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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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General Comments

This paper evaluates the validity of bNMR for the observation of the climate change, ecosystems and wild fire disturbances in permafrost regions through intensive works. The context of this paper is found rational as far as the applicability of Kleinberg (1996) is affirmative. However the conversion model from T2 to pore diameter (Kleinberg, 1996) is developed for sand stone, it is rather questionable that the scenario is applicable to the case of soil.

Specific Comments

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Discussion paper

Major materials in active layer and frozen body close to permafrost table in low land of permafrost regions are soils but not rocks. However the concept of the pore in soil is totally different from that of sandstone, which is the model of Eq.2. The equation is valid if independence of the each pore is able to be rationally assumed. However due to the following empirical and theoretical research evidences, the assumption mentioned above will not be acceptable in soil pores.

<Specific Surface Area>

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.

Table 1. Specific surface area of soils observed with BET method (Akagawa and Syouji, 2004)

<Unfrozen Water Content>

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.

<Thickness of Unfrozen Water>

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.

Figure 1. Temperature dependent unfrozen water thickness (Akagawa and Syouji, 2004)

<Unfrozen Water Distribution>

In addition, pore ice nucleation and growth behavior was studied by Black and Tice (1990) and Akagawa and Syouji (2004) and concluded that ice growth behavior due to freezing is the same as air intrusion behavior due to drying, as shown in Figure 2 and 3.

Figure 2. Thermodynamic condition of water in soils (Akagawa, 2005)

Figure 3. Distribution of water in freezing and drying soil (Black and Tice, 1988)

As the result, one of the conclusion of this article "ice nucleates in the center of pores in soil matrices" should be correct.

<Mobility of unfrozen water>

Regarding to the mobility of unfrozen water, there are two old works that confirmed the mobility of unfrozen water through frost heave research. The temperature of ice lens nucleation and segregation, i.e. "Ts", of alluvial clayey soil, during soil freezing was confirmed to be took place at the negative temperature of -0.8 Deg.C (Akagawa, 1990), as shown in Figure 4. And Ts=-1.4 Deg.C has confirmed in welded tuff (Akagawa et.al., 1988). Therefore water supplying to the segregating ice lens was understood to be supplied from unfrozen portion to growing ice lens through "frozen fringe" of soil and tuff of which temperature was 0 to -0.8 Deg.C and 0 to -1.4 Deg.C, respectively.

Figure 4. Segregation temperature (Ts) observed in frost heave test (Akagawa, 1990)

In other words, water flows from unfrozen soil/tuff to growing ice lens in unfrozen state through unfrozen water film of which thickness is about a few to 20 nm. According to the understanding mentioned above, the terminology "mobile water" used in this article will not be suitable for defining bulk water. In other words, both bulk water and unfrozen water are "mobile water" in the temperature range of positive to -0.8 Deg.C in soil and positive to -1.4 Deg.C in tuff.

< Relation between T2 and unfrozen water thickness>

In addition, a preliminary work (Akagawa, 2005) demonstrated that T2 value of unfrozen water layer becomes shorter less than 1ms as the thickness of unfrozen water becomes less than 10 nm, as shown in Figure 5.

Figure 5. Relation between T2 and unfrozen water thickness (Akagawa, 2005)

The empirical result mentioned above may be indicating that the unfrozen water mobility might vary with the distance from the surface of clay minerals and/or temperature of the unfrozen water as far as the frozen soil is concerned.

<Comments>

As the result, it is inferred that without utilizing the temperature information of the target strata, the reliability of the analysis conducted in this article might be questionable. In addition, since the relationship between thickness of unfrozen film water and T2 vary with soil type (Akagawa, 2005), as shown in Figure 5, some kind of calibration must be required for the each soil type. Therefore it is recommended to comment 1) the applicability of "Eq.2" to soil which has large specific surface area, and 2) the rationality of "Figure 6" of the article by comparing with the specimens sampled from the bore hole, if available.

