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Water on Mars: Detection, Distribution and Implications for Human Exploration – Comprehensive Review

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ABSTRACT

Aqueous fluids have existed on Mars' surface throughout its history, but it is yet unknown when, where, or even if they do so today. Research in this field is still underway. There is still a lot of water on the planet today, but it is primarily locked up in minerals or frozen in the earth's crust, and there is little direct evidence of aquifers.A number of benchmarks have been set for next space programmes due to the predicted increase in space exploration. The arrival of a person on Mars is a significant achievement. But a significant obstacle to successfully settling people on Mars is the absence of water on the planet's surface. It is not feasible to carry the required amount of water from Earth to Mars due to the enormous volume that would be required for a voyage there. Both water and a basis for jet propulsion fuel would be required for human consumption.

Keywords: Mars, liquid water, Water vapor on Mars, In-Situ Resource Utilization on Mars.

INTRODUCTION

The final frontier for humankind is space exploration. There is extensive study being done on a strategy to populate Mars, but any human missions to Mars will need a source of water for both processing and human consumption. NASA has stated a goal to create a device that can extract water from Martian soil due to the lack of free water on the Martian surface (Duke).

Small amounts of water are extant on Mars as vapour in the atmosphere or as low-volume liquid brine that can be found in shallow soil regions, despite the fact that the majority of the water present today is as ice. Exposures inside brand-new impact craters at high latitudes observed by HiRISE (high-resolution imaging science experiment) also reveal bright material interpreted to be ice. Water is only seen in the northern polar ice caps on the surface of Mars. The south pole, which has a permanent carbon dioxide ice cap, as well as the shallow subsurface, where more hospitable circumstances occur, are other locations on Mars that have considerable water reserves.

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Although there is now some liquid water on the Martian surface, it is only present in very thin layers or as dissolved atmospheric moisture, making it an unfavourable habitat for life as we know it. In general, if pure water on the Martian surface were heated to more than its melting point, it would become vapour; otherwise, it would freeze. However, since the average atmospheric pressure on the planet's surface is approximately 600 pascals (0.087 psi), lower than the melting point of water's vapour pressure, there is no significant amount of liquid water present.

Mars, the fourth planet from the Sun, has been a subject of fascination and exploration for scientists and space enthusiasts alike. One of the most intriguing aspects of Mars is the possibility of the existence of water, a vital ingredient for life as we know it. Over the years, scientists have gathered compelling evidence that suggests the presence of water on the Red Planet, igniting further curiosity and raising questions about the potential for habitability and the origins of life beyond Earth.

In the past, the prevailing belief was that Mars was a dry and desolate world, with its thin atmosphere unable to support liquid water on the surface. However, advancements in space exploration technology and the analysis of data from various missions have significantly changed our understanding of the Martian environment.

Achondrites on Mars also offer unmistakable proof of the existence of water over time. These rocks can be viewed as the key to unlocking information about the main geologic processes operating on Mars, identifying its ancient hydrothermal habitats, looking for signs of life, and researching the interaction of water in sampled rocks that have been returned. Additionally, because they can be precisely dated, they can send a message in a bottle about the crucial areas on which upcoming missions should concentrate in order to gather the most scientific data possible regarding the most important issues to be addressed in upcoming robotic and manned sample-return missions to the red planet [11, 12].

Liquid Water on Mars

There has long been evidence of some kind of water on Mars. telescopical observations of bright polar caps began in the seventeenth century, but it wasn't until the twenty-first century that it was determined whether they were mostly made of CO2 or H2O ice [13–15].Early Mars should have had water-rock interactions that influenced both its geomorphology and mineralogy, with the circumstances of alteration (temperature, pH, and salinity) possibly deducible from certain mineral assemblages. Clays, sulphates, halides, and carbonates are present in modest amounts (1% by volume) in Martian meteorites [16], and chemical investigations from the Viking and Mars Pathfinder landing sites suggested that these minerals may be extensively distributed in Martian soils [17, 18].

However, until bigger concentrations could be discovered in their original geologic setting, their origin was very loosely bound. The thermal emission spectrometer on board Mars Global Surveyor identified regional concentrations of more than 10% crystalline grey hematite [19], one of which (Meridiani Planum) was chosen as the landing site for the Mars Exploration Rover (MER) Opportunity, who's in situ investigations revealed an ancient aqueous environment for hematite formation via diagenesis of sandstones comprising up to ∼40% sulphates, including jarosite [20].

