Effects of Soil Hydrophobicity on Water Vapor Characteristics

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Introduction:

Soil water in arid and/or drought-stricken regions primarily exists as vapor phase, and is retained in soil through adsorption to particle surfaces. Despite predictions of greater drought frequencies and durations due to climate change, water vapor characteristics in soil have received relative little attention. Moreover, soil hydrophobicity can be a concern in arid regions because it can prevent infiltration and recharge during periods of precipitation.

Water vapor sorption isotherms (WVSIs) describe the relationship between water contents and water activities (a_w) in soil, representing the ability of soil to retain and release water vapor. Soil hydrophobicity and water vapor sorption are both governed by soil particle surface characteristics, but the feedbacks and interactions between them are not well-understood. At the same time, while the effects of extreme climatic conditions (i.e., cycles of precipitation and drought) have been shown to be a primary factor in expensive soil morphological development, it is not well-understood if **wetting-drying cycles associated with vapor exchange** can have a similar effect.

Objectives:

1) To establish a new set of indices to better quantify WVSIs.
2) To understand the effects of soil hydrophobicity on water vapor sorption and surface morphology development.

Methods:

Samples: Pure minerals – Ca-saturated Kaolinite (KGA-1) and Montmorillonite (SAZ-1 and SWY-1) minerals.

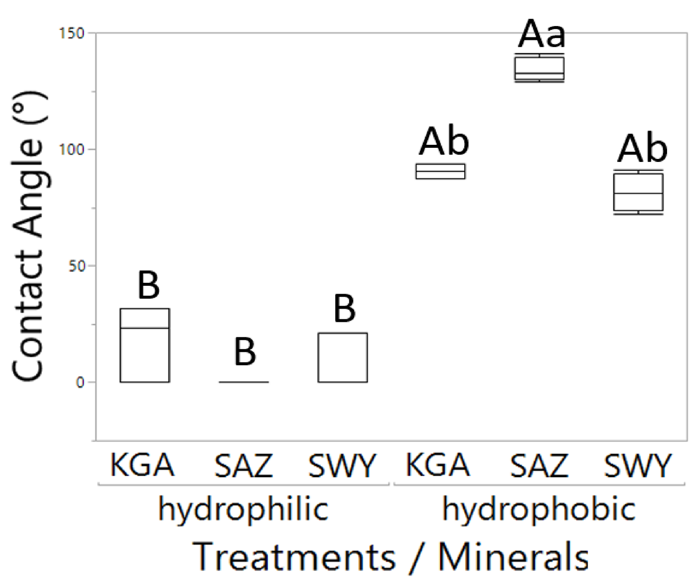
Treatments: 1) Hydrophobic (HO) – mixed 6% Hexadecyltrimethylammonium chlorine (CTAC), 2) Hydrophilic (HI) –without CTAC.

Data: Water vapor sorption isotherms (WVSIs), photographs of samples before and after adsorption-desorption cycle.

Analysis: 1) **WVSI indices** including mean water content (%), curve slope, hysteresis area and shape, were evaluated to quantify differences in vapor sorption between hydrophilic and hydrophobic samples, 2) ImageJ was used to quantify **surface area** of **samples** and **area** and **length** of **cracks**.

Table 1. Summary of mineral properties and treatments.

Minerals	Treatments	Adsorbed CTAC (%)	CEC (meq/100g)	Surface area (m^2/g)
SWY	HI	0.11	76.4	31.82
	HO	3.41	-	-
KGA	HI	0.08	2.00	10.05
	HO	1.18	-	-
SAZ	HI	0.05	120	97.42
	HO	4.03	-	-



Note: Capital characters stand for the significance of differences between treatments for each mineral, lowercase letters stand for the significance of differences between minerals.

Fig. 1. Solid-water contact angle of each treatment.

