate pursuit of pleasure and the avoidance of pain is complicated by memories of the good or bad consequences of past behavior.

This exhibit is intended to show how the simplest elements of the nervous system are built up into the amazing complexities of the brain; similarly, the science of psychology strives to trace an orderly historical sequence from the elementary reactions of an amœba to the most abstruse reasonings of mathematicians.

A few of the myriads of vibrations which constantly rain down upon us are caught by tens of thousands of sense organs, or receptors, scattered almost everywhere on the surface of the body and in its interior. The receptors for smell and taste are able to catch chemical stimuli; the receptors for touch, pressure, hearing, receive mechanical or physical stimuli; the receptors for light, color-waves, heat and cold, are sensitive to radiant energy.

The position of the body in reference to the direction of the force of gravity (balance), as well as the position of the different organs and parts to each other, is indicated by several kinds of "receptor organs" sensitive to pressure and located in the skin, in the tendons of the muscles, in the joints and elsewhere.

When a receptor is excited it starts a current of "negativity" in the ions of the neurons. The discharge of the current at the end of a neuron starts a current in the one above it, and so on by relays along afferent nerves up to the brain; then other currents start in various directions in the cortex of the brain; thence new currents pass down the efferent neurons to the effectors, or motor organs, including muscles around the glands.

THE "SYMPATHETIC" (AUTONOMIC) NERVOUS SYSTEM. The nervous system as a whole is composed of two main divisions: (1) the cerebro-spinal system, including (A) the brain, (B) the cranial nerves, (C) the spinal cord, (D) the spinal nerves; (2) the autonomic nervous system, including a vast network of fibers ending in the unstriated muscular coats of the blood-vessels and in the mucous membranes and other parts of the glands and other internal organs.

The autonomic system comprises two main divisions, sympathetic and para-sympathetic, which oppose each other in regulating the action of the ductless glands, viscera, blood-vessels, etc.

The larger branches of the sympathetic nervous system unite to form a series of ganglia on each side of the spinal cord. Each of these ganglia is connected by delicate branches with the corresponding spinal nerve of the cerebro-spinal system. The ganglia of the sympathetic system arise in the mammalian, human and other embryos from the lateral margins of the neural crests. Hence the sympathetic ganglia are really only differentiated portions of the central nervous system.

SPINAL NERVES. In such a primitive vertebrate as a shark the muscular part of the body is divided into a series of segments called somites, which surround the non-segmental digestive tract and spinal cord. Each somite contains one vertebra and one pair of spinal nerves.

Each spinal nerve issues by two roots, dorsal and ventral, from the spinal cord between the neural arches of the vertebræ. The motor (ventral) root is so called because it motivates the muscles of the trunk and limbs. The dorsal and ventral roots unite to form a common trunk. This subdivides into a dorsal and ventral primary division, both carrying motor and sensory nerve fibers. Smaller branches finally supply the sense organs in the skin and the skeletal muscles beneath. This arrangement, which makes possible the spinal reflex, is found in all vertebrates from fish to man. In certain vertebrates, especially reptiles, those spinal reflexes that cause wriggling of the body may continue long after the cord has been severed; but in the mammals these reflexes are more or less under the control of nerve centers in the brain-stem.

REFLEX ACTION. In the "knee-jerk reflex" a slight tap just below the knee stimulates the sense organs of pressure in the tendon of the extensor muscle of the leg. Nervous impulses then travel up the afferent nerves through the posterior or sensory root of the spinal nerves into the spinal cord itself; there the afferent currents pass into fine terminal nerve branches which come very near to, but do not actually cross over into, equally fine terminal branches of the descend-

ing or efferent nerves. Somehow the currents in the afferent branches induce corresponding currents in the efferent branches and these travel out through the anterior or motor root down the efferent nerves to the nerve endings, or end-plates, which are fastened to the sides of the muscle fibres. The discharge in these end-plates initiates the contraction of the extensor muscles on the thigh and the lower leg suddenly kicks forward.

This reflex is practically automatic or involuntary, since the reaction between afferent and efferent impulses takes place in the spinal cord with little or no control from the brain.

CRANIAL NERVES. The "cranial nerves" are paired nerves that issue from the brain and brain-stem in front of the spinal cord. In all vertebrates from fish to man the cranial nerves are arranged in the following traditional sequence:

NERVE PAIR	NAME	FUNCTION
I	Olfactory	Nerves of smell
II	Optic	Nerves of sight
III	Oculomotor	Motor nerves to four out of the six muscles of the eye-balls, as well as the ciliary muscles and muscles of the iris in the interior of the eyes
IV	Pathetic or Trochlear	Motor nerves to superior oblique muscle of eye-balls
V	Trigeminal	
V 1	Ophthalmic branch	Sensory nerves to front of head
V 2	Superior maxillary branch	Sensory nerves to face, palate
V 3	Mandibular branch	Motor nerves to jaw muscles; Sensory nerves to teeth, anterior part of tongue
VI	Abducent	Motor nerves to external rectus muscle of eye-balls
VII	Facial	In fish the sensory branches go mostly to the lateral line organs of the face, the motor branches to the muscles of the neck and gill covers
VIII	Acoustic	Sensory nerves of the inner ear or labyrinth
IX	Glosso-pharyngeal	Sensory branches to taste organs of the tongue and pharynx Mixed branches to second gill cleft
X	Pneumogastric or Vagus	Sensory and motor branches to lateral line, branchial arches, lungs, heart, stomach
XI	Spinal accessory	Motor nerves to branchial arches and muscles of the neck
XII	Hypoglossal	Motor nerves to muscles of tongue

In mammals nerve XI is derived from part of X, while XII represents one or more of the spinal nerves of lower vertebrates.

