Importance of the Cyclical View in Understanding the Characteristics of Earth's Environment and Resources

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CHARACTERISTICS OF THE PLANET EARTH IN THE SOLAR SYSTEM

Modern science originally based on the atomism and mechanism of European Science, as established in Western Europe in the seventeenth century, has successfully revealed physical characteristics of matter and energy in minute detail. However, although it stresses that any matter composing the solar system or even the universe uniquely follows laws of physics, it has failed to emphasize the characteristics that make Earth the only solar planet habitable by man.

Recent development of planetary geology, fortunately, has enabled us to understand the essential characteristics of the planet Earth. It is not only the existence of the atmosphere, hydrosphere, and lithosphere, but also the behavior of the earth's materials: that is in a dynamic, cyclical movement involving these three spheres, and driven by energy from the sun and the interior of the earth that make life possible. The presence of the biosphere is explained as a subsystem of this cyclic movement (Fig. 1). The importance of these relationships is easily understood when we geologically compare rock behavior on the earth with that on the moon, as explained in a chapter on planetary geology contained in any contemporary geology textbook (Tarbuck and Lutgens, 1987, for example).

WEATHERING AND THE ECOSYSTEM

Consider basalt, a common volcanic rock forming the moon, the ocean floor and volcanoes like Hawaii on the earth, for instance. Most of the basaltic rock on the moon surface formed about three billion years ago and should last for the next billion years without any change in its physical and chemical properties unless an accidental meteoritic collision with the rock occurs. However, on the earth the basaltic rocks are still being formed by volcanic eruption, and those hundreds of millions years old are rarely seen, since any basaltic rock exposed on land is subject to immediate weather-

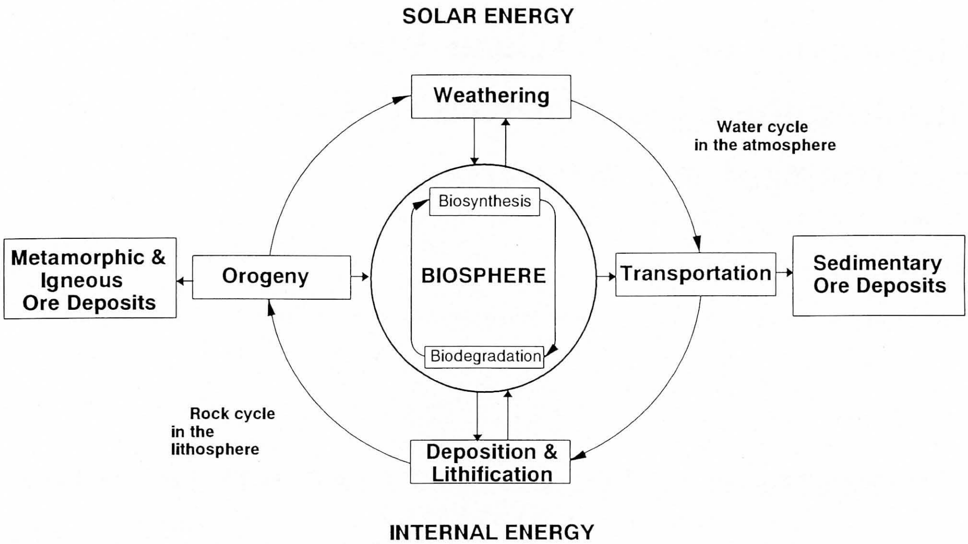

Fig. 1. Schematic diagram of the exogenic and endogenic cycles. These cycles support the biosphere by supplying inorganic nutrients which are produced by the dispersive processes within the cycles. The concentration processes maintained by the earth's gravity produce the ore deposits.

ing. Ice in the rock cavities and plant roots in the rock cracks break the rock into smaller rock fragments and individual mineral grains. The rock-forming minerals are then chemically weathered to form clay minerals and soluble substances as shown below;

$$\underset{\text{Feldspar}}{CaAl_2Si_2O_8\ 2NaAlSi_3O_8} + \underset{\text{Carbonic acid}}{4H_2CO_3} + \underset{\text{Water}}{2nH_2O} \longrightarrow$$

$$\underset{\text{Clay mineral}}{2Al_2(OH)_2Si_4O_{10}\ nH_2O} + \underbrace{2NaHCO_3 + Ca(HCO_3)_2}_{\text{In solution}}$$

Some resistant minor minerals survive as clastic grains. The clastic grains and dissolved substances are transported to the sea by water, ice and the air. During transportation, the clastics may form soil with organic matter and moisture, and the soluble substances are partly absorbed as inorganic nutrients by land plants which feed land animals. During chemical weathering, poisonous minerals such as metal sulfides and arsenic compounds are oxidized into hydroxides and oxides which are usually non-toxic and cause no harm to the ecosystem.

