A Textbook in Environmental Science

V. Subramanian

Alpha Science

A TEXT BOOK IN
ENVIRONMENTAL SCIENCE

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Preface

It is a common practice now a days to open our daily newspapers early in the morning and read about one or other kind of environmental problem facing us. It may be a case of polluted water at some industrial discharge point, or a factory outlet emitting thick smokes or garbage dumped in residential areas. At the same time we also read about court cases whereby the judiciary directs the concerned administrators to remedy a particular bad situation dealing with environment such as the shifting of some polluting industries away from river sites. Awareness for a safe and cleaner environment is now part of formal or informal curriculum even at nursery school levels and many colleges and universities have the subject at the undergraduate level either as an optional or compulsory one for the students. While a large number of books on environment are available in the market most of these books are based with examples from developed countries.

Problems of environment are generally global but we need to address issues that are typically common to developing countries on a local scale and perspective. Hence in this book, as far as possible, example from India and other South Asian countries are used to highlight a particular point.

The book is aimed at first level in the university education system and as such, too much technicalities have been deliberately kept out so that a student, for the first time, gets a broad exposure to problems facing our environment and if this interests the student, then he/she can proceed for a detailed technical readings in specific subject of interest, be it chemical, biological, physical or earth science aspect of studying our environment. The chapters in the book has been so organized that a student first reads about the interdependence of various processes in environment and then gradually gets details of individual processes affecting water, air and soil and is then given data based approaches to evaluate the concept of pollution, possible impact on climate and commonly understood remedial measures. Efforts have also been made to give broad ideas about environmental impact assessment with specific examples. In order to highlight the essential components of science and social science aspects of environment limited policy and legal aspects are also briefly discussed. Gone are the days of specialists since environmental science is truly inter disciplinary and one need to appreciate all possible approaches in solving a given problem and hence this book attempts to give the student a broad appreciation of the inter-play in dealing with all matters that affect our environment. With this background, a student will be able to understand specialized books that may address issues on specific aspects such as water chemistry, modeling, biogeochemical cycles etc. To develop a wider reader base, this paperback book is specially priced to serve the purpose of extensive dissemination of interest and approaches to understanding our environment. An integrated background in physical, biological and earth sciences will help a student understand a given problem better and hopefully this book will serve its purpose in that direction.

Various chapters presented in this book reflects over a quarter century of teaching at post-graduate levels in India and abroad with input received from the present and past students in the class. A simple book covering all the topics listed with examples from the south asian point of view was found lacking; farther, many international books available on the subject strongly reflected regional bias.

Material for this book was painstakingly collected by a large group of researchers, both at student and project level. Funds were made available through a large number of Research projects supported by Ministry of Environment & Forests, Government of India (GOI), Department of Ocean Development, GOI, Department of Science & Technology, GOI, International Geological Correlation Programme, United Nations Educational Scientific & Cultural Organisation and Volkswagen Foundation, Germany and the Special Assistance Programme of the University Grants Commission.

The financial help from these agencies and physical and academic help from students and project staff is gratefully acknowledged. With various levels of sucess with a number of active Website, information retrieval has become relatively easier and this book, though at first level, contains latest data on some of the relevent parameters. In addition to text book the contents of the book will also be useful for anyone planning to take examination in environmental sciences.

V. Subramanian

Contents

CHAPTER 1

Introducing Our Environment

SOLAR ENERGY

The environment we live in represents the inter-play of a number of segments involving the lithosphere (rocks, soil), hydrosphere (water), atmosphere (air) and the biosphere (the living world). The interaction is promoted by energy input. So the basic of all interaction in nature is the input of energy, supplied in plenty by the sun.