In mammals, including man, the general arrangement and distribution of the cranial nerves is substantially the same as in fish but with these important exceptions:

(1) With the abandonment of aquatic life the lateral line system of sense organs has disappeared from the head and neck, and with it the corresponding branches of the seventh cranial nerve.

(2) The gill covers, their sensory organs and special nerves have also disappeared but some of the muscles of the hyoid arch are still present and function in operating the larynx, or voice mechanism.

(3) In the ancestors of the mammals some of the superficial muscles of the neck grew forward under the skin to form the facial or mimetic muscles, carrying with them branches of the seventh or facial nerve (see Case VI).

Modern anatomists have discovered that there are several additional pairs of cranial nerves, not noticed by the older anatomists.

THE BRAIN

[Case VIII]

SENSATION

PALAEOKINESIS: ACTION CONTROLLED BY THE SENSES. The main divisions of the shark's brain correspond to the organs for smelling, seeing, balancing, touching and tasting. The brain is surrounded by these organs and consists of bundles of nerves that come from them and from the spinal cord, the latter being the main mass of nerves from the internal organs, muscles and skin of the body.

The reactions of the shark to its environment are controlled directly by its senses. Thus pleasure and pain produce opposite and immediate direct response. This type of reaction is called palæokinesis (ancient action) in contrast with the more deliberate response of the highest animals, which is more or less controlled by ideas (neokinesis) (Figs. 30 and 31).
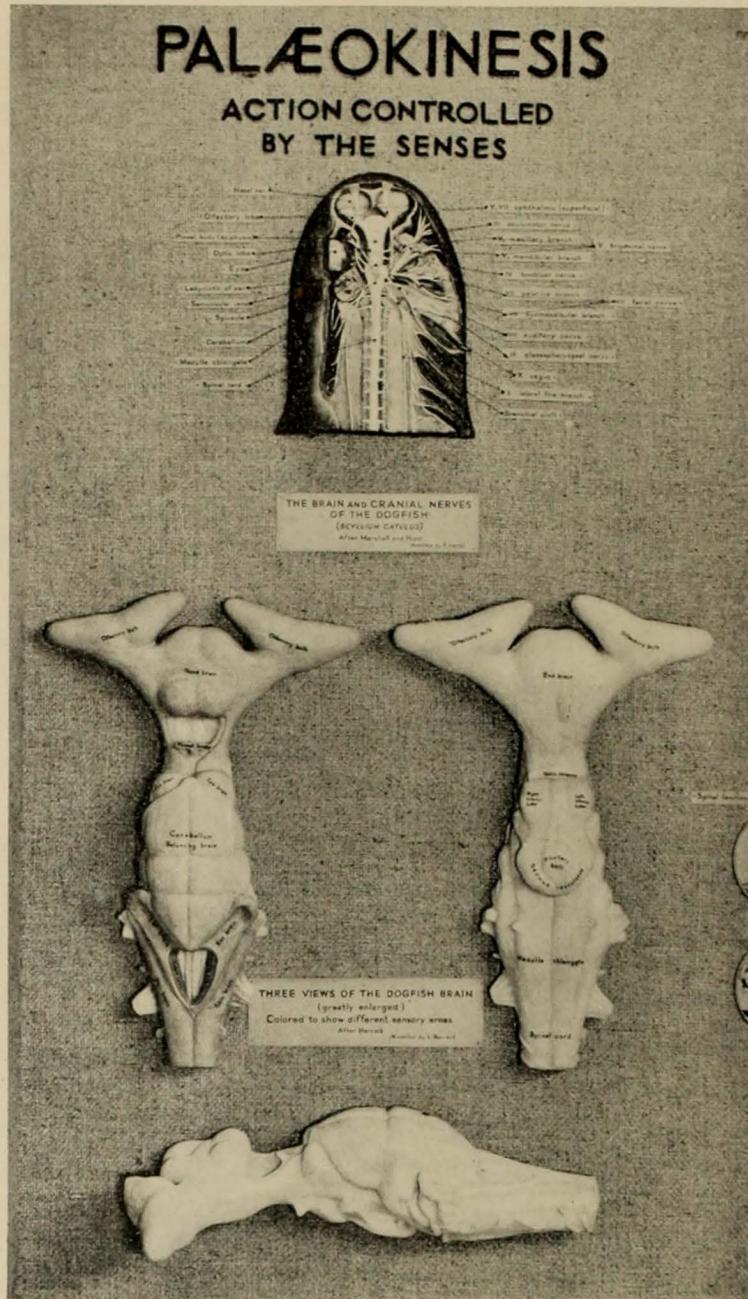
Fig. 30.   In the shark the nose brain, ear brain and cerebel-
lum dominate the midbrain, which in the fish is the main center
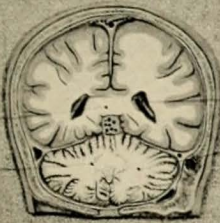of control.

Fig. 31. In man the center of control has moved upward into the cerebral cortex, which dominates all the parts below it.

