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SURFACTANT SORPTION TO SOIL AND GEOLOGIC SAMPLES WITH VARYING MINERALOGICAL AND CHEMICAL PROPERTIES

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Abstract—The sorptive behavior of two surfactants (Triton X-100® and Dowfax® 8390) with two surface soil samples, a subsurface soil sample, a weathered black shale containing large amounts of aged organic matter, an aeolian sand, and two clay minerals (montmorillonite and kaolinite) was examined. Dowfax 8390 (dianionic surfactant) sorption was not detected with any of the samples. In contrast, Triton X-100, an ethoxylated nonionic surfactant, sorbed to all the samples. The mole surfactant sorbed/g sorbent (mol surf/g sorbent) was greater for samples containing large amounts of smectite minerals and nonlinearity of the Triton X-100 isotherm increased in samples low in organic carbon. The X-ray diffraction analysis concluded that the ethoxylate group of Triton X-100 intercalates with montmorillonite. The weathered black shale sample also has a high mol surf/g sorbent value when reacted with Triton X-100 but contains less smectite clay. We suggest that Triton X-100 may be reacting via hydrophobic groups (branched alkyl chain) with the shale sample. Consequently, sorption of alcohol ethoxylate surfactants cannot be predicted solely on the basis of soil attributes such as clay or organic matter content, for it appears that the organic matter–clay organization may predominate in these types of interactions.

Keywords—Soil Surfactant Sorption Triton X-100 Dowfax 8390

INTRODUCTION

The practices of previous and current generations have left behind a legacy of contaminated lands. The use of surfactants in the remediation of contaminated areas is advocated as a promising technology; however, its use may be restricted due to surfactant uptake by soil colloids. The majority of surfactant research has focused on surfactant solubilization of contaminants, surfactant enhanced mobilization, surfactant facilitated desorption, and bioremediation. Only a limited number of recent literature accounts examine surfactant sorption to natural colloids [1–9]. The abundance of surfactant types and differences among soil colloids makes it difficult to study the surfactant–sorbent interaction on a fundamental level; however, it is the loss of surfactant to soil colloids that increases the amount of surfactant required for the remedial process to be successful. The economic implications alone warrant further understanding of surfactant sorption processes.

The critical micelle concentration (CMC) that compensates for surfactant uptake by natural colloids is known as the effective CMC and varies with soil/surfactant type as well as with the soil to solution ratio [1,2]. The effective CMC increases with the quantity of surfactant sorbed to the soil because more surfactant is being removed from the solution phase. Therefore, more surfactant must be added to reach the solution-phase CMC. Despite recent efforts, the quantity of surfactant sorption cannot be predicted based on sorbent attributes. Liu et al. [2] and Urano et al. [3] observed that sorption of nonionic surfactants was proportional to the content of organic matter in the sorbent. Other reports suggest that uptake of nonionic surfactants is related more to mineral content than organic matter [5–7]. Alternatively, anionic surfactants have been observed to be less reactive than nonionic surfactants toward sediment samples [8].

We report here on an investigation of the use of sorbent properties to predict surfactant uptake. Our main objectives were to examine the sorptive behavior of two different surfactants that were selected from two different classes (nonionic and anionic) and have been reported to enhance the aqueous solubility of hydrophobic organic contaminants [8,10] to a variety of soil and geologic samples, to determine the effective CMC for a variety of samples, and to correlate the effective CMC with mineralogical and/or chemical characteristics of the sample.