Figure 1.1 illustrates the interaction involving all segments in response to solar energy that is the driving force for all natural interactions. The incidence of solar radiation on the surface of the earth,

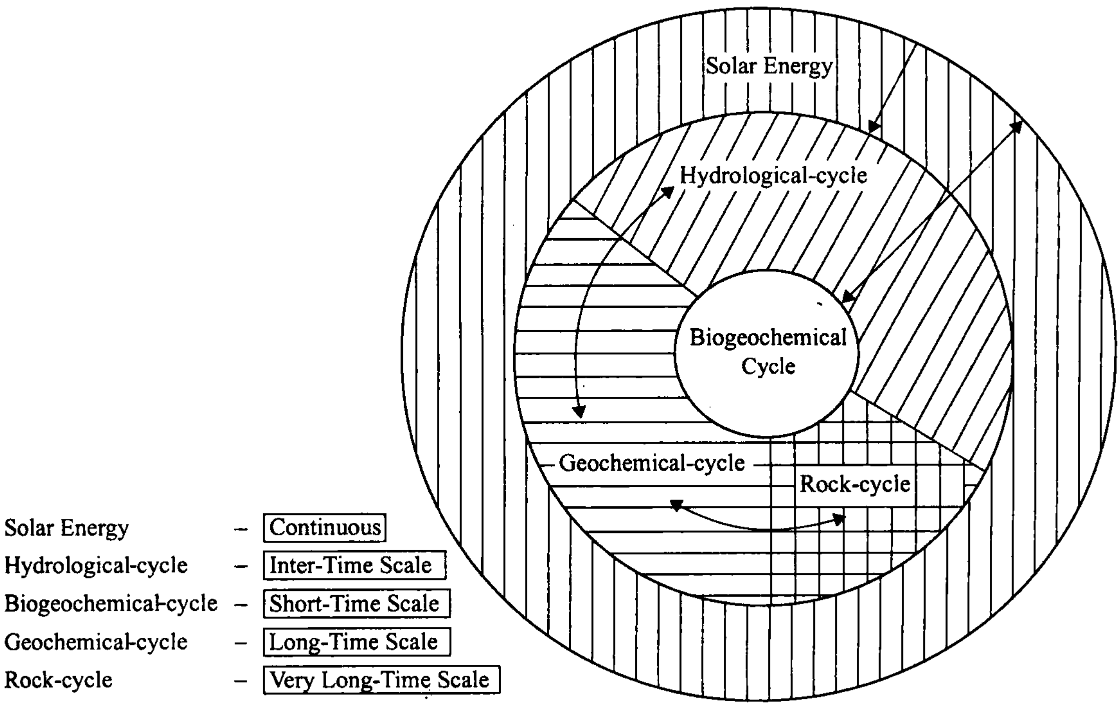

Figure 1.1 Integrating effects of the solar energy based chemical cycles in nature. The driving force behind all forms of cyclic behavior is the energy released by the sun. The inter linkages between various cycles are shown by various shaded areas.

measured as solar constant, varies from place to place due to latitude and longitude. For example, towards the polar region both in the northern and southern hemisphere, there are extremes of daylight in summer and winter: in summer, in these regions, sun shines non-stop with very little time gap between day and night and in fact, in the Scandinavian countries, closer to the arctic, some places are known as the land of mid night sun; on the contrary, in winter, sun hardly comes out at all and practically there are no day times; hence photosynthesis and other biotic processes, totally dependent on solar radiation is effected. In the tropical areas, sunlight is uniformly distributed throughout the year and coupled with favorable rainfall, the landmass here has good vegetation cover suggesting to one strong interaction with water, soil and nutrient movements in the environment.