Touch, Pressure, Pain, Heat, Cold, etc. In the skin of vertebrate animals we find several kinds of sense organs which may be called contact receptors, in contrast with distance receptors, including the eye and ear. The contact receptors give rise to the senses of touch, pressure, pain, heat, cold and perhaps other sensations. They are widely distributed over the skin and are supplied by the cutaneous nerves. The latter lead back to the dorsal roots of the spinal nerves and thence up the spinal cord to the medulla oblongata of the brain-stem, where the centers for these senses are located.

The muscles, tendons and joints of the body are also supplied with end organs that are sensitive to pressure. Movements of one part on another, or even the arrest of movements as in fixed postures, stimulate the end organs in the tendons and joints and thus inform the brain of the position and state of tension of each part. These receptors are innervated by branches of the spinal nerves.

Other receptors, called enteroceptors, located in the viscera and in the muscular parts of the heart and blood-vessels, appear to be sensitive to the pressure of gases and liquids, while still other receptors in the intestines may be sensitive to chemical stimuli of the body fluids. The viscera are innervated by the vagus nerve (parasympathetic) and sympathetic systems.

Smell. The olfactory receptors, or organs for the sense of smell, are classed as chemo-receptors because they are stimulated by certain chemical substances dissolved in olfactory mucous, a watery solvent. These solutions affect the sensory hairs of the olfactory epithelium, perhaps by reacting with the solutions contained therein.

There is evidence that the sense of smell was very highly developed in the oldest types of fishes and that there has been a marked reduction of this power in the nearer ancestors of man. In a certain large shark, according to Haldane and Huxley, the olfactory epithelium (which is greatly infolded and packed into the olfactory capsules) had an immense area, estimated at twenty-four square feet. In a dog, which like most ordinary mammals has a relatively keen sense of smell, the olfactory epithelium if unfolded would cover about ten or more square inches. In man, although the nasal cavity is lined with mucous membrane, only a very small area (about one-fourth of a square inch) is supplied with the branches of the olfactory nerve, all the rest being insensitive to smell.

Similarly, those parts of the brain which relate to the sense of smell have become much reduced in man and his nearest relatives, the anthropoid apes.

TASTE. "Taste buds," or receptors for taste stimuli, in the human adult are located in several places, chiefly on the tongue, epiglottis and soft palate.

The four principal tastes are differently distributed on the surface of the tongue: "sour" is best noted on the sides of the tongue; "saline" on the sides and tip; "sweet" at the tip; and "bitter" at the base.

Three, or possibly four, of the paired cranial nerves include gustatory fibres. The chorda tympani branch of the seventh nerve separates from the lingual nerve (a branch of the fifth) and sends gustatory fibres to the anterior two-thirds of the tongue. The glosso-pharyngeal, or ninth, supplies the posterior third of the tongue, including the foliate and vallate papillæ; while branches of the tenth (vagus) are distributed to the larynx, the epiglottis and to a small area at the most posterior part of the tongue itself. In human fetuses and babes taste buds are more widely distributed than in the adult.

In the brain afferent nerve fibres from the taste buds discharge their currents into "nuclei," or centers in the medulla oblongata. Then by relays the gustatory messages are conveyed to the brain. The kind of response of the brain as a whole to these stimuli will depend in part upon the data supplied by the various centers of memory and association (See Fig. 31, Neokinesis).

SIGHT. The "basic patent," or most fundamental feature of the eye, is the battery of light-cells (rods and cones) in the retina, whereby the energy of the light waves is converted into visual nerve impulses which travel along the optic nerve to the brain.

The rods of the retina contain "rhodopsin," or visual purple, and it is possible that the decomposition of visual purple under the influence of light causes excitation of the rods. The cones have no visual purple but probably do contain some other photo-sensitive compound.

The efficiency of the light-cells is immensely increased by the fact that the eye as a whole is a natural camera, whose chief parts are as follows: (1) a dark chamber, in which the light is admitted only through a small circular aperture called the pupil; (2) a sensitive plate called the retina; (3) a lens for focussing the image; (4) muscles of accommodation for altering the curvature and focal length of the lens; (5) a contractile iris for regulating the amount of light admitted to the chamber.

But the eye is a living camera, all of whose parts have to be fed with materials for maintenance and growth. Hence it possesses a great many features not found in an ordinary camera. The retina, for example, is crowded with nutrient blood-vessels, which supply the many layers of rods and cones.

A small circular spot called the fovea, which lies within the macula on the back of each retina, is far more sensitive to light than is the surrounding area. These sensitive spots enable the two eyes to converge on a single small object. This convergence is effected by the coöperation of the two sets of eye muscles. Each eye is moved by six muscles, which together form a cone surrounding the optic nerve. Focussing is done by muscles attached to the lens.

The cornea, or transparent front window of the eye, is continuous with the sclerotic coat. Specks of dirt, sand, etc., are washed off by tears from the lacrymal gland in the outer corner of the eye.

In primitive vertebrates the optic lobes on the upper part of the midbrain were the chief receiving centers for visual stimuli, but as the neopallium, or higher brain, became larger and more complex (Fig. 32), the "optic radiation" on the occipital surface of the cerebrum became increasingly important; in the mammals the old optic lobes serve as reflex centers for the eye muscles.

In the anthropoids and man nerve fibers from each eye cross over to the opposite half of the brain; others go directly to the same side of the brain. This makes possible complete overlap of the two visual fields, resulting in "stereoscopic vision."