MATERIALS AND METHODS

Collection and handling of samples

Samples were chosen to include a wide range of physicochemical properties. We used three soil samples—two chernozemic A horizons, a solonetzic B horizon—two geologic parent materials, and two pure clay minerals. The black chernozemic sample (A horizon—Malmo soil series) was collected from the Ellerslie Research Station located south of Edmonton, Alberta, Canada. The brown chernozemic sample (A horizon—Chin soil series) was obtained near Lethbridge, Alberta. Both of these soil samples are high in native organic matter. The third soil sample, a black solonetz (B horizon—Duagh soil series), was acquired just northeast of Edmonton, Alberta. All soil samples were developed on glacial till and/or lacustrine material and contained smectite clays. The two geologic samples included a weathered, Cretaceous age, black shale that had inclusions of coal, sampled along the banks of Blackmud Creek, located south of Edmonton, Alberta, and eolian sand collected near Bruderhiem, Alberta. The soil and geologic samples were air dried and passed through a 2-mm sieve to remove stones and/or other nonsoil material such as roots and twigs. The clay standards, Ca-saturated montmorillonite (STx-1) and

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kaolinite (KGa-1b) were purchased from the Source Clay Minerals Repository in Columbia, Missouri, USA. All samples were ground to pass a 106-μm sieve prior to sorption experiments.

Measurement of sorbent properties

Total carbon was measured by high temperature (900°C) combustion (Leco Furnace, Denver, CO, USA) followed by infrared quantification of the evolved CO_2. Inorganic carbon was determined by acidifying the sample, collecting the evolved CO_2 in a KOH trap, and quantifying the amount of inorganic carbon by back titration with dilute acid [11]. Organic carbon was calculated by difference. Cation exchange capacity was measured as outlined by Mckeague [12]. Sand, silt, and clay fractions were isolated by sonification and sedimentation [13].

Surfactant solutions

Triton X-100® was purchased from ICN Biomedicals (Aurora, OH, USA). Dowfax® 8390 was provided by Dow Chemical (Midland, MI, USA). The Dowfax 8390 sample was received at a concentration of 35% by weight. Both surfactants were used as received. Surfactant solutions were prepared by dilution with a 0.01 M K_2SO_4 solution (pH adjusted to 6.5) that contained 10^{-4} M $HgCl_2$ to inhibit microbial activity. Surfactant solutions were stored at 4°C when not being used in sorption experiments.

Sorption experiments

The sorbent was placed in a 50-ml Pyrex® glass centrifuge tube at a soil to solution ratio that would result in 20 to 80% of surfactant loss from solution; consequently, the soil to solution ratio varied from 1:40 to 1:400. Sorbent mass was determined on an oven-dry basis. Five glass beads (6 mm in diameter) were then added to the test tube to facilitate mixing, followed by the addition of 45 ml of surfactant solution. The tubes were sealed with Teflon®-lined screw caps and allowed to equilibrate at room temperature on a rotating mixer (20 rpm) for approximately 48 h (preliminary tests indicated that apparent equilibrium was reached well before this time). After the 48-h time period, the test tubes were removed from the mixer and allowed to settle overnight. The samples were then centrifuged for 30 min at 1,750 *g*. The supernatant was removed and stored at 4°C in glass vials until further analysis.

Surface tension measurements

Surface tension measurements were performed using a semiautomatic Fisher Scientific Surface Tensiomat® (Fairlawn, NJ, USA). The apparent surface tension of each sample was measured in triplicate. The platinum-iridium ring was rinsed with deionized water for each replicate measurement. Between samples, it was rinsed with deionized water, followed by acetone and then passed through a flame until it was orange-red in color. A correction factor that considered ring geometry was calculated with an equation provided by the manufacturer and applied to obtain surface tension values. The CMC and effective CMC were taken to be the inflection point of a curve of surface tension versus the log of surfactant concentration [2]. We have calculated the ΔCMC, defined as

