Geobiology and geomicrobiology: importance and need for studies in the Indian context

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The discovery of life on another planet would represent the greatest scientific and ultimately societal event of this century, and perhaps of all times[1]. The recent discoveries of microbes that thrive in extreme environments (such as hydrothermal vents/deep ocean floor) have improved our understanding about how life might have begun on earth, and have strengthened the perceived probability that similar kinds of microorganisms/life forms may exist on other planets. Such grand and exciting scientific discoveries are now possible because of advances in the fields of geobiology (the study of the interactions that occur between the biosphere and the geosphere) and geomicrobiology (the interaction between microorganisms and their metabolic processes with geological and geochemical processes).

Geobiologists aim to understand how life originated and evolved. Furthermore, they aim to identify how environmental conditions influence these processes and how these processes have influenced their environments. The earth is like a natural laboratory and many 'experiments' have already been conducted over the course of its evolution. Current and future investigations will improve our ability to understand the relevant records, interpret them and make predictions, and thereby have a more detailed understanding of the complete history of the earth.

Geomicrobiology requires varied expertise in subjects ranging from geology, geochemistry, mineralogy to microbiology, and microbial ecology. In nature, geological and biological processes are not separate, and they influence each other in profound ways. Microbes have lived at the earth's surface for most (about 85%) of the time since the earth was formed. There is now general agreement about the importance of microbiological activities in shaping the earth's hydrosphere and atmosphere. However, it is only in the past decade that geologists, microbiologists, geohydrologists and geochemists have recognized the significance of these microbial activities. Microbes affect and are affected by virtually all geochemical processes that occur at the earth's surface, as well as deep within its subsurface. For example, they drive the earth's global biogeochemical cycles (C, N and S), mediate mineral dissolution and precipitation, and facilitate aqueous redox processes.

There are many potential practical and scientific benefits that might arise from the study of geobiology outlined below.

Biogeochemical cycles: It is clear that microorganisms are an essential part of the bio-geocycling of elements (C, N and S) between the surface of the earth and the surrounding atmosphere.

Waste cleaning and degradation: Bacteria are used to clean up oil spills and polychlorinated biphenols in water/soil.

Metal mobility: Certain microbes have proven ability to transform toxic, soluble metals into insoluable ones by their mediation by affecting the redox process.

Bioleaching: This is a biochemical process by which specific metals in the ores can be concentrated. It is commonly used in the gold and copper mining industries by employing certain specific bacterial species. During these microbial feats, obviously these bacteria gain energy during the process of concentration of metals from the ores.

Understanding climate change: Clues to global warming are likely to lie inside microbial cells, since multitudes of these tiny organisms emit and deplete enormous amounts of gases (e.g. carbon dioxide and methane) that trap heat around the earth.

Cave geomicrobiology: This field deals with the microscopic life that resides in caves and its interactions with minerals, including mineral dissolution/precipitation. Speleothems can be used like ice cores to provide a proxy record of past climate changes.

Energy security: Microbes in the organic-rich sediments under the ocean floor produce huge amounts of methane gas. Researchers estimate that this methane store amounts to about twice that of recoverable gas, oil and coal deposits on the entire planet. The trapped gas which exists in crystalline form combines with water in the form of methane hydrates.

Extraterrestrial matter: Geomicrobiology is not only important for life on earth, but may be important in astrobiological studies. In 1996, scientists announced that they had found what they believed to be fossils of tiny microbes in a meteorite from Mars. The discoveries of microbes that thrive in extreme environments have expanded notions about how life began on earth and strengthened the perceived probabilities that similar microbes may exist on other planets.

New light has been shed on some geological puzzles by looking at them through a biological lens. For example, banded iron formations (BIFs) are one of the most abundant chemical precipitates from the Precambrian period. The unique feature of BIFs is that these sedimentary rocks are no longer formed like during the Precambrian period, and consist of repeated thin layers of iron oxides with bands of shale and chert. These rock records provide clues about the ocean and atmospheric chemistry, sea-floor hydrothermal activities and the sediment microbial communities during the Precambrian period. There is still no agreement among geoscientists about how BIFs are related to the ancient environmental conditions. Some geochemists believe that BIFs could form by direct oxidation of iron by autotrophic (non-photosynthetic) microbes. The conventional concept is that the banded iron layers are the result of oxygen released by photosynthetic cyanobacteria, combining with dissolved iron in the earth's oceans to form insoluble iron oxides. It is estimated that the total amount of oxygen locked up in the banded iron beds is perhaps 20 times the volume of oxygen present in the modern atmosphere.