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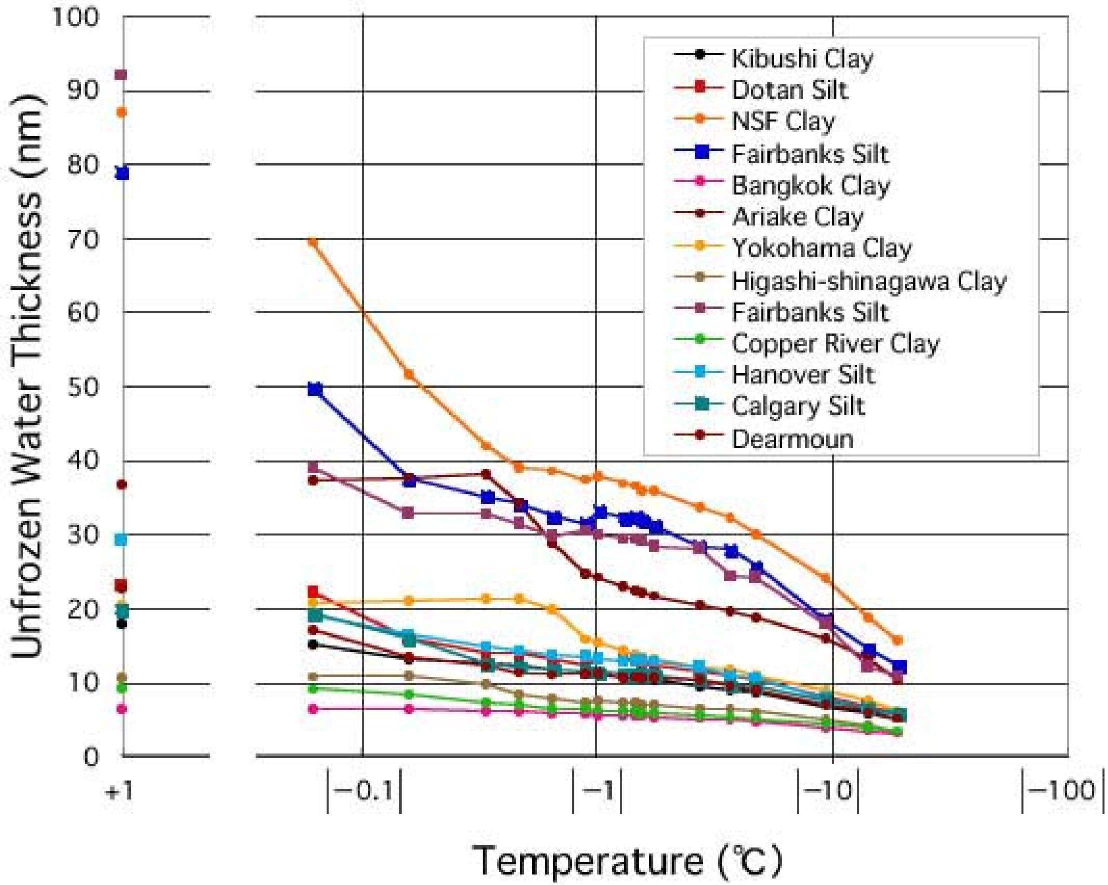
Unfrozen Water Thickness (nm)
100
90
80
70
60
50
40
30
20
10
0
+1
−0.1
−1
−10
−100
Temperature (℃)
Kibushi Clay
Dotan Silt
NSF Clay
Fairbanks Silt
Bangkok Clay
Ariake Clay
Yokohama Clay
Higashi-shinagawa Clay
Fairbanks Silt
Copper River Clay
Hanover Silt
Calgary Silt
Dearmoun

Fig. 1.

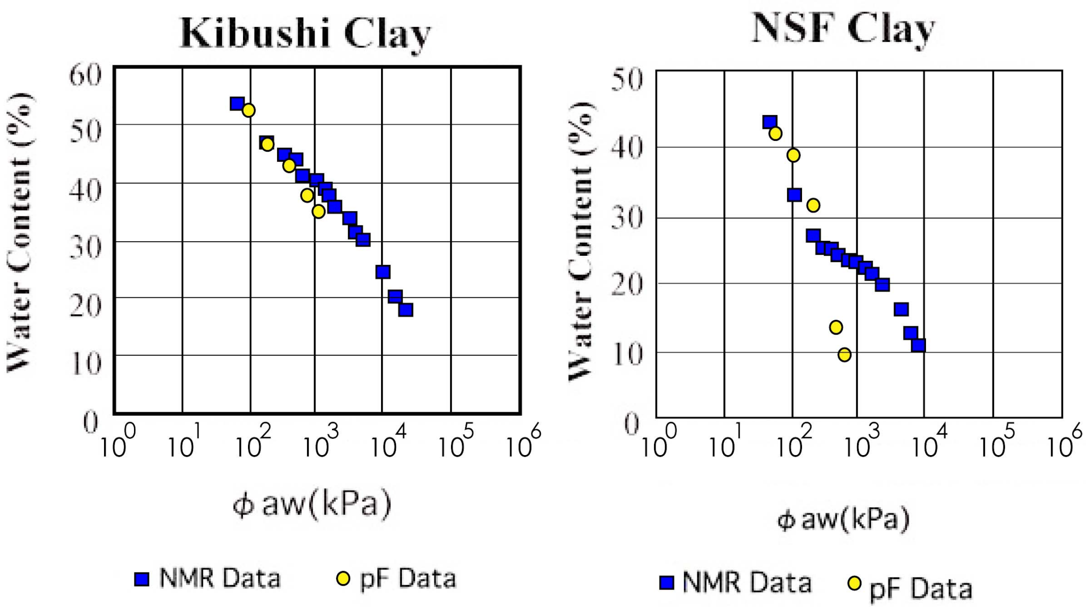

Fig. 2.