$$\Delta\text{CMC} = \text{effective CMC} - \text{CMC} \quad (1)$$

Quantification of Triton X-100

The release of dissolved organic carbon from some of the samples interfered with the use of direct ultraviolet spectroscopy to measure the quantity of Triton X-100 in solution. Therefore, a modified version of the cobalt thiocyanate active substance (CTAS) method was used [14–17]. This method is based on the principal of phase transfer. Ethoxylated surfactants form a stable complex with the ammonium cobalt thiocyanate salt to form the CTAS [18]. In the absence of ethoxylated surfactants, the salt remains in the aqueous phase; alternatively, the presence of surfactant results in the formation of the CTAS, which is soluble in the organic phase. Therefore, the amount of CTAS in the organic phase is directly proportional to the amount of surfactant in the sample. The CTAS method used in this study entailed the addition of 30 ml of surfactant solution (high concentrations were diluted prior to this step), 30 ml of the cobalt thiocyanate reagent (2.6 M of ammonium thiocyanate and 0.10 M of cobalt (II) nitrate hexahydrate), and 5 ml of dichloromethane into a 250-ml separatory funnel. The mixture was shaken for approximately 1 min, then 30 ml of a saturated sodium chloride solution was added and the layers were allowed to separate for approximately 10 min. The dichloromethane layer was removed and the absorbance measured at 320 nm on a Unicam SP1800 ultraviolet spectrometer (Cambridge, UK). For samples that did not release dissolved organic carbon, both the CTAS and direct ultraviolet method were used and no difference was observed between the results from each method (data not shown).

Quantification of Dowfax 8390

A Waters 510 high performance liquid chromatograph (HPLC) equipped with a Waters 481 ultraviolet detector (Fairchild, OH, USA) was used for Dowfax 8390 quantification. A flow rate of 1.8 ml/min, a mobile phase of 50% HPLC-grade acetonitrile (Fisher Scientific), and a 150- × 4.6-mm Supelcosil™ C18 reverse phase column (Sigma-Aldrich, St. Louis, MO, USA) were used. Dowfax 8390 was measured at 254 nm and quantified using the total peak areas with respect to that of external standards.

Removal of soil organic matter

In one experiment, the soil organic matter was removed from a subsample of the black chernozemic soil sample. This was done by repeated additions of concentrated hydrogen peroxide in combination with gentle heating. Once foaming ceased, the sample was gently heated to dryness, washed with deionized water, and centrifuged. Rinsing was repeated two more times, after which the sample was air dried and ground to pass a 106-μm sieve.

X-ray diffraction

Ca-saturated montmorillonite was reacted with Triton X-100 at below CMC (0.1 mM) or above CMC (4 mM). A treatment with no Triton X-100 and only 0.01 M K_2SO_4 served as the control. The experiment continued as outlined in the surfactant sorption methodology. After centrifugation, the supernatant was removed and the sorbent was analyzed by X-ray diffraction to determine the d-spacing. Oriented specimens of the samples were analyzed at 0% relative humidity on a Philips diffractometer (Model 1710, Philips Electronics, Scarborough, ON, Canada) equipped with a LiF curved crystal monochromator using CoKα radiation generated at 50 kV and

Table 1. Sorbent properties[a]

Sample	% OC	CEC (cmoles[+]/kg)	% Sand	% Silt	% Clay	Clay minerals (in relative order of abundance)
Black chernozem	4.83	36	30	55	15	Montmorillonite, kaolinite, and mica[b]
Brown chernozem	1.72	22	58	26	16	Montmorillonite, kaolinite, and mica[c]
Sand	0.055	2	97	1	2	Not applicable
Shale	51.23	101	ND	ND	ND	Not applicable
Solonetz	1.63	41	5	25	70	Montmorillonite, kaolinite, and mica[d]
Kaolinite	0.00	8	0	0	100	Kaolinite
Montmorillonite	0.00	84	0	0	100	Montmorillonite

[a] OC = organic carbon; CEC = cation exchange capacity; ND = not determined.
[b] [28].
[c] [29].
[d] [30].

25 mA. Step sizes of 0.05° 2θ and an accumulation time of 2 s/step were used for data acquisition.

