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EFFECTS OF WATER ON THE ELECTRICAL PROPERTIES OF PLANETARY REGOLITHS

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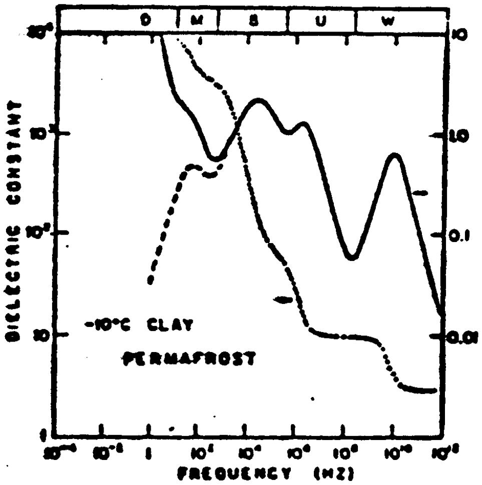
The effects of water on the electrical properties of porous or granular materials are numerous. Four parameters (amount of water relative to the specific surface area of the host material, the concentration and type of impurities in the water, temperature, and pressure) primarily determine the state of the water: 1) free liquid water, 2) solid structured ice (or hydrate), and 3) vicinal (the water of restricted mobility and freedom near an interface, possibly structured water). A fifth parameter, frequency, determines which of several water related mechanisms will be observed in the electrical properties.

Figure 1 illustrates the effects of representative water related mechanisms on the electrical properties of permafrost. The permafrost is approximately 50% by volume water and ice with the remainder being nonsmectite clays and a trace of organic materials. The dielectric constant (dotted line) and loss tangent (solid line is the total loss, dashed line is without DC conductivity loss) are shown versus frequency at -10°C, 162 kPa, and 1750 kg/m^3. The regions labelled above the figure outline the frequencies for which various mechanisms dominate. D is the region of ionic conduction (DC conductivity) through the unfrozen water sheath surrounding the clay particles. M is a Maxwell-Wagner type of colloidal response due to the interaction of the unfrozen water with colloidal clay



particles. B is the relaxation of structural defects in ice. U is the region of relaxation of organic molecules in the unfrozen water sheath around the colloidal clay particles (or it may be a clathrate-hydrate relaxation). W is the relaxation of the unfrozen water moleclues themselves. All of these mechanisms are related to the presence of water. Only in the region well above 10 GHz are the electrical properties of this material independent of the water (though they become dependent again in the far-IR due to the O-H stretching).

The electrical properties of materials are extremely sensitive to very small amounts of water. At 298K, the DC resistivity of a solid basalt is typically on the order of 10^{12} ohm-m (completely dry in 10^{-6} Pa vacuum). A single monolayer of water (0.01 wt% typical) will decrease the dry resistivity by an order of magnitude, and an amount as small as 0.002 wt% is detectable. At a frequency of 10 Hz, no change in electrical properties is observed until more than a physisorbed monolayer of water is present, but very small amounts of water in addition to the physisorbed monolayer produce drastic changes in electrical properties.

Water produces such drastic changes in electrical properties because it is a highly polar molecule. Liquid water below its relaxation frequency (near 10^{10} Hz at 298K) has a dielectric constant of about 80, while ice (relaxation frequency near 10^4 Hz) has a value near 100. The DC resistivity of extremely pure water is about 10^5 ohm-m and of very pure ice in about 10^7 ohm-m. A typical silicate material on the other hand has a dielectric constant of about 8 and a DC resistivity of 10^{12} ohm-m or greater. These properties are all extremely temperature dependent, but do illustrate the relative importance of water in basalt and similar materials where the electrical properties of the water are an order of magnitude more significant than those of the basalt.

In planetary regoliths, the surface pressure of 10^{-10} Pa is too low for water to be present on the surfaces of Mercury and the Moon, and studies of lunar samples have confirmed that the electrical properties are those to be expected for silicate materials in the complete absence of water. Earth, Venus, and Mars would be expected to be entirely different, however, due to their atmospheres.

On the surface of Venus, the temperature and pressure are 741K and 9.4 MPa. In this environment, water is completely dissociated and has a dielectric constant of about 2. DC resistivities of the silicates will be about 10^4 ohm-m, while water will be far higher. Thus the presence of water will have no appreciable effect on the electrical properties of the surface of Venus.

Mars has a pressure and temperature regime which is quite variable and could allow the stable presence of both liquid and solid water. At the mean surface temperature and pressure of 213K and 0.6 kPa, the electrical properties above 10^4 are indistinguishable from those of the surface of the Moon as all of the water is frozen solid while at lower frequencies the other mechanisms of Figure 1 above may still be important. At higher temperatures, more of the higher frequency mechanisms become active.

On the surface of the Earth, water is abundant and found in a variety of forms. Figure 1 above illustrates several of the more representative mechanisms in permafrost, though others are found in geothermal environments, near sulfide mineralization, and so on.

Thus, it appears that water only has a significant effect on the electrical properties of planetary regoliths for the surface of the Earth, and in very restricted circumstances for the surface of Mars. The Moon, Venus, and Mercury have environments that are too inhospitable for water to alter the electrical properties from those of completely dry silicate materials.

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COMMENTS

Brass: I'd like to comment on the possibility that the graph of the dielectric constant versus the temperature profile could be due to melting of ice below 0°C in the presence of salt. Would you be able to see evidence for pure water?

Olhoeft: It depends on the wave length you're looking at. There are possibilities for doing that.

Martin: In other words, to see it, you'd almost have to do a spectral scan.

Olhoeft: That, or you'd have to pick a wave length that sits on top of one of those mechanisms. There were five of them in the permafrost that were available.

Rossiter: What percent of water was in the schematic figure of the spectrum?

Olhoeft: That was an extreme case, because it had 50% by volume of water in it.

Low: Is there any way of isolating the dielectric constant of the water in a water-clay or water-silicate mixture?

Olhoeft: No. There are formulas that have been tried, but there's such a strong dependence upon how much water you've got there and what it's doing at the interface, more than anything else. I've been using mainly distilled water and allowing whatever material I'm putting in to alter it. The story changes considerably if you're working with brines.

Huguenin: Could you distinguish between salt brines and the ion-rich interlayer water in clays? The Martian dust is not a simple clay-like material, but rather an intimate mixture of residual silicate, chlorides, nitrates, sulphates, oxides, and carbonates. It seems to me that it may be difficult to isolate salty ground water (brines) from the dust electrical properties. It would also be interesting to determine the electrical properties of surface oxidant ions on the unweathered soil fraction.

Olhoeft: This research is currently in progress, and there is enough to do to keep a hundred scientists busy. We hope to be able eventually to isolate these effects.