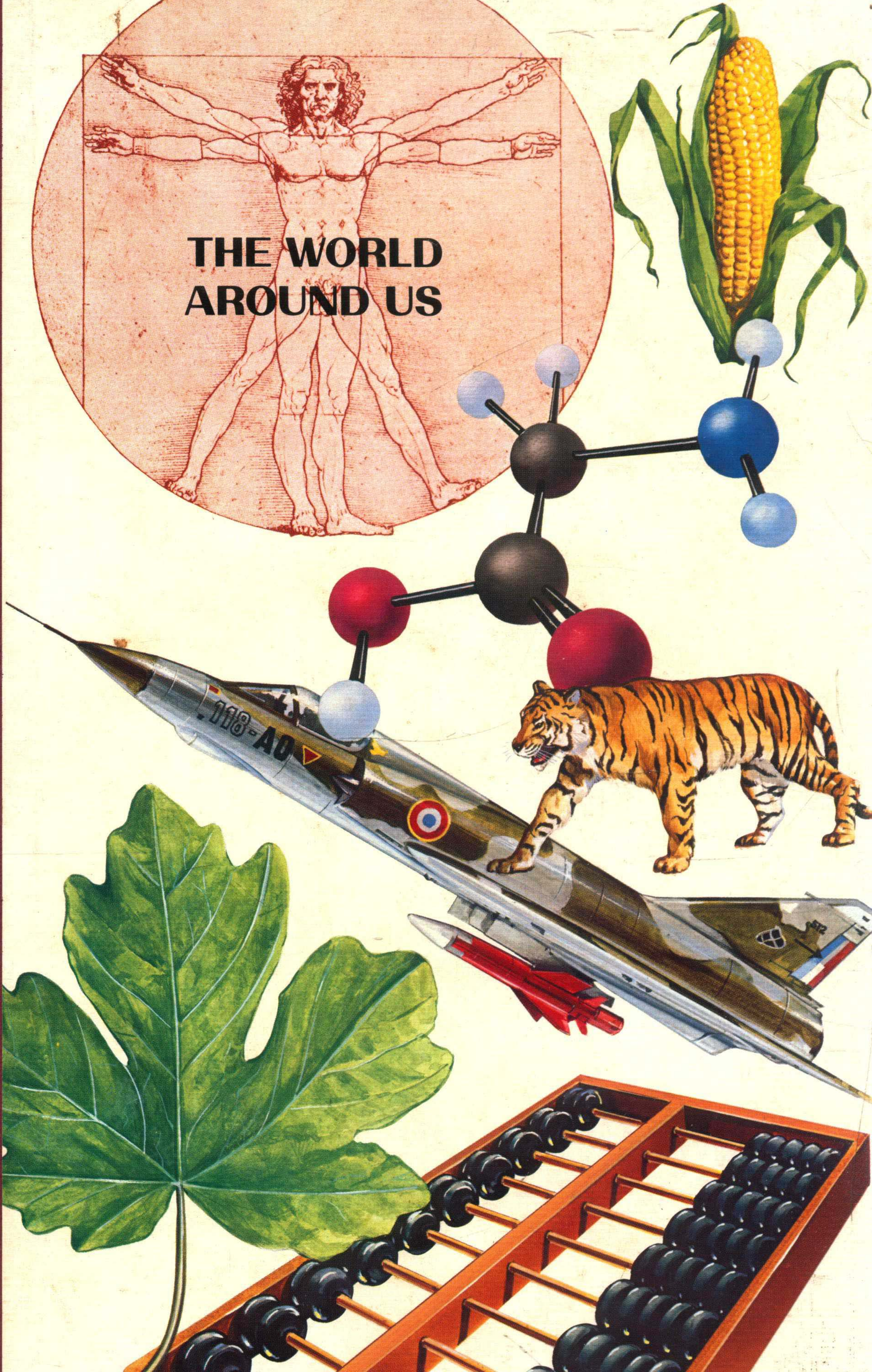
SCIENCE AND TECHNOLOGY ILLUSTRATED

THE WORLD AROUND US



Science Technology

The World Around Us

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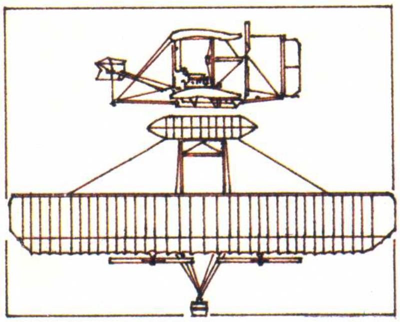

