



On the Prospect of Fossil Fuel on Planet Mars

Shawki Al Dallal

College of Graduate studies and Research,
Ahlia University, P.O.Box 10878

ABSTRACT

Planet Mars has long been a source of attraction to astronomers and scientists. In 1976, the Viking probes inaugurated the beginning of a new era in human history by searching for primitive lifeforms on Mars. Successive Martian missions have discovered evidence, in the form of dried rivers and lake beds, of the prior abundance of water on the Martian surface leading to conjecture that, millions of years ago, some kind of primeval lifeforms, supported by chemical and biological processes, are at the origin of formation of fossil fuel on planet Mars. One hypothesis even maintains that conditions on Mars, in its early history, resembled, to a major extent, the environment reigning on Earth in its embryonic stage. Petroleum has been the outcome of this natural environment on Earth. It is argued that nascent conditions on Mars developed a fertile environment leading to the formation of fossil fuel. The aim of this paper is to investigate the prospect of such hypothesis, and to examine the likelihood that subterranean resources being extant in Mars in view of the latest data gathered by Martian probes. Analysis shows that kerogen is a viable signature of the potential presence of fossil fuel on Mars, and this result comports with preliminary findings of the Martian Rovers.

Keywords: Fossil fuel, Planet Mars, Petroleum, Kerogen, Aqueous minerals, catagenesis.

INTRODUCTION

Fossil fuel is the primary source of energy on planet Earth. Its origin dates back to the early history of the planet. A study of the environment reigning on Earth during that epoch may shed light on the processes leading to the formation of fossil fuel. It turns out that these processes involve complex chemistry supported by some sort of bacterial lifeforms in aqueous surroundings. These findings can be generalized to include other solar system bodies exhibiting similar environment during a certain phase of their evolution. The presence of water is a key element in the search for lifeforms of any kind. Since the 1960s, space probes have visited all planets and other bodies in the solar system. On the 18th of November 2019, scientists gathered sufficient evidence to conclude that liquid water is present beneath the icy surface of the Jovian moon Europa with an estimated layer of water around 100 km, and an outer crust of solid ice of approximately 10-30 km in thickness [1] [2]. A salty ocean was discovered beneath the surface of Ganymede that may contain more water than all the Earth's oceans combined [3] [4] [5]. More than 100 geysers have been identified on Saturn's moon Enceladus [6] and, in 2018, scientists reported the detection of complex macromolecular organisms in its jet plumes [7] [8]. Titan is the only moon in the Solar System exhibiting a dense atmosphere in which evidence of a subsurface ocean has been found [9]. However, harsh, inhospitable environments characterize all planets, moons, and other celestial bodies extant in the Solar System beyond

the asteroid belt, and the main scientific interest in their investigation is to address fundamental questions about the characteristics of the building blocks of our solar system and the search for primitive lifeforms that would contribute to a better understanding of the origin of life on Earth. On the one hand, Mercury and Venus, given their proximity to the Sun, receive a great amount of heat antithetical to supporting any kind of lifeform. By an ample margin relative to other planets in the Solar System, Mars, on the other hand, rates as the most suitable habitat, apart from Earth, able to potentially accommodate some kind of lifeforms. The atmosphere of Mars consists primarily of carbon dioxide (95.32%), molecular nitrogen (2.6%), and argon (1.9%) [10]. Therefore, the burning of fossil fuel on Mars will not adversely impact the atmospheric environment as on Earth. Until recently, about 56 space missions have been launched to investigate various aspects of the Martian environment, but only 28 were successful with seven of them still being operational (2021). Figure (1) depicts the distribution of successful and failed missions to Planet Mars. In 1971, the USSR's Mars 3 Lander made the first successful soft landing on the planet's surface [11]. In 1975, Viking 1 and Viking 2 discovered a myriad of geological forms that typically develop from the presence of large amounts of water and conducted, for the first time, biological experiments designed to search for life in the Martian soil [12]. The American Mars Exploration Program is a long-term effort to explore Mars making use of orbital spacecrafts, landers, and rovers to explore the climate, natural resources and existence, or potential thereof, of lifeforms -- if any -- on Mars [13]. Since the early 1980s, a series of fly-by probes, orbiters, and landers have been dispatched to Mars that have incrementally advanced our knowledge about the planet. The most successful missions were Mars Global Surveyor (1996), Mars Climate Orbiter (1998), Mars Odyssey (2001), Mars Pathfinder (2003), Mars Reconnaissance Orbiter (2005), Spirit and Opportunity Rovers (2003) and Curiosity Rover (2011), and lately Perseverance Mars Probe (2020), China's Zhurong probe (2021), and the European ExoMars 2022 mission is planned to launch on 20 September 2022. These space vehicles are scheduled to collect a huge amount of data on the climate, geology, and environment of Mars.

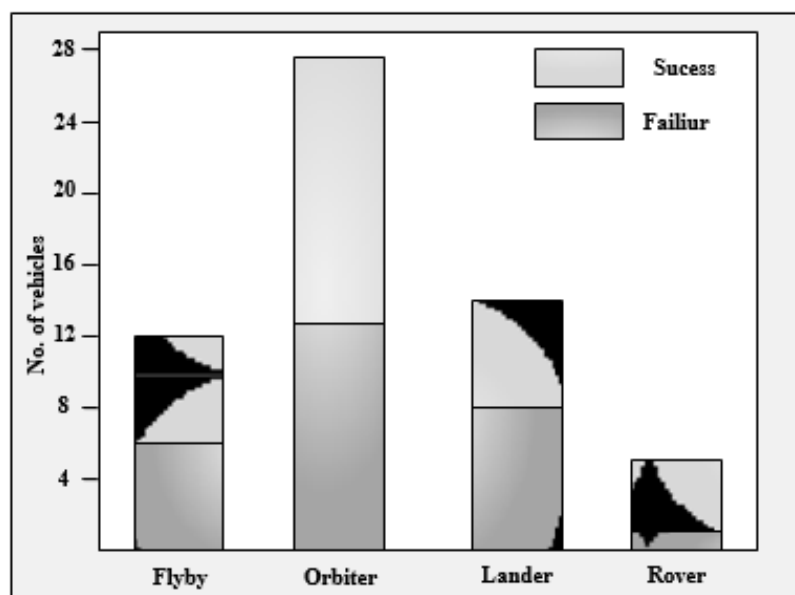


Figure (1): The distribution of various spacecrafts sent to Mars. Among the 56 missions, only 27 are successful.