The position of the paired eyes in primitive vertebrates is on the sides of the head but in the mammals there is a tendency for the eyes to be directed forward. Finally in the anthropoid apes and man the eyes look wholly forward and are not only capable of converging on an object but can both follow an object moving in any direction within the combined field of vision (biconjugate movement) [Case 26].

In the vertebrates the eyes arise in the embryo as pockets in the medullary folds of the future brain. The optic stalk and cup then grow outward from the base of the rapidly swelling midbrain. When the optic cup touches the outer layer it gives out a chemical substance that causes the ectoderm to thicken into a lens.

Fig. 32.   The Rise of the human brain (Wall Chart 7).

From fish to man the brain increases in complexity and in the size of certain parts, especially the forebrain. In the lower forms the forebrain functions chiefly in connection with the "olfactory bulbs," and smelling nerves. In the mammals the upper part of the forebrain becomes differentiated as the neopallium, or new brain, gradually assumes control and finally becomes greatly convoluted or infolded, largely concealing, especially in the side and top views, the older parts of the brain.

Although the forms whose brains are figured above are all living at the present day and therefore not ancestral one to the other, their brains represent a progressive series from lower to higher types.
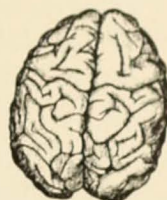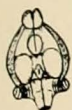
BASE   LEFT SIDE   TOP
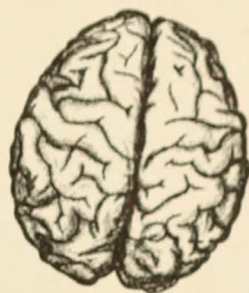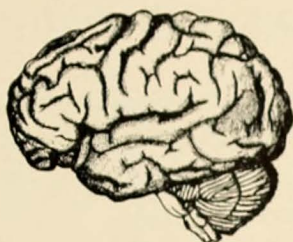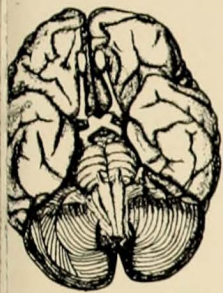
MAN

ANTHROPOID APE
(GORILLA)

PRIMITIVE ANTHROPOID
(GIBBON)

PREPRIMATE
(TREE-SHREW)

LOWLY MAMMAL
(OPOSSUM)

GENERALIZED REPTILE
(SPHENODON)

TAILED AMPHIBIAN
(NEWT)

PRIMITIVE FISH
(SHARK)

Fig. 32.

63

The general structure of the eye throughout the vertebrates is remarkably constant, the chief differences between the eyes of fishes and those of land-living vertebrates being that in the former the lens is more convex and its focal distance shorter.

HEARING. The organ of hearing (Fig. 33) is classed among the mechanical receptors because it responds to mechanical stimuli, which in this case are the pulsations of sound waves in the air against the tympanum, or ear-drum. The outer ear (concha) and its tube (the external auditory meatus) serve merely to collect and conduct the sound waves to the tightly stretched ear-drum. The latter is located at the entrance to the tympanic cavity, which in turn leads to the Eustachian tube (tuba auditiva), connecting with the throat. The degree of tension of the ear-drum is regulated by the tensor tympani muscle, the tendon of which is fastened into the handle of the hammer, or malleus. The latter is the outermost of a chain of three little bones (ossicula auditus) that transmit vibrations of the ear-drum to the membrane of the oval window (fenestra ovalis) of the inner ear (see p. 51).

The three little bones are geared together in such a way that the relatively wide but weak oscillations of the ear-drum are transformed into much shorter but more powerful thrusts of the foot-plate of the stirrup, or stapes. The vibrations of the latter start waves in the liquid that fills the snail-shell, or cochlea; this in turn contains the organ of Corti, or true organ of hearing.

The waves of pressure travel up the liquid in the coils of the cochlea in the upper division thereof (scala vestibuli), passing over the sensory hairs of the acoustic epithelium and thus initiating nerve currents which pass through the afferent acoustic nerves to their centers in the brain-stem. Numerous relays pass thence to and from the temporal lobe and other parts of the brain. After reaching the top of the cochlea the pressure waves come down the lower division of the coil (scala tympani) and appear to escape through the vibrations of the membrane covering the round window (fenestra rotunda) at the lower end of the cochlea. The cochlea seems to analyze sound waves by some mechanism for sympathetic vibrations. Since the sensory cells of the organ of Corti are arranged in a spirally-wound series, it is possible that they are sensitive, like the wires of a piano, to different wave lengths. Other structures in the ear, for example the basilar membrane, have been considered as the significant part in the resonating apparatus.