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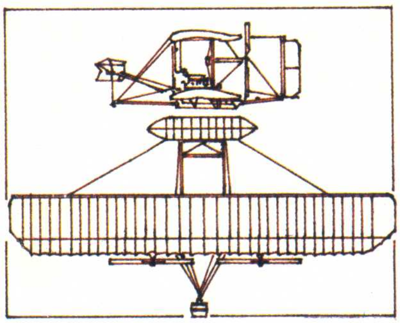
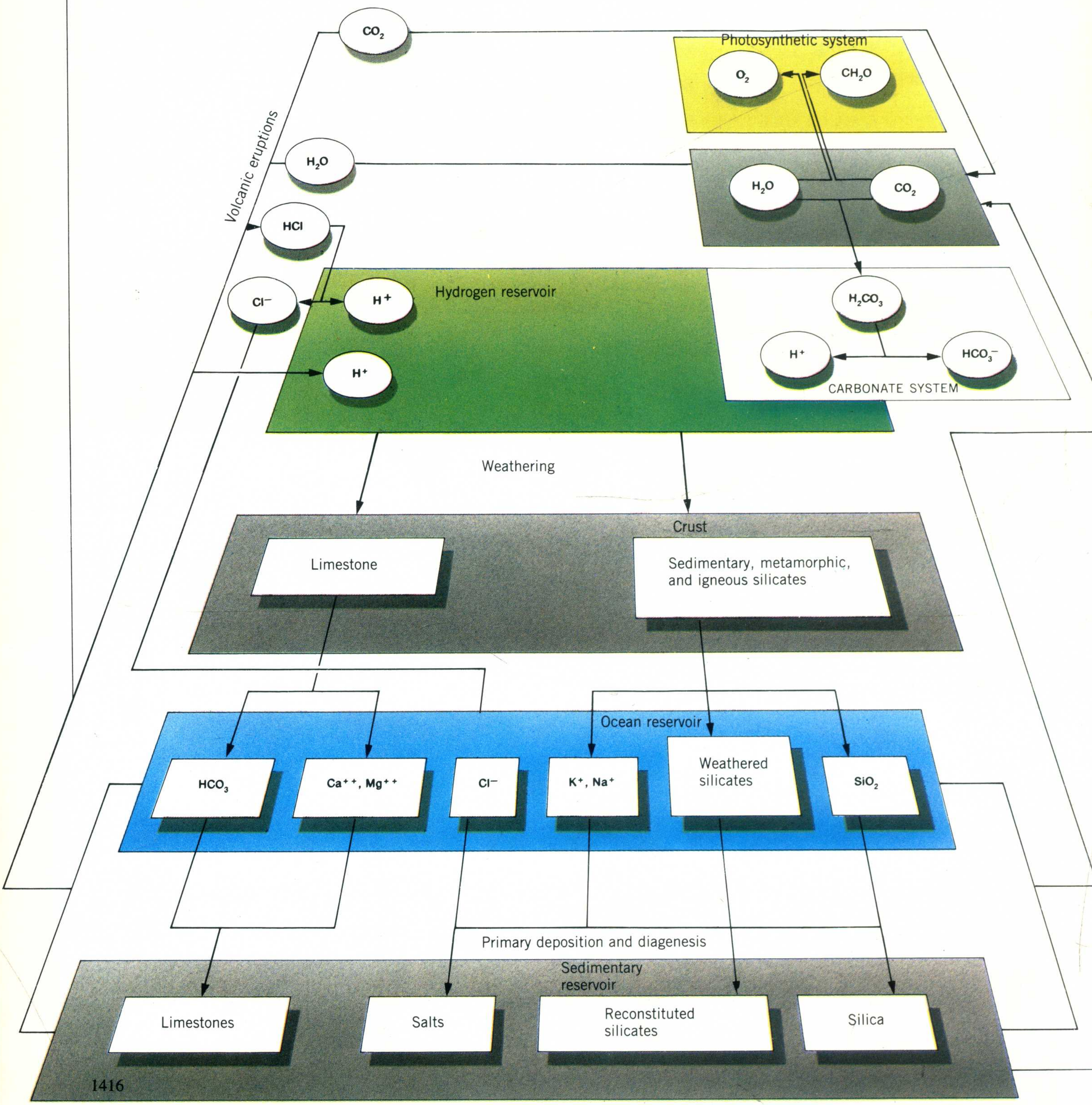


Geochemistry

What is the Moon made of? The comedians used to say "green cheese," until one day an astronaut brought back samples of lunar rock. For the core of the Earth we have no such samples, but chemistry provides some ingenious ways of calculating what is probably there.

