Estimation of ice and liquid water on martian analogue soils at temperatures below 0°C by means of dielectric spectroscopy

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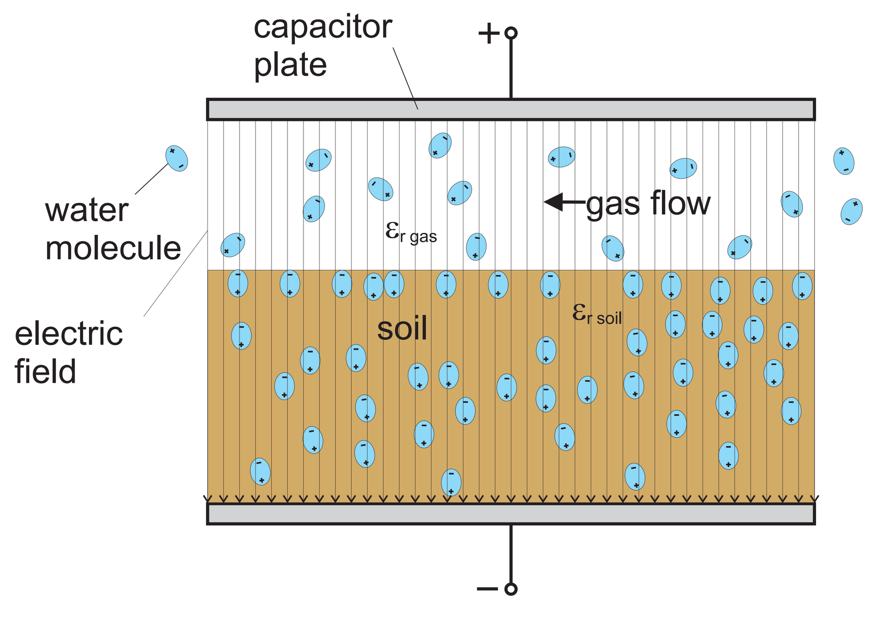
Recent observations on Mars as well as experimental investigations indicate that water could be a key factor of current physical and chemical processes on the martian surface, e.g. rheologic phenomena like downslope flows and seepages *[Kereszturi et al., 2010]*. Therefore it is of particular interest to get more information about the amount of water and its dielectric properties that remains in a liquid like state in martian analog soils at temperatures below 0°C. The detection of liquid water is also a key element for the classification of the habitability of Mars. In this context, a plate capacitor has been developed *[Lorek 2008]* to obtain isothermal dielectric spectra of fine grained soils in the frequency range from 10 Hz to 1.1 MHz at martian like temperatures down to -70 °C.

Experimental technique

This measurement system is based on a plate capacitor *(Fig. 1)* and measures the dielectric soil properties in dependence on the soil moisture *(Fig. 2, 3)* in the temperature range from +25°C to -75°C. Two martian analogue soils have been investigated: a Ca-Bentonit (specific surface of 215 m²/g, up to 9.4 %w/w gravimetric water content) and JSC Mars 1, a volcanic ash (specific surface of 146 m²/g, up to 7.4 %w/w).



Capacitor with defined air-layer above the material under investigation

Fig. 1: working principle

$$C = \varepsilon_0 \cdot \varepsilon_{r(soil,gas)} \cdot \frac{A}{d}$$

C	*capacitor capacitance*
ε_0	*permittivity of free space*
ε_r	*soil and gas permittivity*
A	*capacitor plate area of one plate*
d	*distance between the plates*