HYDROLOGICAL CYCLE

The hydrological cycle involves the movement of water in our environment. Water acts as a carrier for essential materials such as nutrients, sediments and dissolved gases and in turn can be viewed as consisting of a number of segments: rivers, oceans, atmosphere (moisture/vapor) and ground water besides the frozen polar region with solid ice. Thus water occurs in all its three physical forms in the cycle and this can be illustrated schematically in Figure 1.2. The largest amount of water is in the oceans but the water here is saline but the largest amount of fresh or sweet water is in the polar region in the form of ice and far away from populated areas and hence not easily available for use by us. Total water available on the surface of the earth is about $1454193 \times 10^3\,km^3$. Of this large amount, nearly 94.2% is in the oceans and less than 1% is fresh water available for us as rivers the rest being in polar region. A very small fraction is permanently locked up in both biosphere and the atmosphere. Table 1.1 illustrates uneven distribution of water in our world today. Also given in the table is the relative precipitation and evaporation on various continents highlighting natural spacial disparities in the fundamental hydrological processes operating today. Though the South American continent is the wettest, it also looses the largest amount by evaporation and each continent maintains balance between evaporation, precipitation and river run-off. One can notice that overall the earth maintain a balance between what is coming in as precipitation and what is lost as evaporation and river run-off and this no loss-no gain process has been there from very long time within various landmass. Ground water is much more than surface waters, but not all ground waters are sweet waters, particularly in coastal areas, many groundwater's are saline and not fit for drinking water purposes. Through the efficiency of the natural cyclic processes propelled by the solar energy, the limited fresh water is repeatedly recycled in our environment as shown in the illustration. Rivers transfer the fresh water from land to oceans and are the most dynamic component in the hydrological cycle. Being an excellent solvent, water carries a number of dissolved substances such as dissolved oxygen (required for aquatic organisms), essential nutrients (such as phosphorous, nitrogen) required by all living organisms and also unwanted or man-introduced (anthropogenic) substances or pollutants. Since water is constantly and efficiently transferred from one part to the other in the hydrological cycle, all dissolved materials are also proportionately transferred. Hence water is the most common carrier of both wanted and unwanted materials in our environment.

Both Figure 1.2 and Table 1.1 show the hydrological cycle in terms of volume of water in each segments or reservoir. The hydrological cycle can also be simplified in terms of quantity of transfers that take place between various reservoirs in response to various hydrological processes: This is illustrated in Figure 1.2 with numbers of each transfers and they are summarised in Table 1.2.

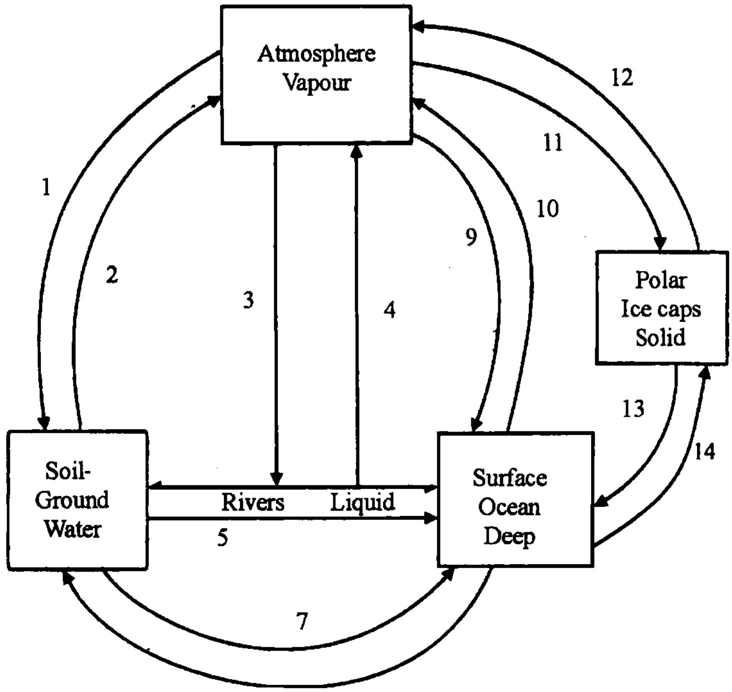

Figure 1.2 The hydrological cycle. Various numbers refere to individual transfers between different sectors. (1) precipitation over soil; (2) evaporation of soil moisture; (3) precipitation over rivers and other water bodies; (4) evaporation of exposed water bodies; (5) river run off to oceans; (6) sea water intrusion into land areas; (7) groundwater discharge to sea directly in coastal areas; (8) sea water seepage into the ground water; (9) precipitation over sea areas; (10) evaporation of sea water; (11) precipitation over the polar regions; (12) evaporation from the poles; (13) melting of polar water; (14) freezing of sea water. Not all such transfers are equally important.