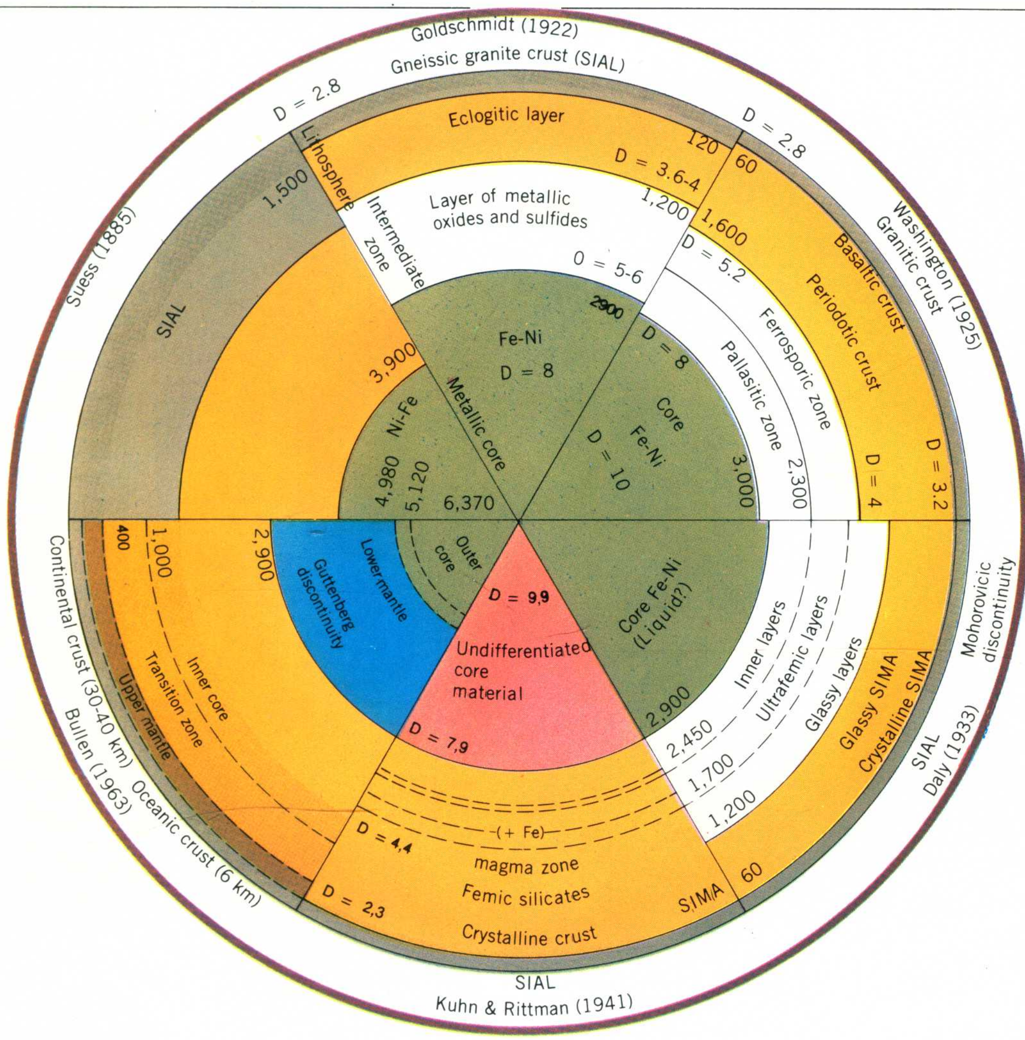
Geochemistry is the application of the practical techniques of chemistry to the materials of the Earth as well as to other celestial bodies such as the Moon and the planets. Samples of the actual rocks are most informative, but much information can be gleaned from satellite observations and by analyzing meteorites that have fallen onto the Earth from outer space.

The atomic building blocks of chemistry are the elements, of which 90 are known on the Earth. By optical analysis, fairly accurate estimates can be made of the quantities of each element in the Solar System as a whole; this is known as its cosmic abundance. By far the most common element is the lightest one, hydrogen; helium is a close second. Then follow carbon, oxygen, nitrogen, silicon, iron, and the others in rapidly decreasing abundances. According to cosmologists (astronomers who study the Universe), the elements are manufactured during reac-



Left: Diagram sums up the relationship among the different geochemical cycles active in the Earth's crust. Other related cycles are thought to function in the interior of the planet, but it is not yet possible to study them directly, and thus they remain a matter of conjecture.