The semicircular canals are sometimes called the chief organs of balance, or equilibration, because they supply sensory stimuli that vary
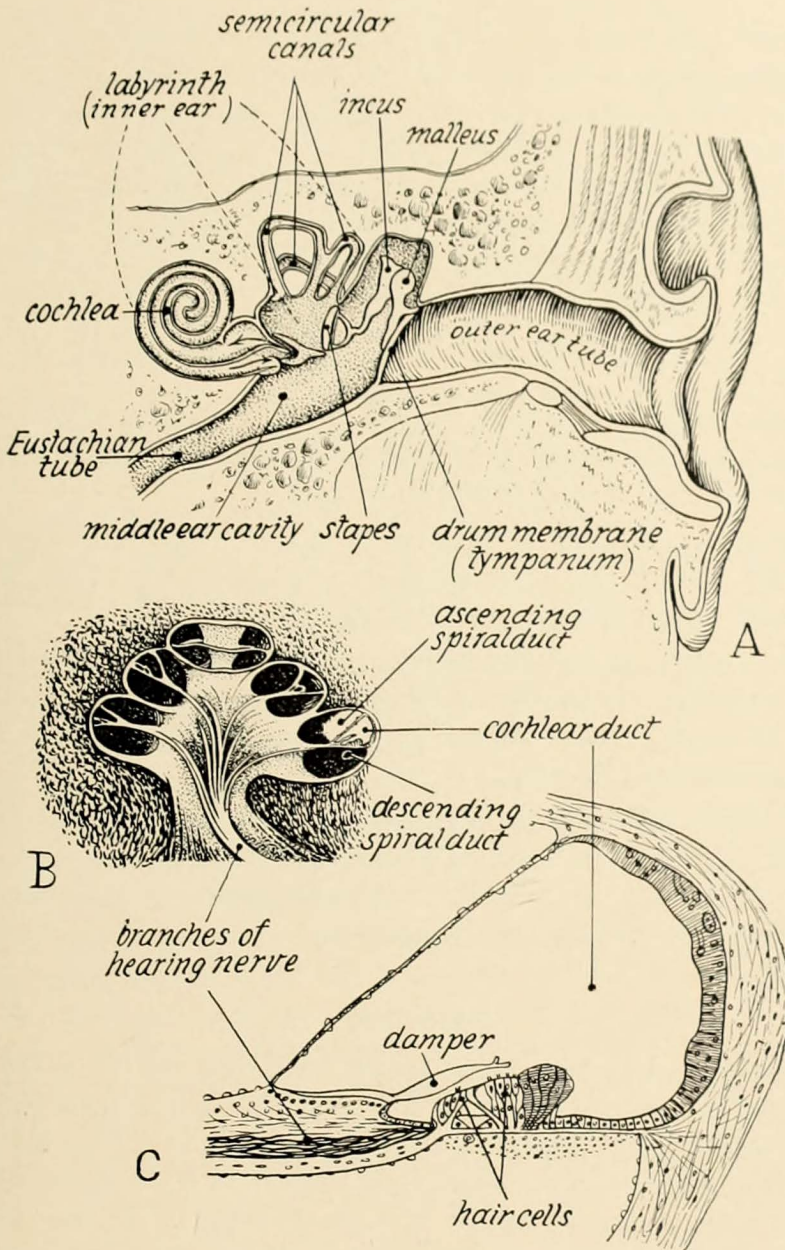
Courtesy G. P. Putnam's Sons

Fig. 33.   The Human Organ of Hearing and Balance.
A.   Transverse section.
B.   Diagram section of the cochlea, showing the ascending and descending
     spiral duct and the cochlear duct containing the organ of Corti, or
     true organ of hearing.
C.   Greatly enlarged view of the cochlear duct, showing the organ of
     Corti with its damper, hair cells and hearing nerves.
         (A and C, after Cunningham.)

according to the inclination of the head toward the pull of the earth's gravitation. There are three semicircular canals, the anterior vertical, posterior vertical, and external or horizontal canals, arranged at right angles to each other in the three planes of space. They are supposed to act like spirit-levels. The canals are filled with liquid and lined with sensory hair-cells, which are connected with nerve fibres from the upper division of the eighth cranial nerve. The chief centers of balance are in the medulla and cerebellum. The absence of direct connections with the cortex of the cerebrum indicates that the mechanism for equilibration is largely reflex.

Semicircular canals were present in the very oldest known fossil vertebrates and are remarkably constant in their general arrangement in the existing vertebrates from fish to man.

The cochlea, or organ of hearing, on the other hand, first appears in the higher reptiles and becomes fully developed only in the highest vertebrates, which are the birds and mammals.

The acoustic, or eighth pair of cranial nerves, is in series with the vagus, or tenth, and the entire labyrinth, including its nerves, is regarded as a highly differentiated and specialized portion of the lateral line organ system of fishes.

The entire labyrinth, or inner ear, arises in the early embryo as a pocket of ciliated epithelium, an infolding of ectoderm. In later stages this pocket becomes divided: the dorsal half gives rise to the canals and the utriculus, the ventral, to the cochlea.

RESPONSE

MEMORY. The first "basic patent" for memory is the fact that when a nerve current comes up to the brain from a sense organ, it induces another discharge or series of discharges, in the cortex of the brain itself, and that these discharges appear to leave some physical traces behind them, analogous perhaps to stains. To use a crude analogy, the more intense and wide-spread the sensory discharges, the deeper the stains will be and the longer time it will take to wash them out. In this connection it is an interesting fact that there is a close resemblance between the "curve of forgetting" and the curve of times necessary for washing out dye-stains in certain tissues.

The second physical basis of memory is the fact that every "center" in the brain is connected with many other centers by "association fibres." Adjacent sensory and motor areas on the surface of the cortex are connected by short association fibres, while long association

fibres connect the occipital, parietal and temporal lobes with each other and with the frontal lobe, toward which the association fibres converge. The millions of "afferent" fibres come up to the cortex from the sense organs, passing through such crowded pathways as the thalamus, the lenticulate nucleus and the corona radiata, and the currents that they discharge leave their traces in many parts of the brain.

Memory, both conscious and unconscious, is the first basis of the "conditioned reflex," and eventually of habit-forming and the learning process. "The burnt child fears the fire," and even a pike will soon learn not to strike his nose against the glass in an aquarium.

