

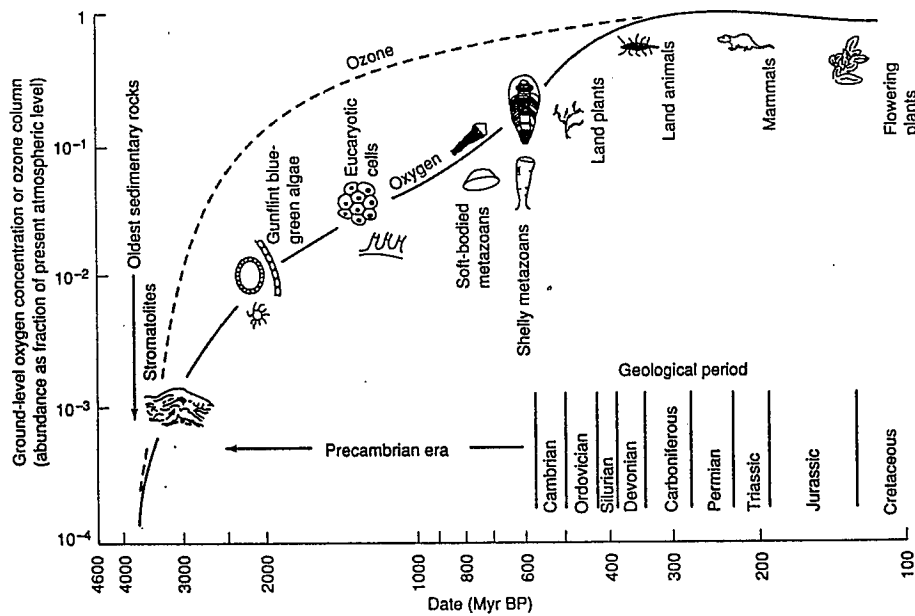
### *Teacher Background Information: The Earth in Space*

**Introduction:** Like the lapis lazuli gem it resembles, the blue, cloud enveloped planet that we recognize immediately from satellite pictures appears remarkably stable. One intuitively thinks of the chemical constituents of the Earth as being among the few constant properties of a changing world. It is clear now that they must be regarded, like the Earth itself, as having evolved through a number of different stages over a long period of time. The evolution has occurred as a result of perturbations or variations in chemical cycling between all the components: the atmosphere, oceans, the solid surface, by tectonic activity and modification due to volcanic activity, by changes in the intensity of solar radiation and by the interplay of the atmosphere with the flora and fauna. An understanding of the concepts of change, stability and instability within the system are crucial to the study of Earth system science.

Constant change has characterized the Earth since its beginning some 4.5 billion years ago. The composition of the Earth is the natural by-product of energy generation in stars and successive waves of stellar birth and death in our galaxy. We can learn much about the materials from which the Earth was formed by the simple act of picking up a pen. Made of carbon compounds and metals, the pen--- and indeed the Earth itself--- is representative of the cosmic pattern of abundances. Except for hydrogen and helium, which easily slip the gravitational grip of a small planet, the elements of the Earth are the elements of the Universe, formed by stars and dispersed throughout the galaxy. Whereas the Sun is 99 percent hydrogen and helium, the 1 percent of more complex nuclei include traces of iron and other heavy elements. Thus, the solar system must have formed from elements synthesized by previous generations of stars. Like silver candlesticks from your grandmother, we have inherited the carbon and oxygen produced by ancestral stars.