Cold, dry and bathed in ultraviolet radiation, the contemporary Martian surface is hostile to any kind of lifeforms on its surface. In contrast, however, early Mars was warm, wet, and replete with networks of rivers, lakes, and seas [14] [15]. Few billions of years ago, the Martian environment was much more hospitable to life as on Earth [16] [17]. Biological markers extant in rocks, lakes and rivers beds, in addition to geologic evidence in the form of fossilization, support the contention that micro- organisms proliferated in such environments [18] [19] [20].

The possible existence of oil and natural gas on Mars has drawn the attention of many groups of scientists [21] [22] [23]. A potential signature of subsurface biological activities would be gas generated by some kind of lifeforms, percolating up to the surface and venting in the Martian atmosphere [21]. The likelihood of the presence of subsurface oil and natural gas on Mars may cause seepage of hydrocarbon-based gases such as methane [24] [25] [26]. However, likelihood falls short of certainty and, therefore, additional data collection, through alternative means of collection, is prescribed. In this vein, future prospects of infrared gas detection and imaging technologies hold, to that end, substantial promise but, perforce, their prospects, balanced against their limitations, need to be comprehensively evaluated [8 21]. Detailed geological, chemical and biological studies with the aim of discovering fossil fuel on Mars, focus largely on processes occurring in diverse types of rocks and soil [27] [28] [29] [30] [31]. Given that fossil fuel is a viable outcome of these processes, it is not surprising that fossilization in early history of Mars has been extensively studied by scientists [32] [33] [34]. In this backdrop, the current paper elucidates the complexities -- in geological, chemical and biological terms -- involved in transforming fossils into oil and gas.

The first part of this paper explores the early history of nascent Earth, and the role of water and geological features in setting a fertile environment to produce fossil fuel will be investigated. This attempt identifies the most important biological and chemical signatures that could be used as a gauge to pinpoint similar processes on Mars.

The second part of this work investigates the geological data revealed by Martian orbiter spacecrafts and rovers. This includes the history, origin, and distribution networks of water in the early epoch of the Martian evolution. In this approach the main chemical and biological processes shaping the various features and structures discovered on Mars are identified. The role of the aqueous environment in promoting these processes will be highlighted.

The last part of this work highlights the latest findings of the Curiosity rover in its quest of biosignature of organic material and how they are compared with the expected processes leading to the formation of fossil fuel on Earth.

FOSSIL FUEL ON EARTH, COMPOSITION AND FORMATION

Petroleum is a naturally occurring hydrocarbon exhibiting various molecular weights and may contain miscellaneous organic compounds. It includes crude oil in addition to liquid, gaseous, and solid hydrocarbons. Its composition is generally modeled by the undersurface pressure and temperature, where lighter hydrocarbons such as methane, ethane, propane, and butane are in a gaseous state, whereas pentane and heavier hydrocarbons are in a liquid or solid state.

Crude oil consists primarily of gaseous and solid hydrocarbons in addition to other organic compounds. Hydrocarbons are mostly alkanes (paraffins), cycloalkanes (naphthenes), and various aromatic molecules, or more complicated chemicals like asphaltenes. Organic compounds in crude oil include nitrogen, oxygen, and sulfur, in addition to trace amount of metals such as iron, nickel, copper, and vanadium. In addition, many oil reservoirs contain live bacteria [35]

Petroleum as Fossilized Organics

Petroleum is originally derived from fossilized organic material such as zooplankton and algae [36] [37]. Remains of these fossilized organics remain settled at the sea or lake bed where they are ultimately covered with stagnant water (devoid of dissolved oxygen) or sediment, such as mud and silt, faster than they could decompose aerobically. When further layers settled to the sea or lake bed, intense heat and pressure built up in the lower regions, causing the organic matter to change into a waxy material known as kerogen. This material is found in various oil shales around the world. As heat increases, a process known as catagenesis transforms kerogen into liquid and gaseous hydrocarbons. Formation of petroleum occurs by hydrocarbon pyrolysis via endothermic reactions at high temperature and pressure. Bacteria play a decisive role in the process. Aerobic bacteria are organisms that can survive or grow in an oxygenated environment, whereas anaerobic organisms do not require oxygen for growth, and even die in its presence. In the absence of enough oxygen, aerobic bacteria were prevented from decaying the organic matter buried under a layer of sediment or water. On the other hand, anaerobic bacteria find the environment suitable for reducing sulfates and nitrates among other matter to H_2S and N_2 respectively.

Anaerobic bacteria cause matter to break apart mostly via hydrolysis where polysaccharide and proteins were hydrolyzed to simple sugars and amino acids respectively. The enzymes of the anaerobic bacteria will further accelerate the oxidation rates. In this case, amino acids went through oxidative deamination to imino acids. These in turn reacted further to produce ammonia and α -keto acids. The anaerobic decay products of amino acids, monosaccharides, phenols, and aldehydes combined to produce fulvic acids [37].

Formation of Kerogen

At a depth of about 10 m below the water sediment, the action of anaerobic bacteria slows down and ceases. The mixture at this depth contained mainly fulvic acids, unreacted or partially reacted fats and waxes, in addition to slightly modified lignin, resins, and other hydrocarbons [37]. As layers of organic matter settling to the lake or sea bed increases, intense heat and pressure starts to build up in the lower region. In this harsh environment, the mixture of compound begins to combine to produce kerogen. In a similar fashion, phenol and formaldehyde molecules react to urea-formaldehyde resins. However, kerogen formation occurred in a more complex manner due to bigger variety of reactants [37].

From Kerogen to Fossil Fuel

Formation of kerogen is a half way point between organic matter and fossil fuel. It reaches to a depth of 1 km from the Earth's surface where temperature may reach 50 °C. When kerogen is exposed to oxygen; it is oxidized and thus lost. Alternatively, it could be buried deeper inside the Earth's crust and subject to the environment that allows its transformation slowly to fossil

fuel. In this case, catagenesis promote the process through reactions that were mostly radical rearrangement of kerogen. Such reactions took thousands of years in the absence of external reactants. Kerogen reacted towards two classes of products. The first is carbon rich with low H/C ratio (e.g., anthracene), and the second is hydrogen rich with high H/C ratio (e.g., methane).

