Global Change:

Geological Processes, Past & Present

by Raymond A. Price

As part of the planning for the proposed International Geosphere-Biosphere Program on Global Change, the International Council of Scientific Unions has established several working groups to define the "core" directions for the program. This article is a modified version of the report of the group on

Geological Processes, Past and Present, chaired by the author and to be presented to the ICSU General Assembly in September. It outlines briefly the background, framework and recommended key elements for the geological component of the program. (Ed.)

The Geological Perspective

We live in a time of biotic crisis. Profound changes in the biosphere and the geosphere have been the hallmark of mankind's recent and rapid emergence as the dominant species of the earth and of the accelerating growth of our global technological civilization. Our perceptions of the real nature and full significance of these changes are impaired, because, when viewed from the perspective of a human lifetime or of the span of human history, they are so pervasive as to be regarded as the normal course of events on a stable earth. However when viewed from the perspective of the geological record, rapid growth in the human population, in the per capita consumption of natural resources, and in the disruption of established ecosystems represent drastic departures from the state of stable dynamic equilibrium that characterizes most of earth history.

For example, the extinction rate of North American mammals rose to 1,000 times more than the geologic background rate after the first arrival there of *Homo sapiens*, and this rate seems to be increasing exponentially. With the large-scale destruction of large natural ecosystems, such as tropical rain forests, the disappearance of faunal and floral species has reached alarming proportions. There are also disturbing major losses in the global stock of basic natural resources, such as fertile soils, potable water, and secure food supplies, and foreboding changes in the world climate loom ahead due to the "greenhouse gases" (e.g. Dickinson and Cicerone, 1986). The scope, magnitude and implications of these anthropogenic changes, and of the "natural" changes with which they interact, need to be clarified.

Living organisms and their physical and chemical environments are mutually dependent. The Earth was made habitable when anaerobic and cyano-bacteria gave it oxygen. The surface-water chemistry of the oceans has been steadily "fractionated" by plankton so that they can reproduce and flourish. The symbiosis of different life forms and the Earth's surface environment has been compared to the functioning of a multicellular organism (the Gaia concept of Lovelock, 1979). Humans are dependent upon other forms of

life for the air they breathe, for the food they eat, and, to a certain extent, for the water they drink; nevertheless the activities of the human population are making the Earth as a whole less habitable. The growth in the size, demands and impacts of the human population might be compared to the growth of a malignant tumor in the global organism. The International Geosphere-Biosphere Program (IGBP) on Global Change will provide an opportunity for a diagnosis and a prognosis for this ailment (for background to the IGBP see Malone and Roederer, 1985; and Anon, 1986).

The Evolution of the Global Ecosystem

The record of the development of our global ecosystem provides an essential framework for assessing the nature and significance of contemporary global change. This record, which spans more than 3.8 billion years, is preserved in variable detail and precision in the lithosphere and is characterized by episodes of profound global change separating much more stable intervals. Working out this record will provide both a baseline against which to compare and evaluate contemporary global change, and a framework within which to explain the basic processes in the coupled geosphere-biosphere system.

The obvious focus for the unravelling of the geological record of change is the Quaternary Period, spanning the last 2 million years. Of particular importance is the Holocene Epoch, the last 10,000 years, including the time during which ice sheets retreated and explosive growth in the human population occurred.

Understanding the record of global changes in marine and terrestrial fauna and flora, climate, paleogeography and the main biogeochemical cycles during the Quaternary is a particularly urgent and daunting challenge. The available data base is very large, widely dispersed, highly variable from place to place, poorly correlated with respect to time, and inadequately coordinated. However, new technological developments offer great scope for improvements and an IGBP on Global Change could provide the necessary stimulus and coordination to achieve this.

The analysis of past environmental and climatic changes requires the use of both direct and "proxy" data comprising long time series from human and natural recording of past conditions and events. Direct data include information on the composition and density of floral and faunal assemblages, and on the volume and content of the soil and water. The proxy data come from analyses of ice and sediment cores, varved sediments, tree rings and so forth. Their correct interpretation, in terms of paleoecology, environment or climate, depends on good transfer functions based on an appropriate knowledge of present-day boundary conditions in biological, chemical, and physical variables. This in turn can be achieved only if an effective collaboration exists between scientists studying modern ecosystems and those reconstructing their origin and evolution.