The organic materials produced on land are eventually transported to the sea together with the weathered materials and nurture the marine life in the coastal zone, as well as that in the hemipelagic and pelagic zones. It is often supposed that the growth of plants on land and phytoplankton in the sea depends upon solar energy, water and air. In reality, however, their growth is controlled essentially by availability of inorganic nutrients produced by weathering, as exemplified by the fact that the biological productivity of the pelagic zone is as low as that in deserts on land, although there is plenty of water and sunlight in the pelagic zone. Since land animals, including human beings, take in the minerals indispensable for their metabolism through plants, it may be said the biosphere is largely supported by weathering.

If weathering were the only process operating on earth, the continental blocks would be denuded within 30 million years to form very flat low land, and the process would cease even though the atmospheric circulation and precipitation are maintained by solar energy. If that has been the case in the past, the evolution of land life should have been much limited because of the lack of soil renewal and diminishing of the supply of inorganic nutrients. However, land plants and animals have been evolved and have flourished since the first appearance of land plants about 400 million years ago. This indicates that mountains never disappeared and weathering continued through that period of time.

All the weathered materials are finally transported to the ocean basins, where the particulate materials deposit as clastic rocks such as conglomerate, sandstone and mudstone, and the soluble substances precipitate as chemical rocks such as limestone, chert and rock salt. These rocks may be lifted above sea level again by earth movements to undergo another exogenic cycle, i.e., subaerial weathering and transportation, or they may be transported into the deep mantle by a subducting plate and melt to form magma, the molten rock which may eventually erupt on land to form volcanoes. Or they may be depressed by plate motion into the deep crust and metamorphosed by heat and pressure to form metamorphic rocks such as marble, gneiss and schist. These rocks and strata may be uplifted regionally by orogeny to form mountain ranges such as the Himalayas and the Alps. This endogenic cycle, i.e., subsurface rock transport, is maintained by energy from the earth's interior. Thus internal earth energy may be one of the key factors in evolution of life since it controls the weathering rate by seismicity, volcanism and orogeny (Harada, 1991).

THE ROLE OF INTERNAL ENERGY IN MAINTAINING THE BIOSPHERE

In addition to maintaining the ecosystem on land and in the sea by driving the endogenic and exogenic cycles, the internal energy supports another kind of ecosystem on the deep-ocean floor. Along the rift valley of the Mid-Oceanic Ridge, where molten mantle material upwells continuously to form the new ocean floor, there exist hydrothermal vents which build new rock edifices called 'chimney'. Fluids escaping from the vents contain high levels of hydrogen sulfide. Although the gas is toxic to most life, certain bacteria can metabolize it and form the base of the food chain of the deep-sea life around the vents. The community usually consists of tube worms, brachyuran crabs, limpets, clams and zoarcid fish. More than a dozen hydrothermal areas with such a community have been found to date in the Pacific, Atlantic and Indian Oceans since 1977. As the Mid-Oceanic Ridge snakes around the globe for 74,000 kilometers, a huge amount of biomass must be supported by this hydrothermal system, which is run by the earth's internal energy (National Geographic Society, 1992).

Another type of deep-sea life has been found recently on the continent-side slope of trenches around the Japanese Islands. Clusters of clams inhabit several areas where cold fluids seep out. These communities appear to be nurtured by hydrocarbons contained in the cold fluids which are squeezed from deep-buried sedimentary strata by compressive pressure produced by the subducting Pacific Plate, and migrate upwards along the fractures originated by faulting (KAIKO II Research Group, 1987). Although this type of community has been found thus far only in the Japanese Trenches, a large amount of biomass probably exists in the other trenches along the rim of the Pacific Ocean.

These deep-sea animals supported by the earth's internal energy, supply organic nutrients into the deep-sea water which upwells to the ocean surface and thereby nurture the life in the pelagic zone. Thus the internal energy plays an essential role in maintaining the biosphere as a whole. Consequently, it can be deduced that human immigration to a planet like Mars is impossible. Even if the warming of Mars's atmosphere were somehow attained, the planet has lost most of its internal energy and is not capable of driving the exogenic and endogenic cycles any more. Therefore it is apparent that human beings have to live on the earth at least in the foreseable future despite the explosion of world population, degradation of the global environment, and exhaustion of natural resources. There is nowhere else to live.