For life to exist as we know it, liquid water is necessary. If the environment's temperature (T) and partial pressure (P) values fall within the liquid region of the phase-state diagram and the atmosphere is saturated against liquid water, that is, if the Relative Humidity (RH) -with respect to liquid water- is 100%, it can be stable on the surface of a planet. These prerequisites, as shown in the water phase diagram, are universal, which means they must be fulfilled regardless of whether liquid water is sought on Earth, Mars, or any other possibly liveable planet.

On Mars, the majority of these variables change with the seasons and the day, therefore these circumstances can only be satisfied briefly and locally, which can cause temporary water stability, evaporation, condensation, sublimation, and other processes. The triple point of water is 273.16 K and 6.11 mbar, respectively.

Water Vapor on Mars

Water vapor, the gaseous form of water, plays a crucial role in understanding the water cycle and potential habitability on Mars. While the planet's thin atmosphere poses challenges for liquid water to exist on the surface, water vapor has been detected in the Martian atmosphere, providing valuable insights into the planet's past and present.

The presence of water vapor on Mars was first confirmed by the Viking missions in the 1970s. Since then, subsequent missions, including the Mars Global Surveyor, Mars Express, and the Mars Reconnaissance Orbiter, have provided further evidence of its existence.

Water vapor on Mars is a dynamic component of the planet's atmosphere, experiencing seasonal variations and localized concentrations. During Martian summers, when the temperature rises, water ice in the polar caps and subsurface can sublimate directly into the atmosphere, leading to increased water vapor levels. As the seasons change, some of the water vapor condenses and freezes again, contributing to the seasonal growth and retreat of the polar ice caps.

The Mount Wilson 100-inch reflector, an Earth-based telescope, made the first discovery of water vapour in the Martian atmosphere in 1963 [21]. Later, the water vapour readings of the mean column density of 10- 20 precipitable micrometres (pr m) were validated by the Mariner 9 spacecraft using its Infrared Interferometer Spectrometer (IRIS) instrument [22]. After some time, the Viking orbiter's Mars Atmospheric Water Detectors (MAWD) revealed that, depending on the location and time of year, the overall column abundance can range between 0-100 pr m. This outcome also suggested that water vapour was being exchanged with the surface [23].

In recent years, more precise measurements and observations have shed light on the distribution and behavior of water vapor on Mars. The Mars Science Laboratory's Curiosity rover and the European Space Agency's ExoMars Trace Gas Orbiter have provided valuable data about the vertical and horizontal distribution of water vapor in the Martian atmosphere.

These missions have revealed that water vapor is not uniformly distributed but exhibits localized concentrations known as water vapor plumes or transient events. These plumes can occur at different altitudes and latitudes, often associated with specific surface features such as impact craters or regions where subsurface water ice is exposed.

The discovery of water vapor plumes on Mars has sparked excitement and speculation about the potential sources and implications. It raises intriguing possibilities of subsurface water reservoirs, geothermal activity, or even the presence of transient liquid water, although the latter is still a topic of ongoing investigation and debate.

Understanding the behavior of water vapor on Mars is crucial for determining the planet's past climate, its potential for sustaining microbial life, and planning future manned missions. It provides vital clues about the planet's water cycle, atmospheric dynamics, and the history of water-related processes that have shaped the Martian landscape.

Evidence from Rocks and Minerals

Although it is generally recognised that there was once a time in Mars' past when there was an abundance of water, none of those enormous expanses of liquid water still exist. A small portion of this water is present on modern Mars as ice or trapped in the structures of abundant water-rich materials made of sulphates and clay minerals (phyllosilicates). According to studies of hydrogen isotopic ratios, asteroids and comets from farther away than 2.5 astronomical units (AU) are the main suppliers of water on Mars, which is equivalent to 6% to 27% of the ocean's current volume on Earth. The first discovery of hydrated minerals on Mars was made by the Spectro-imaging instrument (OMEGA) aboard Mars Express.

The information showed that there had formerly been a lot of liquid water present on the planet's surface for extended periods of time. Nearly the entire surface of the earth has been mapped by the OMEGA (Figure 1), with some regions having resolutions as low as one kilometre. Two distinct classes of hydrated minerals, so named because they include water in their crystalline structure and offer a clear mineralogical record of activities involving water, have been detected by the device [24–28].