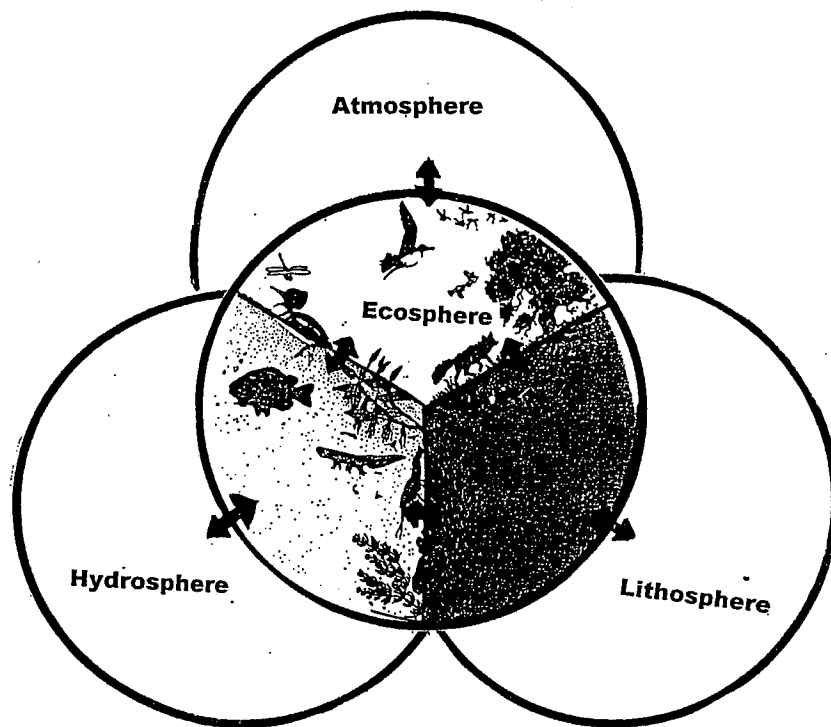
From the onset, heat and gravity shaped the evolution of the planet. These forces were gradually joined by the global effects of the emergence of life, the assemblage of organisms which was allowed to crawl out of the oceans and to be sustained by the formation of the atmosphere. The details of the evolution of the original atmosphere are debated. In reality, we have no direct information on the chemistry of the hydrosphere or the atmosphere for the first 99.9% of Earth's history. Some facts, however, are relatively certain. For example, it is evident that carbon dioxide played a crucial role; it was available to assist in maintaining surface temperatures within the liquid water range which ultimately allowed life to develop and maintain itself. The other major components were nitrogen, hydrogen and water, with perhaps smaller amounts of hydrogen sulfide, ammonia and methane. There was originally no free oxygen. As life developed, interactions between the different spheres of the Earth's system eventually gave rise to increasing levels of atmospheric oxygen and ozone, which began to shield the

surface of the planet from lethal ultraviolet radiation. This shielding eventually permitted enhanced biological evolution on land. With the existence of water rich, oxygenated atmosphere, climate and chemistry were capable of playing important roles in the Earth's physical, chemical and biological development. They were in turn affected themselves as that development assumed scales comparable with those of nature.



A reconstruction of the evolutionary development of the oxygen and ozone in the Earth's atmosphere.

The *Earth system* consists of many interacting *subsystems*, including the ocean, air and land. The specific constituents of these subsystems are interdependent and any study of them is highly interdisciplinary. Clearly, then, a definition of the Earth system is not fixed--- it has a fluid dimension--- its extent depends on the time scale and the myriad of variables being considered. Although many details are unknown, we do know that the Earth and the materials that compose it are finite, that there are relatively fixed supplies of certain elements, or nutrients, which are essential to life and which circulate in the environment. These materials are physically transported (via wind and water, for instance) to places where they are needed, and by means of chemical transformation are cast into forms taken up by life. These nutrients move in biogeochemical cycles, a term that describes the interaction of life, air, sea, land and the Earth's chemical compounds. One way that climate makes its influence felt is by regulating the flow of materials. The nutrients help to determine the composition of the atmosphere, which, in turn, determines the climate.