Fig. 2: capacitor formula

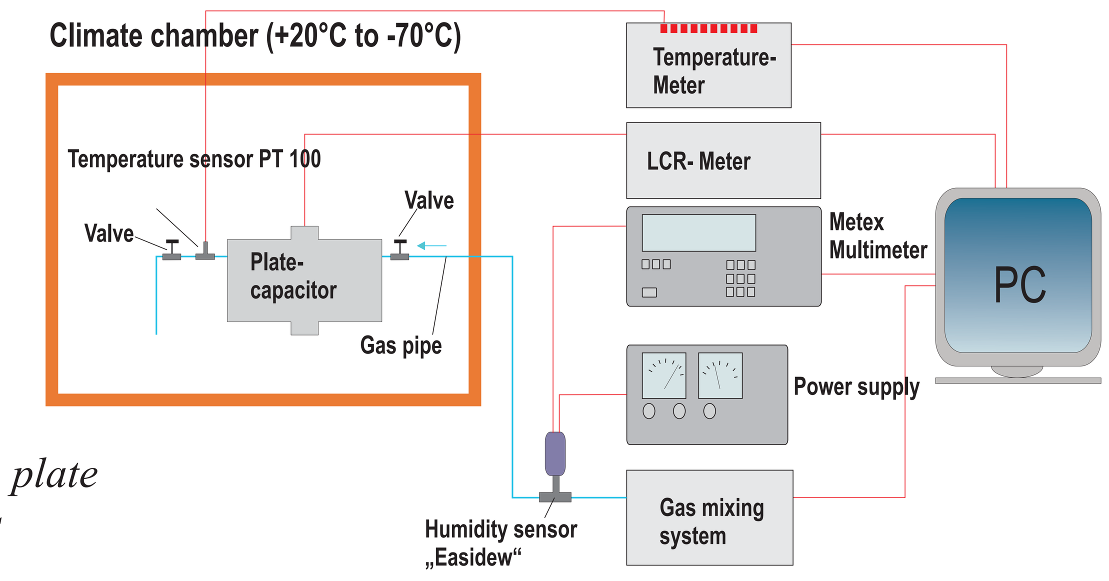


Fig. 3: Experiment design

Dielectric relaxation behaviour

Three soil-specific relaxation processes are observed in the investigated frequency-temperature range *(see Fig. 4)*: two weak high frequency processes (bound or confined water as well as ice) and a strong low frequency process due to counter ion relaxation and the Maxwell-Wagner effect. To characterise the dielectric relaxation behaviour a generalized dielectric relaxation model *(GDR, [Wagner et al. 2010])*:

$$\tilde{\varepsilon}_{r,eff}(\omega,T) - \varepsilon_\infty = \sum_{i=1}^{3} \frac{\Delta\varepsilon_i(T)}{\left[j\omega\tau_i(T)\right]^{\alpha_i} + \left[j\omega\tau_i(T)\right]^{\beta_i}}$$

is applied assuming three active relaxation processes with relaxation time τ_i, of the i-th process according to an Eyring equation *[Wagner et al. 2009]*:

$$\tau_i(T) = \kappa_i \frac{h}{k_B T} \exp\left(\frac{E_{a,i}}{RT}\right)$$

ω	*angular frequency*
T	*absolute temperature*
$\Delta\iota_e$	*relaxation strength*
α_i ,$\Delta\beta_i$	*stretching exponents*
h	*Planck-constant,*
k_B	*Boltzmann constant*
κ_i	*transmission coefficient*
R	*gas constant*
$E_{a,i}$	*apparent activation energy*