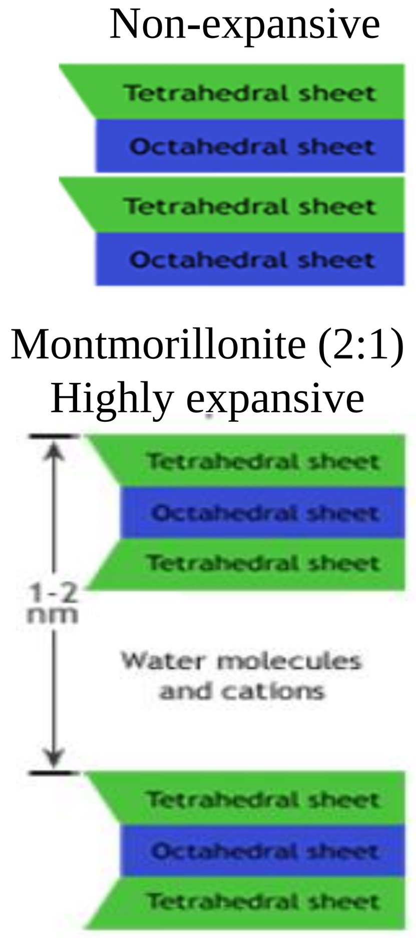
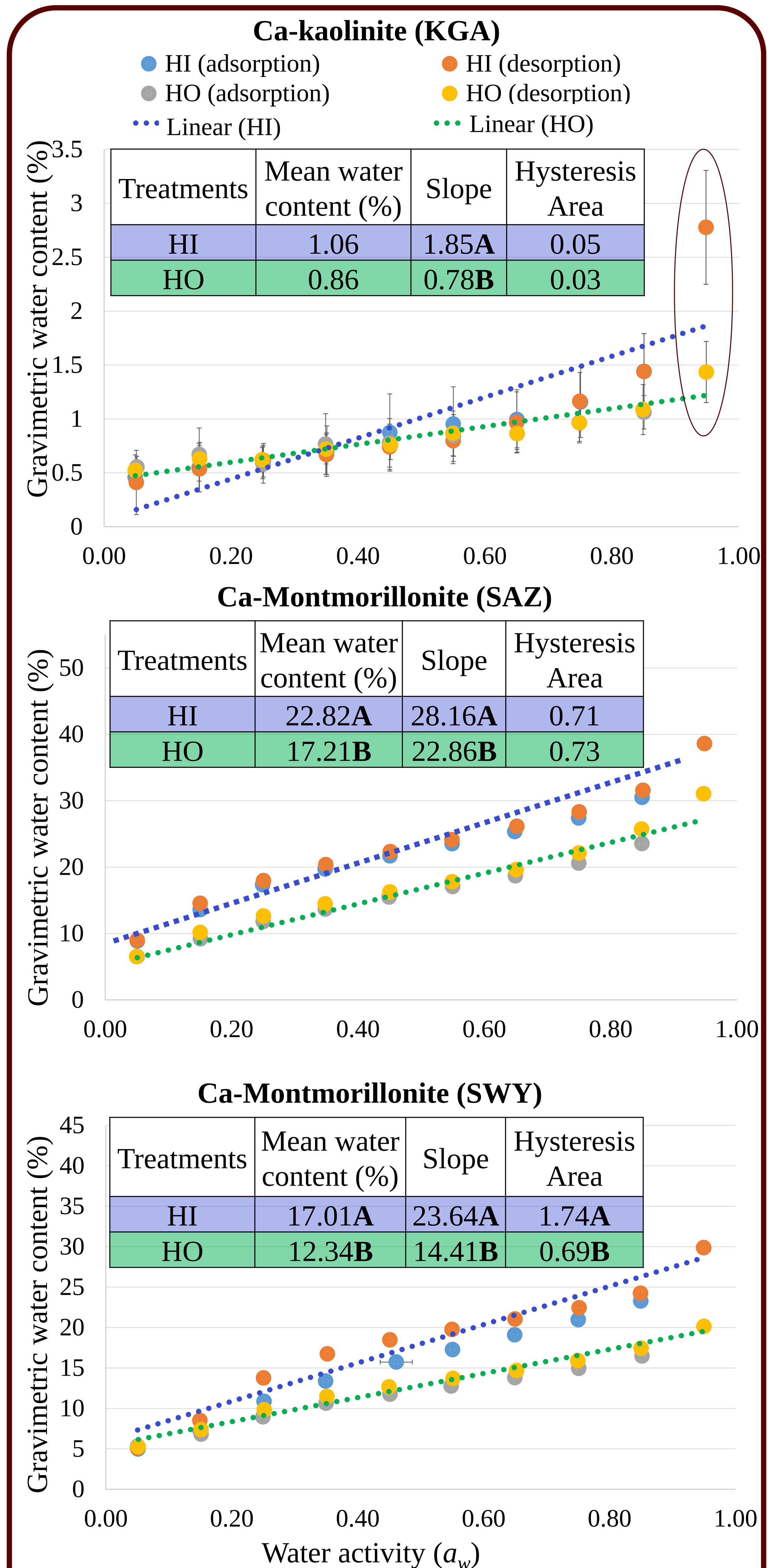


Fig. 2. Mineral structures of kaolinite and montmorillonite.