Right: Comparison of successive models for the structure of the Earth's interior, beginning with the Suess model of 1885.



tions within the stars under enormous heat and pressure. Our own Sun is one such star.

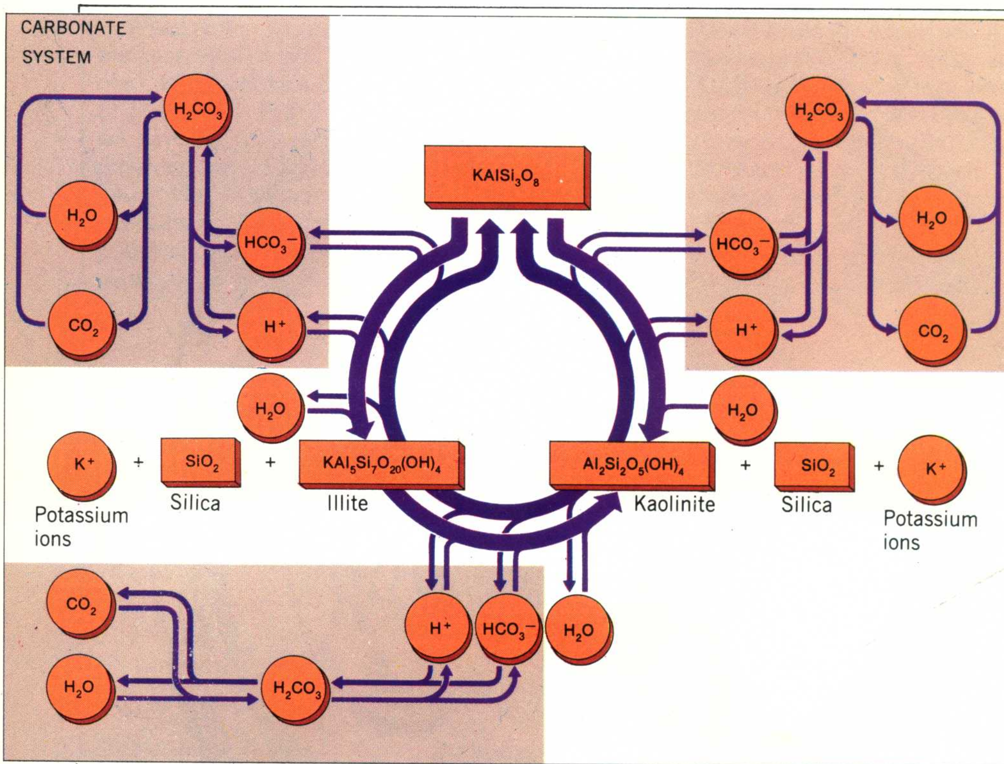
Composition of the Earth

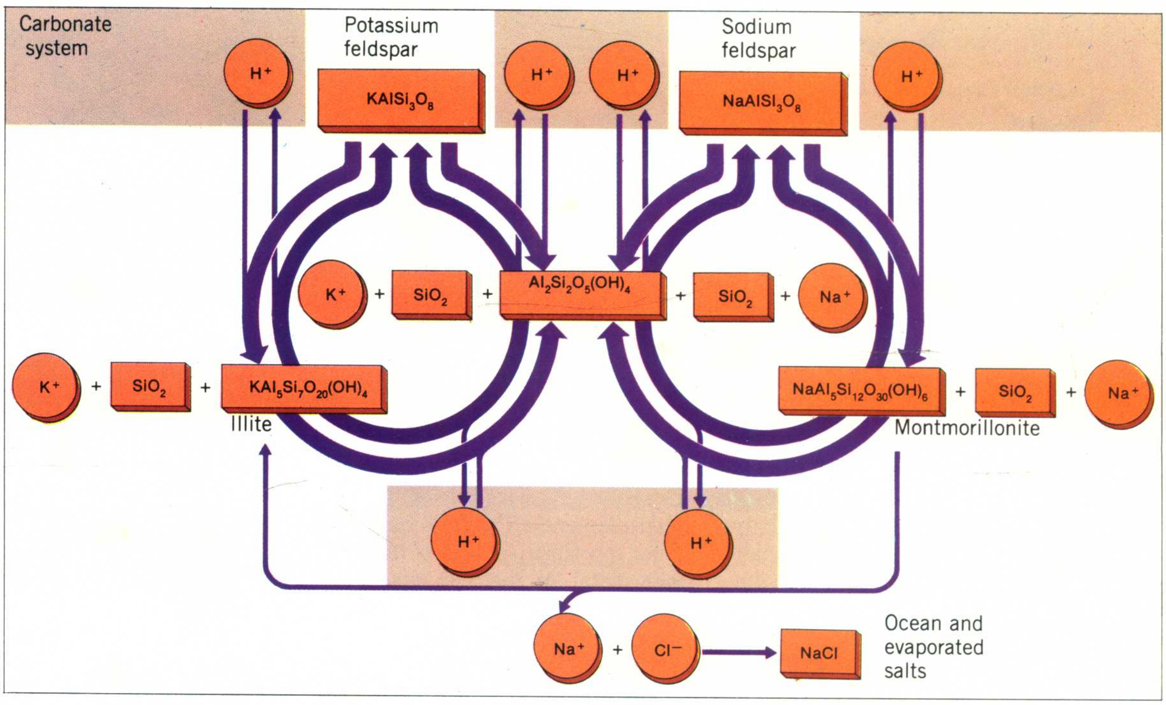
Geochemists can make an excellent synthesis of the average composition of the Earth's crust; the mantle and core are more difficult. Since specimens of the upper surface of the mantle are occasionally thrown out by volcanoes or thrust up during mountain-building, scientists do have some idea of the composition of the mantle. When meteorites fall from the sky, we see them as messengers from the Solar System that may represent the fallout from a planet that exploded (probably from overheating) in a very early stage of history. What makes meteorites so fascinating to sample and analyze is that they have a wide range of composition, from the "stony" ones, which look rather like the Earth's crust, to the "iron" ones, which seem to match what we believe exists in the Earth's core. Thus, we have information on the Earth's crust, mantle, and core, but in decreasing order of certitude.

There are several different approaches that can be followed in calculating the composition of the Earth, but they all seem to lead to a fairly good level of agreement on the following analysis: iron, 35 percent; oxygen, 29 percent; silicon, 14 percent; magnesium, 11 percent; sulfur, 3 percent. There are smaller quantities of nickel, sodium, calcium, titanium, and other elements. The high quantity of iron is not too surprising. It is the most abundant metal in the Universe and is extremely dense. The gravitational separation of elements within the Earth's hot interior would make it (with possibly nickel and/or sulfur) naturally settle into the core. For the rest, silicon and oxygen are the key elements of the silicates, the common components of all the major rocks of both crust and mantle.