There are three main types of kerogens: type I (algae), type II (litinic), and type III (humic). All three types were formed from algae, plankton, and woody plants [16]. There is a fourth type but it has no hydrocarbon potential. The classic Van Krevelen diagram is generally used for classifying organic matter in sediment. In this diagram, the ratio H/C (Hydrogen/Carbon) and O/C (Oxygen/Carbon) are plotted in vertical and horizontal axis respectively, as shown in Fig. (2). Deep inside the Earth's crust, kerogen is subject to conditions driving it to slowly transform to fossil fuels like petroleum. This process happens through catagenesis in which reactions were mostly radical rearrangement of kerogen. Catagenesis happened at relatively low temperature (60 to several hundred °C), and is pyrolytic in nature. Pyrolysis was possible given the long reaction time involved. The source of heat triggering catagenesis came from the decomposition of radioactive minerals of the crust, mainly ^{40}K , ^{232}Th , ^{238}U , and ^{235}U . The heat variation exhibits geothermal gradient of typically 10-30 °C/km of depth from the Earth's surface [37]. The temperature range in which oil forms is often referred to as an "oil window". Below this temperature range oil remains trapped in the form of kerogen.

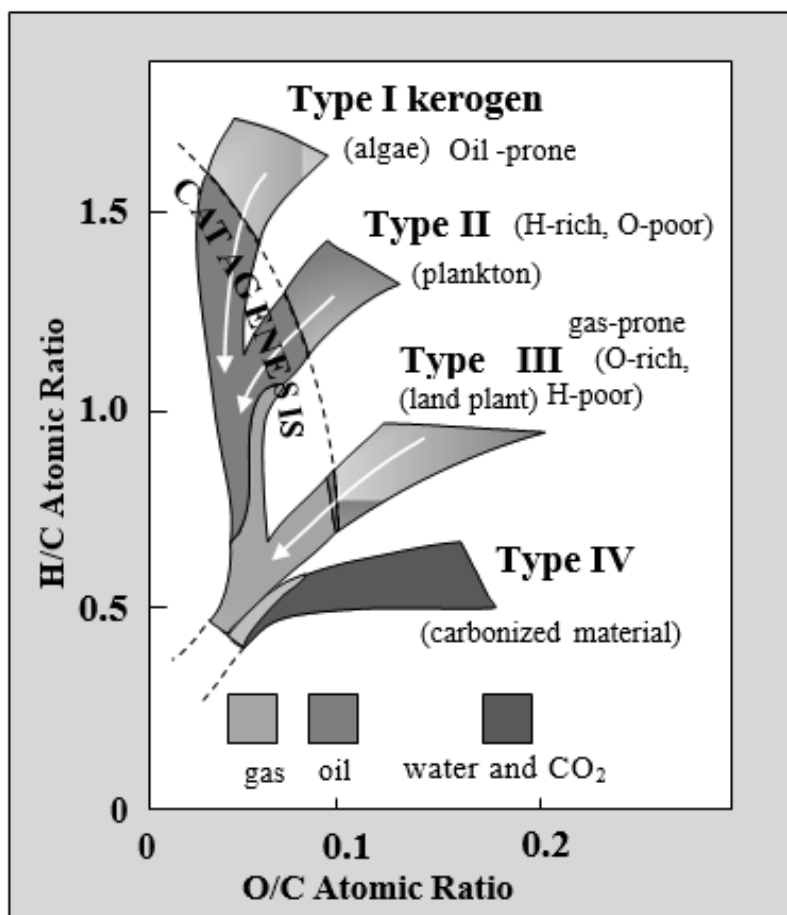


Figure (2): Classification of kerogen by (H/C) and (O/C) atomic ratios.

As a conclusion, aqueous environment on Earth at its early history has been hospitable to the initiation of chemical and biological processes leading to the formation of kerogen, and ultimately to fossil fuel. Kerogen is therefore a viable signature of the existence of fossil fuel on Mars.

MARTIAN WATER WORLD

Our present knowledge about the geological data and history of water on planet Mars dates back to fifty years of space exploration, either by vehicles exploring the Martian surface, or by satellite missions orbiting the planet. It is widely accepted that Mars had abundant water very early in its history, but all large areas of liquid water have since disappeared. Accumulated lines of evidence indicate the abundance of water ice on Mars which may have played a significant role in its geological history [38] [39]. The bulk volume of water existing on the Martian surface at present is in the form of ice concentrated particularly at the planet's North Pole ice cap [40], and beneath the present carbon dioxide cap at the planet's South Pole. The amount of water detected at or near the Martian surface amounts to about 21 million km² of ice. When melted it will be enough to cover the whole planet to a depth of 35 meters [41].

Recently, on November 2016, NASA announced the discovery of large amount of underground ice on Mars which is equivalent to the volume of water in Lake Superior [42] [43] [44]. More recently, Italian scientists announced in July 2018 the discovery of a subglacial lake on Mars, situated at about 1.5 Km below the southern pole ice cap and extending sideways about 20 km [45] [46].

At the early history of the planet formation, some 3.8 billion ago, the Martian atmosphere may have had a higher density atmosphere and higher surface temperatures [47] [48] [49]. These conditions may allow a vast amount of liquid water to disperse on the surface and possibly the formation of a large ocean [50] [51] covering up to one third of the planet's surface [52] [53] [54].

Further evidence of the abundance of water in Mars early history is derived from rocks and minerals analysis. However, large areas of liquid water have since disappeared. Certain fraction of the Martian water is retained as ice locked into structure of abundant water-rich materials [55] [56]. The source of Martian water has been provided by studies of hydrogen isotopic ratios, indicating that asteroids and comets are the main source of Mars water on Mars [57].

Water and Aqueous Minerals

On Earth, all chemical weathering is ensured by the presence of water [58]. Therefore, many secondary minerals are devoid of water, but still need water to form. Examples of these minerals include carbonates, some sulfates (e.g., anhydrite), and metallic oxides such as iron oxide mineral hematite. On Mars, on the other hand, few of these weathering products may theoretically form without the need of water or only with scant amounts present in icy form or as thin monolayers [59] [60].