Results:



Ca-kaolinite (KGA)

Treatments	Mean water content (%)	Slope	Hysteresis Area
HI	1.06	1.85**A**	0.05
HO	0.86	0.78**B**	0.03

Ca-Montmorillonite (SAZ)

Treatments	Mean water content (%)	Slope	Hysteresis Area
HI	22.82**A**	28.16**A**	0.71
HO	17.21**B**	22.86**B**	0.73

Ca-Montmorillonite (SWY)

Treatments	Mean water content (%)	Slope	Hysteresis Area
HI	17.01**A**	23.64**A**	1.74**A**
HO	12.34**B**	14.41**B**	0.69**B**

Fig. 3. WVSI of hydrophobic and hydrophilic Ca-saturated montmorillonite and kaolinite.

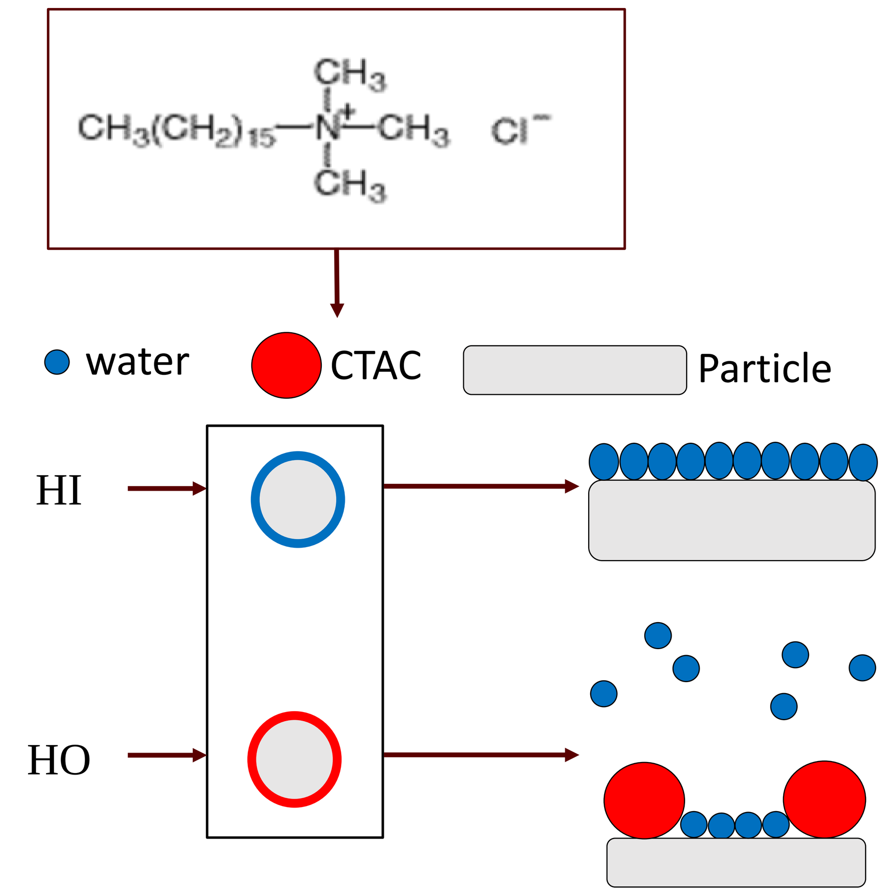


Fig. 4. Conceptual model of hydrophobic coating prevention on water vapor sorption.