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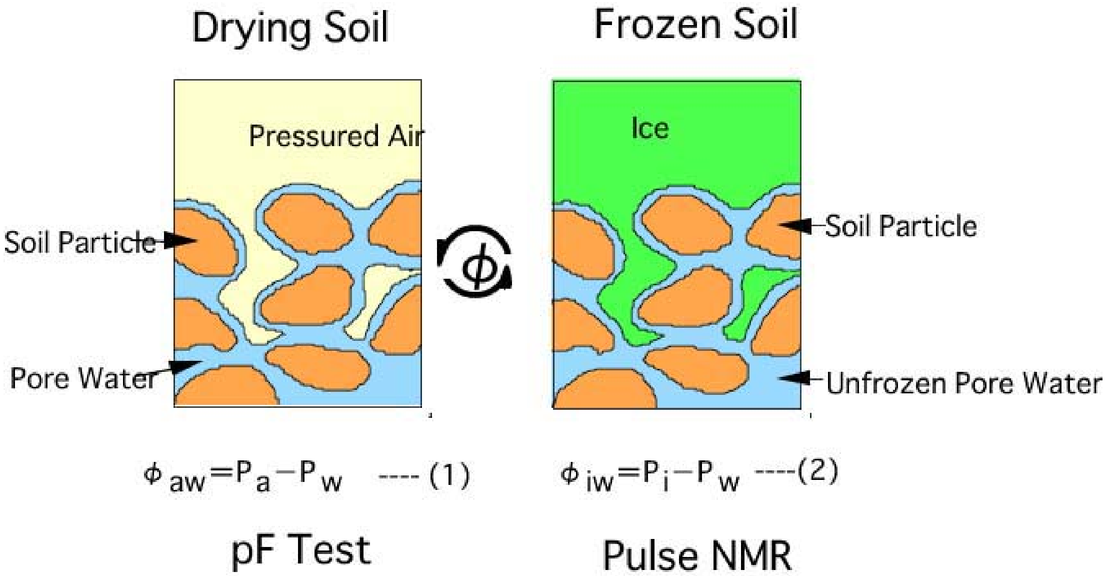

Fig. 3.

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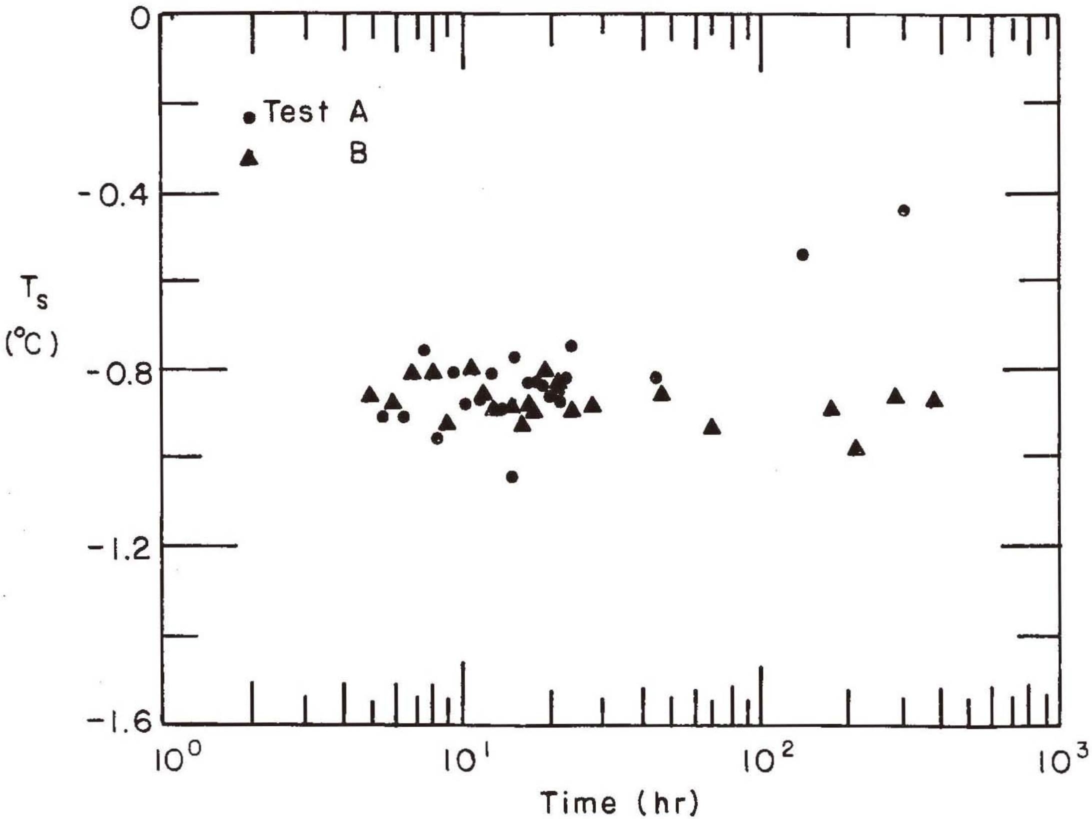

