

Of course depending upon the width of the inhabitable belt, as the day will pass the temperature will vary, perhaps much more than what we are used to between various seasons on Earth. To escape the rising heat or the impending cold, the population would be forced to migrate towards darker or brighter sides, depending upon the time of the day, perhaps for hundreds or thousands of kilometres, depending upon the temperature variations and the size of the planet and width of the dusk band. We on Earth have day-night cycle with working or sleeping hours. With no day-night cycle, denizens of the tidally-locked planet would perhaps not evolve with sleep as a necessary ingredient of their daily life. Even on Earth there are perhaps many species, e.g., ants, which never sleep and work ceaselessly. May be denizens of the tidally-locked planet will also work incessantly their whole lives, migrating from one place to another without pause or stop. Rest assured there might be no rest for the whole day on such a planet. With no day-night cycle, no sleeping and waking hours, no office or school going daily routines followed by leisurely weekends, with perhaps hardly any diversions and adding to it the drudgery of restless migrations from one place to another, the life might sound dull to us denizens of the present-day Earth, but to the denizens of the tidally-locked planet it might not sound so boring as they would have evolved within a very different system with a very different “life-style”.

Further Reading:

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**Introduction:**

Chemosynthetic microbial activity could share similarities between Martian and Earth systems. Recent discoveries on Earth suggest that wherever there is organic matter, water and energy, there is also life existing over a broad range of temperature, pressure, pH and other environmental conditions. As these factors are also common in space, it is possible that there is life in the outer space [e.g., 1]. Mars, the planet that most closely resembles Earth, shows evidence for water, past or present, and could be the focus of searching for life in the form of prokaryotes. Besides, the red colour of the planet is attributed to the dominance of oxidized Fe content. On Earth red clays are believed to be aeolian (wind-borne) Fe-rich dust deposited over geological time on land or on the sea-floor. Similar situation may be expected on Mars. However, more details can be known after mission data like that of Curiosity and our very own Mars Orbiter Mission (MOM) is examined. The greater part of Mars is arid and shows evidences for volcanic activity [2]. Some of the other characteristics that could resemble life on Mars include oligotrophy and chemosynthesis based on redox chemistry of metals in Central Indian Basin (CIB) sediments. The surface of Mars at present may be too harsh and this UV-bathed surface may be microbially sterile. Signatures if any could be only belonging to microbial fossil relicts here. However, deeper below, away from sunlight microbial life may still be persistent in case free-water or mineral-bound or chemically bound water is available. It is to be recalled that life on Earth exists in the deep-biosphere thousands of meters below land surface or the deep-sea floor. In such locations chemosynthetic mode of survival is the one way of life that has been understood so far. The present study therefore examined the patterns of distribution of chemosynthetic bacteria in the deep-sea red clay sediments of CIB along with chemosynthetic rates and Adenosine Triphosphate Profiles (ATP) and sediment properties as a prelude to drawing parallels between Earth and Mars systems as and when samples from Mars missions would be made available.

Chemolithoautotrophy and Martian Life:

Chemolithoautotrophs are those microbes capable of fixing inorganic carbon, CO₂ into living material by means of energy produced from an oxidation reaction of an inorganic compound. On Earth, there are many groups of such microorganisms. Some respire aerobically using O₂, but many operate anaerobically using NO₃ as a terminal electron acceptor in respiration instead of O₂. Other kinds of bacteria can also use sulphate, carbonate/carbon dioxide and carbon monoxide, or oxidised iron or other metals as terminal electron acceptors in respiration [3]. In order to test the possibilities suggested by hypothetical scenario for extant or relatively recently extinct Martian life two sets of

information may be required. First, we need more information bearing on the likelihood of geothermal or volcanic activities on Mars. Second, the Observer Missions should provide us with further information on the presence of near surface water. In addition, we need information on the water content of the deeper subsurface of Mars. Such information may not be available until actual on-site drilling takes place during a rover or other sample return mission [3].

