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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 Dr. Akagawa for his thorough and detailed comments. The additional citations and information provided will enrich the paper. Specific comments are below.

- Regarding the use of NMR in unconsolidated media several clarifications can be made that may have not been evident in the initial manuscript. While it is accurate that porous media NMR was originally developed by the oil and gas industry where aquifers are often consolidated sandstone, there exists a wealth of examples of applying the Schlumberger-Doll and Timur-Coates equations to derive reliable permeability estimates in unconsolidated porous media (e.g. Knight et

al. 2012, Legchenko et al. 2004, Behroozmand et al. 2015, and Parsekian et al. 2015).

The use of NMR to characterize multiphase systems whereby one phase does not give appreciable signal (also considering unsaturated systems as an analogue for the ice phase) is somewhat less developed (Song 2010, Parsekian et al. 2013, and Walsh et al. 2014).

Given the rich literature in this space, we feel quite confident in the applicability of NMR measurements in the given context. These references have been added to the manuscript.

- *For example, the specific surface area of sandstone distributes around a few m2/g whereas that of clay and soil distribute from a few to 100m2/g, as shown in Table 1 (Akagawa and Syouji, 2004). The specific surface area of fine soil is about a few to 50 times larger than that of sandstone.*

  Regarding the surface area to volume concerns of soil types: NMR instrumentation has shown capable of providing reliable estimates in unconsolidated media including clay layers (Knight et al. 2016) as well as tight oil and gas reservoirs with similar partial and corresponding (S/V) (Xiao et al. 2012); although in these situations calibration of the coefficients in the Timur-Coates and Schlumberger-Doll equations may be necessary (specifically with regards to absolute pore sizes and permeabilities). The need for calibration was a primary motivation for the pore-scale simulations which we included in the manuscript. It has also been demonstrated that the cutoff values differentiating bound, and mobile water are much less sensitive than the exponential factors in permeability estimation.

- *Regarding to unfrozen water content, it is well known experimentally (Williams, 1964) and theoretically (Kuroda, 1985) that the fine soil has considerable amount of unfrozen water in subzero temperature. Even the amount sharply decreases from 0 to -1 Deg.C , it still exist at -20 Deg.C.*

Indeed, this is consistent with our findings and well known; we have added the additional references. Our primary interest is in characterising critical permafrost near 0° C where understanding the dynamics between the phases is important in management and forecasting.

- *Regarding to the distribution of unfrozen water, it is discussed with its thickness from the surface of clayey minerals but not discussed with pore diameter. Because the specific surface area of fine soils is so extensive and the clayey minerals are generally plate-like shape, unfrozen water is believed to be distributed right on the surface of clayey minerals. The thickness of unfrozen water ranges from 10 to 100 nm at -0.1 Deg.C and 5 to 40 nm at -1 Deg.C (Akagawa and Syouji, 2004), as shown in Figure 1. Therefore unfrozen water decreases by thinning its thickness as its temperature decreases.*

  Thank you for making this point, which will also benefit from clarification. While we do expect to see some clay-bound water in these media, the NMR instrumentation is fairly insensitive to this water ($T_2 < 3.6$ ms). As such we do not surmise to be detecting the whole extent of clay bound water within the media. You are correct that for very small pores the T_2 times will become vanishingly small and will not be detectable using the instrumentation we have. Please remember, the sediments are primarily silty in nature (e.g. Fig. 2 and Table 1)–which from scanning electron imaging (Moraes et al. 2015) can be reasonably approximated using sphere packs or similar–hence our choice of models for simulation. The pore scale simulation scales are on the order of μm rather than nm, and the clay grains are effectively below the resolving power of μCT imaging. The pore-scale simulations are consistent with liquid-phase water distributed primarily at the surface of the pore matrix.

  Specifically regarding the applicability of equation 2, we find it completely applicable due to the combination of (1) the NMR instrument being largely insensitive to the clay-bound water (and thus the distorted S:V) combined with the lack of

sampled clay soils, and (2) that we do not assume anything beyond the surface area to volume ratio (i.e. we do not quantitatively define pore sizes and shapes). The relative size relationships within the soils under investigation hold.

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