Model fitting and statistical tests

The isotherms for Triton X-100 sorption to the soil and geologic samples vary in shape; therefore, we elected to use two isotherm models because the variation in shape would not be satisfied by one model alone. The first model applied to the data was the linear form ($x/m = K_{linear}C_e$), where x/m represents the quantity of solute sorbed per mass sorbent (mg/g), C_e is the equilibrium concentration (mg/L), and K_{linear} is a constant related to sorbate affinity for the sorbent (L/g). The Langmuir model was the second model applied to the data ($x/m = K_{Langmuir}bC_e/(1 + K_{Langmuir}C_e)$), where x/m and C_e are the same as the linear model, $K_{Langmuir}$ is a constant related to binding energy (L/mg), and b represents the maximum in sorption to the solid (mg/g). Linear and Langmuir isotherm curve fitting was performed using Origin™, Version 4.1 (Microal Softward, Northampton, MA, USA) at $p \leq 0.05$.

The fit of the linear versus Langmuir model was tested by calculating the F statistic from the difference of the residual sum of squares between the models divided by the residual mean square for the nonlinear model [19]. The calculated F values were compared to tabular F values at $p \leq 0.001$ with 1 and $n - pdf$, where n is the number of observations and p is the number of parameters in the more complex model. If the calculated F value is less than the tabulated F value, use of the more complex model (Langmuir) is not justified by the data [19].

RESULTS

Sorbent and surfactant properties

The soil samples exhibit varying carbon (1.63–4.83%) and clay (15–70%) contents. Although the clay content varies, the mineralogical compositions of the clay fractions are similar among these samples (Table 1). The sand is low in organic carbon (0.055%) and contains mostly sand-sized particles (97%). The shale sample has the highest organic carbon content of all the samples (51.23%) and is mostly composed of organic matter. The particle size distribution is not listed in Table 1 because this sample is geologic and could not be broken into smaller particles by sonification. Hence, any particle size measurement would be an artifact of sample handling. The CMC for Dowfax 8390 is fourfold higher than that of Triton X-100 (Table 2).

Dowfax 8390 effective CMC and ΔCMC

The effective CMC was determined from the inflection point of the surface tension–log surfactant concentration curve. For the black chernozemic sample, there was no difference between the CMC and effective CMC; however, the surfactant surface tension after reacting with soil became constant at a lower value than the surfactant in the absence of soil (Fig. 1). This may be attributed to the production of dissolved organic carbon in these samples as the presence of electrolytes and/or low molecular weight organic compounds may alter the observed surface tension value [2,20]. These measurements did not detect a change in the CMC for Dowfax 8390 after sorption to soil or geosorbents. An effective CMC was not detected with all other sorbents. Hence, for Dowfax 8390, the effective CMC = CMC and the ΔCMC = 0 for all samples used in this study.

Triton X-100 effective CMC and ΔCMC

The ΔCMC for Triton X-100 was positive after equilibration with the sorbents. Figure 2 displays the typical displacement of the CMC in the presence of soil material. In the studies reported here, the sorbent to solution ratios vary for each sorbent–surfactant reaction. Liu et al. [2] reported that the value of the effective CMC was dependent on the sorbent to water ratio. To compare the ΔCMC data among samples properly, the values were normalized to soil mass by dividing the ΔCMC by sorbent mass and multiplying the volume of surfactant used to yield mole of surfactant sorbed/g sorbent (mol surf/g sor-

Table 2. Pertinent surfactant properties

Surfactant	Chemical formula	Surfactant class	Molecular weight (g/mol)	CMC[a] (mol/L)
Dowfax 8390	$C_{16}H_{33}C_{12}H_7O(SO_3Na)_2$	Anionic	643	8.0×10^{-4}
Triton X-100	$C_8H_{17}C_6H_4O(CH_2CH_2O)_{9.5}H$	Nonionic	625	2.0×10^{-4}

[a] CMC = critical micelle concentration; measured in this study.