Central Indian Basin sediments as potential Martian Analogues:

It may be difficult to get identical Martian analogues on Earth especially under the deep-sea in the first instance. However, the argument that Earth and Mars had similar origin and hence there could be similarities in the chemical composition of the two systems cannot be ruled out. Consequently, there could be similarities in the early life viz. microbes if existing on Mars. The following conditions make deep-sea pelagic red clays of CIB a potential Martian analogue:

- » Abundance of CO₂ below calcite compensation depth
- » Net upward thrust of fluid flow in seabed resembling subsurface flow in Mars
- » Temperature gradients in waters especially during volcanic explosions
- » Iron in oxidized state
- » Saline condition of at least 35 ppt or more
- » Very low organic matter < 0.1% of total sediment weight

The Approach:

Our present approach is to consider the possibilities of defining and quantifying analogous microbes and their processes among the presently available deep-sea data and the little currently available Martian data [4, 5, 6; Das, unpublished;] and to continue comparison with the on-site Martian exploratory data in future. For this futuristic approach it is necessary to re-analyse the Microbial Ecology, Genetics and Energetics data of CIB and maintain these Earth-Analogue Data Archives for comparing with actual Mars On-site Data as and when it would be made accessible. This would be done in the following two steps in the first phase of Earth-Analogue Data Archiving Process:

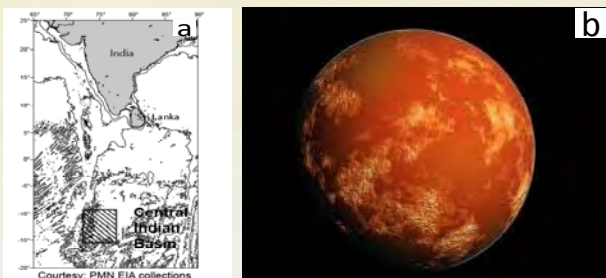


Figure 1: The Fe³⁺ dominated Red Sediments on (a) Earth [Red Clay Area (RCA) of Central Indian Ocean Basin, Courtesy: Polymetallic nodules- environmental impact assessment program, NIO-Goa, India] and (b) Mars [Courtesy: Google images]

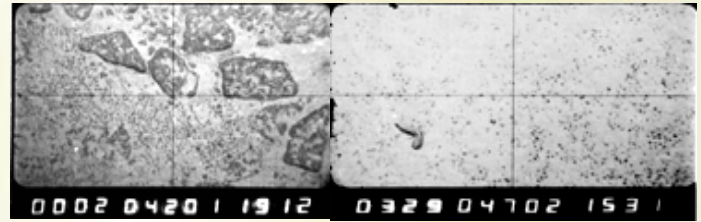


Figure 2: Images of the deep-sea sediment of the Central Indian Ocean Basin

- » Decipher patterns of genetic and biogeochemical constitutions of deep-sea red clays
- » Strengthen base reference in present CIB for comparison with Mars samples in future

In the second phase of actual Mars On-site Data Generation (possibly during future Rover Missions) these archived data could be useful for first order comparison:

- » Find analogy between present deep-sea data archives and future Martian on-site revelations
- » Draw plausible parallel between two planetary systems in future missions
- » Throw light on universality/commonality of Origin of Life on the two sister planets

Parameters examined in red clays to be extended to analogous processes on Martian planet:

The following parameters crucial for analysis of microbial biogeochemistry are used in the present deep-sea analogue studies and would be implemented for actual Martian soil samples in future:

- » Microbial abundance in terms of total counts
- » Diversity of culture dependent and independent Chemosynthetic bacteria
- » Dark fixation of CO₂ as proxy for microbial chemosynthetic activity
- » Community composition RFLP/ DGGE/ 454 pyrosequencing
- » Energy flow in terms of ATP (Adenosine triphosphate)
- » System sustainance in terms of heat-photon flux calculation

Salient results towards the analogue studies:

Chemosynthetic bacteria in CIB red clays: Some of the cultured isolates showing potential chemosynthetic activity from the red clays showed affiliation to *Halomonas* sp. W7-7 (99%), *Halomonas* sp. MAN K46 (99%), *Halomonas* sp. EB 312 (99%), Uncultured bacterium clone 24B33 (96%), Uncultured actinobacterium CN-1 SL2_EO5 (98%), *Dietzia* sp. WR-3 (96%), *Dietzia* sp. ice-oil-71 (99%), *Dietzia* sp. Mali 88-02 (98%), *Dietzia* sp. (84%), *Dietzia* sp. (96%), *Haererehalobacter* sp. (96, 94%), *Halomonas* sp. (98, 94, 90%), *Salinicola* sp. (93, 97%), *Brevibacterium frigoritolerans* (98%), and *Bacillus* sp. (98%). The values in the parentheses indicate the percentage similarity of genetic code of the sample bacteria of CIB to the genus name available from genomic databases.