Fig. 4.

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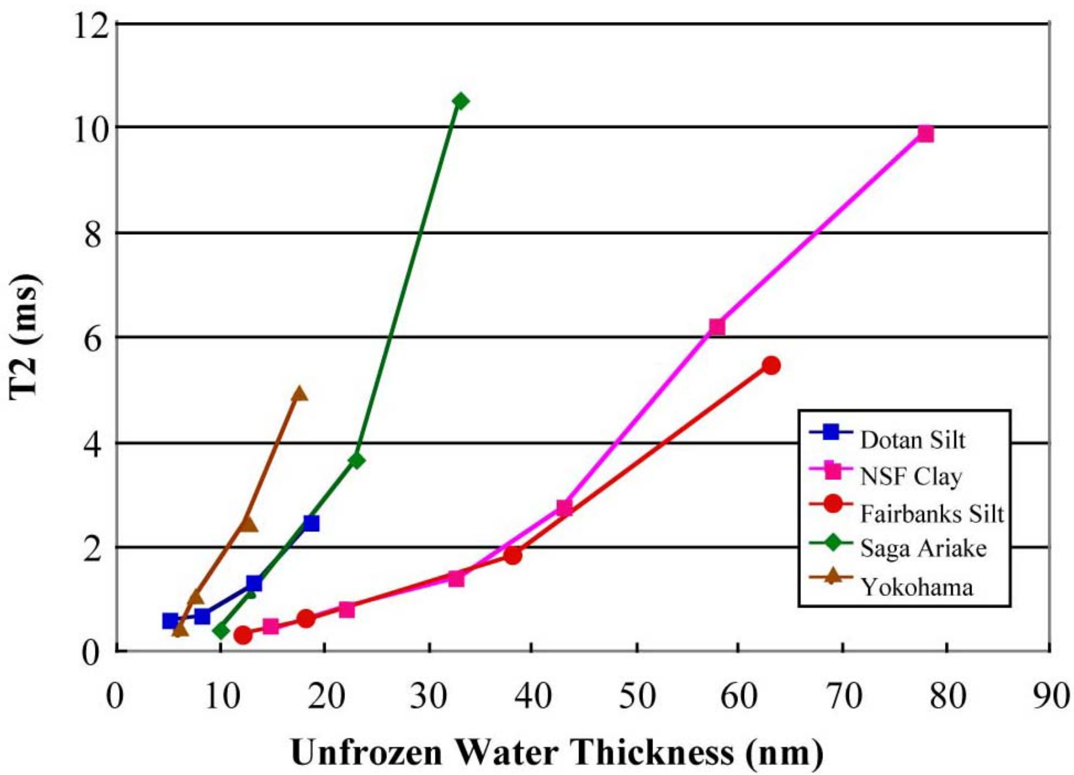

Fig. 5.

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Table 1. Specific surface area of soils observed with BET method (Akagawa and Syouji, 2004)

Soil Name	Specific Surface Area (m^2/g)
Higashi-Shinagawa Clay	100.9
Bangkok Clay	50.6
Saga-Ariake Clay	37.5
Kibushi Clay	35.9
Copper River Clay	33.9
Yokohama Clay	31.3
NSF Clay	6.2
Dotan Silt	21.4
Calgary Silt	11.3
Dearmoun Silt	8.9
Fairbanks Silt	4.3
Hanover Silt	7.4

Fig. 6.