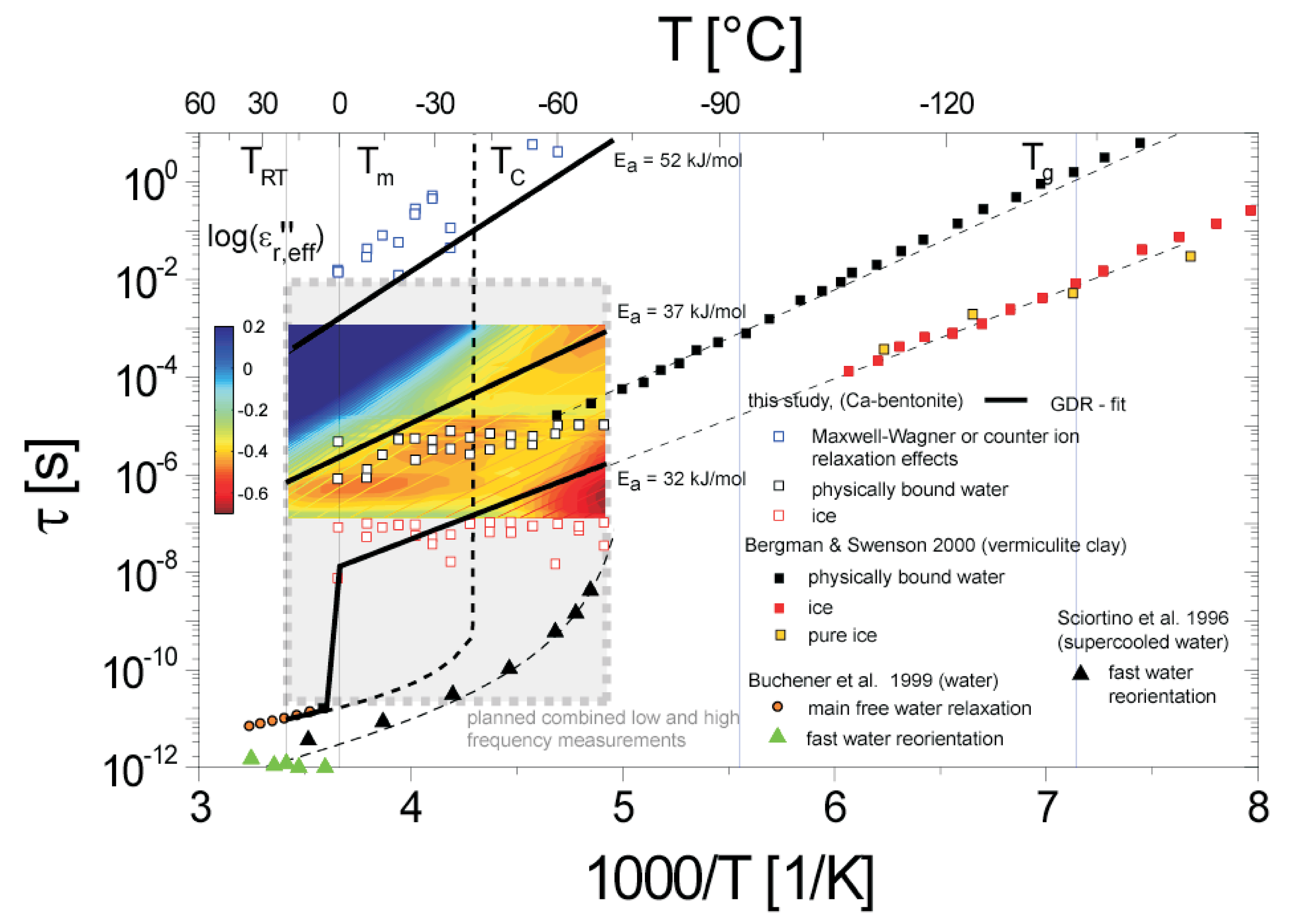


Fig. 4: Relaxation map of expected dielectric relaxation processes in soil in comparison to and pure water/ice.

Results and conclusion

The real part of effective complex soil permittivity at 350 kHz was used to determine ice and liquid like water content by means of the Birchak or CRIM equation.

Measured real part of the permittivity of JSC Mars 1 (Fig. 5) at a constant water content of 2,3; 2,0; 1,6 mono layers and bentonite (Fig. 6) at a constant water content of 1.7, 1.3, 0.7 mono layers at normal pressure and at a measurement frequency of 350 kHz in the temperature range from 25 °C to -70 °C.

There is evidence that 1.3 mono layers of water remains in a liquid like state at -70 °C for bentonite and 2.3 mono layers for JSC Mars 1.

