SUBSURFACE EXPLORATION FOR WATER ON MARS

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Introduction: Water is involved in many geological and biological processes and has many unusual properties. The unique detection of water requires looking for a method that can characterize something unique about the existence or occurrence of water or of some process that is a result of the behavior of water. There are many methods that can detect the presence of water but few that can unambiguously and uniquely identify it as being water. Most methods rely on detecting the motion of all or parts of the water molecule [1]. Each method has advantages and disadvantages in subsurface exploration, but those that are the most unambiguous detectors of water do not work to adequate depths of exploration (hundreds of meters to kilometers). The methods that can least ambiguously detect water to depths of kilometers are combined electromagnetic and seismic exploration for the Bjerrum defect dielectric and elastic relaxation process in water ice and the seismoelectric coupled process for liquid water in a pore space.

Electromagnetic Exploration: By exciting motion in charged particles, electromagnetic waves are generated. The interaction of these waves with matter is a function of the frequency of excitation of the wave. At low frequencies (below 1 MHz), these waves diffuse into the ground through a process called electromagnetic induction, and there are many methods and techniques available to use EM induction for subsurface exploration [2]. At high frequencies (above 1 MHz), the waves propagate and the most common exploration method is called ground penetrating radar [3]. The depth of subsurface exploration is a function of material properties and frequency, with lower frequencies penetrating deeper. The resolving ability of the methods general improves with increasing frequency. Grimm [4] and Olhoeft [5] have reviewed the prospects for low and high frequency electromagnetic systems on Mars.

These electromagnetic systems respond to geometry and the material properties characterized by electrical conductivity, dielectric permittivity, and magnetic permeability [6]. The electrical conductivity and dielectric permittivity of soils and rocks are a function of their water content and properties. Water presence has no impact on magnetic permeability (unless water changes iron oxidation state by corrosion). At low frequencies, the electrical conductivity is a very sensitive indicator of the amount, chemistry, state and distribution of water [7]. However, there are a large number of factors that determine electrical conductivity, making it a very nonunique detector of water.

Frozen water as ice Ih has a Bjerrum defect in its structure which results in a dielectric relaxation process in the kilohertz frequency range [8]. The detection of the frequency response of this dielectric relaxation is a less ambiguous indicator of water. It is not unique, however, as geometry or magnetic relaxation processes [9] may also possibly produce similar responses in electromagnetic exploration systems.

Seismic Exploration: If instead of propagating an electromagnetic wave, a physical particle motion is excited, then an elastic wave will propagate and seismic methods of subsurface exploration are employed. As in electromagnetic methods, lower frequencies penetrate deeper but higher frequencies have higher resolution. The same defect in ice as produced the dielectric relaxation in the kilohertz frequencies also produces an elastic relaxation response [8]. Finding both the dielectric relaxation with an electromagnetic measurement and the elastic relaxation with a seismic or acoustic measurement produces not only a unique indicator of water ice, but it also indicates the temperature of the ice.

The viscous motion of liquid water inside a pore space is one of the main causes of attenuation for elastic wave propagation [10, 11]. The lack of water on the moon is the reason why the low frequency seismic attenuation is so low [12]. High frequency attenuation is dominantly by scattering.

Water Exploration: The search for subsurface water at depths greater than one meter is relatively difficult. To first order, the seismic Q is a good large volume average indicator of water presence. If the Q is in the thousands or higher like the Earth's moon, then there is no significant water present. If the Q is in the tens, then water is present in the subsurface comparable to the Earth. In between, the details of the Q versus frequency from a few hertz to kilohertz will indicate the amount and form of water (liquid or frozen). Around a few hertz, both seismic and electromagnetic measurements can penetrate to kilometers depth of investigation.

If the seismic Q versus frequency and the electromagnetic Q versus frequency show relaxation processes in the kilohertz region, then the Bjerrum defect model [8] can be used to identify and estimate the amount of frozen water ice Ih present and the temperature of the ice. Kilohertz depth of penetration may be as much as kilometers for electromagnetic methods, but will likely be hundreds of meters or even much less for seismic methods. This requires confirmation that there are no obscuring or confusing magnetic relaxation processes present, and it requires information about electromagnetic and seismic noise levels.

If the electrical conductivity is very low at low frequencies, then little liquid water is present. If it is very high, then the possibility exists for significant amounts of water to be present. However, conductive minerals like salt brines, mineralogical clay minerals, metallic minerals, and high temperature materials (dry geothermal) may also be highly conductive and thus confuse the search for water. Some of this could be sorted out by measuring electrical properties as a function of frequency and temperature as the bulk of the confusing mineralogies exhibit distinctive electrochemical responses [13].

To focus further on water, if low frequency measurements show a low seismic Q and a high electrical conductivity, and there is no distinctive electrochemical signature of reactive mineralogy, then the coupled process, seismoelectric method should be used. In this, a seismic wave propagates, exciting water movement (if present) inside fractures and pore spaces. The electrical charge accumulation at pore walls is carried along by flowing fluids inside the pore, requiring an electrical counter current to maintain charge neutrality. The counter current flow through a finite electrical conductivity fluid generates a voltage measured as a streaming potential [14, 15, 16]. The correlated seismic source and electrical response is a low ambiguity indicator of the presence of liquid water. If there is no response, then there is no mobile liquid water. There may be adsorbed water.

Discussion: The search for water on Mars is compounded by several factors. The high iron content soils on Mars are known from Viking and Pathfinder [17] to be magnetic at low frequencies. However, the lack of knowledge about detailed magnetic mineralogy means there is no information about their frequency and temperature dependence on Mars. The possibility exists for strong magnetic responses with high variability over frequency ranges of significance to both high and low frequency electromagnetic methods, and for high variability over diurnal and seasonal temperature ranges.

The lack of knowledge about the electromagnetic noise spectrum on Mars makes design of an adequate electromagnetic exploration system difficult.

Seismic measurements of Q are difficult on the earth, and the complete lack of successful seismic measurements on Mars leaves much to be desired, with a long list of unknowns (noise, coupling, etc.).

The alternative to deep electromagnetic and seismic exploration for water on Mars is blind drilling. Given the mass and costs of transport, and the odds of success in the face of geological heterogeneity, drilling must be preceded by adequate geophysical exploration.

In order to design an adequate geophysical exploration program for water, electromagnetic and seismic noise levels must be measured on Mars. The magnetic mineralogy must be determined and the impacts on electromagnetics must be studied. The Mars range temperature dependence of the properties of water bearing systems must be studied for the range of mineralogies expected. Seismic coupling of instruments to Mars dusts and soils under Mars ambient temperature and pressure must be studied.

At the end of these measurements and studies, the range of water contents and conditions that could be detected on Mars and over what range of geologies and depths could then be accurately predicted.

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