Memory is of the highest value in all vertebrates, including man, because it enables its possessor to profit by experience, to "see things coming" and to make effective adjustments before the storm breaks or before a given course of action leads to disaster.

SPEECH. While all the senses such as touch, taste, smell, sight and hearing are constantly pouring their stimuli into the brain, the brain also responds in various ways, as by bodily movements, by an increased glandular secretion, or perhaps by arrested movement with heightened internal pressure. Finally, in the case of man, response may issue in speech or in its shorthand record which is called thinking. Spoken words, considered as purely physical events, are merely noises caused by puffs of air rushing across the vocal cords of the larynx and variously checked or otherwise modified by the action of the larynx, tongue, palate, teeth and lips.

The larynx represents a highly specialized derivative of the complex gill-arch apparatus of the fish. The several bones of the larynx may be followed backward along the descending scale of living vertebrates to the corresponding parts in the branchial skeleton of the fish, and this is true of each of the muscles of the larynx. The skeleton of the tongue is derived from parts of the hyoid arch and of the median bars of the branchial arches. The muscles of the tongue are innervated by branches of the hypoglossal, the twelfth cranial nerve, while those of the larynx are supplied by the tenth. It is noteworthy that these same cranial nerves, the tenth and the twelfth, also supply the tongue and branchial muscles of lower vertebrates.

THOUGHT. In neurological terms, thinking may be defined as a more or less organized series of discharges, in the surface layers of the brain, of the various "association systems," acting in unison with each other; reacting to present sensory patterns but always conditioned by emotional stresses left over from past sensory, motor and associational discharges.

Due to these diversely conditioned reactions established by past experience and habit, similar sensory-motor patterns do not always induce the same associational responses. On the other hand, a characteristic part of a pattern often induces the same response as does the whole pattern.

Thinking involves a process which may be compared with the projection of two streams of pictures upon the same screen. The first stream includes such reflections of the outer world as are transmitted by the sense organs and their nerves; the second stream is composed of the blurred, distorted images furnished by memory. The "screen" is found in the projection areas of the "association systems," especially those on the frontal lobes of the brain.

Thinking may be defined as the process of matching new sensory patterns with the memories of past ones and of responding in different ways to identities and differences between these patterns. Thinking, in this sense, apparently goes on in all the higher animals, including man, and is developed with the increase in size and complexity of the prefrontal projection centers.

In verbalized thinking, which is peculiar to man, complex sensory patterns are represented by relatively simple auditory and visual verbal symbols. These symbols, through a series of historical events, now have a more or less uniform significance to all normal persons speaking the same language. Hence words are the currency of thought.

In scientific thinking there is an emotional stress or passion to analyze sensory patterns, to make close comparisons and measurements, to distinguish between symbols of identical wholes and symbols of wholes that are superficially similar but fundamentally distinct, and finally to trace historical and causal sequences in all fields open to human investigation.

NEOKINESIS: ACTION CONTROLLED BY IDEAS. In the lower vertebrates, as typified by the shark, response to sensory stimuli is largely direct. A "good" smell in the water causes the animal to turn toward the sources of the pleasant stimulus, to swim toward it and to devour it. Memory of past results plays comparatively little part in modifying behavior. In higher animals, on the other hand, only "reflex" acts are free from the restraining or encouraging influence of memory. Perhaps all conscious acts are "conditioned" by memories or ideas, which are generated or conveyed by the complex association tracts of the neopallium, or higher brain (Fig. 31).

The peculiarly human power of speech has made it possible for ideas to be handed down from generation to generation and to be built up into systems of social control that tend either to encourage or to inhibit particular responses to sensory stimuli.

EPITOME

THE RISING SCALE OF LIFE

The existence of a rising scale of life ("l'échelle des êtres") leading from the lowest one-celled organisms to man was suspected by some of the ancient Greeks and demonstrated by the naturalists of the eighteenth and nineteenth centuries, especially Lamarck, Darwin and Haeckel. It remained for the palæontologists of the nineteenth and twentieth centuries to discover a long series of extinct vertebrates from successive ages of the earth, forms which carry forward the story of the origin and rise of prehuman and human characteristics in an orderly and well established sequence (Fig. 4).

The earliest known forerunners of the vertebrates were the ostracoderms, or jawless fishes, whose fossil remains are found in rocks of the Ordovician and Silurian periods; the age of the oldest of these fossils is estimated at nearly five hundred millions of years. From this time onward the vertebrates are known from more and more branches. Many of these branches became extinct, but others went on and gave rise to new branches; both old and new branches together form the Tree of Life. The definition and classification of these larger and smaller branches belong in the fields of zoölogy and palæontology; but a practical knowledge of the Tree of Life is a necessary prerequisite for correct appreciation of the fossil record of evolution, from fish to man (Figs. 8, 24, 36).

NATURE'S "BASIC PATENTS"

When Nature at last works out a new and successful mechanical device in one group of animals and in one part of the world, she bequeaths this treasure to their diversified descendants in many lands. The "one-piece jaw" arose among the earliest mammals of the Triassic age (Figs. 26, 27) and was transmitted with innumerable modifications in detail to countless millions of later mammals, including man.

Another example of an important "basic patent" is the neopallium, or higher brain, which likewise arose in the earliest mammals as a super-control system (see Fig. 32); in the higher mammals it has become the organ of intelligence.