ROCK CYCLE

Rocks that are exposed on the surface of the earth, are weathered, eroded by wind and water and deposited in oceans where they settle down after a long time and still after a very long time (many millions of years) compacted into sedimentary rocks. These rocks, in turn due to the pressure of overlying sediments and water (hydrostatic and lithostatic pressure) buried deeper and deeper into the earth so that at some point in time, due to certain processes in the oceans-continent boundaries, are sub-ducted or sucked into the deep layers of the earth thereby becoming a part of the continental earth once again. After uplifting of these mass of rocks over long periods, the weathering and erosion processes remove them once again. The rock cycle is illustrated in Figure 1.3. Thus in the rock cycle masses of rock materials are transferred from continents to oceans and back to continent in a cyclic fashion. Wind and water helps in these processes. Time scale of various transfers vary from a few million years to even a few billion years.

Table 1.1 Hydrological cycle and the water balance

Total water on the earth = 1454193000 km^3 (note: 1 litre = 1000 cm^3 and 1 km^3 = 10^{12} litres

Total fresh water = 64366000 km^3 or 4.42% of the total (of this, rivers carry only 40000 km^3 or 0.002% of the total)

Total salt water (ocean) 1338000000 km^3 or 94.2% of the total

Others (glaciers etc) 20067860 km^3 or 1.38% of the total

Continent	Precipitation (cm)	Evaporation (cm)	Run-off (cm)
Asia	696	420	276
Europe	657	375	282
Africa	696	582	114
North America	645	403	242
South America	1564	946	618
Oceania	803	534	269
Antartica	169	28	141
Average Continental	746	480	266

GEOCHEMICAL CYCLE

Geochemical cycle links the rock cycle with that of water cycle and refers to transport and transfer of dissolved and solid substances through our environment on a time scale representing natural reactions involving rocks or soils, water, atmosphere and to some extent the biosphere. Figure 1.4 illustrates the geochemical cycle. As then terminology suggests, it is a chemical interaction of lithospheric materials with other components primarily the lithospheric and hydrospheric components. During the process of weathering (that means water reacting with rocks and minerals) and erosion (removal or transportation of weather materials), some chemicals are transported in dissolved form and some are carried in solid

Table 1.2 Fluxes and reservoirs in hydrological cycle

Reservoirs	Transfers
Ground water and soil (15, 43)	Biospherea Oceansx
Biosphere (0.002)	Lakes and Rivers Ground water
Lakes and Rivers (0.127)	Run-off (0.036) Precipitation (0.107)
Atmosphere (0.0155)	To and from all reservoirs
Ice caps (43.4)	Evaporation; (0.071)
Oceans (1400)	Precipitation: (0.398) Evaporation (0.434)

All numbers are in units of million km^3. Transfers without numbers are qualitatively and locally important. *Data from Berner and Berner (1996)*

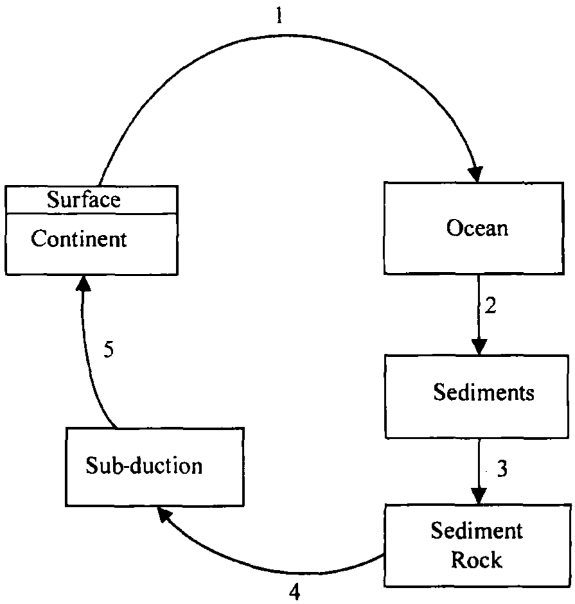

Figure 1.3 The rock cycle. (1) weathering and erosion; (2) deposition in oceans; (3) burial and compaction; (4) sub-duction under ocean-continent boundaries; (5) up-liftment/volcanic activities.