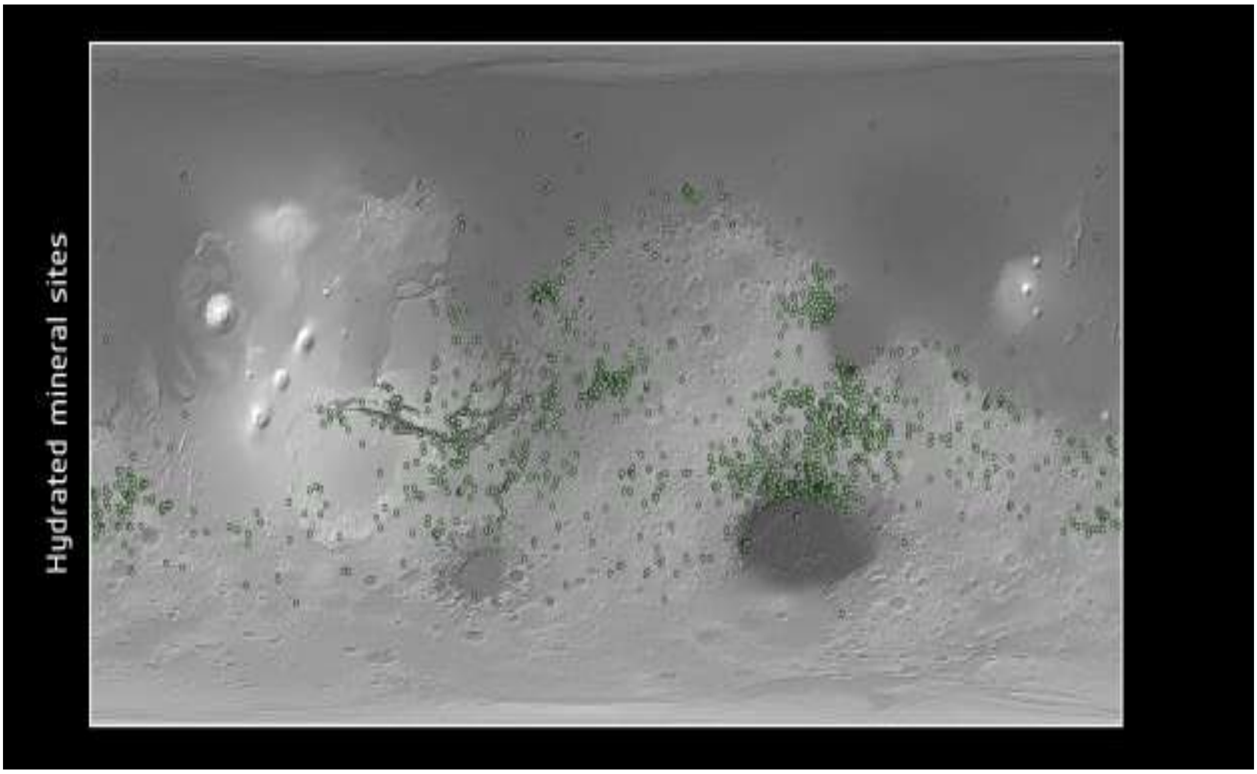

Fig. 1 Mars' hydrated minerals map

Atmosphere-regolith water exchange on Mars

The air is referred to as being saturated with water vapour when the partial pressure of water vapour in it equals the saturation vapour pressure above the surface. If the partial pressure of water vapour in the air is more than the saturation vapour pressure, the air is said to be supersaturated. When a surface is saturated, there is a deposit of water vapour there because the rate of condensation to the surface is greater than the rate of evaporation from the surface. The difference between partial pressure and saturation pressure, total air pressure, and temperature are only a few of the variables that affect condensation rate [29].Both the liquid and ice phases can transmit water vapour molecules to the surface. The rate of evaporation from the surface will exceed the rate of condensation to the surface when the partial pressure of water vapour is less than the saturation vapour pressure.

The exchange of water between the Martian atmosphere and the regolith (the layer of loose rocky material covering solid bedrock) is an essential process that shapes the hydrological cycle on Mars. While the planet's thin atmosphere poses challenges for liquid water to exist on the surface, the interaction between the atmosphere and regolith plays a crucial role in understanding the water cycle and the potential availability of water resources.