Aqueous minerals are reliable indicators of the type of existing environment when the minerals formed. Basalt is the primary rock type on Mars. The rocks are igneous fine-grained and made up predominantly of mafic silicate minerals such as olivine, pyroxene and plagioclase feldspar

[61]. Chemical weathering has the effect of consuming water and other reactive chemical species by draining them from mobile reservoir like the atmosphere and hydrosphere and sequestering them inside rocks and minerals. Once exposed to water and atmospheric gas, these minerals become chemically transformed into new type of minerals that may incorporate water in their crystalline structure in form of H_2O or hydroxyl (OH). Typical example of hydrated or hydroxylated minerals detected on Mars encompasses iron hydroxide, goethite, gypsum, kieserite, opaline silica, and phyllosilicates, which are a form of clay mineral such as kaolinite and montmorillonite. All of these minerals have been discovered on Mars [62]. Figure (3) shows various types of Martian rocks that exhibit features indicative of a terrain that has been once inundated with water.

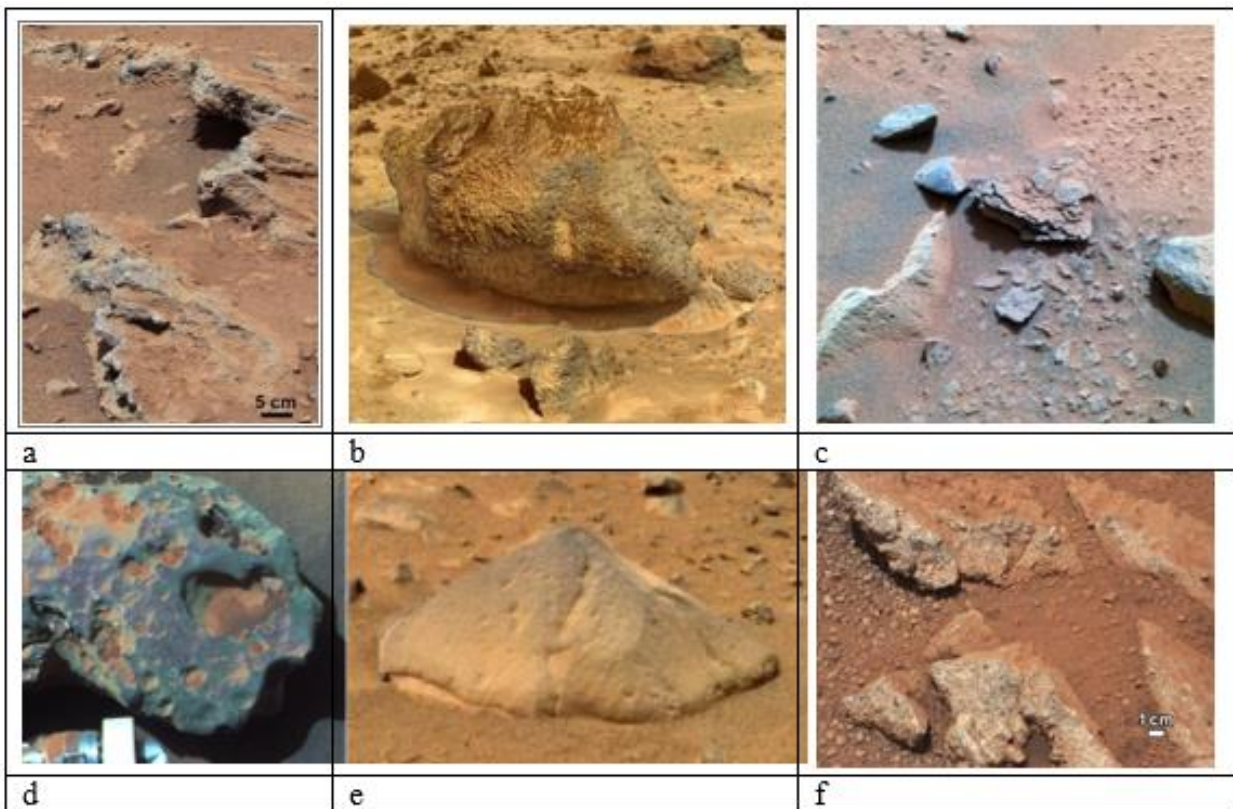


Figure (3): Examples of Martian rocks and meteorites taken by Mars rovers. Certain of these rocks exhibit features indicative of a terrain inundated with water.

a) Remnants of Ancient Streambed on Mars. NASA's Curiosity rover found evidence for an ancient, flowing stream on Mars at a few sites. The image features exposed bedrock made up of smaller fragments cemented together forming a sedimentary conglomerate (Credit: NASA/JPL-Caltech/MSSS). b) Yogi Rock on Mars is a meter-size rock about 5 meters away from Mars Pathfinder lander and was the second rock visited by the Sojourner Rover's alpha proton X-ray spectrometer (Credit: NASA/JPL/Dr. Timothy Parker) c) Image taken by the Mars Exploration Rover Spirit is centered on an unusually flaky rock called Mimi. Mimi is only one of many features in the area known as "Stone Council," but looks very different from any rock that scientists have seen at the Gusev Crater site so far (Credit: NASA/JPL/Cornell). d) Image of a meteorite taken by NASA's Mars Exploration Rover Opportunity found and examined in

September 2010 (NASA/JPL-Caltech/Cornell University). e) Adirondack Rock on Mars imaged by rover Spirit (Credit: NASA/JPL). f) Image from NASA's Curiosity rover for a Martian rock called Link. The outcrop characteristics are consistent with a sedimentary conglomerate, or a rock that was formed by the deposition of water and is composed of many smaller rounded rocks cemented together (Credit: NASA/JPL-Caltech/MSSS).

The amount of water stored in the Martian crust as hydrate minerals has been examined by instruments on the Opportunity rover at Meridiani Planum. Mineralogical models suggest that the sulfate deposits there could contain up to 22% water weight [63].

pH and the oxidation – reduction potential (Eh) is among the most important indicators of the type of minerals produced in the above conditions. For example, low pH favors the formation of sulfate mineral jarosite, whereas phyllosilicates usually form in water of moderate to high pH. On the other hand, Eh is an indicator of the oxidation state of the aqueous system. Consequently, pH and Eh together are indicators of the type of minerals that are most likely to form. Therefore, past environment conditions on Mars can be inferred by analyzing the type of minerals present in the rocks.