Geochemists are generally agreed today that the core is about 91 percent iron and 8 percent nickel. In the overlying mantle, in contrast, there is a silicate melt, comprised of silica, 38 percent; magnesium oxide, 24 percent; ferrous oxide, 12 percent; ferrous sulfate, 6 percent; aluminum oxide, 2.5 percent; calcium oxide, 2.0 percent; and minor components. When samples of the mantle are brought to the surface, they are generally in the form of peridotite, a very dense, greenish-black rock. Probably during the early heating of the Earth, there was a bit-by-bit melting, with the denser (iron-nickel) fractions settling down by gravity, letting the lighter mantle material rise. This settling out has probably not come to an end, because radioactivity continues to generate heat, and this, so to speak, keeps the pot boiling. As with a pot of soup simmering on the kitchen stove, heat applied to the bottom keeps hot currents rising (convection currents), stirring up the soup. The same thing applies in the mantle.

Finally, there is the crust. The light material rises during convection and cools near the surface, to become hard and solid. It has been compared to the slag of light impurities from iron ore that rises to the surface in a blast furnace. In the continental crust (the oldest part of the Earth's surface), the average composition is silica, 60 percent; aluminum oxide, 16 percent; ferrous oxide and hematite, 7 percent; calcium oxide, 5 percent; sodium monoxide, 3.9 percent; magnesium oxide, 3.6





Above and right: Chemical models show how silicate minerals in igneous rock are transformed into different mineral compounds through reactions involving atmospheric carbon dioxide in the form of carbonic acid and, right, through the activity of hydrogen ions.

percent; potassium oxide, 3.2 percent. This is not far from the average composition of granite (which consists of quartz, feldspar, and iron-magnesium minerals). Since granite is believed to come from the melting of sediments carried down into the upper mantle at subjecting plate boundaries, it is interesting that an average mixture of sediments gives an almost identical chemical analysis.