← Figure 1: North-central Saudi Arabia near the city of Ha'il. The complex tectonic pattern of the region is accentuated by the sand-filled valleys. ESA photo, Spacelab 1, 1983.

The importance of the tropical belt in terms of the concentration of energy coming from solar radiation and of the production of the biomass of the Earth must be stressed. Because a serious lack of knowledge exists here, a special effort should be devoted to these sensitive areas, and to a careful reconstruction of all environmental changes that have affected them during the past million, and particularly the past few thousands of years.

A multidisciplinary team approach is obviously required. Because of contemporary technology and scientific specialization, fundamental research on problems of this type by individual scientists is commonly now ineffective or even impossible. A variety of disciplines and instruments must be integrated, including systematic field observations and sampling, remote sensing (Fig. 1), stable isotope analysis, geomagnetics, microprobe analysis, micro- and macro-paleo-biology and field radar. This spectrum of disciplines and instruments seldom occurs in the same institute or even in the same country and, accordingly, important projects will depend upon effective national and international cooperation.

The evolution of global ecosystems can be reconstructed by comparing their modern and ancient counterparts. Paleofloral and paleofaunal maps for various past times can provide the basis for determining the annual production and the rates of destruction or accumulation of critical biological materials. Maps of this type can be prepared on the basis of systematic sampling of lake sediments, tree rings and ice cores, for example, along well chosen "biogeotraverses" that cross the main gradients of the ecosystems, from oceans to continents, from high to low latitudes, from glacial to temperate regions, or from deserts to tropical forests. Cores of sediments deposited in the oceans (Fig. 2) and in lakes are of particular importance because they can provide continuous records of temporal changes in biological, geochemical, isotopic, magnetic and physical signals.

In summary, the goals of such a coordinated effort on the geological record of changes in the global ecosystem would be to elucidate the nature, timing, causes, and consequences of past global change and to provide a framework for the analysis of contemporary global change. A closely correlated and consistent data base on the record of global change in both terrestrial and marine realms should be established as the basis for realistic and quantitative process models of contemporary global change.

→ Figure 2: Core from ODP Hole C45C in Baffin Bay showing gradational change from bioturbated muddy sand to darker, muddy silt at top. Note glacial dropstones in both lithologies. Photo courtesy of ODP/TAMU.

The Rock Cycle

The continual flow of material between the surface and the interior of the Earth, which drives lithospheric plates over its surface, has an important long-term influence on lithosphere-biosphere relationships. The flux of new ocean crust from the mantle at the mid-ocean ridges amounts to about $10 \text{ km}^3/\text{yr}$, and a somewhat greater volume of older lithosphere (with all or part of its water-saturated sedimentary cover) descends toward the interior of the Earth in subduction zones. The dominant process in the cooling of newly formed oceanic crust is the circulation through it of cold sea water. This process, which entails large-scale chemical exchange between the hydrosphere and the lithosphere, occurs at a rate sufficient to process the entire volume of the ocean every 8 million years.

The movement of the lithospheric plates has had a major long-term influence on oceanic and atmospheric circulation and on global climate. Neotectonic movements, as in the Himalayan region (Fig. 3), have influenced climatic change over shorter periods. Catastrophic volcanic activity associated with plate movements has the capacity for profound effects on the global ecosystem over even shorter periods.

Anthropogenically induced disruptions in the global ecosystem arise from the vast utilization of mineral and energy resources for fuel and in agricultural, manufacturing and chemical industries. These quantitatively involve a material flux now equivalent in volume to that of new oceanic crust from the interior of the Earth. Because of the growing rate and the cumulative impact of these disruptions of the natural systems, they need to be very carefully evaluated. A most important area of investigation of global change is, therefore, the study of geochemical and biogeochemical cycles, especially of those involving biologically limiting and toxic elements (Cook, 1984).