Resemblance between relatives is normally due to inheritance from one or more common ancestors. Therefore when two animals of different species resemble each other in possessing numerous "basic patents" in common, it is inferred that they are more or less closely related by descent from a common ancestor.

MAN'S HABITUS AND HERITAGE

The later additions to an animal's capital stock of "basic patents" usually fit him for some special way of locomotion, such as climbing, running, walking, swimming, flying, or for some particular range of food habits. The totality of these newer adaptations is called the HABITUS. The older adaptations, which he has inherited from very distant ancestors, are grouped together as his ANATOMICAL HERITAGE.

Man's HABITUS includes his fully erect posture and all that this implies in the unique details of his backbone, pelvis and feet. His habitus also includes his enormous brain, his diminished jaws and his power of speech. As to his ANATOMICAL HERITAGE, he shares a very great number of deep-seated anatomical and physiological characters with the anthropoid apes, especially the gorilla and the chimpanzee.

THE PRINCIPLE OF CHANGING FUNCTION AND STRUCTURE

Many of the most striking of man's characteristics have arisen by "descent with modification" and through "change of function and structure."

Thus man's skilful hands, with which he has built up his civilizations, represents the modified fore feet of remote quadrupedal ancestors (Fig. 8). His feet, which are now so well adapted for supporting the body in an upright posture, have been derived by "descent with modification" and through "change of function" from grasping organs not unlike those of the gorilla (Figs. 17, 18).

During such changes in function there are marked changes in the relative sizes of certain parts. Thus in the immediate ancestors of man the thumb (Fig. 16) became longer, the hand wider, the outer toes (Fig. 17) shorter, the femur (Fig. 8, I, J) longer, while opposite changes took place in the orang-utan, which became highly specialized for arboreal life.

Man's much admired face is molded upon the fish-trap of a creature that was no higher than a shark; his voice, which he now broadcasts over the world, issues from an apparatus originally made out of the gill-bars of a fish; his very brain, by means of which he has discovered space-time and plumbed the depth of the atom, began as a simple automatic mechanism for directing his motor and digestive apparatus toward his next meal.
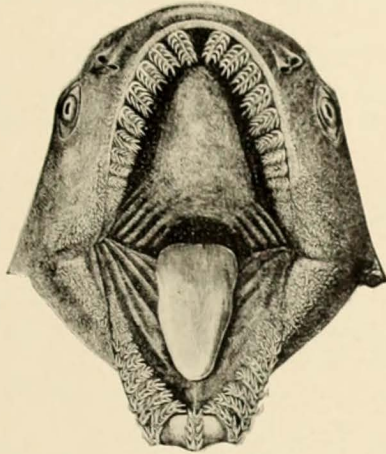
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MAN AMONG THE PRIMATES