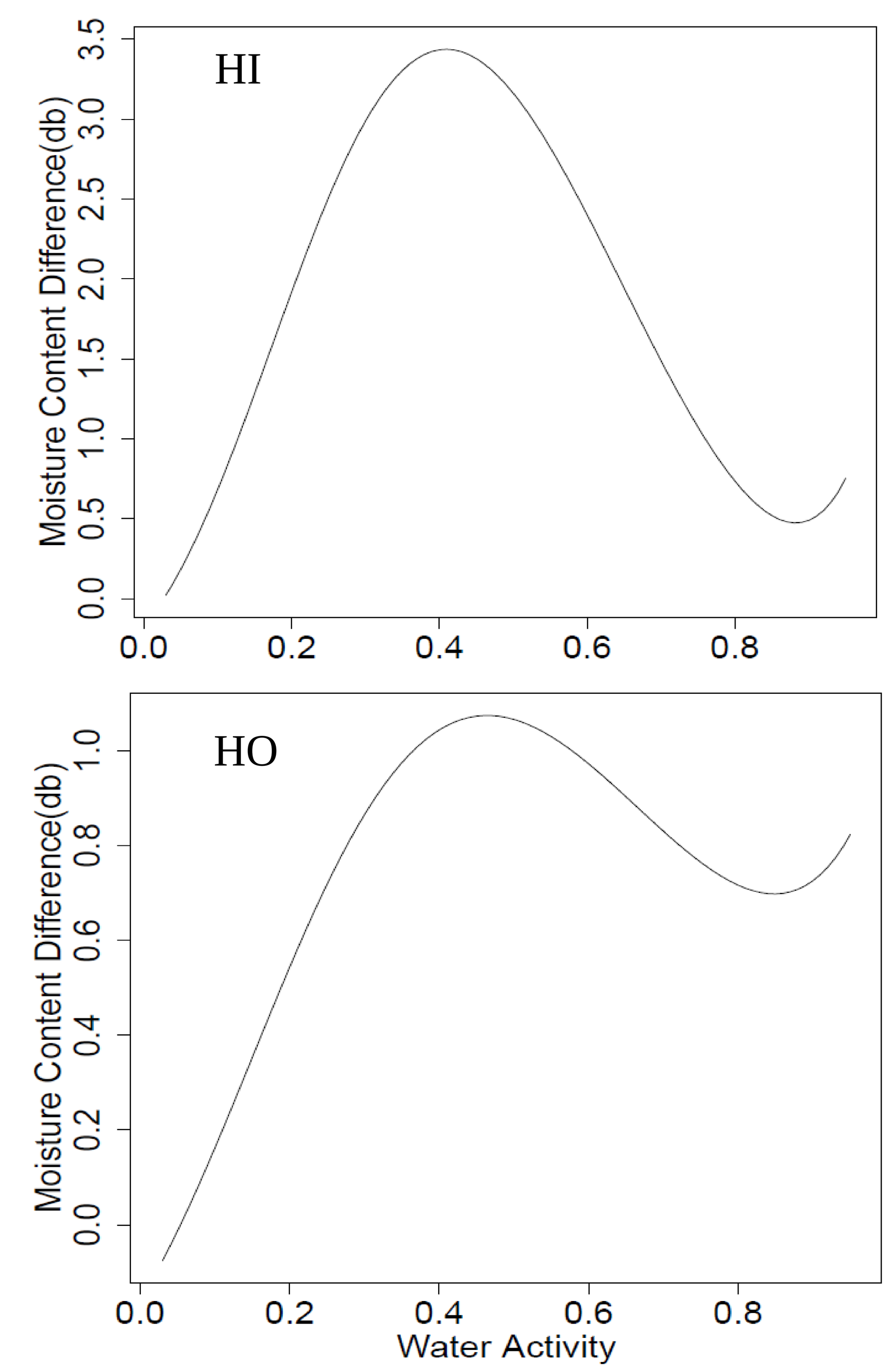


Fig. 5. Hysteresis shape of hydrophobic and hydrophilic Ca-montmorillonite (SWY).