For example, it appears that the phosphorus cycle (Fig. 4) has varied markedly with time. This means that a non-steady state model must be used, and this has far-reaching implications for the evolution of the hydrosphere and biosphere. Studies need to be undertaken to identify the pathways, sinks and reservoirs of the natural cycle. Superimposed on this is the vast use of phosphate fertilizers, often on destabilized soils in semi-arid environments where rates of erosion can be very high. The consequences of this for both the phosphorus cycle and the whole ecosystem need to be evaluated.

In modelling the sources and sinks for anthropogenic and natural materials in the geological environment, it will be necessary to assess quantitatively the amount of material transported from the continents and deposited in the world's estuaries, deltas and ocean basins. Remote sensing technology offers the capability to identify sources and estimate amounts of contemporary runoff of continental materials on a global scale.

Volcanology and Global Change

Gigantic eruptions, particularly those situated at convergent plate margins, can have a major impact on life on both local and global scales (Fig. 5). The greatest and most disastrous eruption in recorded history occurred in 1815 on the island of Sumbawa, Indonesia. The paroxysmal eruption, which was accompanied by a caldera formation, took place at Mount Tambora and killed about 90,000 people. About 100 km^3 of volcanic dust were ejected into the atmosphere, filling the sky so densely with a cloud that it hid the sun and resulted in a summerless period in certain parts of Europe and North America.

In 1883 another gigantic blast took place. Krakatau volcanic island spewed about 18 km^3 of volcanic dust in the atmosphere. It was estimated that the thermal energy in the hot material erupted by Krakatau was equal to that of 5,000 megatons of hydrogen bombs, although only 5% of the Krakatau thermal energy was converted to mechanical energy, and its release was spread over a day's time. During the cataclysm, 36,000 people were swept away by tidal waves caused by the collapse of the volcanic island complex. The tsunami travelled at a speed exceeding 500 km/h westward across the Indian Ocean and into the Atlantic.

Volcanoes also deliver sulphur, chlorine and other chemical elements and particulates to the troposphere and stratosphere causing perturbations over significant spans of time. Volcanic activity clearly is a factor that must be considered in any comprehensive assessment of global change.

An international, long-range study should thus be established of caldera eruptions such as Krakatau and Tambora, including their temporal and petrogenetic evolution. This should be accompanied by a program of detailed monitoring of volcanoes on convergent plate margins that are likely to generate calderas in the future (Souther et al., 1984). Other related studies might include the character of volcanic emissions and how they vary with time, and the physical, chemical and dynamic processes through which volcanic ejecta modify the atmosphere. Remote sensing from satellites can be used to monitor the amounts and distribution of material injected into the atmosphere by gigantic eruptions, and also to monitor emissions of SO_2 and of other gases.

Figure 3: In the western Himalaya powerful neotectonic movements result in rapid erosion. (Photo by M.P. Searle)

Soil Resources

Soil forms a direct physical, chemical and biological link between the lithosphere and the biosphere. The soil cover acts as a reservoir for water, and for major and minor nutrients, and serves as the matrix that supports both the natural terrestrial ecosystem and human agriculture. The increasing demands for food, plant materials and energy necessitate an improved understanding of efficient soil management, including the dynamic processes controlling both the origin and evolution of soils, and their erosion and degradation.

Soil erosion displays very large temporal, spatial and climatic variability. A cover of vegetation reduces this, but rainfall following dry spells can lead to substantial erosional losses. Heavy rainfall in the tropics also leads to high erosion rates, and appreciable losses commonly occur on

Figure 4: The global phosphorus cycle, showing contents of major reservoirs and fluxes between them. From Anon 1986.

Figure 5: Volcanoes at a convergent margin. Mount St. Helens, Washington, showing to the left the area most affected by the 1980 eruptive blast (covered with fresh snow). Note plume of volcanic gases from the summit caldera. Mt. Rainier in the background.

cultivated land. Not enough is known about rates of soil erosion and formation to assess their impact on sustained biological production of food, energy and plant materials.

Maximization of the carrying capacity of the earth to meet human demands for food, energy and raw materials, requires determination of suitability and production rates of soils of different characteristics, and the delineation of the effects of fertilizers on their trace element balance. Soil erosion can be minimized through preservation measures, and old weathered soils can be recovered by dressing them with nutrient elements such as cobalt, zinc, arsenic, manganese, copper and magnesium.