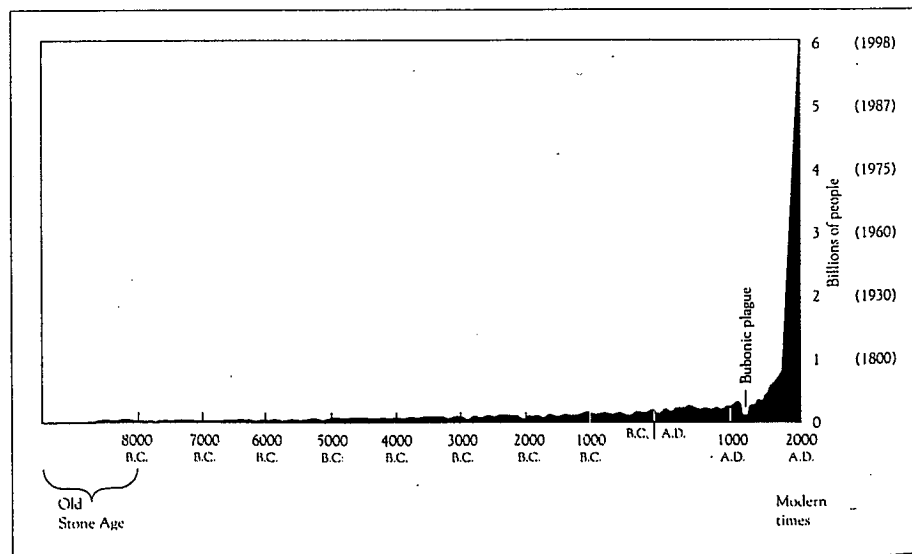


The Earth's *climate system* is one of the subsystems, as characterized by available solar energy, temperature and precipitation. Most discussions of the Earth's climate system, as intricate as it is, center around its physical entity, made up of air, water and ice. Climate also influences --- and is influenced by life on Earth. Therefore, a wider definition of the Earth's climate also encompasses its life forms. Climate history over the past 4.6 billion years is recorded in rocks, fossils and other records, and as with the system as a whole, do not support a notion of constancy; rather they depict a world in which climate change, rather than constancy is the norm.

The ability of early organisms to survive in world very different from the one we know today depended on their finding the appropriate ecological niche in which the proper chemical and physical environment was available. Over the geological long-term, life has contributed to the evolution of the environment, just as the changing environment has shaped the formation or sustainability of the organisms. Despite perpetual debates over the how life started and the precise mechanisms of its evolution, life and the environment, more specifically climate, can be said to have coevolved; their mutual influence is well established over geological history. If we humans consider ourselves part of life ---that is part of this natural system --- then it could be argued that our collective impact on the Earth means that we may have a significant coevolutionary role in the future of the planet.

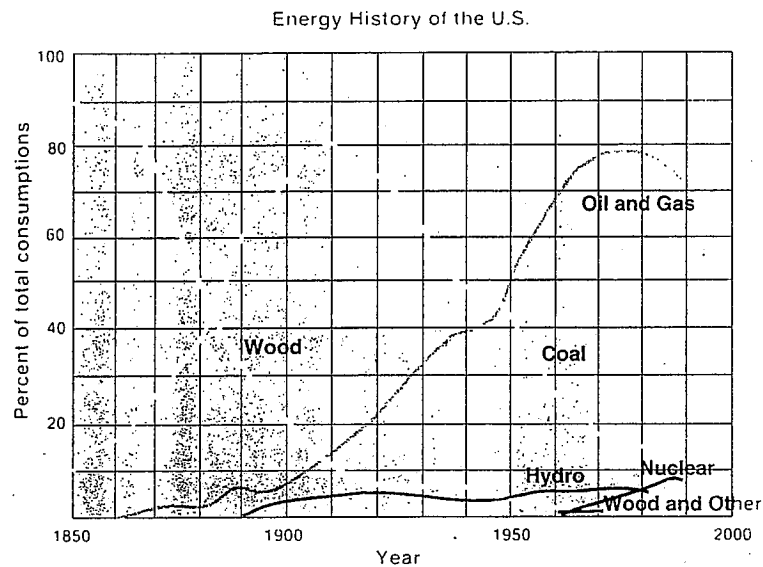
The climate change that may be occurring now is disturbingly different from the relatively slow, steady cycles of ice ages and interglacials that have sculpted the face of the Earth over the past two million years. It is being caused by a prolific and industrious species bent on maintaining a productive but affluent lifestyle. In a way, it should not be surprising that *Homo sapiens* should have such an impact on the dynamics of the Earth's system. But the human impact has been amplified to an extraordinary degree not only by our numbers, but also by our ability to fashion tools and technologies that increase our power to change the world. Here is a species that began by taming fire and has since learned to replicate the fusion energy of the Sun in a hydrogen bomb.

Along the way, humans discovered the vast stores of energy locked up in subterranean pockets of oil, coal and natural gas ---- the fuels that stoked the boilers of the Industrial Revolution and still power our productive but prolific lifestyle today. Just since World War II, the economic output of the industrialized countries has increased over five times. But there has been a hidden cost. All of that combustion ---- in power plants and factories and automobiles --- has transformed hundreds of billions of tons of ancient buried carbon into a great burst of carbon dioxide gas that is significantly altering the atmosphere. The incineration of forests worldwide, by releasing more carbon dioxide, has added greatly to the problem