The subsurface provides an alternative route to aqueous minerals formation. This process is achieved by hydrothermal fluids migrating through pores and fissures. The hydrothermal system may be driven by nearby magma bodies or as a result of residual heat generated by large impacts [64]. In Earth's oceanic crust, serpentinization is an important type of hydrothermal alteration. This process occurs when sea water migrates through ultramafic and basaltic rocks. Water-rock reaction may cause the oxidation of ferrous iron present in olivine pyroxene to produce ferric iron (mineral magnetite) and releasing molecular hydrogen as a byproduct. This process contributes to the creation of highly alkaline and reducing (low Eh) environment, and leading to the formation of certain phyllosilicates (serpentine minerals) and other carbonate minerals. These together form a rock known as serpentinite, and had the potential to store a lot of water (as hydroxyl) in its crystalline structure. Hypothetical serpentinites in ancient Martian highlands could hold as much as 500 meters thick global equivalent layer of water [65]. The hydrogen gas produced in the process can be a viable energy source for chemosynthetic organisms or it can react with CO₂ to produce methane gas. This is a non-biological source of the trace amount of methane reported in the Martian atmosphere [66].

Martian Meteorites

Further evidence of abundance of water on the old Martian surface is provided by over 60 meteorites that have been found to come from Mars [67]. Some of these meteorites were exposed to water prior to being ejected from the Martian surface due to asteroid impact. Basaltic shergottites have been exposed to liquid water prior to being ejected into space. Another class of meteorites is nakhlite that were suffused with liquid water around 620 million years ago and ejected from Mars 10.75 million years ago and fell to Earth within the last 10000 years [68]. The highest percentage of water has been discovered in the Martian meteorite NWA 7034, and it exceeds by one order of magnitude most other meteorites. It resembles the basalt studied by rover missions, and may be found in the early Amazonian epoch [69] [70].

In 1996, a group of scientists reported the discovery of microfossils in a Martian meteorite dubbed Allen Hills 84001 [71]. It was found that the organic matter in the meteorite is of terrestrial origin [72].

Rivers, Lakes and Ocean on Mars

Our knowledge about water on Mars has been revolutionized by the findings of Mariner 9 spacecraft in 1971. Images taken by the spacecraft revealed that floods of water created deep valleys, eroded groves into bedrocks, and flowed thousands of kilometers [73]. Figure (4) shows branching rivers in Osuga Valles on Mars caused by overland flooding. Analysis of the data published in June 2010 revealed 40000 river valleys on Mars. These valleys are classified either as dendritic, widely distributed, and forming Noachian-age valley networks, or exceptionally large, single-thread, isolated, and related to the Hesperian-age outflow channels.

Inverted relief features have also been discovered on Mars. These structures occur when sediments are deposited on the floor of a stream and then become resistant to erosion, perhaps by cementation. In a second stage, erosion removes the covering layer and thus making the former stream visible. Many inverted streams have been discovered by Mars Global Surveyor and other probes in various regions of Mars including the Medusae Fossae formation [74], Miyamoto crater [75], Saheki Crater [76], and Juventae Plateau [77].

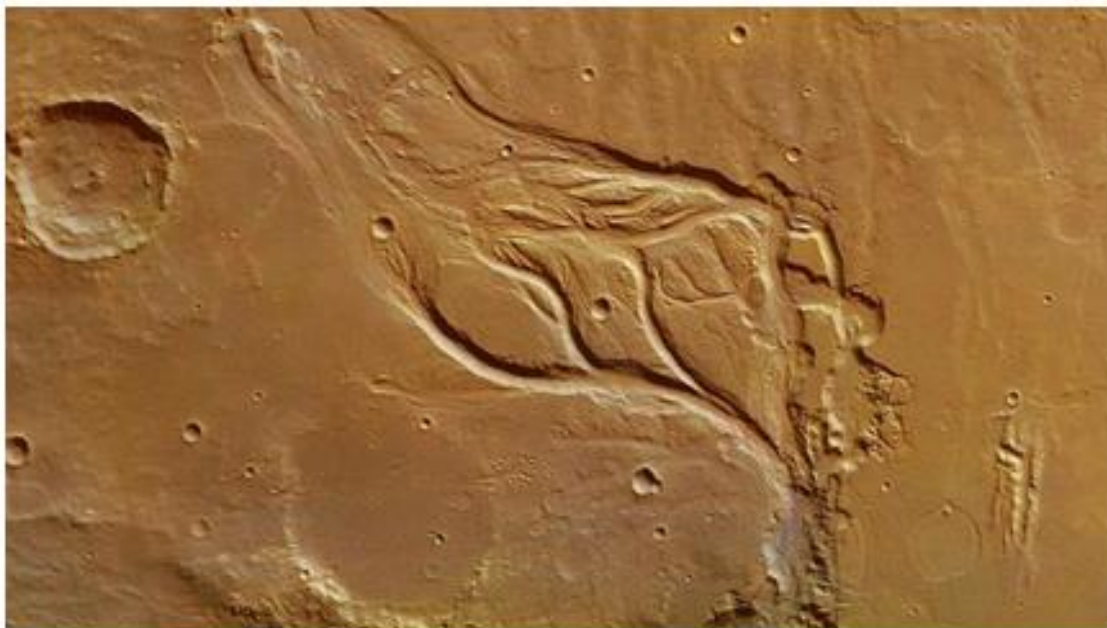


Figure (4): Branching rivers in Osuga Valles on Mars caused by overland flooding.
Credit: ESA/DLR/FU Berlin).

Martian Water Basins

Martian probes discovered a variety of water bodies on Mars, including lake basins, deltas, outflow channels, river beds, and even dried ocean. In the following section, we give a brief description of each of these water remnant structures.

Lake Basins

Many forms of lake basins have been discovered on Mars. Some of these basins are as large as the Caspian Sea or Black Sea on Earth. These lakes were fed by river valleys networks. Certain areas containing lakes known as Terra Sirenum had its overflow crossing Ma'adim Vallis into Gusev Crater and explored by Mars Exploration Rover Spirit. Some lakes are probably formed by precipitation, whereas others were formed by ground water [78] [79]. Traces of these lakes were found in the Argyre basin [38] [39], the Hellas basin [80], and probably in Valle Marineris. Some of these lakes were likely hosted by impact craters. Several channels were discovered to connect lake basins near Ares Vallis. Once one lake is filled up, the outflowed water covered the channels to a lower area where another lake would form [81] [82].