New nuclear methods, based on isotopes produced *in situ* by cosmic rays can provide estimates of rates of soil production and erosion. The shorter lived isotopes ^{39}Ar and ^{14}C are particularly well suited for this purpose. Longer lived isotopes ^{26}Al and ^{10}Be are ideal for assessing erosion rates and the evolutionary history of rock weathering products.

In studying the global effects of changes in land cover on soil, such as due to deforestation or desertification, remote sensing will again be of substantial use. It will be possible to monitor soils as they lose their carbon content (through lower emissivity), oxidize (increased red ferric iron) or lateritize (detection of hydrate bands). It will also be possible to monitor the movement of erosional products across the land surfaces (e.g. sand dunes) and in lakes, rivers and to the sea.

A global assessment of the impact of human activities on the landscape, coupled with a global assessment of soil resources, including their chemical and physical characteristics, is essential for addressing the question of future availability of food and energy to meet the growing needs of the human population. This is an urgent challenge that must be addressed by any comprehensive program on global change.

Summary

Our initiatives relating to the lithosphere and soils should be considered in the overall IGBP planning process:

- The analysis of the geological record of the evolution of our global ecosystem, with emphasis on the past 2 million years, and particularly the last 10,000 years.
- A global assessment of future soil resources and on the impact of human activities on the landscape.

- Studies of gigantic volcanic eruptions and their impact on climate and the global environment.
- The analysis of anthropogenic effects on geochemical and biogeochemical cycles, especially those involving bio-limiting or toxic elements.

The development of well-conceived research plans and of an appropriate coordination and management structure for an IGBP on Global Change requires careful, in-depth consideration by a multidisciplinary array of scientists. One very effective approach to this critical challenge would be to convene Dahlem-style planning workshops. These would involve 50 to 75 individuals, each of whom would be expected to submit, prior to the actual workshop, written critical assessments of a group of invited position papers. At the beginning of a full-time workshop of about one week's duration, these position papers and critical assessments would form the framework for well-structured discussions leading to specific, relatively detailed operational goals and working plans.

Acknowledgements

This article is based mainly on a two-day workshop held in Washington in February 1986 following the IUGS 25th anniversary symposium on "Geology and Problems of Global Change" reported elsewhere in this issue of *Episodes*. Participants in the workshop were B. Bolin (Sweden), C. Drake (U.S.A.), H. Faure (France), K. Hsu (Switzerland), J. Katili (Indonesia), D. Lal (India), R. Rutland (Australia), L. Walter (U.S.A.) and the author. The full version of this article is to be published, together with the reports from the IGBP working groups, by ICSU Press.

Raymond A. Price is Director General of the Geological Survey of Canada (601 Booth Street, Ottawa, Ontario, Canada K1A 0E8). Former President of the Inter-Union Commission on the Lithosphere, he is well known for his work on the tectonics of the Canadian Rockies. Dr. Price is Chairman of the ICSU Working Group "Geological Process, Past and Present."

References

- Anon, 1986. Global changes in the geosphere-biosphere: initial priorities for an IGBP. U.S. Committee for an IGBP, NRC Commission on Physical Sciences, Mathematics and Resources, National Academy Press, Washington, 91p.
- Cook, R.B., 1984. Major biogeochemical cycles and anthropogenic changes. *Episodes*, vol. 7, no. 2, p. 3-7.
- Dickinson, R.E. and Cicerone, R.J., 1986. Future global warming from atmospheric trace gases. *Nature*, vol. 319, p. 109-115.
- Lovelock, J.E., 1979. *Gaia: a new look at life on Earth*. Oxford University Press, Oxford, 157p.
- Malone, T.F. and Roederer, J.G., 1985. *Global change*. Cambridge University Press (for ICSU Press), Cambridge 512p.
- Souther, J.G., Tilling, R.I. and Punongbayan, R.S., 1984. Forecasting eruptions in the Circum-Pacific. *Episodes*, vol. 7, no. 4, p. 10-18.