Man's position on the tree of life is among the primates
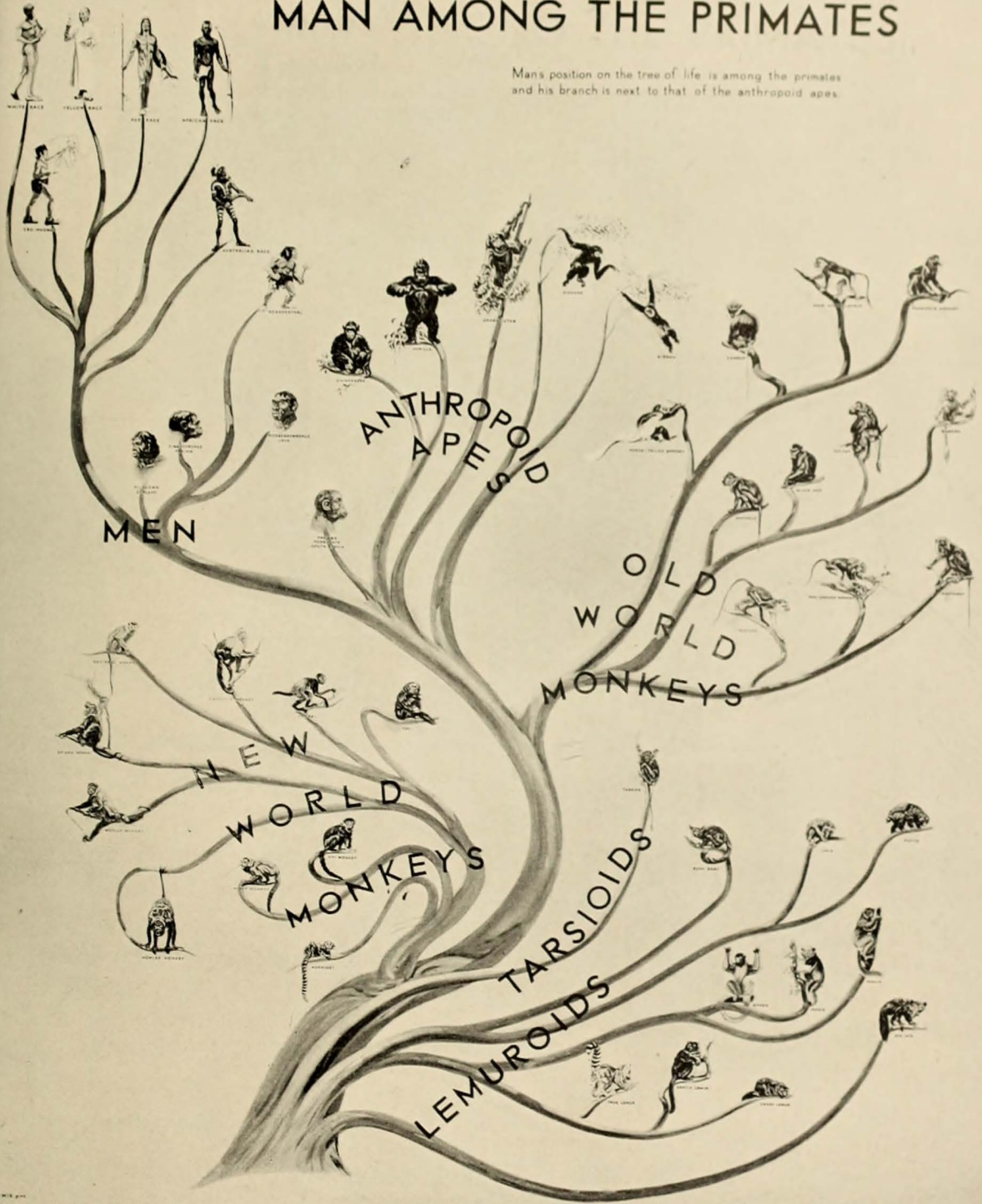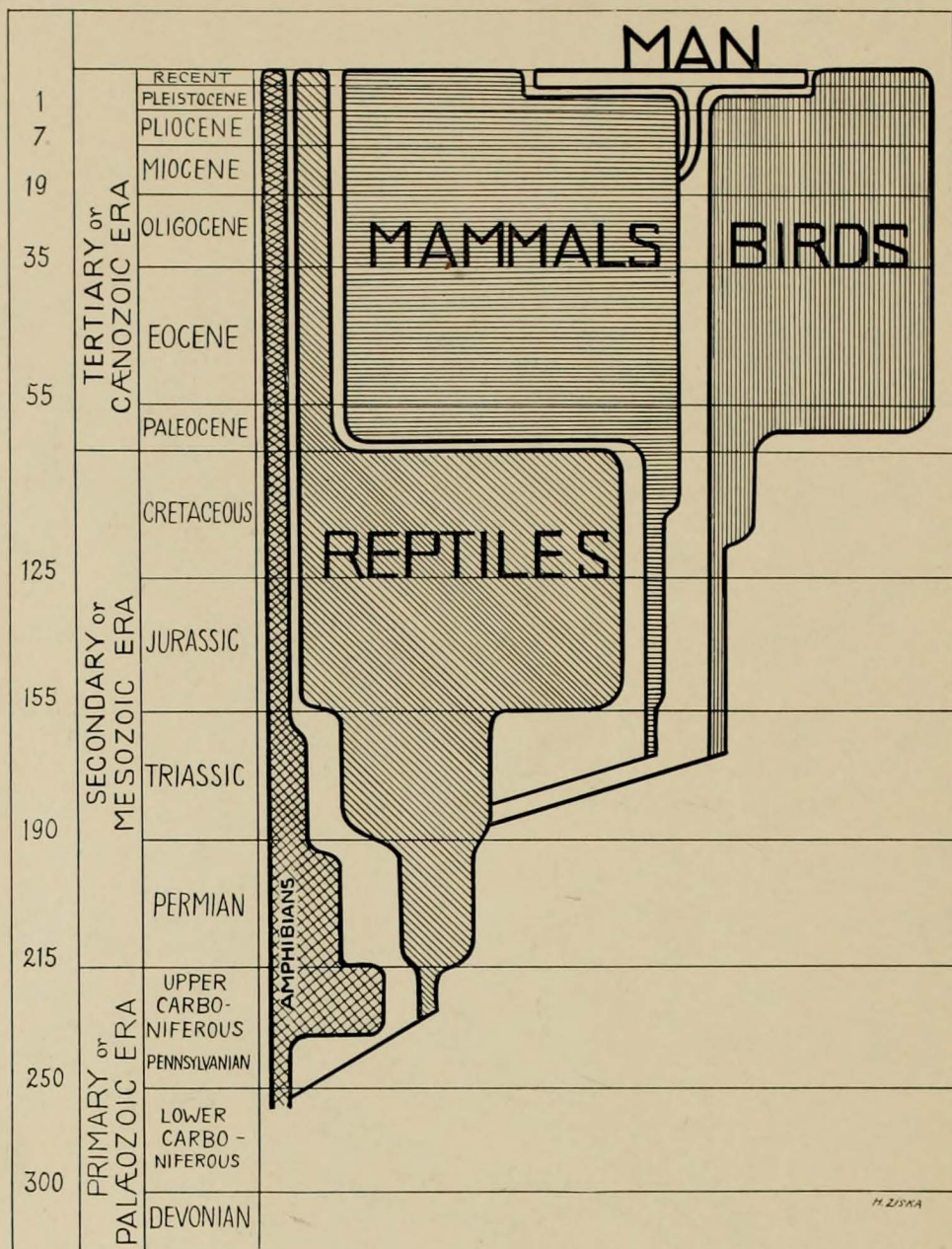and his branch is next to that of the anthropoid apes.

MEN

ANTHROPOID APES

OLD WORLD MONKEYS

NEW WORLD MONKEYS

TARSIOIDS

LEMUROIDS

Fig. 35.   Man among the Primates (Wall Chart 6).

75

Fig. 36.   Man's Emergence in Geologic Time.

Numerals at left stand for millions of years since beginning of period, according to rate of "radium emanation" from uranium minerals, based on Barrell's estimates.

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