- » *Chemosynthetic activity*: Prima facie results show highest carbon fixation (C-Fixation) in the pelagic red clays upto 10-10,000 nmol g⁻¹ dry wt day⁻¹. These observations could be indicative of enhanced chemosynthetic activity in the organically deplete but volcanically active area [4]. The only data available on chemosynthesis at present for comparison is the famous Viking I radiolabelled experiment data which was much disputed three decades ago. Carbon uptake of CIB red clays shows 100-100,000 radioactive counts. The same for Mars soils done earlier by Viking I robots [5, Bianciardi et. al, 2012]] recorded 10,000 counts. This result is pretty striking and indicates huge possibility of detecting Martian microbial life. The apparent “life-less” red planet shows more activity than the lowest readings in the deep-sea microbial activity on Earth.
- » *454 pyrosequencing*: Our pyrosequencing studies suggest that heat and light liberated in the process of the hydrovolcanic alterations could have supported even photosynthesis [Van Dover, 2000]. This inference is linked to the presence of high numbers of tags belonging aerobic anoxygenic phototrophic bacteria. Other rare genera which are believed to have shaped the planetary processes included psychrophilic, mesophilic (eg. Flavobacterium) and thermophilic (eg. unknown Thermomicrobia) forms. In the pyrosequence, data fragments of genomic sequences or tags are detected and matched with available databases to find out the taxonomic identity of a microbe. In Fig. 3, many cases show that the detected microbial sequences can be indentified up to phylum or order or family level but the genus or species may be new or unknown as yet. These sequences are labelled as unknown and the percentage of tags belonging to such unknown genera or species are plotted in Fig. 3.
- » *Evidence of methane and sulfur bacteria*: Presence of Desulfuromonas and Methylobacterium could indicate traces of processes involving the sulphur and methane cycles as they could occur in Martian surface/ subsurface. Their presence could indicate that either there could be a diffused flow of hydrothermally influenced fluids at present in these deep sea clays or they are remnants of once dominant genera during volcanic eruptions or micro-ecological successions following responses to post eruption geochemical processes.
- » *Adenosine Triphosphate (ATP)*: Anomalously high ATP in the range 100-10,000 ng g⁻¹. ATP is the universal energy currency of all living forms and profiles show its ubiquitous presence in CIB pelagic red clays.
- » *Numerical simulations*: Explicit finite difference model showed microbial nitrification-denitrification couple and enhanced chemosynthetic activity in the pelagic red clays in response to chemical phase changes due to hydrovolcanic alterations. Alterations could have occurred between 100-1000 year time scales before present. A focused jet of initial mass and heat flow could have got converted to a diffused flow with passage of time [Das

et. al, 2011].

- » *Heat-photon flux*: A question arises as to what supports the microbial biome in organically deplete red clay. Moreover why are there phototrophs in completely dark realms? We hypothesize that heat generated from hydrothermal crust cooling can liberate enough energy to support phototrophic microbes. This is a current subject of our research and we hope to come out with established formulations soon. The inhabitants of extreme environments like acidophiles in acid mine drainages, thermophiles in hot vents; psychrophiles in ice sheets are well-known and easily explainable. But microbes are also known to be strange inhabitants of the most unlikely environments like the phototrophs in dark realms. Such existence has been speculated by Van Dover (2000). However, these existences are not illogical but throw light into life's most uncanny secrets. Similarly unlikely analogues and anomalous populations in Martian and Earth environments may expose some hitherto unforeseen clues to the “Origin of Life” in planetary systems.

Discussion:

A fine time when India has successfully launched MOM, it is most appropriate for the scientific community besides space scientists to contribute towards finding suitable analogues of Martian soils, sediments and rocks. In a series of discussions with eminent scientists and scholars we realize that in this nascent phase of inter-disciplinary research many definitions and understanding are largely obscure to most of us. For example, sometimes even the term “Martian analogue” appears ambiguous. Many peers have often criticized the concept of “Martian analogues in deep-sea sediments”.

It possibly might appear to readers that we are trying to search Martian particles/ debris/ life units etc. (like the well known SNC (Shergottites, Nakhilites, and Chassigny) meteorite that had fallen from Mars to Earth, in the abyssal depths of deep-sea floor. Therefore questions arise about the elusiveness of the concept, the flaws in the preservation of the fallen debris and other associated ambiguity. We clarify that deep-sea clays could act as some sort of proxy for Martian red soil just as for example any mammalian carcass could serve as a proxy for human body for a start. The present hypothesis states that the deep-ocean red clays could be suitable Martian analogues. We don't imply that we are searching for any Martian debris in the deep abyss. Earlier, researchers have used many terrestrial analogues like Atacama Desert (Chile), Death Valley (CA), and the California Coast [Bonaccorsi et. al, 2010] for comparability with Mars soils. Many others have concentrated on under-sea volcanoes and vents and proposed them as extra-terrestrial analogues [Prieur, 2005]. But, to the best of our knowledge none have ventured so far into the extensive expanse of red clays in the sea floor which is intriguing. However, this is not surprising because largest amount of research energy was concentrated in vents or to coastal