DISPERSAL AND CONCENTRATION PROCESSES IN EARTH CYCLES

Within the geological cycles that have already been described there are incorporated a set of processes of dispersal or dilution, and concentration or condensation. Weathering is one of the dispersal processes while sedimentation is one of concentration. These processes are operating continuously and simultaneously among the spheres as well as within a single sphere. For example, water evaporates into the atmosphere by absorbing heat from the land and the sea. At a high altitude, water vapor condenses to form precipitation, releasing the heat into space. This water cycle has kept the climate of the earth fairly constant through time. When precipitation falls to the ground again, it concentrates suspended dust and soluble gases like CO_2, SOx and NOx in the air which are then dispersed by the wind. Thus, the atmosphere is kept clean both chemically and physically. Rain water with these soluble gases becomes effectively neutralized by weathering rocks on land. In a sense acid rain is a good indication that the cleansing mechanism is still functioning well. On the other hand, compounds like Freon gas are too stable to concentrate into precipitation, so they penetrate freely into the stratosphere and destroy the ozone layer, especially in the polar regions where the air converges by cooling.

Within the biosphere, concentration and dispersal processes are well recognized as biosynthesis and biodegradation. Any life form is a product of biosynthesis. Excreta and corpses are used for food by other organisms and finally decompose into simpler substances such as water and carbon dioxide, which may be used for photosynthesis. Even the most dangerous poison loses its toxicity through biodegradation. However, toxic chemical compounds such as DDT and PCBs are so stable that they are scarcely decomposed through the dispersal process and cause much harm to the ecosystem when they concentrate through the food chain.

The concentration processes in the lithosphere play an important role. For instance, gravitational force and wave energy sort out sediment particles during transportation and sometimes concentrate specific minerals in a certain places. Placer gold and black sand are good examples. During metamorphism and igneous activity, certain elements are mobilized and concentrate to form ore deposits. Fossil fuels are also produced by concentration processes involving both heat and pressure.

THE EARTH'S ENVIRONMENT AND RESOURCES

Based on the geological observation of dynamic, cyclical movement on earth, the so-called environment can be regarded as the dispersal process, or the field where it operates in which any waste disappears. As far as the waste put in the environment is natural, regardless of whether it is organic or inorganic, it will be disintegrated into simpler, non-toxic substances which are used for biosynthesis or are condensed to form new materials such as sedimentary rocks.

Since the capacity and rate of dispersal process within a particular field is limited by several factors such as temperature, precipitation and humidity, an excessive load may reach a local environment and cause environmental problems such as smog and red tide. Also, any substance stable in the natural environment such as agricultural chemicals and industrial plastics, released in a local environment unavoidably causes harm in the field of concentration to the existing ecosystem. Since earth material as a whole circulate seamlessly and endlessly, any local input of excessive or toxic wastes eventually influences the global environment.

In the same manner, natural resources can be regarded as the substances resulting from concentration processes that are restricted to certain materials, locations and times. Although the amount of materials that undergo the dispersal and concentration processes is balanced as a whole, the concentration process is more restricted in location and the time in which it operates when compared with the dispersal process. For example, rice farming is limited geographically and its harvest time is also limited, while the decay of organic materials generally occurs anywhere throughout the year. By this reasoning, it is easily explained why the distribution and amount of resources are limited in location and time especially in the case of underground mineral resources. It also is easily deduced that mineral-ore genesis is hardly expected on the moon and Mars, where cyclic processes ceased much earlier than on Earth, namely more than two billion years ago, and that no fossil fuels exist there because no life has developed (Harada, 1990). Thus, the most distinctive property of matter on the earth is not derived from its composition nor structure but from its natural cyclical processing over geologic time.

CAUSE OF ENVIRONMENTAL CRISIS AND EXHAUSTION OF NATURAL RESOURCES

The trend in modern physics is away from mechanical determinism and some physicists are trying to describe nature more dynamically. Most engineers and economists, however, are still seized by the static view of classical physics and the idea of human dominance over nature. For instance, the concept of economic growth premises mass production and mass consumption on the assumption that mineral and energy resources are available infinitely by transporting them from somewhere on Earth, and that any waste will eventually disappear by natural processes. Modern technology supporting industrial production, is still trying to produce new and exotic matreials by neglecting, consciously or unconsciously, the fate of the products and residual products disposed in natural environment, and by believing that the environmental crisis and exhaustion of resources are two different phenomena.