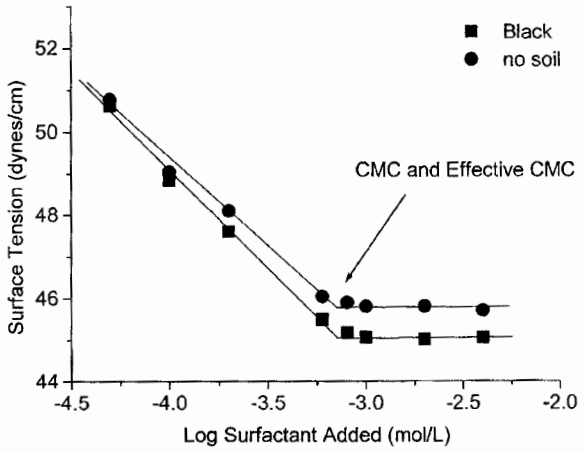

Fig. 1. Effective critical micelle concentration for Dowfax 8390 equilibrated with the black chernozemic soil sample.

bent). The resulting mol surf/g sorbent value is independent of the soil to solution ratio used in the batch equilibration procedure. The mol surf/g sorbent value is lowest for kaolinite and highest for montmorillonite (Table 3). The solonetz and shale samples also sorbed appreciable amounts of Triton X-100. There appears to be a relationship between the sorbent clay content and mineralogy with the mol surf/g sorbent value. Furthermore, the mol surf/g sorbent values of the black, brown, and solonetz samples do not support a strict correlation with organic carbon content.

Sorption isotherms

Dowfax 8390 uptake was not detected for any of the sorbents used in this study. Absence of Dowfax 8390 uptake corroborates the results from other research performed in our laboratory with contaminated soil samples and a study by Rouse et al. [8]. Alternatively, Triton X-100 uptake to the soil and geosorbents was observed with all the sorbents. The isotherms for Triton X-100 vary in shape and the linear isotherm r^2 values range considerably among sorbents (Table 4). The samples with organic matter contents greater than 1% (black, brown, shale, and solonetz) have linear isotherms with similar r^2 values between 0.84 and 0.88. Alternatively, the samples containing little or no organic carbon (sand, kaolinite, montmorillonite) have linear isotherms with lower r^2 values of 0.64, 0.75, and 0.48, respectively. The difference in F values from the model discrimination test indicates that the sorption isotherm data is best described using the Langmuir model (Table 4). The difference in F values is considerably larger for those sorbents containing low or no organic matter. In a subsequent experiment, the organic matter from the black chernozemic soil sample was removed to examine the role of organic matter in Triton X-100 sorption (Fig. 3). Both the mol surf/g sorbent value and isotherm nonlinearity increased from that of the original sample (Tables 3 and 4). Isotherm nonlinearity was observed to increase with the removal of organic matter. Furthermore, the difference in F values from the model discrimination test is more than three times greater for the black sample after organic matter removal.

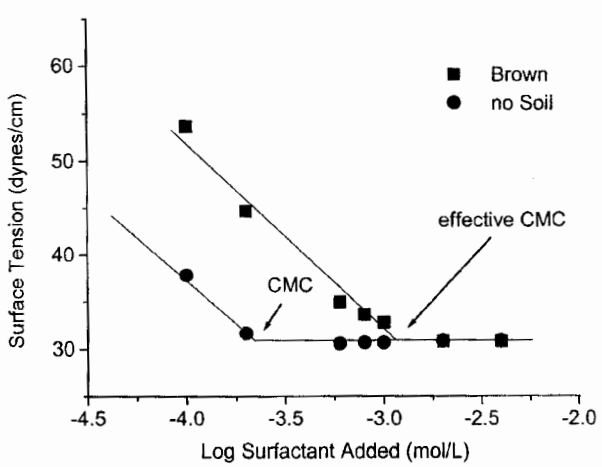

Fig. 2. Effective critical micelle concentration for Triton X-100 equilibrated with the brown chernozemic soil sample.