Chemical Associations

A pioneer of geochemistry half a century ago, Victor Goldschmidt, noticed that the chemical elements allied themselves with one another in curious ways within the Earth. Those that tend to segregate with iron he called siderophile ("iron-loving"): elements like nickel, cobalt, osmium, iridium, platinum, gold, and carbon. Then he saw that the calcophile elements ally themselves with copper and are commonly found concentrated in ore deposits. In fact, this is very fortunate for mankind, because they commonly include copper, zinc, and other of our most useful and important metals. The lightophile ("rock-loving") elements include oxygen, fluorine, uranium, and many others. These are the most common constituents of ordinary rock and (as salts) of seawater. The biophile elements are "life-loving" and are found in both animals and plants and in the atmosphere: oxygen, nitrogen, and the rare gases like helium, neon, and argon. The reasons for these preferred (but not exclusive) associations are related to the varied properties of the elements, their position in the periodic table,and the size and valence of the atoms.

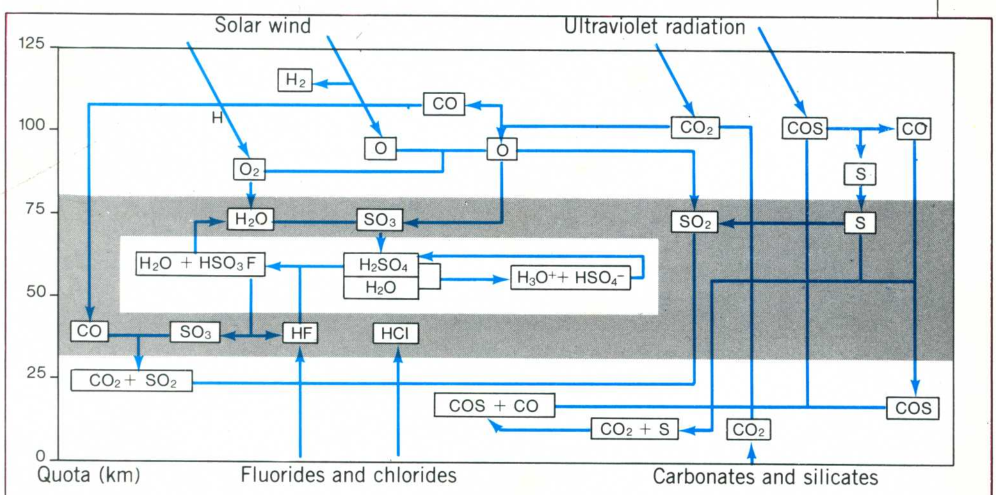
Geochemical Cycles

Geochemistry also concerns itself very much with tracing the cycles of elements in the land, ocean, and atmosphere. The Earth is by no means static. It is always changing, invisibly to the observer, but in terms of geologic time it is highly dynamic. For example, so-called juvenile waters constantly rise with molten rock (magma) from the mantle and bring new supplies of volatile elements to volcanic vents. Many of these gasses have been recycled, having been carried down from the Earth's surface as sediments by subduction (the dragging down of crystal plates during mountain-building).

Within the atmosphere and ocean, the hydrologic cycle is constantly taking water

INORGANIC MOLECULES	
• OH^-	Hydroxyl group
• H_2O	Water
• H_2	Hydrogen
• NH_3	Ammonia
• SiO	Silicon monoxide
• H_2S	Hydrogen sulphide
• SO	Sulfur oxide
• HD	Deuterium hydride
• N_2H-	
• HDO	Deuterium monoxide
ORGANIC MOLECULES	
• OH	Methyladene
• ON	Cyanogen
• CO	Carbon monoxide
• CS	Carbon monosulfide
• H_2CO	Formaldehyde
• HCN	Hydrocyanic acid
• HCOOH	Formic acid
• HC_3N	Cyanoacetylene
• CH_3OH	Methyl alcohol
• CH_3CN	Methyl cyanide
• HNCO	Isocyanic acid
• H_2CS	Thioformaldehyde
• NH_2COH	Formamide
• CH_3C_2H	Methylacetylene
• CH_4CO	Acetaldehyde
• CH_2NH	Methamine
• HNC	Isocyanic acid
• $(CH_3)_2O$	Demethyl ether
• C_2H	Acetylene radical (?)
• CH_3CH_2OH	Ethyl alcohol
• CH_3NH_2	Methylamine
• $(CH_4?)$	Methane
• DCN	Deuterium cyanide
• H_2C_2HCN	Ethylene cyanide
MOLECULES FOUND IN COMETS	
• HEAD	CH, OH, C_2, C_3, CH, NH, NH_2 (visible spectrum) H_2O (Bradfield, 1974) (radio spectrum) CH_3CN, HCN (Kohoutek, 1973) (radio spectrum)
• TAIL	CO^-, CO_2^-, N_2^-, CH^-, OH^- (visible spectrum) H_2O^- (Kohoutek, 1973) (visible spectrum)
• Hypothetical parent molecules	H_2 CH_4 NH_3 H_2CO CH_3CN