The results indicate a reasonable agreement *(Fig. 7)* with predictions made from the sandwich-model of interfacial water *[Moehlmann, 2008]*.

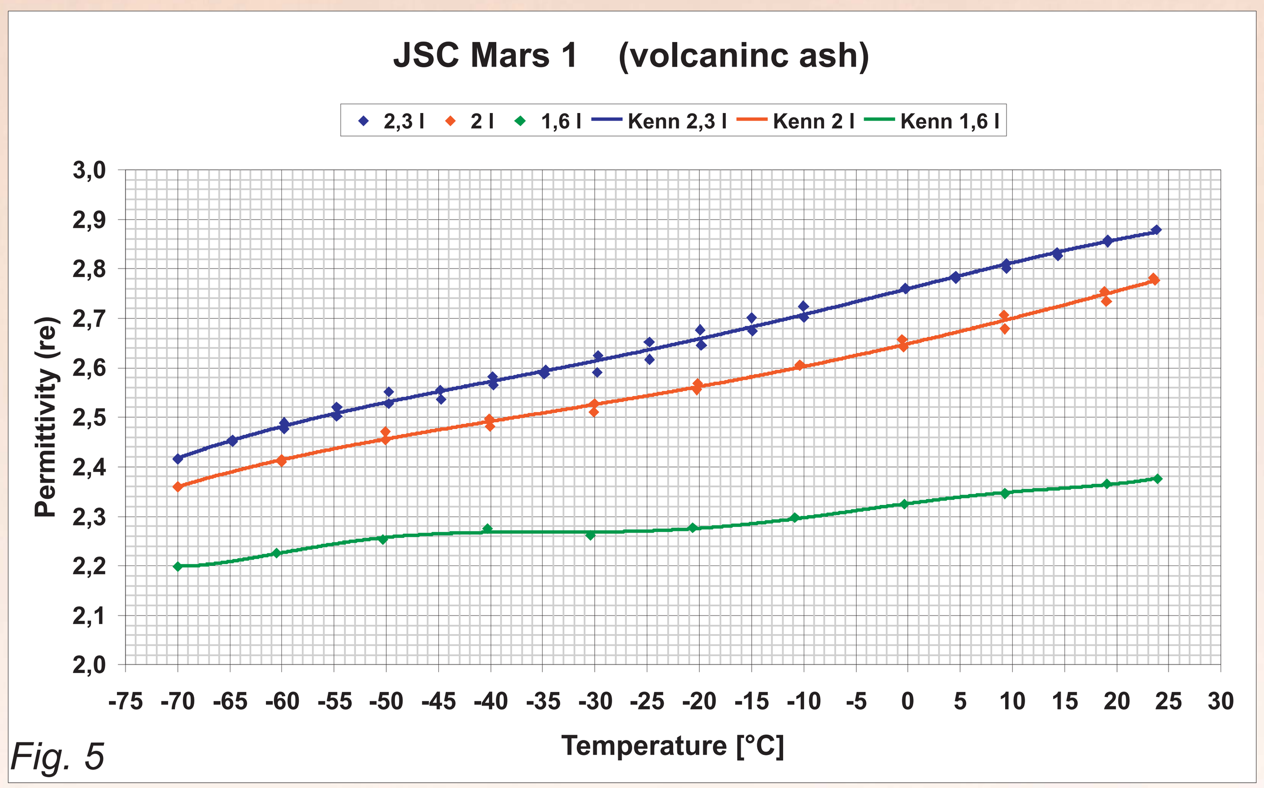


Fig. 5

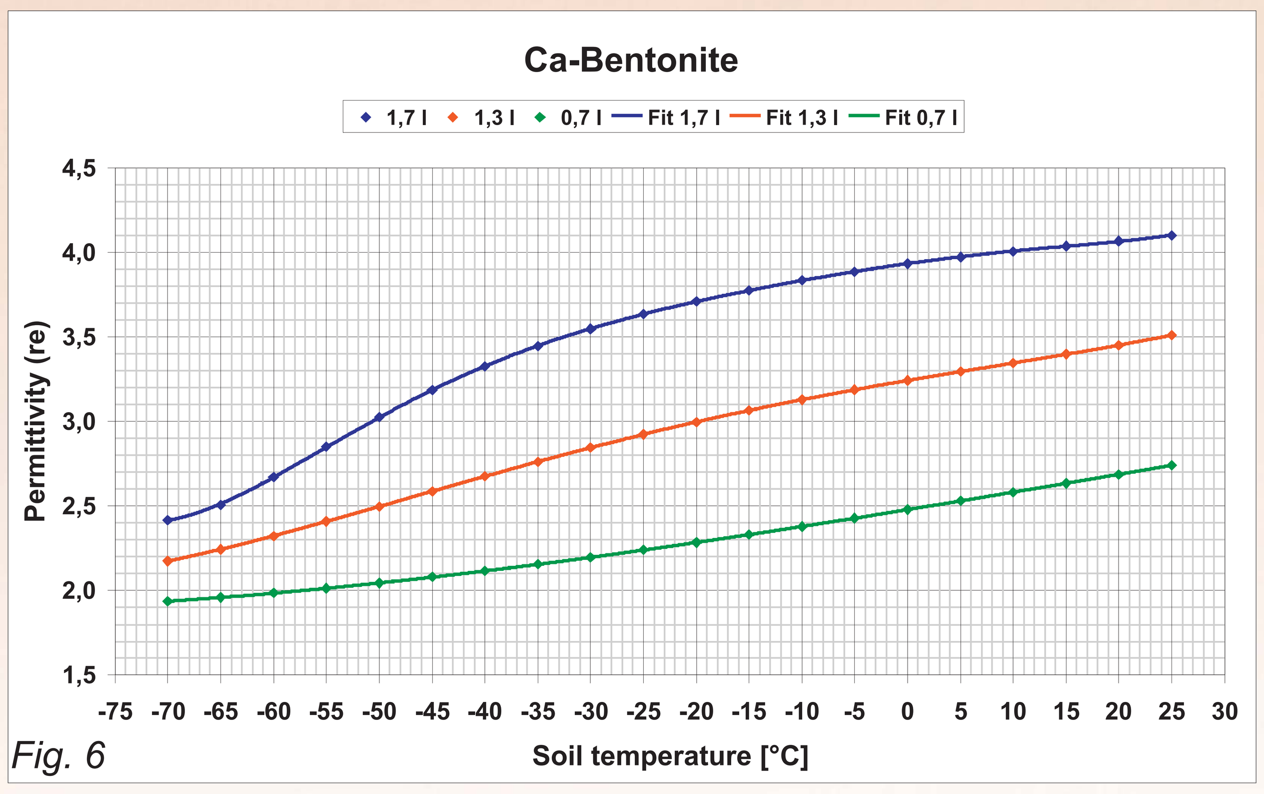


Fig. 6

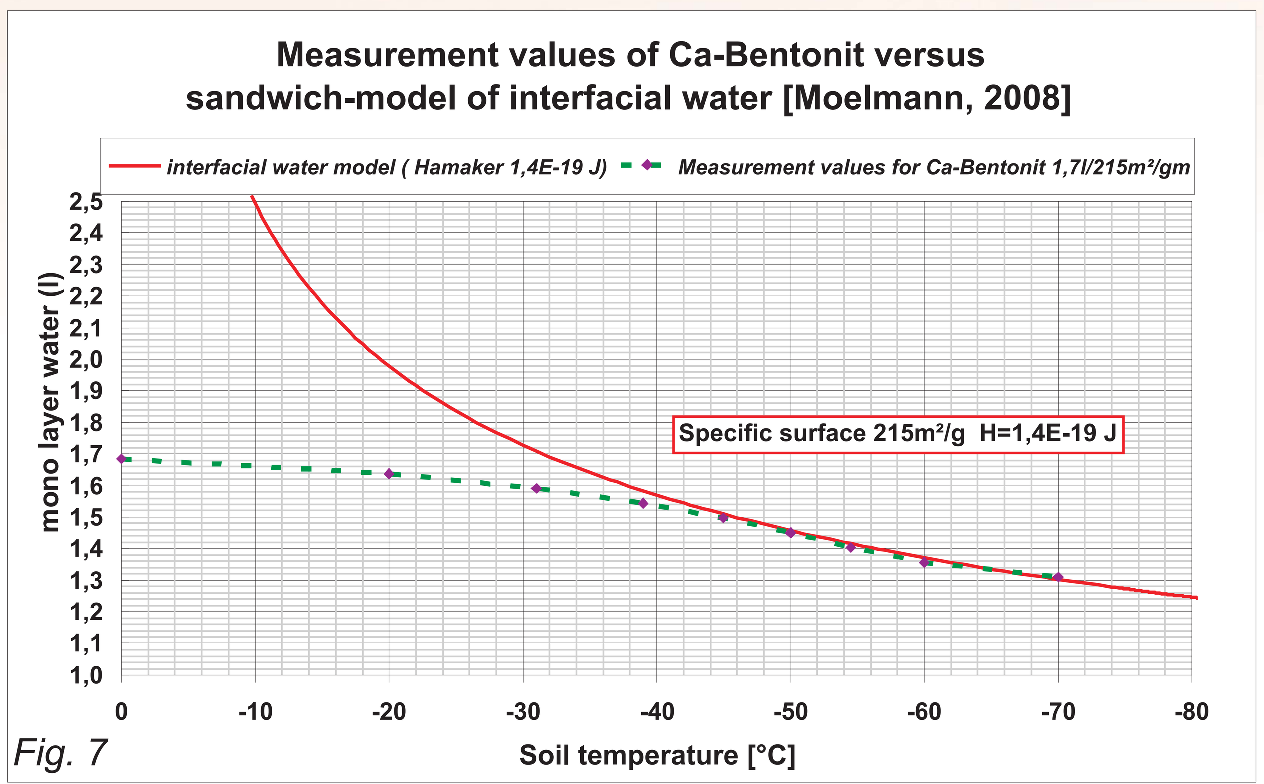


Fig. 7

$$\varepsilon_B^\alpha = V_{jTB} \cdot \varepsilon_{TB}^\alpha + V_{jL} \cdot \varepsilon_L^\alpha + V_{jflW} \cdot \varepsilon_{flW}^\alpha + V_{jI} \cdot \varepsilon_I^\alpha$$