Table 3. Triton X-100 effective CMC, ΔCMC, and normalized ΔCMC[a]

Sample	Effective CMC (mol/L)	ΔCMC (mol/L)	Normalized ΔCMC to soil-to-solution ratio (mol surf/g sorbent)
Black	6.31×10^{-4}	4.31×10^{-4}	4.4×10^{-5}
Black, OM	8.91×10^{-4}	6.91×10^{-4}	7.74×10^{-5}
Brown	1.26×10^{-3}	1.06×10^{-3}	5.40×10^{-5}
Sand	5.01×10^{-4}	3.01×10^{-4}	1.30×10^{-5}
Shale	1.00×10^{-3}	8.00×10^{-4}	2.85×10^{-4}
Solonetz	1.12×10^{-3}	9.20×10^{-4}	1.96×10^{-4}
Kaolinite	2.5×10^{-4}	5.00×10^{-5}	2.14×10^{-6}
Montmorillonite	1.32×10^{-3}	1.12×10^{-3}	5.40×10^{-4}

[a] CMC = critical micelle concentration; OM = organic matter.

X-ray diffraction of Triton X-100 and montmorillonite

The X-ray diffractograms of three different treatments are depicted in Figure 4. Pattern A is of the control (montmorillonite reacted with 0.01 M K_2SO_4) and reveals a d-spacing of 1.01 nm, as is expected for a 2:1 clay mineral in the absence of water [21]. The peak in pattern B is diffuse and broader than that observed in pattern A but still has an average d-spacing of 1.01 nm. Such a broad peak suggests incomplete intercalation, with some minerals contracted and some minerals remaining partially expanded [22].

Large applications of surfactant to montmorillonite (pattern C) yielded a d-spacing of 1.43 nm, whereas the control sample yielded a sharp peak at 1.01 nm. If the surfactant was being sorbed into the interlayer space of the mineral, then the increase in d-spacing would be in proportion to the size of the surfactant. The thickness of the ethoxylate group is equal to the sum of one C-C bond and two C-H bonds. The O-H bond is shorter than the other two bonds; thus, the maximum thickness of the molecule will be determined from the C-C and C-H bonds. Using bond lengths from Streitwieser and Heathcock [23], we calculated d = (0.154 nm + 2[0.11 nm]) = 0.374 nm. Based on the molecular size of the ethoxylate tail and the mineral structure of montmorillonite, the resulting d-spacing should be 1.384 nm. The theoretical value is in good agreement with the observed value of 1.43 nm.

DISCUSSION

The behavior of Dowfax 8390 and Triton X-100 with several soil and geologic samples was observed to be different.

Table 4. Triton X-100 isotherm parameters and statistical analysis[a]

Sample	K_{linear} (ml/g)	Linear isotherm r^2	$K_{Langmuir}$ (L/g)	b (mg/g)	Langmuir isotherm r^2	$F_{calc} - F_{table}$[b]	N
Black	42.77	0.880	4.59	53.72	0.972	40.49	7
Black, OM	36.64	0.714	4.36	66.13	0.964	148.06	9
Brown	57.54	0.872	1.12	115.92	0.974	40.59	7
Sand	4.11	0.644	7.83	8.34	0.997	259.23	6
Shale	174.85	0.882	1.45	359.97	0.959	519.55	9
Solonetz	132.04	0.844	1.40	289.94	0.958	1,638.73	9
Kaolinite	3.69	0.746	3.18	7.17	0.978	38.97	9
Montmorillonite	187.52	0.482	7.79	596.72	0.985	36.69	9

[a] N = number of observations; OM = organic matter.
[b] A positive difference in F values indicates the Langmuir model is justified by the data.