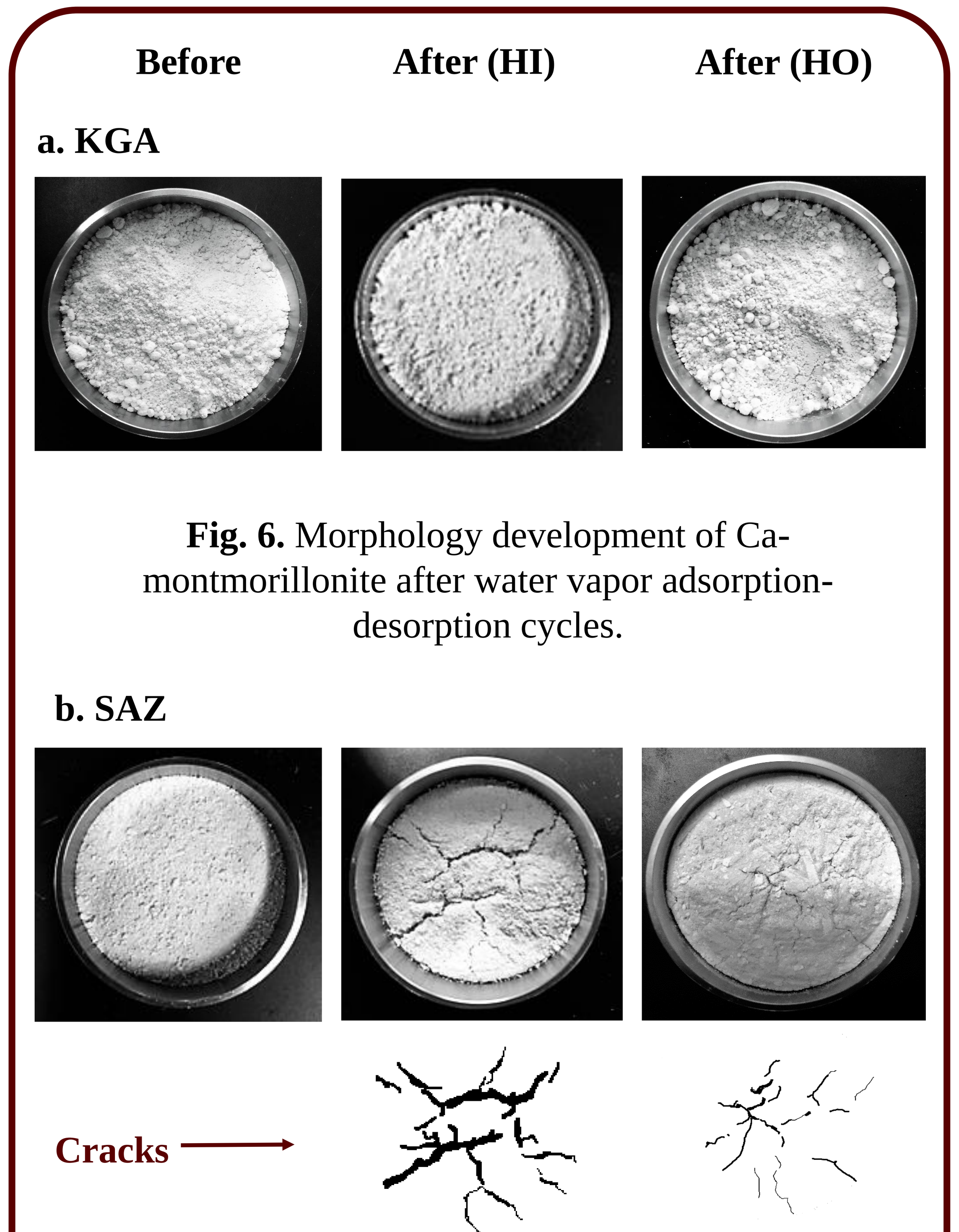


Fig. 6. Morphology development of Ca-montmorillonite after water vapor adsorption-desorption cycles.

SAZ	Before	After(HI)	After(HO)
Shrinkage (cm^2)	0.00	1.86**A**	0.68**B**
Crack area (cm^2)	0.00	1.28**A**	0.42**B**
Crack length (cm)	0.00	15.81**A**	13.54**B**

SWY	Before	After(HI)	After(HO)
Shrinkage (cm^2)	0.00	0.63**A**	0.22**B**
Crack area (cm^2)	0.00	0.00	0.00
Crack length (cm)	0.00	0.00	0.00

1) Hydrophobic samples absorbed less water than hydrophilic samples **(Fig. 3)** as the CTAC surface coating repelled water molecules **(Fig. 4)**. The montmorillonite samples showed differences in absorption through the entire range of water content, whereas the kaolinite samples only differed at the highest water activity, a_w =0.95 (indicated by the circle in the top panel of **Fig. 3**). This finding suggests that hydrophobicity may inhibit capillary condensation.

2) WVSIs of hydrophobic samples have significantly lower slope than hydrophilic samples **(Fig. 3)**. The SWY samples showed differences in the magnitude of hysteresis **(Fig. 5)**; the SAZ and KGA samples had little hysteresis, likely due to a lack of interlayer space in kaolinite and low interlayer space in Ca-saturated montmorillonites **(Fig. 2)**.

3) Vapor adsorption-desorption cycle induced shrinkage in montmorillonites, while the kaolinite samples did not show shrinkage. Hydrophobic samples have significant lower shrinkage area (i.e., area of cracks plus the annular gap) than hydrophilic samples. The cracks in the hydrophobic SAZ were also smaller (in terms of both area and length) than those in the hydrophilic samples **(Fig.6)**.

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Conclusions :

1) Hydrophobic surfaces prevent water vapor adsorption and condensation.
2) Swelling soils may potentially undergo morphological development in response to cyclical vapor exchange, and hydrophobic surfaces may inhibit the adsorption of water, mineral shrink, and the formation of shrinkage cracks.

Future Directions :

1) We will next study the effects on hysteresis by using sodium-saturated samples.
2) We will also work to understand how and at what concentrations hydrophobic organic components can affect vapor movement and retention, and then compare this behavior to the threshold(s) for liquid water.