Water on Mars primarily exists in three forms: as ice in the polar caps and subsurface, as water vapor in the atmosphere, and potentially as liquid brines in specific conditions. The exchange between the atmosphere and regolith occurs through several processes:

1. **Sublimation and Deposition**

Sublimation is the process by which ice directly transitions into vapor without going through the liquid phase. In the Martian environment, ice in the regolith can sublimate when exposed to sunlight or due to geothermal activity, releasing water vapor into the atmosphere. Conversely, during colder periods, water vapor in the atmosphere can directly deposit as ice onto the regolith.

2. **Adsorption and Desorption**

The regolith on Mars has properties that allow it to adsorb or retain water molecules from the atmosphere. Water vapor in the atmosphere can chemically bind to the surface of minerals in the regolith through adsorption. This adsorbed water can be released back into the atmosphere through desorption, driven by temperature changes or other factors.

3. **Dust Particle Interaction**

Martian dust particles also play a role in the exchange of water between the atmosphere and regolith. These particles can act as condensation nuclei, providing surfaces for water vapor to condense onto, forming frost or ice. Conversely, water ice on dust particles can sublimate, releasing water vapor into the atmosphere.Understanding the dynamics of the atmosphere-regolith water exchange is crucial for studying Mars' water cycle and potential habitability. It helps scientists determine the availability and distribution of water resources on the planet and assess the viability of sustaining future human missions.

Recent research and observations from missions like the Phoenix lander, the Mars Science Laboratory's Curiosity rover, and the Mars Reconnaissance Orbiter have provided valuable insights into the exchange processes. These missions have detected and analysed water ice and vapor in the regolith, studied frost formation and sublimation, and examined the composition and properties of the Martian soil.By studying the atmosphere-regolith water exchange, scientists can also gain insights into Mars' climate history, geological processes, and the potential for past or present habitability. Ongoing and future missions, such as the Perseverance rover and the planned Mars Sample Return mission, will continue to investigate these processes and provide a more comprehensive understanding of water dynamics on the Red Planet.

Polar Ice Cap on Mars

Mars does have polar ice caps composed of water ice and carbon dioxide ice, also known as dry ice.At the north pole of Mars, there is a large ice cap called the "North Polar Cap." It consists primarily of water ice with a layer of dust and Martian soil covering it. This cap experiences seasonal changes, with the ice cap shrinking in the Martian summer and expanding in the winter.On Mars, the ice caps are different from the rest of the planet. Similar to the ice caps in the Arctic and Antarctic on Earth, the polar ice on Mars contracts in the summer and swells in the winter [30]. These ice caps are primarily made of carbon dioxide that has been formed; as the ice caps melt, the carbon dioxide sublimates to gas and enters the atmosphere. A significant source of atmospheric water during the northern summer on Mars is the remaining north polar cap [31].