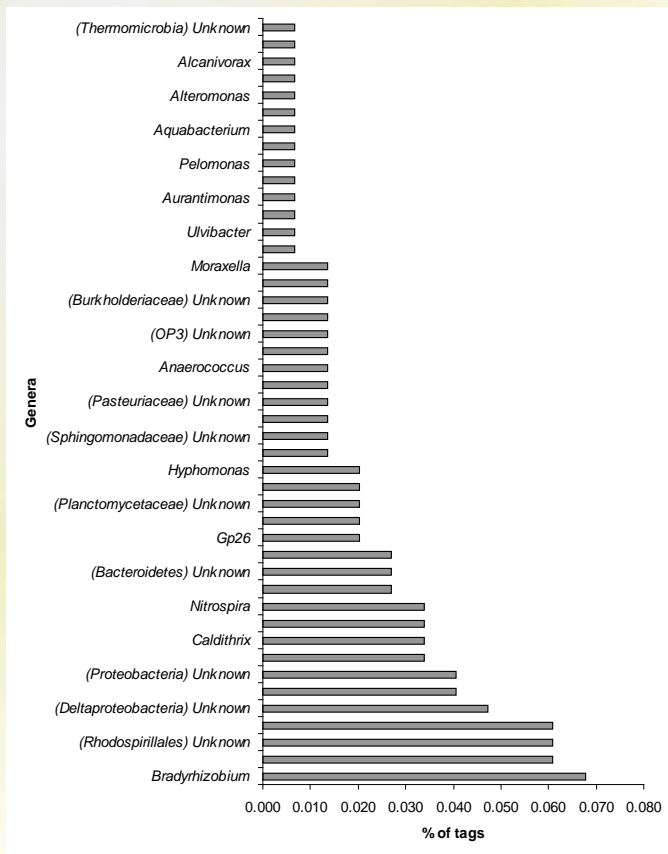


Figure 3: Rare bacterial genera of hydrovolcanically altered red clays of CIB. Note the presence of hyperthermophilic *Thermomicrobia* and anaerobic *Anaerococcus* in permanently cold and present aerobic environment, indicative of past geological events and activity

oceans as the red clays are far from the continents and not always logistically accessible. In fact the study of chemosynthesis in the red clays itself is very new [Das et. al, 2011]. To add an extra icing on the cake we also have a few low-temperature hydrothermally altered red clays [Nath et. al, 2008] from the CIB, making it convenient to analyze the microbial processes in red clays with and without volcanic signature. It would be pertinent here to mention that pressure is a significant parameter especially in the deep-sea due to the high hydrostatic load. However two things should be remembered with regards to microbial life under pressure. Microbial life per se is rather more dependent on molecular diffusion and other small forces rather than big forces like gravity and high hydrostatic pressure. So as such it could be a flawed criticism that a microbial cell would explode or implode due to hydrostatic pressure. A sub-micron level cell is too small to physically realize the effect of pressure unlike a fish or a blue whale or a human. However, what matters is the effect of pressure on enzymatic reactions which involve a series of changes in volumes of products and reactants that are in other words inversely related to pressure. Some reactions like first order reactions and radio-active decay are totally independent of pressure [Macdonald, 1975]. Thus the concept of pressure is far more complex and needs to be addressed according to which enzymatic reactions are involved.

Therefore for the first order detection pressure is less crucial, unlike temperature which directly influences rates of molecular diffusion and thereby the entire microbial life.

Another important proxy parameter is ATP, which is the biological currency of energy. It is the form of energy that most living forms use. However, some primitive microbes could survive on pyrophosphate molecules for their energy requirement. Detection of such molecules could be a proxy or signature of extant (presently alive) and active microbial life. Thus ATP measurement could be very crucial. In addition, the ability of technology to enhance the detection limits would enable researchers to detect sub-pico-molar range of ATP, a range more suitable for Martian environment. Thus, we would have in our data sets details of both hydrothermally altered and unaltered red clays. Upon analyses of the MOM data and comparison with the “Deep-Sea Analogue” experiments data and data from literature, the following new knowledge may emerge:

- » Low-temperature mineral fluid inclusions precipitated in the presence of microorganisms extinct or extant [Parnell et. al, 2002]
- » Potential autochthonous (unique to) aerobic or anaerobic chemolithoautotrophic inhabitants of Mars that survive through the oxidation of inorganic compounds and fixation of carbon dioxide [Cousins, 2010]
- » Possibility of numerous chemosynthetic pathways due to the disequilibrium and reduced chemical species that result from the mixing of high- and low-temperature fluids [Cousins, 2010, Gaidos and Marion, 2003]
- » Mars-specific chemolithotrophic metabolism - Theoretical possibilities and constraints to calculation [McCollom and Shock, 1997]
- » Geo-chemical models to evaluate the amounts of chemical energy available in potential biological environments like Martian hydrothermal systems [Vamed et. al, 2003]

Conclusion:

To conclude we may say that a large amount of geothermal energy is possibly getting converted to ATP during microbial redox reactions. Hydrothermal activity and associated rock alteration processes may be highly relevant in these deep-sea sediments and planetary systems like Mars. The high chemosynthetic potential could be attributed to reported volcanic activity in the vicinity of the pelagic red clay realm in the CIB. Red clays of CIB are possibly one among the nearest analogues to Martian systems, on Earth.

Future scope:

The analogies with deep-sea sediments aim at understanding:

- » The fundamentals of evolution of life on Earth and allied systems and possibility of extant life on Mars
- » Therefore it seeks the co-operation and collaboration with the payload projects of MOM especially the Mars Colour Camera (MCC), Thermal Imaging Spectrometer

(TIS), and Methane Sensor for Mars (MSM)

» It requests links to future space sample-return missions to Earth [Das et. al, 2011, Das et. al, 2012]

Acknowledgement:

The authors thank Director-CSIR-NIO, for support. Award of CSIR fellowships (JRF-SRF and RA for AD; SRF for BSM), PLANEX-PRL, MoES-GOI are acknowledged for financial support. Leaders and members of GAP 2128 and GAP2694, NIO-Goa were co-operative. Discussion with Dr. Shyam Prasad, B. Nagender Nath and Rahul Sharma, Geological Oceanography, NIO-Goa and comments from an anonymous internal reviewer helped improve the contents of the manuscript. Mr. S. Jaishankar provided the base map and MSc dissertation students, Jamuna and Gomati provided able technical assistance. Pyrosequencing analysis was carried out under the aegis of ICoMM (International Census of Marine Microbes).

Further reading:

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Introduction:

Radar is a useful remote sensing tool for studying planetary geology because it is sensitive to the composition, structure, and roughness of the surface and can penetrate most of the surface materials to reveal information about buried rocks or potential layering. Many of the planetary bodies of our solar system including Venus, Mars, Moon, Saturn's icy satellites, the icy Galilean satellites Europa, Ganymede and Callisto were studied using ground-based radio telescopes and orbital radar systems. For example, early work at Arecibo and Haystack Observatory in the 70's & 80's provided almost full nearside coverage of the Moon at 7.5 m, 70 cm, and 3.8 cm wavelengths. Observations of the icy Galilean satellites conducted during 1987-1991 with the Arecibo 13 cm - system and the Goldstone 3.5 cm system yielded significant improvements in our knowledge of the satellites' radar properties.

Radar polarimetry has the potential to provide additional information about surface physical properties beyond what can be obtained from single polarization backscatter measurements. Recent polarimetric imaging using Arecibo and Green Bank telescopes has included Venus and the Moon. Much interest in polarimetric studies of the lunar surface has been generated with the availability of data from two orbital polarimetric radars since 2009. In this article, starting with a brief background on the theory and observations, some of the unique and interesting results obtained from the polarimetric radar studies of the Moon are discussed.

Polarimetric radar:

The simplest form of imaging Synthetic Aperture Radar (SAR) transmits on one polarization, and receives on the same (like) polarization, like the radars on the Magellan and Cassini missions. Conventional dual-polarized radars transmit on one polarization, and then receive simultaneously on two polarizations, one being the same as that which was transmitted, and the other its orthogonal counterpart, known respectively as the like- and cross-polarized channels (Raney et al., 2011). In both of these cases, the primary data products received can be generally termed as 'images' since they do not include the relative phase between the two receiver channels. As a result, analysis of such datasets has to be carried out using minimal options like simply using the ratios or differences of their respective images. For instance, the radar on the Magellan mission to Venus measured only horizontal (H) polarization, except for a few orbits where the spacecraft was rotated to measure the vertical (V) polarization. The Cassini radar also operated in single polarization to probe the properties of Saturn's icy satellites.