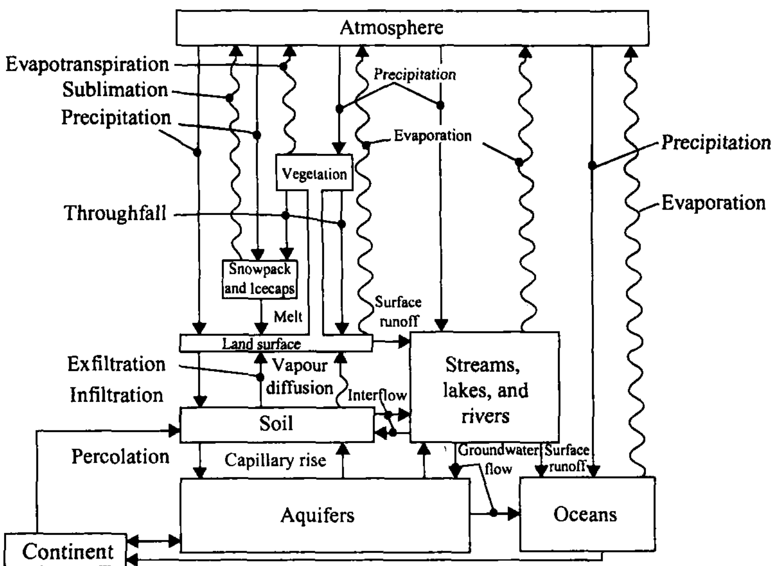

Figure 1.4 Geochemical cycle. Various sub-segments that move water and the solute and sediment load in the cycle. Not all are at the same degree or time scale of importance. The cycle essentially represent the movement of water and hence whatever it carries. *(Adapted from Engmann and Gurney, 1970)*

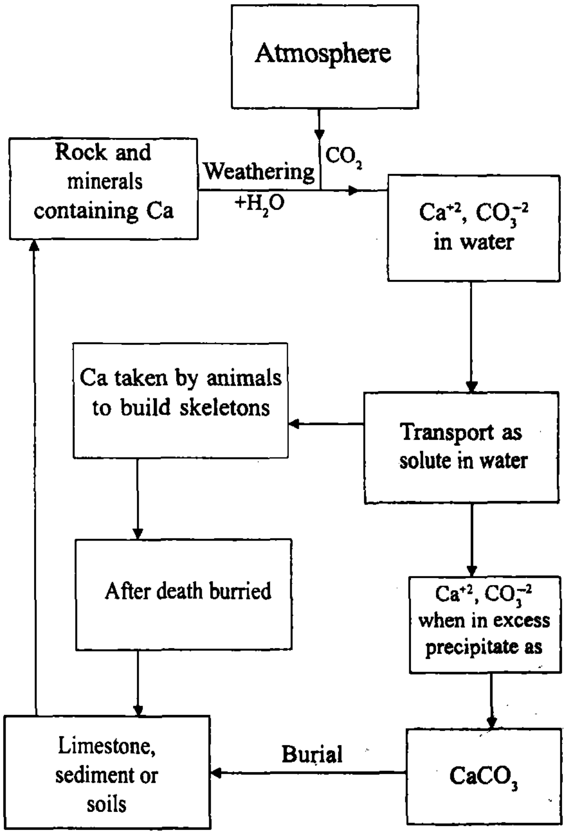

Figure 1.5 Example of geochemical cycle for Ca. For other elements, some part of the cycle may be more important than other parts. Note both the organic and inorganic role of Ca.