Eridania Lake/Sea

This is an ancient lake occupying an area of roughly 1.1 million square kilometers [83]. The deepest point is around 2400 meters, and its total volume is 562000 km^3 , and thus it contains more water than all other Martian lakes together. It is estimated that Eridania lake/sea holds more than 9 times as much water as all of North American's Great lakes [84], and even larger than the Caspian Sea. A valley of networks surrounded the lake, suggesting that they emptied in the lake [85] [86]. Figure (5) shows a map of Eridania Lake with an estimated depth in its different parts.

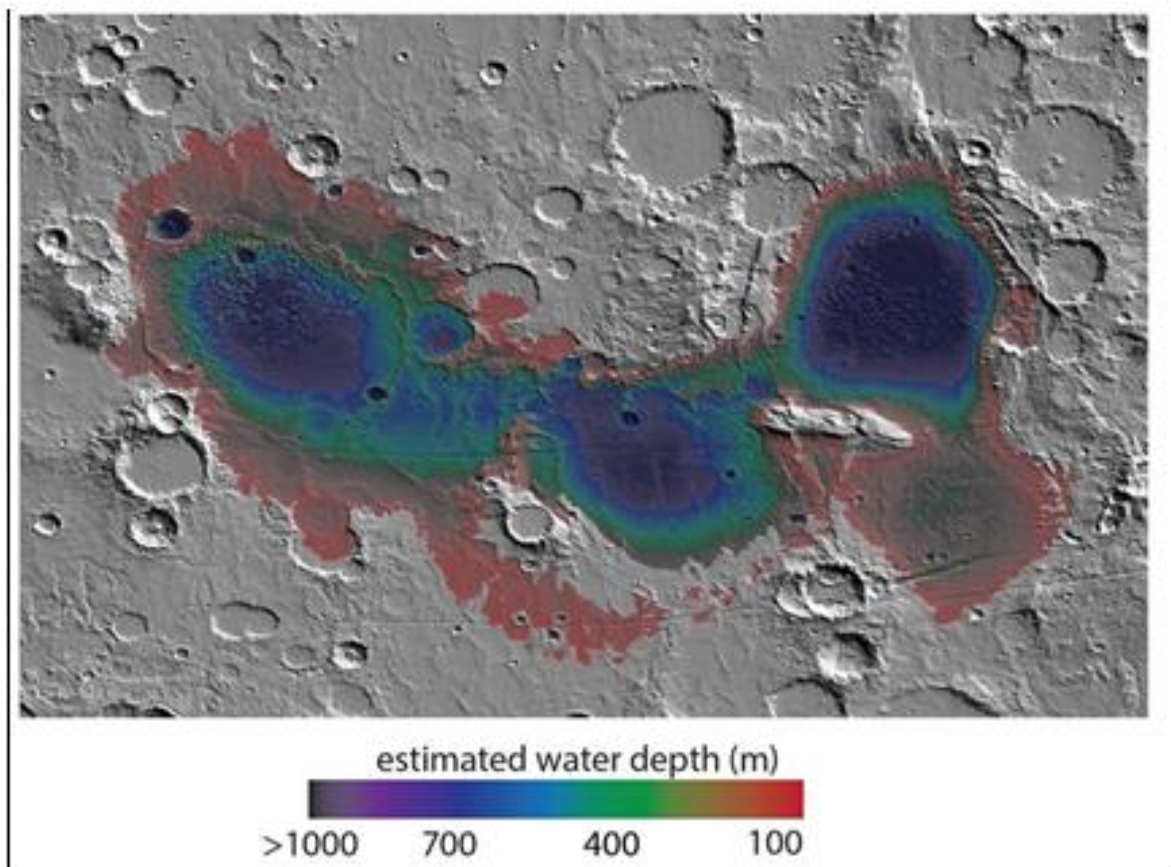


Figure (5); Map showing estimated water depth in different parts of Eridania Sea. This map is about 850 km across. (Credit: Jim Secosky and NASA).

Martian Deltas

Research work indicated that deltas have been formed in certain Martian lakes [53], which is a major sign that at a certain epoch Mars has been endowed by a lot of liquid water. Deltas are usually formed in stable water to keep sediment from washing away, and furthermore, their formation requires deep water for a long period of time. Traces of Deltas on Mars have been found over a wide geological range, and particularly on the hypothesized former northern ocean on Mars [53]. The structure and distribution of these deltas has been the target of many orbital missions. Figure (6) shows grooved channels of an ancient river delta drift through Jezero crater on Mars.