We attribute these differences to surfactant charge. Dowfax 8390 is dianionic; therefore, it should be electrostatically repelled by soil constituents and not sorb as much as other surfactants, particularly those from the nonionic class. Evidence from this study and by Rouse et al. [8] support the hypothesis of surfactant repulsion by the sorbent as an explanation for undetectable surfactant uptake. The lack of sorption is an advantage for surfactant-facilitated soil remediation as Dowfax 8390 sorption to soil/geologic material may be minimal.

Alternatively, Triton X-100 was observed to react with all sorbents tested. Because Triton X-100 is nonionic, it is likely to react with soil particles via hydrogen bonding or van der Waals forces. The value mol surf/g sorbent was observed to be greatest for samples with large quantities of clay minerals. A comparison between the two surface soil samples (black and brown) reveals that the brown sample, which contains less organic matter, sorbed more than twice the amount of Triton X-100 than the black sample. The solonetzic soil sample also provided similar evidence for the mineral portion of the sample as the dominant contributor to sorption of Triton X-100. Furthermore, isotherm nonlinearity increased with a decline in organic carbon content (Table 4). Additionally, the value of mol surf/g sorbent and isotherm nonlinearity increased when the organic matter was removed from the black sample. Finally, statistical analyses indicate that the data are described better with the Langmuir model, noting that the difference in F values was greatest for samples that do not contain large amounts of organic carbon. From these observations, we infer that mineral surfaces are more favorable for Triton X-100 sorption and may be blocked by organic matter.

The X-ray diffraction data provide strong evidence that Triton X-100 intercalates with montmorillonite, even at low

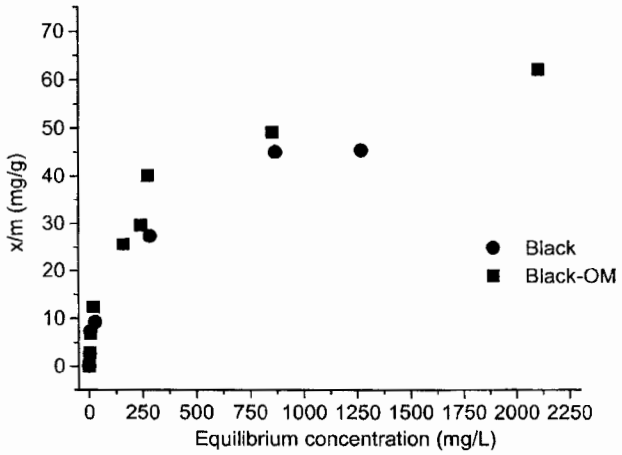

Fig. 3. Triton X-100 sorption isotherm to the black soil sample before and after organic matter removal.