ε_B	*DC – soil*
ε_{TB}	*DC - dry soil*
V_{jTB}	*volumetric part - dry soil at total volume of soil*
ε_L	*DC - air*
V_{jL}	*volumetric part - air at total volume of soil*
ε_{flW}	*DC - liquid water in soil*
V_{jflW}	*volumetric part - liquid water at total volume of soil*
ε_I	*DC - ice*
V_{jI}	*volumetric part - ice at total volume of soil*
α	*0,5*

Birchak- or CRIM equation

Bergman, R. and Swenson, J. (2000) Nature, 403, 283-286.
Buchner, R., Barthel, J., and Stauber, J. (1999) Chem. Phys. Let. 306(1-2):57–63.
Kereszturi, A. et al., (2010) Icarus, 207,S.149
Lorek, A, (2008), Universität Potsdam, Dissertation
Möhlmann, D., (2008) Icarus, 195, S. 131–139
Sciortino, F., Gallo, P., Tartaglia, P., and Chen, S.-H. (1996) Phys. Rev. E (54) 6, 6331-6343.
Wagner, N., Bonitz, F., Emmerich, K, Kupfer, K. (2010) IEEE Trans.Geo. Rem. Sens. (accepted).
Wagner, N. and Scheuermann, A. (2009) Can. Geotechn. J. 46(10) 1202-1215.