from the ocean by evaporation and pouring it onto the land as rain, which then weathers and erodes rock. The chemically dissolved elements are then moved about in the groundwater and in rivers or become incorporated in plants and animals. It all goes back eventually into the sediments, thence by subduction and melting, so that it becomes eventually recycled. Perhaps this is geochemistry's greatest lesson. Nothing is destroyed on Earth. With time, lots of time, almost everything gets recycled.



The study of geochemistry would be incomplete if cosmochemistry were not included. The chemical nature of the Universe is, after all, responsible for the initial stages of the Earth's formation. *Top:* Photograph of the Earth taken from the Mariner 10 space probe.

Above: Diagram shows how solar radiation in ultraviolet wavelengths triggers reactions in compounds that have been identified in interstellar gases.

Geodesy

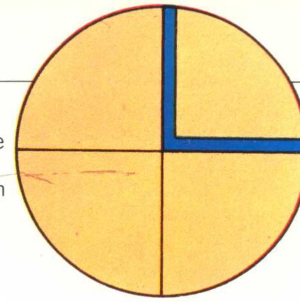
The scientific study of the shape and dimensions of the Earth is called geodesy. A peculiar problem faced by those who would measure it is that the Earth is always changing. Convection currents disturb its interior, tidal and inertial stresses pull on its exterior, and the land distribution over its surface, such as glaciers and volcanoes as well as the Earth's crust itself, is constantly shifting. That group of geologists called geomorphologists—those who study the Earth's structures—are able to recognize recent displacements of the Earth's crust, which they call neotectonics. These include the visible traces of displaced faults (fractures of the crust), coastlines that are elevated or depressed, and river valleys that are rejuvenated or "drowned." They have developed very accurate instruments to measure the rates of such movements.

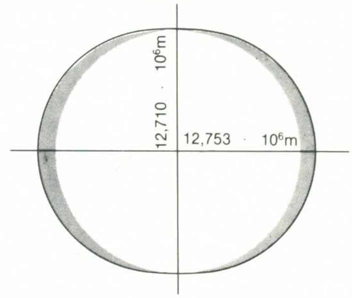
The exact shape of the Earth has only recently been measured, thanks to satellite observations. It turns out that the globe is really more pear-shaped than, as was thought, like an orange. We could imagine an "ideal" Earth with a uniform layer of water, the surface of which would be a plane corresponding to sea level. This is called the geoid. Satellite surveys have shown that curious distortions of the geoid exist that may exceed 300 feet (100 m) in height. Probably they are caused by irregularities in gravity, which are the results of uneven arrangement of matter within the Earth.

Mapping

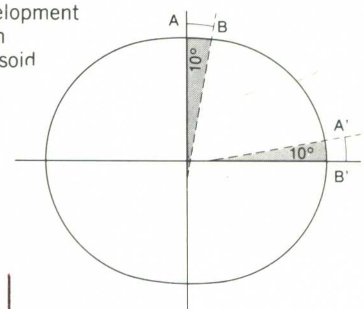
The first step in making a map of a new territory is to construct what is called a geodetic network, which consists of endless sets of imaginary triangles, connecting the survey points in the manner of the geodesic dome used by some architects. First, the surveyors measure out one side of the first triangle (called the baseline) on some flat terrain, calculating the length with extreme care; they then erect marker poles or build permanent "signals" or "stations" at each end (the station is usually like a small fire tower), where a survey instrument may be set up on a tripod. The type of instrument usually employed is called a theodolite—a short telescope that can be rotated horizontally through a 360° circle. Once it is set up at one sta-