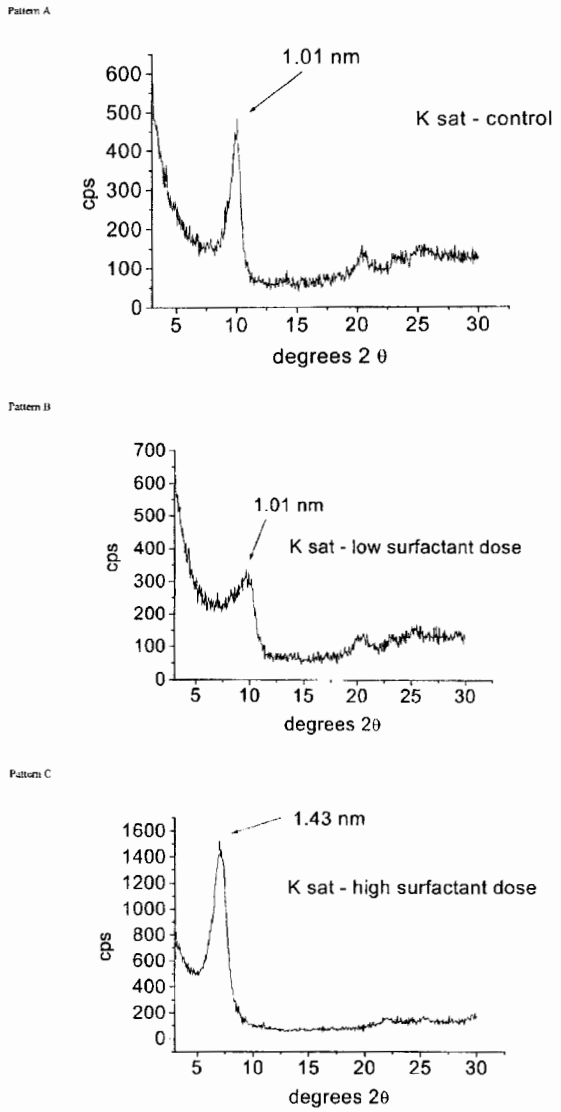

Fig. 4. X-ray diffractograms of montmorillonite equilibrated with 0.01 M K_2SO_4 (pattern A), 0.1 mM Triton X-100 (pattern B), and 4.0 mM Triton X-100 (pattern C).

concentrations. These findings agree with Law and Kunze [24] and Platikanov et al. [25], who reported intercalation of similar nonionic surfactants with montmorillonite. Evidence from the X-ray diffraction study supports the conclusion that the ethoxylate chain enters the interlayer spaces of montmorillonite. Furthermore, Cano and Dorn [6] reported an increase in alcohol ethoxylate surfactant sorption with the clay content of four different sediments. Brownawell et al. [5] reported that sorption quantity and isotherm nonlinearity increased with the number of ethoxylate groups in the surfactant. These accounts in conjunction with our own data suggest that the ethoxylate chain readily intercalates with expanding clay minerals.

The shale sample, which is predominantly comprised of organic matter [26], also interacted strongly with Triton X-100. The high amount of organic matter and low mineral content implies that the ethoxylate tail-clay interaction may not be the prominent mechanism between Triton X-100 and the shale sample. The branched alkyl chain or the aromatic portion of the surfactant may interact with the organic phase of the shale sample. The linear isotherm correlation coefficient is the highest for the shale, also supporting the notion of another type of sorption mechanism. Narkis and Ben-David [27] studied the sorption of nonionic surfactants to activated carbon and montmorillonite. They concluded that nonylphenol ethoxylated surfactants interact with montmorillonite via the hydrophilic portion (ethoxylate chain) and with activated carbon via hydrophobic groups. This report in conjunction with our observations support the concept that Triton X-100 may have sorbed to the shale sample by another means that cannot be described by the ethoxylate chain–clay mineral interaction.

Urano et al. [3] reported a linear relationship between alcohol ethoxylate surfactant sorption and sediment organic carbon content; however, we did not find such a correlation nor did Brownawell et al. [5]. Cano and Dorn [6,7] observed a linear relationship between the alcohol ethoxylate surfactant sorption and the clay content of four sediments. Again, results from our study and that of Brownawell et al. [5] contradict a linear relationship between surfactant sorption and clay content but reveal that it is the content of expanding clays, rather than total clay content, that is related to surfactant sorption. Furthermore, Brownawell et al. [5] suggest that the presence of expanding 2:1 clay minerals prevented the strong correlation observed by Urano et al. [3]. We suggest that neither clay nor organic matter content alone is a suitable attribute to predict alcohol ethoxylate surfactant sorption to soil and geologic samples. The increase in the mol surf/g sorbent for the black sample after the majority of the organic matter was removed supports the hypothesis that there is a strong correlation between alcohol ethoxylate surfactants and the mineral portion of soil samples and implies that organic matter may impede this sorption reaction. However, the high mol surf/g sorbent value for the shale sample suggests that Triton X-100 can sorb via other mechanisms. Therefore, it may not be clay or organic matter alone that governs these sorption reactions but a combination of both. Finally, it is evident that sample characteristics are of great importance when attempting to predict alcohol ethoxylate surfactant uptake, especially if the sample contains both organic matter and expanding clay minerals.

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