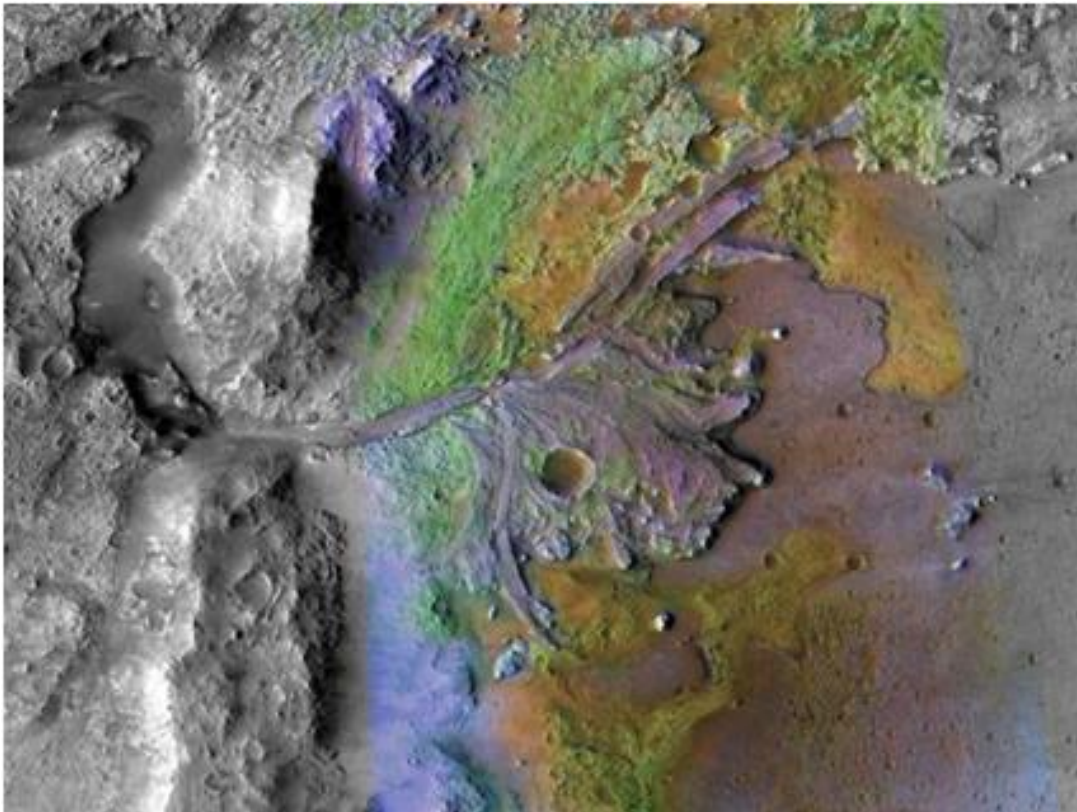


Figure (6): Grooved channels of an ancient river delta drift through Jezero crater on Mars. (Credit: NASA/JPL-Caltech/MSSS/JHUAPL).

Groundwater

Some authors argued that the branching valley networks were formed by slow seepage of ground water from the subsurface essentially as springs [87]. This interpretation is supported by the fact that the upstream ends of many valleys in such a network begin with box canyon or "amphitheater" heads. However, certain researchers dispute this model and argued that the absence of fine scale heads to valley networks has been created by their removal as a result of weathering or impact gardening [88]. An important role played by groundwater on Mars is its role in controlling broad scale of sedimentation patterns and processes [89]. This hypothesis implies that groundwater with dissolved minerals surfaced around craters and contribute to the formation of layers by adding minerals, particularly sulphate and cementing sediments [90]

[91]. Data from the Mars Reconnaissance Orbiter show that the same kind of sediments exists in a large area that includes Arabia Tera [92]. Relatively recently, NASA's Mars Global Surveyor spacecraft reported what looked like evidence of underground water seeping up to the surface, as shown in Fig. (7).

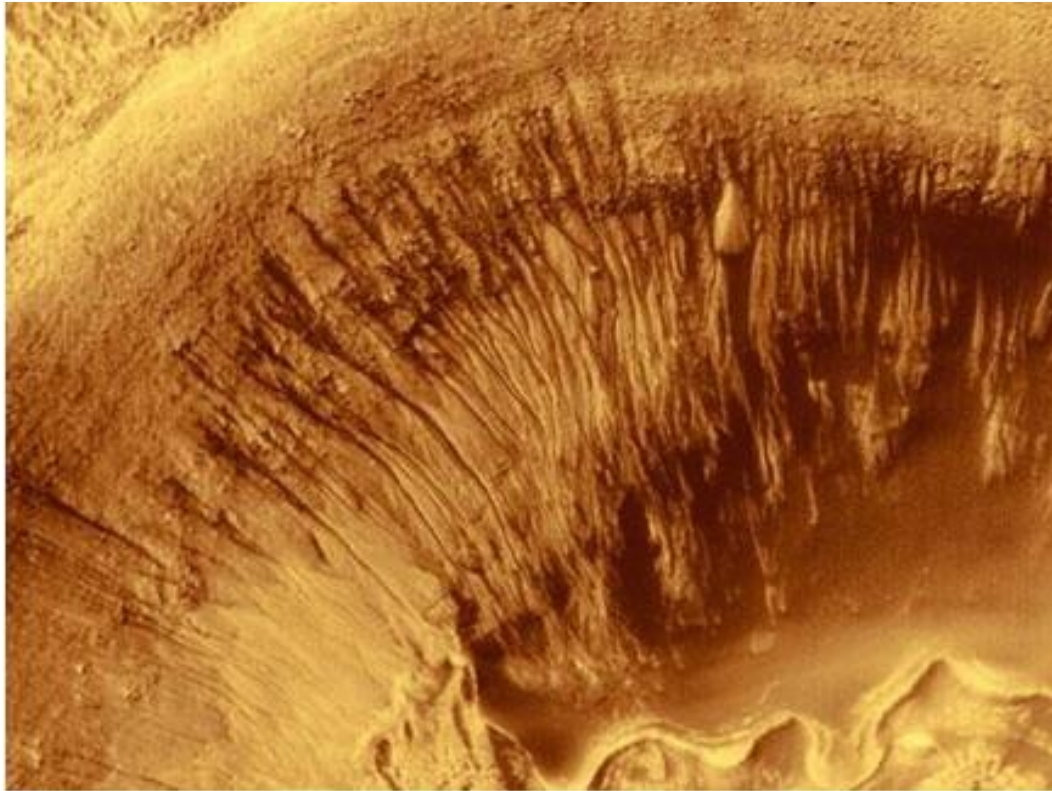


Figure (7): In mid-2000 NASA's Mars Global Surveyor spacecraft reported what looked like evidence of underground water seeping up to the surface relatively recently. (Credit: NASA/MGS).

Recently, European scientists demonstrated geological evidence of an ancient planet-wide groundwater system that has been connected to a putative vast ocean [93] [94]. In September 2019, researchers reported that insight lander received a mysterious magnetic pulse, and magnetic oscillations consistent with a planet-wide reservoir of deep underground water [95].

Mars Ocean Hypothesis

Many scientists proposed that the Vastitas Borealis basin was once the location of an ocean of liquid water, dubbed Oceanus Borealis [96]. It was argued that, in the planet's geological history, nearly one third of the surface of Mars was covered by liquid ocean [97]. This basin is a region that lays 4-5 km below the planetary elevation. Oceanus borealis would have been surrounded by two major putative shorelines. The higher one, known as Arabia shoreline, dates back to a time period of approximately 3.8 billion years, and can be traced all around Mars except through the Tharsis volcanic region. The lower shore, dubbed the Deuteronilus, follows the Vastitas Borealis formation [88].