or sediment form. Geochemical cycle tries to interpret the processes involved in these interactions and the fate of individual elements in the environment. In a typical case, a mineral is subjected to chemical interaction with water and looses out some constituents to water as solute component. A simple mineral such as $CaCO_3$ (calcium carbonate or limestone) upon reaction with water will release certain amount of Ca ions (Ca^{++}) and carbonate (CO_3^-) ions to water; both these solute phases will travel in the water till such time they are removed either due to some other chemical interaction in the water or due to precipitation, due to supersaturation, of $CaCO_3$ from water. Geochemical cycle traces the pathway of individual elements through the various "spheres" and removal and addition are followed up all along. Figure 1.5 illustrates the geochemical cycle for a common element Ca.

BIOGEOCHEMICAL CYCLE

As the terminology implies, biogeochemistry is a border line subject involving three basic branches of natural (bio-), earth sciences (geo-) and physical (chemistry) sciences. On one hand living organisms

Table 1.3

Stage 1	Elements according to the need: *Essential elements*—example, Carbon (C), Nitrogen (N), Phosphorous (P) *Minor elements*—example, Sodium (Na), Potassium (K) *Trace elements*—example, Iron (Fe), Copper (Cu) *Toxic elements*—example, Mercury (Hg), Arsenic (As)
Stage 2	The availability of the above mentioned elements from: The earth generally from the top few centimeters (cm) of the soil profile
Stage 3	The physico-chemical mechanisms that make the needs: Of the biological systems from the pedospheric layers Of the earth in response to micro-environmental Changes in parameters such as pH (acidity), Eh Redox potentials, chemical interaction of water Soil mineral matter and water

are involved and on the other, substances such as nutrients are made available to these organisms either through soil (pedosphere) or through water (hydrosphere). Of course there are certain organisms that can get their nutrients through the atmosphere. The living organisms while differing vastly among themselves in size, morphology and physiology, share all the same a basic feature common to all of them that is their ability to metabolise their requirements in the habitat they live. Since matter contained in life is cyclic, all processes involving living matter has also got to be cyclic. As was shown in the earlier figures, all the segments or reservoirs are linked to each other in both directions that means, in each reservoir, something goes in and something else comes out. In the biogeochemical cycle, elemental transfers are involved with the organic world playing a central role. Hence, such transfers can be viewed in three stages as shown in Table 1.3.

Let us illustrate the biogeochemical cycle using carbon as an example. In the biosphere, carbon is present as the building block of plants and animals in the form of a number of carbon compounds such as carbohydrates, proteins, amino acids, humic acids, sugars and peptides. Carbon enters the biological system either through geological processes (weathering of carbon bearing minerals or rocks such as limestone (see Figure 1.5) or chemical processes directly from the atmosphere through photo-synthesis. When the organisms dies out (decay) the carbon is released back to the atmosphere or when the organic compounds break up aerobically (under the influence of oxygen) or an-aerobically (in the absence of oxygen) or the carbon in some form or the other gets incorporated as a mineral matter (limestone) or coal so that it is returned to the lithosphere. There are two forms of carbon-organic form that constitutes the biomass and the inorganic form that travels in water as bicarbonate (HCO_3^{-1}) or in soils as $CaCO_3$ or present in the atmosphere as CO_2 or CO. The biogeochemical cycle of carbon is simplified in Figure 1.6.

Various processes that transfer both organic and inorganic form of carbon are shown to give some ideas about interaction among the various reservoirs in the system. While the cycle shown can be seen as a global scale process, the biogeochemical behavior of essential elements may be looked upon in a local scale also such as transfer of Phosphorous between soil, plant and water in an agricultural field and the transfer of CH_4 (methane gas) between soil, plant and atmosphere in rice field and swamps.