Another example of such a geological puzzle is the mineral dolomite. There was a time in geological history, when dolomite was formed on the earth in great quantities, e.g. the Dolomite Mountains in the Italian Alps. Dolomite precipitation is mediated by a group of sulphate-reducing bacteria. Currently, dolomite is formed in only a few selected locations such as salt flats and lagoons. Its mineral composition includes magnesium, calcium and carbonate ions, which are common enough in sea water, but the conditions necessary for arranging these components in the ordered, alternating layers that form dolomite are not common today. These conditions and the group of sulphate-reducing bacteria may once have been far more prevalent.

The study of geobiology in India is increasingly necessary and important as the country undertakes its first Arctic expedition to study bacterial life and climate change along with interdisciplinary research on areas like glaciology, biology, geology, marine science, aurora physics, environmental science and rocket-probe studies. The Arctic environment is believed to be a huge reservoir of hydrocarbon and mineral reserves. This expedition is the first step in India's Arctic research programme and the plan is to send a full-fledged oceanographic expedition using the country's own research vessel to the region by 2009. The research base 'Himadri' will function under the coordination of the National Centre for Antarctic and Ocean Research, Goa[2].

India has established its presence in Antarctica since December 1981, when the first expedition sailed from Goa. Since then, the Department of Ocean Development (now the Ministry of Earth Sciences, Government of India) has been launching annual scientific research expeditions to Antarctica to study issues relating to palaeoclimate, atmospheric science, depletion of ozone layer, etc. Various disciplines of polar science research are being covered by India in Antarctica, such as atmospheric science, biological, earth, chemical and medical science. Geobiological studies of the Arctic and Antarctic could be included in these research programmes to understand about life under extreme conditions. Another practical example where knowledge of geomicrobiology can be used is the arsenic contamination in West Bengal, as there are increasing evidences that this is a geomicrobiological phenomenon and most of the work has been carried out so far by hydrogeochemists and not by geomicrobiologists[3]. Another interesting area of research is the interaction between the geosphere and biosphere in the extreme environments found in the deep seafloor in the Indian Ocean. Many such areas can be identified.

Our understanding of the role of organisms as geological agents is still in its infancy, and exciting discoveries and advances in geobiology and geomicrobiology are likely to come from all areas of these expanding disciplines[4]. In the Western world, rapid changes are taking place. Some of the institutions where geobiological and geomicrobiological research has been given prime focus include the following: the Geological Society of America has established a Geobiology and Geomicrobiology Division; the University of Bergen, Norway has started a Centre for Geobiology (Norwegian Centre for Excellence) and the University of Aarhus, Denmark has started a Center for Geomicrobiology. Formal geobiology programmes[5] are offered by the Arizona State University, the California Institute of Technology, Harvard University, Indiana University, Ludwig–Maximilians University of Munich, Massachusetts Institute of Technology, Rutgers University, the University of California, the University of Illinois, the University of Oxford, the University of Rhode Island, the University of Toronto, and the University of Western Ontario. Formal geomicrobiology[5] programmes are offered by Louisiana State University; Miami University; the University of Bristol; the University of California, Berkeley; the University of Idaho; the University of Illinois; the University of Kansas; the University of Oklahoma; the University of Texas; the University of Wisconsin and Washington University. The National Science Foundation, USA[6] has recognized the importance of measuring and understanding the processes and dynamics that shape the physical, chemical and biological environment and has been funding geobiological research for several years.

In the Indian scenario, geologists are not trained in microbiology and vice versa. DST, New Delhi, in its vision paper on earth sciences[7], has emphasized interactive geoscientific studies – 'Increased understanding of the earth processes as well as emerging newer concepts and methodologies requires interactive research programmes involving geoscientists, physicists, chemists, biologists and mathematicians'. Geobiology is not specifically mentioned as a thrust area and therefore there is an urgent need to initiate such studies. This pioneer field should be recognized as a thrust area and should be strongly supported as one of the new, important frontier areas of knowledge. Geobiology is not yet included on the model curriculum list of the approved UGC courses[8]. Therefore, there is an urgent need to offer formal programmes in geobiology/geomicrobiology at the postgraduate level, so that the Indian students have the opportunity to explore this frontier area of research.

We believe time is ripe to solemnize the marriage between geology and biology, rather than allow the casual dating. Philosopher–historian Will Durant in the 19th century stated: 'Civilization exists by geological consent, subject to change without notice', but with advances in geobiology, we are coming to the realization in the 21st century that 'Civilization exists by geo-biological consent', of course subject to change without notice as geology affects biology and vice versa, and together they affect the hydrosphere and atmosphere. We may conclude that geobiology is a tool which can be applied to answer fundamental questions with applications on earth and beyond.

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