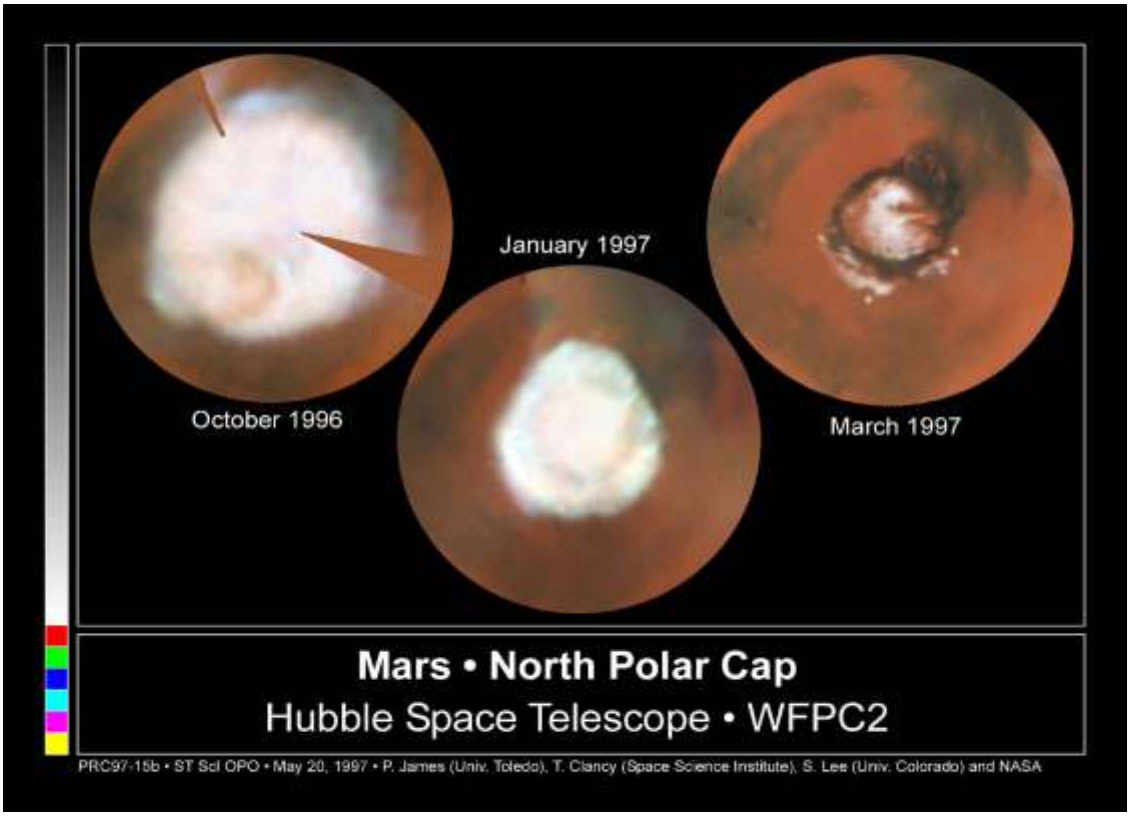

Fig. 2. Images from NASA's Hubble Space Telescope (HST) was looking directly down on the Martian North Pole taken at three different months. During October 1996 early spring, images taken between 8th and 15th, the ice cap extends down to 60N latitude. But as the temperature warms and spring approaches in January 1997, the carbon dioxide ice sublimates to the atmosphere. The ice caps have fully retreated by March 1997, leaving just the residual ice cap. Image credit: JPL/NASA/STScI.

In-Situ Resource Utilization on Mars

In-situ resource utilization (ISRU) refers to the concept of using resources available in the environment of another celestial body, such as Mars, to sustain human exploration and potentially colonization. ISRU aims to reduce the dependency on Earth for necessary supplies by utilizing local resources on Mars.Mars possesses several resources that could be potentially used for ISRU:

1. **Water**

Mars is known to have subsurface water ice at its polar regions and possibly in underground reservoirs. Water can be extracted, purified, and used for drinking, agriculture, and the production of oxygen and hydrogen for life support systems and rocket propellant.

2. **Carbon Dioxide (CO_2) Atmosphere**

Mars has a thin atmosphere composed mostly of carbon dioxide. CO_2 can be processed and split into oxygen and carbon monoxide, with the oxygen used for breathing and as an oxidizer for rocket propellant.

3. **Regolith**

The Martian soil, or regolith, can be processed to extract useful materials. It contains various elements such as iron, silicon, aluminum, and sulfur, which could be used for construction, manufacturing, and energy production.

4. **Solar Energy**

Mars receives sunlight, and its thin atmosphere allows a significant amount of solar energy to reach the surface. Solar panels can be deployed to harness this energy for power generation, reducing the reliance on other energy sources.The term "in-situ resource utilisation" (ISRU) refers to all the new procedures that will be created to enable the local extraction and modification of resources in space to aid exploration. The Perseverance rover's MOXIE (Mars Oxygen In-Situ Resource Utilisation Experiment) absorbs CO_2 from the Martian atmosphere and electrochemically divides it into O_2 and CO for use in Mars exploration [32].Before being released back into the Mars atmosphere together with the CO and other exhaust products, the O_2 is then examined for purity. This illustrates how upcoming Mars exploration teams can harvest oxygen from the Martian atmosphere for respiration and use as fuel.

CONCLUSION

The presence of water on Mars is of great interest to scientists as it is a crucial resource for potential human exploration and colonization. Water can be used for sustaining life, producing breathable oxygen, and generating rocket propellant. Additionally, the presence of water may indicate the possibility of past or present microbial life on Mars.Ongoing research continues to investigate the distribution, abundance, and properties of water on Mars, including subsurface reservoirs and the potential for liquid water beneath the surface. New missions, such as NASA's Mars Perseverance rover and the upcoming European Space Agency's ExoMars mission, are equipped with advanced instruments to further explore Mars' water resources and search for signs of past or present life.

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