More accurate data has been provided by Mars Orbiter Laser Altimeter (MOLA) in 1999 by measuring the altitude of all terrain on Mars. It was found that the watershed for such an ocean would have covered about 75% of the planet [98]. The existence of liquid water on early Mars would have certainly required a warmer climate and dense atmosphere [99] [100]. Furthermore, the large number of valley networks strongly supports the possibility of hydrological cycle on the planet in the past [90]. However, the existence of a primordial ocean on early Mars remains controversial, and the various interpretations advanced on its favor have been challenged [101] [102]. The conjectured 2-billion-year-old shoreline does not follow a line of constant gravitational potential. This discrepancy could be due to a change in distribution of Mars mass, probably resulting from volcanic eruptions or meteor impact [103]. Research work published in 2015 presented evidence for an ancient Martian Ocean in the planet's northern hemisphere comparable to the size of Earth's Arctic Ocean, or approximately 19% of the Martian surface. This data was derived from the ratio of water and deuterium in modern Martian atmosphere as compared to the ratio found on Earth. The amount of deuterium found on Mars exceeds that on Earth by eight folds, suggesting that ancient Mars had appreciably high level of water.

Further evidence for a northern ocean was published in May 2016. This work describes the alteration of the surface in Ismenius Lacus by two tsunamis caused by asteroids striking the ocean, and has been strong enough to create 30 km diameter crater [104]. The shorelines feature of the putative ocean may have been washed away by these tsunami events [105].

CURIOSITY ROVER, THE SEARCH FOR A BIOSIGNATURE

Curiosity Rover is one of the most valuable Martian missions. It landed on Mars in 2012, and since then provided a wealth of data, particularly on searching for biosignatures that provide evidence of primitive lifeforms that existed and evolved in certain epoch of the Martian history. In 2018 the Rover has sifted sample of soil and ground-up rock searching for signs of organic molecules. These molecules are unlocked from sample by baking them in an oven to temperatures between 600 – 860 °C, a range where all known contamination is removed. The resulting fumes are then fed to a spectrometer to identify molecules by weight. The organic signal reflects dozens or hundreds of various small carbon molecules, probably in the form of small rings and strands known as aromatics and aliphatics respectively [106]. Few organic molecules such as sulfur-bearing rings known as thiophenes were abundant enough to be detected directly. The mass pattern of these molecules resembles what is obtained on Earth by kerogen that we discussed in the first part of this paper. Kerogen, when combined with sulfur compounds can be preserved across billions of years [106]. At this stage, it is interesting to ask if kerogen on Mars is a biosignature arising from ancient remains of algae as explained in sec. (2.2). Many ideas have been advanced to elucidate the source of kerogen on Mars. It is thought that carbon-rich meteorites containing kerogen-like compounds falling on Mars may be at the origin of these findings. The compounds could have also been formed by reactions driven by ancient volcanos. However, other scientists claim that there is only small possibility that curiosity Rover dug into a site where ancient meteorite fell. Nondestructive testing by Curiosity Rover involves using cups that frees organic compounds bonded in rock, and thus avoiding the need to break them apart and destroy them at high temperatures. Technical problems prevented the Rover from achieving this task. Nevertheless, the findings of Curiosity Rover are worth pursuing by future Martian missions. Four missions are planned for the coming two

years. The most relevant for searching of lifeforms are the Mars Perseverance rover, and the Europe's Rosalind Franklin rover. Perseverance rover will address questions about the potential for life on Mars, including searching for signs of past microbial life itself. Rosalind Franklin, on the other hand, can drill deeper than Curiosity, to soil depths better protected from radiation. It is expected that sample return mission will impact our approach to identify the nature and content of Martian rocks and soil. The main objective of Martian sample return missions would be to collect rock and dust samples and then return them to Earth. These missions are considered a very powerful type of exploration, because the analysis is freed from the time, budget, and constraints of spacecraft sensors [107]. Mars sample-return mission (MSR) is described by the planetary science community as one of the most important robotic missions, particularly due to its high expected scientific return [108]. Three models have been advanced for an MSR mission, namely, NASA-ESA proposal, a Russian proposal (Mars-Grunt), and a Chinese proposal. In April 2018, a letter of intent signed by NASA and ESA to lay down a basis for a Mars sample-return mission [109] [110]. Many concepts have been advanced for Martian sample return missions. An artist concept of one of these missions is shown in Fig. (8). Therefore, the findings of Curiosity Rover justify sample return mission that could possibly eliminate all discrepancies in analyzing Martian soil. On Earth there is the potential to dissolve away nonorganic molecules and take a full index of the remaining organic ones. This may include fatty acids with an even number of carbon atoms - a signature of the presence of lifeforms.



Figure (8): Artist concept of sample return mission from Mars (Credit: NASA/JPL).

CONCLUSION

Mars is the most hospitable planet in the Solar System for the purposes of future manned space missions. Fossil fuel is a viable source of energy on Mars, and searching of evidence about its existence is one of the most important tasks for these missions. This is supported by the fact that CO₂ emissions will not add much to the Martian atmosphere consisting almost entirely of carbon dioxide. Therefore, searching for evidence of the existence fossil fuel on Mars holds merit.

In the first part of this paper, it was determined that the aqueous environment played a crucial role in the formation of fossil fuel in the early history of Earth. In this context, kerogen emerges as a possible biosignature utile in identifying similar processes leading to the formation of fossil fuel on Mars.

In the second part, it was determined that the aqueous environment in the early history of Mars supported a biosphere conducive to the ultimate formation of hydrocarbons.

Data sent by various Martian probes confirm that Mars has been once replete with large reservoirs of water in form of rivers, deltas, lakes and underground channels – not to mention even a possible ocean. It has been displayed that such an aqueous environment would create ideal conditions for primitive bioforms, such as zooplankton and algae, to proliferate and thrive.

Significantly, it was demonstrated that bioforms can be transformed, through chemical and biological processes, to kerogen and, as a final by-product, catagenesis transforms kerogen into liquid and gaseous hydrocarbons.

In the last part of this paper, the findings, based on analysis of data garnered from the Martian Rovers in general and the Curiosity Rover in particular, are equivocal. Analysis of samples extracted from the Martian subsurface indicates the presence of kerogen in the soil. However, no consensus was obtained as to the origin of the discovered kerogen.

It is concluded that future Martian missions can elucidate the origin of kerogen on Mars as an important step towards confirming – or refuting -- the existence of fossil fuel in the subsurface of the planet. A Martian sample return missions is indispensable to provide additional data with the necessary precision required for thorough analysis, in labs on Earth. Such missions will settle the issue dispositively.

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