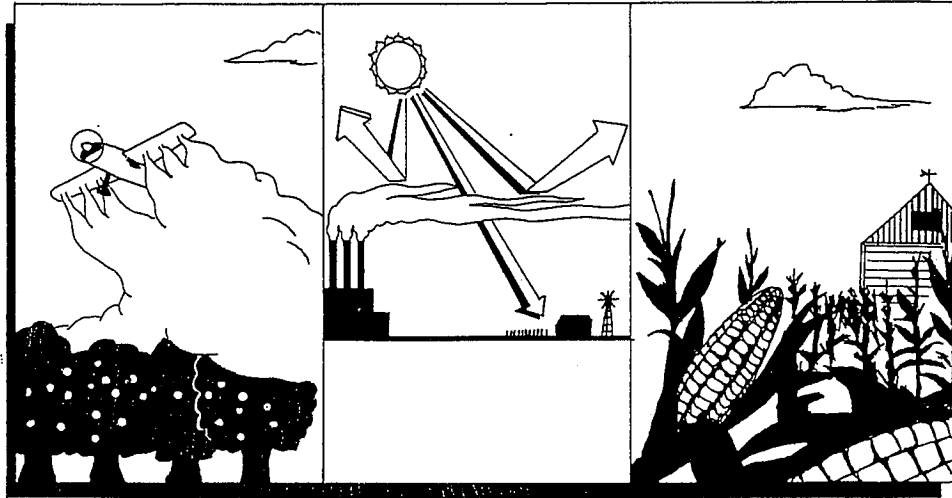
The current trends of population growth, the demands for increased standards of living and the use of technology and organizations to attain these growth oriented goals all contribute to the pollution of the system. In the United States in 1989, a total of about 4.5 billion metric tons of natural resources was consumed --- about 18 metric tons per person. Construction materials accounted for about 1.8 billion metric tons of the total, energy fuel for another 1.7 billion metric tons, and food (meats and grains) for about 317 million metric tons.

Consumption in 1989 also included 317 metric tons of industrial materials, 109 million metric tons of metals, 157 million metric tons of forestry products, 107 million metric tons of nonrenewable organic materials such as asphalt and chemicals, and 6.7 million metric tons of natural fibers. Americans consume 22 percent of the world's oil, even though they make up just 5 percent of the world's population. We live in a time when one person commutes to work in an automobile that typically expends the energy consumed by 140 horses. In a year, a typical consumer's car burns so much gasoline that it releases more than three times its own weight in carbon dioxide into the atmosphere.



This pattern of consumption in the developed countries (i.e. United States) generally appears self-indulgent to developing countries still struggling to meet basic human needs for many of their people (i.e. India). For example, in the United States, where the average annual income is reported at \$19,309, residential homeowners spend about \$7.5 billion a year to care for their lawns and families spend about \$9 billion a year on video games for their children. In India, with an average family size of about 5, the reported per capita annual income (based on purchasing power parity) is about \$601 or \$3500 per family of five. Most of India's 850 million people do not even meet their basic minimum food, clothing and shelter needs, tap water is available to only 35 percent of urban households and 18 percent of rural households, and sanitation services to only 37 percent of urban homes and 8 percent of rural homes.

Both of these resource use patterns take a heavy toll on the Earth's natural resources. In the affluent developed countries nonsustainable consumption patterns over long periods of time are being promoted at every level of society and depleting stocks of nonrenewable resources. Developing countries are simply attempting to guarantee the basic needs for the majority of their people, while avoiding those unsustainable patterns. Unfortunately, their large and growing populations are increasing the pressure on already overtaxed natural resources such as forests, grasslands and rivers, in some cases to the point of destruction.



Disrupting Chemical  
Cycling Systems

Changing the  
Flow of Energy

Reducing  
Diversity

As a result, over the past 100 years, the atmospheric concentrations of heat trapping gases has risen 30 percent and by the latter half of the next century, it is likely that the amount of carbon dioxide will have doubled from pre-industrial levels. Moreover, other heat trapping gases such as methane, nitrous oxide, and CFCs generated by human agricultural and industrial activity have risen and are expected to eventually equal, if not exceed the warming effect of carbon dioxide. Thus, an era has been initiated in which humans are longer simply polluting a lake or a river, or cutting down a particular forest, but changing the composition and possibly the dynamics of one of the essential components of the planet --- the atmosphere. Because of the intimate link between the atmosphere and the Earth's other components ---- the oceans, the soil, the sheets of ice at the poles, the flow of energy from the Sun, and the web of life itself, humans have, in an instant of geological time, taken hold of the reins that will guide this rare blue sphere into an uncertain future.