This anthropocentric attitude developed with the Industrial Revolution has culminated in the reality of mass transportation by thermal engines and production of new materials by chemical synthesis. Both inventions set the Europeans free from the regional environmental and resource restrictions which control agricultural and industrial productions, respectively, as shown in the Figure 2 and Table 1. But the engine is the main culprit of air pollution, acid rain, climatic change and exhaustion of

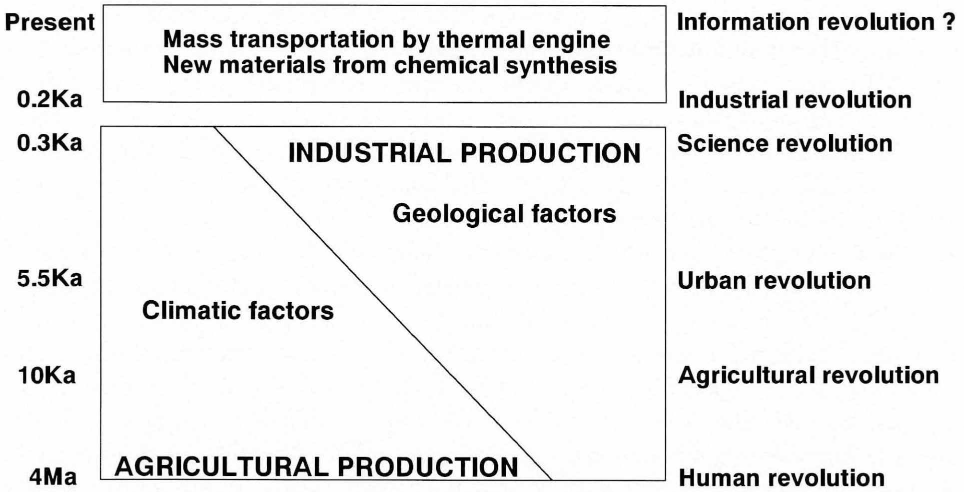

Fig. 2. Historical change of the relationship between human life and natural environment. When the human revolution took place about four million years ago, the climatic factors in natural environment predominantly influenced the human life. However, as the time went, and especially after the urban revolution, about 5,500 years ago, industrial production become more important than the agricultural one, and so did the geological factors. Nevertheless, the climatic factors always restricted the human life, as the food was only supplied from local farms. The industrial revolution, about 200 years ago, released the industry and, to lesser extent, agriculture from these environmental restrictions by the mass transportation and synthetic materials such as plastics, ferilizer, and agricultural chemicals. See Table 1 for the explanation of the climatic and geologic factors.

Table 1 Natural factors consisting of natural environment

Climatic factors	Geologic factors
Precipitation	Mineral resources
Temperature	Regional topography
Local relief	Land properties
Soil	Volcanism
Vegetation	Seismic activity

fossil fuels, and the chemical industry has been the major cause of soil and water pollution, damaging the ecosystem on a global scale. Therefore, the more economic growth is attained by the traditional manner, the more damage will be necessarily added to the global environment. Unless we change this course, the ruin of modern civilization awaits us, although a conceptual term, 'sustainable development', is being praised.

Technology is a way to utilize nature for human life, but an understanding of nature, chiefly through science, must be an essential factor in technological development. Modern technology often still applies the percepts of the old European Science, unfortunately, inevitably causing much harm to the global environment (Harada, 1992). In order to overcome the present crisis, therefore, it is important that we, as scientists, renovate our understanding of the earth and instruct others, namely, philosophers, engineers, economists, and the general public, in the prospects for man and our future on planet Earth. For this purpose, it should be useful to re-evaluate ancient sciences such as Chinese, Indian and Arabic Sciences from the geological point of view.

REFERENCES

Harada, K. (1990): Chapter 6 Is there any resources on the Moon? *Chikyu-ni-tuite (About the Earth)*, Kokusai-Shoin Co., Tokyo, pp. 115-127 (in Japanese).

Harada, K. (1991): The relationships of the biosphere to exogenetic and endogenetic cycles: An earth science approach to the establishment of a global philosophy. *Comparative Civilization*, 7: 176-186 (in Japanese).

Harada, K. (1992): Cause of the global environmental crisis: Possibility of Japanese earth scientists constructing a new global view. *J. Sedimentological Soc. Japan*, 36: 77-82 (in Japanese with English summary).

KAIKO II Research Group (Ed.) (1987): *6000 Meters Deep: A Trip to the Japanese Trenches. Photographic Records of the* Nautile *Dives in the Japanese Subduction zones.* Tokyo Univ. Press, Tokyo, 105 pp.

National Geographic Society (1992): World Ocean Floor: Pacific/Indian Ocean Floors, *Supplement to the National Geographic*, 181 (6): 70A.

Tarbuck, E. J. and Lutgens, F. K. (1987): Chapter 20 Planetary Geology, *The Earth* (Second Ed.), Merril, Columbus, U. S. A., 520-556 pp.