SUBSURFACE GEOPHYSICAL DETECTION METHODS TO UNIQUELY LOCATE 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 ocurrence 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. Each method has advantages and disadvantages in subsurface exploration, and they are discussed in terms of shallow to deep subsurface exploration potential.

Infrared: Bending and stretching motions of bonds between the hydrogen and oxygen atoms in the water molecule produce distinct and unique identifying features in the infrared spectrum [1] that may be used to uniquely identify the presence and amount of water. Unfortunately the depth of penetration is only microns, limiting this technique to surface characterization and making it unsuitable for subsurface investigations. It is however suitable for use from orbital and earth based remote sensing observations.

Neutron: Neutrons are scattered by the cross section of hydrogen in water [2], allowing a water detection method that is commonly used in oil well and water well logging [3]. However, this requires a source of neutrons and the depth of penetration is only tens of centimeters, severely limiting its potential for deep subsurface investigation. Gamma ray methods [3] are also used sometimes but the depth of investigation is also limited to tens of centimeters.

NMR: Nuclear magnetic resonance is a method that exploits the precession of the proton spin as a magnetic field orientation is changed [4]. In terrestrial applications, one magnetic field is supplied by the earth and a second artificial field is generated to cause the proton to precess. The frequency is at or below the kilohertz range, allowing deep penetration, but the lack of a magnetic field on Mars and the power and weight requirements to generate two fields would be very costly on Mars. NMR can measure the unfrozen water content of soil-water-ice mixtures [5]. The presence of magnetic minerals may also complicate the interpretation of NMR measurements [6] so the answer is not unique.

Electrical: In the absence of water, nearly all rocks and most minerals are very good electrical insulators [7], which become more conductive upon the addition of water. The most sensitive indication of the presence of water is given by electrical resistivity or conductivity measurements, which can detect less than monolayer quantities of adsorbed water [8, 9]. These can see kilometers deep when appropriately configured, but require contact with the ground (and are thus not suitable for aircraft, orbital or other remote observations), and do not uniquely identify water [7, 8]. Streaming potential relies upon the electrokinetic response of water moving through fractured or porous materials [10], requires ground contact, and can only uniquely identify water if it can track the response through a known water pressure fluctuation in time (weather, seasons, climate, or see seismoelectric below) as otherwise it can be ambiguous with several electrochemical processes [11]. The dielectric relaxation from the orientational polarization of the liquid water molecule produces a unique indicator of water near 10 GHz [12], but at that frequency the penetration is less than a meter. A similar dielectric relaxation occurs in water ice near a few kHz [13, 14] and for clathrate hydrate ices near a few MHz [15]. These relaxations could be measured to depths of hundreds of meters using electrostatic capacitative coupling methods or electromagnetic techniques. In these cases, the dielectric relaxations would produce frequency dependence in electrostatic or electromagnetic measurements that can be used to determine water presence, state, and amount.

Electromagnetic: Electromagnetic methods respond to the electrical and magnetic properties of soil and rocks. These include low frequency electromagnetic diffusion (induction) methods [16] and high frequency electromagnetic wave propagation (ground penetrating radar) methods [17]. They do not require ground contact and may be performed (with limitations) from the surface, aircraft or orbit. At the lowest frequencies, electromagnetic responses are dominantly controlled by electrical conductivity and geometry, and at the highest frequencies they are controlled by frequency dependent dielectric permittivity and geometry. As they are electromagnetic measurements, the magnetic properties are also important, but we know little about the dynamic properties of magnetic minerals on Mars other than there are magnetic minerals [18].

It is expected that low frequency (below 1 kHz) instruments on Mars could detect the presence of liquid water to depths of kilometers [19], but not uniquely identify it. Instruments between 1 and 10 kHz could detect water ice and identify it by the ice dielectric relaxation peak frequency [14], probably to depths of hundreds of meters. Instruments at ground penetrating radar frequencies of 1 to 10 MHz could detect water ice to depths of tens to hundreds of meters and identify clathrate hydrate ices but not water ice. Instruments at ground penetrating radar frequencies of tens to hundreds of MHz could detect water ice to depths of tens of meters, but only identify it through geological context. There is a possibility of detecting liquid water at these frequencies to depths of tens of meters and bounding an identification through the observed frequency dependence of the response [20]. However, all these depths and possibilities are uncertain without knowing more about the radiofrequency noise levels, surface and volume electromagnetic scattering distributions and magnetic mineralogy on Mars [21].

Seismic: Elastic properties also respond to the motion of water. The Q (quality factor related to seismic attenuation) of the moon is in the tens of thousands because there is no liquid (water or other fluids) to move and lose energy through viscous dissipation processes [22, 23]. In contrast, the Q of the earth is typically in the tens because of the presence of fluids (not just water, but oil, and partial melts). A general observation on Mars that the Q is high and similar to the moon would rule out widespread water.

Water ice also produces an elastic relaxation similar to the dielectric relaxation noted earlier and by the same root mechanism [14]. Unfortunately, in the kilohertz range where it would be observed, acoustic elastic wave propagation exhibits very high attenuation in loose soils and high scattering from meter size blocks, so depth of investigation is limited to tens of meters. If both dielectric and elastic relaxations were observed, however, that would be a unique identification of water ice, and the relaxation frequency would indicate the temperature of the ice, while the relaxation amplitude would indicate the amount of ice present.

Seismoelectric: The propagation of an elastic wave through a porous material containing water causes the water to move relative to the host material, generating a streaming potential [10]. The combination of a seismic source producing an electrical response is a coupled process called the seismoelectric effect [24]. The water, oil and service companies hold great hope that this effect may be used to measure fluid conductivity in the ground [25, 26]. In terrestrial environments, it is a difficult measurement to make and the effect is not entirely understood. However, on a lower seismic and electromagnetic noise Mars (ignoring wind), it might be the best way to uniquely identify the presence of kilometers deep water.

Recommendation: To detect shallow subsurface water and ice on Mars, start with electromagnetic methods, which are the easiest to implement, then move to deeper searches with seismic and seismoelectic coupled processes. To uniquely identify water, use the dielectric and elastic relaxations or seismoelectric coupled processes.

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