The oldest carbon-bearing organic world known to man so far is about 3.5 billion years (3.5 thousand million) old whereas the age of the earth at present is estimated to be about 4.5 billion years. In spite of the complexity of the various processes shown in Figure 1.6, carbon is being cycled through our

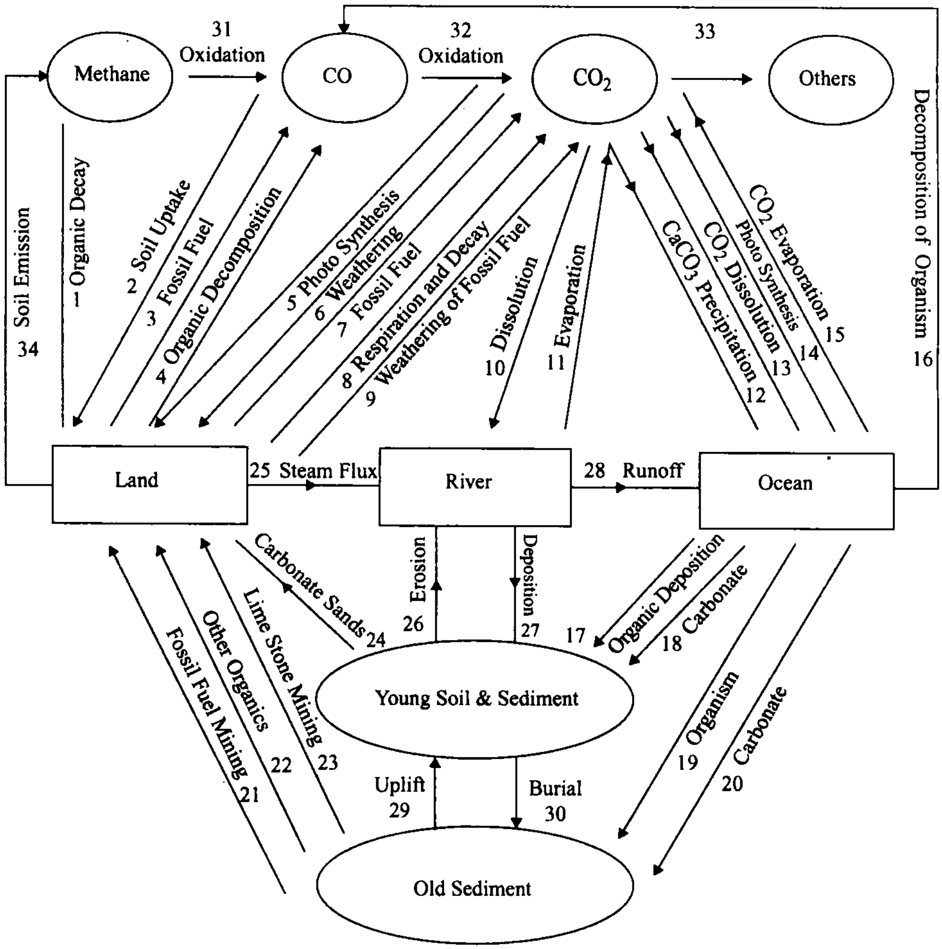

Figure 1.6 The carbon cycle. Note the quantity of various transfers across interfaces. Both inorganic and organic carbon are involved in the cycle. Simplified after *Berner and Berner (1996)*

environment relatively un-affected through such a long geological time though in recent decades due to fossil fuel burning (thermal power plants) and other large scale activities, the carbon reservoir and transfers to and from atmosphere is particularly getting affected. We will deal with this topic in detail in a later section on air pollution. From a single cell amoebae some 3.5 billion years ago, organisms progressively went through complex biological evolution as a function of geological time in response to changing external environment and hence changing habitat. The link between time and evolution is established through changes such as CO_2 levels in the atmosphere prevailing at a given time CO_2 levels, availability of nutrients such as N and P. Geochemical evidences through rock records show that about 2.5 billion years ago, the atmospheric CO_2 was at least 100 times higher than today and O_2 levels negligible compared to present day levels. Hence the various segments shown in Figure 1.6 have been continuously interacting with each other through such vast time scale maintain to the cyclic behavior of carbon and other elements. Excessive constituents in any one segment was removed over a period of time to other segments so that the overall biogeochemical behavior of individual constituents are not affected.