Sphere cross section

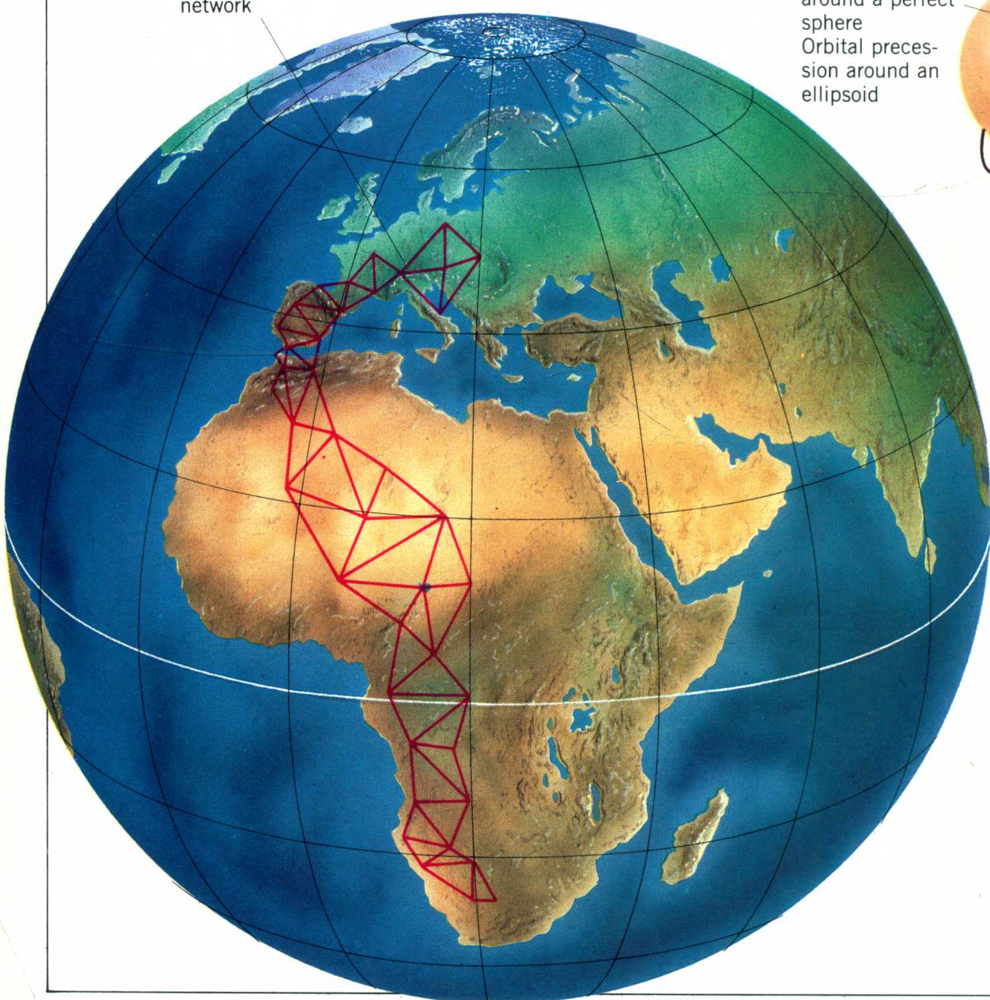




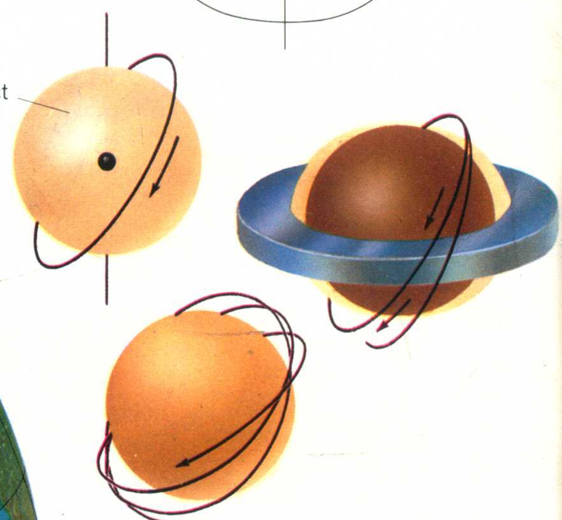
Development of an ellipsoid



Geodetic mapping network



Ideal orbit around a perfect sphere
Orbital precession around an ellipsoid



Left: The globe, with a network of geodetic mapping triangles stretching from South Africa to Eastern Europe.

Above: Series of globes and cross sections representing various criteria by which the Earth's form may be considered. For practical purposes, it is convenient to think of the planet as a perfect sphere, as in the cross section at top. Below this sphere is the mathematical development of an ellipsoid more nearly representing the Earth's true shape. Directly above are illustrated the implications of the planet's ellipsoid form for a satellite in Earth orbit. One effect of the bulge at the Earth's equator is that satellite orbits vary slightly with each passage around the planet, a phenomenon called precession.

Right: Illustration of how the position of a satellite in Earth orbit is measured simultaneously both photographically and with laser telemetry systems from different points on the planetary surface. This system is an aid to precision mapmaking.