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Interactive comment on "*In situ* nuclear magnetic resonance response of permafrost and active layer soil in boreal and tundra ecosystems" *by* M. Andy Kass et al.

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We thank the referee for the constructive and positive comments, and have consequently added material into the manuscript. Specific responses to comments listed below.

- *Petrophysical models of NMR-response from hydrocarbon exploration base on the assumption of a combination of water in oil in the pore space. In this case, the water will always cover the pore wall due to its bipolar character and thus affinity to the negatively charged pore-wall. The oil volume will be isolated from the relaxing pore wall and thus show relatively long decay-times. For common*

pore-space geometries this water will be a thin film and is thus called capillary water. Only for large pores or low oil volumes this water will have sufficiently large volume-to-surface ratios to show longer relaxation times > 30ms → free water. The authors recognize this limitation. Nevertheless they refer to this classification throughout the manuscript, even though they show in the course of the paper to be invalid. Additionally, the relaxation spectra in figure 5 give no evidence of a multiexponential distribution indicating different classes of water. The classification by hydrocarbon threshold values is misleading. I suggest to eliminate from the interpretation of the recorded data.

  For the case of water-wet rocks the reviewer is correct but the NMR response in oil-wet rocks exhibit the opposite behaviour. We believe the reviewer may be mistaking using T_2 for (fluid typing) rather than its use as a single phase permeability indicator. In environmental applications the use of cutoff values as an interpretation tool differentiating bound and mobile water are common (e.g. Behroozmand et al., 2015 and Knight et al., 2016). We acknowledge that without additional calibration these actual cutoff values are somewhat arbitrary, but have proven to be a useful as approximate bounds. The distributions are reasonably insensitive to small perturbations of these cutoff values. We have added discussion and references to the manuscript further highlighting the limitation of uncalibrated cutoffs. It may be useful for future literature to avoid the term capillary-bound and instead develop a new term in an unconsolidated setting to avoid confusion.

  Figure 5 shows a distribution of exponentials (roughly log-normal distribution of pore sizes around a mean), but indeed does not conclusively indicate two separate populations of pore sizes.

- *Water in pores at or below the freezing point will be exposed to the forces of the negatively charged pore-wall and the crystallization to ice. As the numerical model clearly shows a model with ice-covered pore-walls cannot explain the measured data, while an ice-filled pore center qualitatively fits. Nevertheless, a* *description of the model with a homogeneous center of crystalline ice and a film of fluid water at the relaxing pore-wall is somewhat over-simplified. At the local freezing point (probably below 0C, due to the presence of the pore wall) water will most probably not form a homogeneous crystal, but more likely a slush of ice and water. While solid ice at low temperatures has no measurable NMR-signal, in temperate ice, intercrystalline water is present in quantities that generate measurable NMR-signals at long relaxation times. A slush of ice and water will generate similar signals as the ice-filled pore in the study. Thus the model may be used to qualitatively differentiate the two models of ice crystals in the center vs. ice covered pore walls. For a more quantitative analysis of the NMR-responses, the model is not suitable.*

The pore scale model is included as first-order approximation of the distribution of the water and ice phases, and is not intended to capture the dynamics comprehensively. In addition, clay grains are below the resolution of the model scale. Regarding the NMR signal of slush, it depends on the mobility of the spins within the pores. If the ice fully occludes access to grain wall, then very long T_2 times will be observed. It would also be possible for the slush to result in restricted diffusion within the pores, which additionally could enhance the T_2 times. In our data we do not observe this phenomenon of long T_2 as depth increases and freezing is anticipated to also become more complete. However, a future rigorous laboratory study using a similar instrument in controlled freezing conditions would be fascinating to attempt to observe the phenomenon. We have added commentary discussing the consequences of nucleating ice characteristics to the manuscript.

References

Behroozmand, A., Keating, K., and E. Auken, 2015, *A review of the principles and applications of the NMR technique for near-surface characterization*. *Surveys in Geophysics*, **36**(1), p.

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