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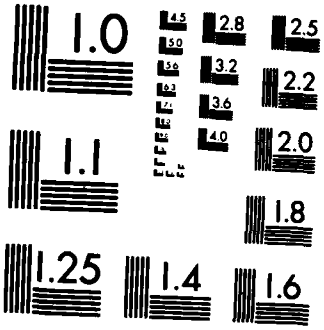
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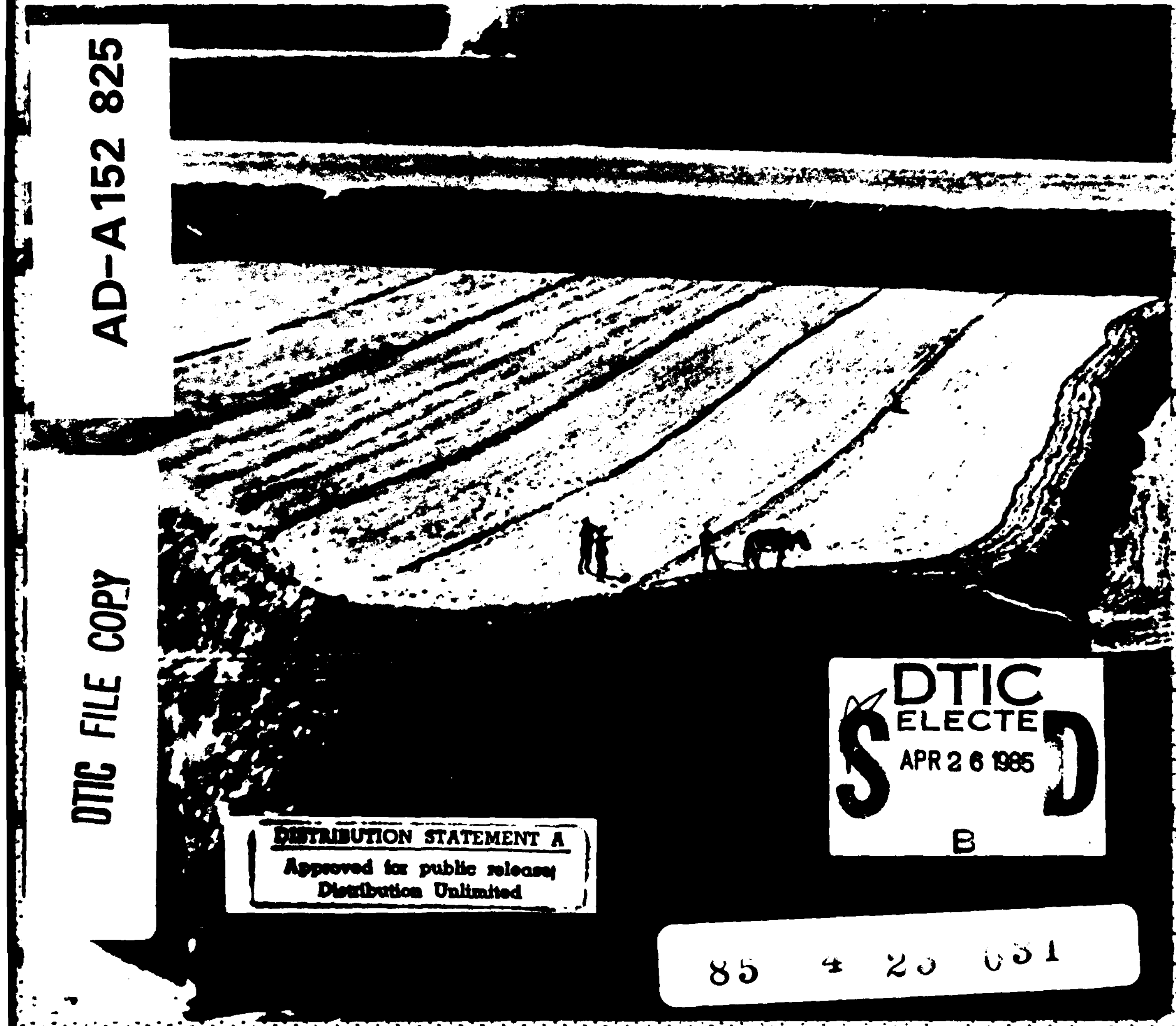
CRREL
REPORT 84-16

US Army Corps of Engineers
Cold Regions Research &
Engineering Laboratory

The effects of soluble salts on the unfrozen water contents of the Lanzhou, P.R.C., silt



For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

Cover: Landscape of Loess Plateau in the vicinity of Lanzhou. Samples are derived from similar deposits. (Photograph by Jerry Brown, October 1981.)

CRREL Report 84-16

June 1984

The effects of soluble salts on the unfrozen water contents of the Lanzhou, P.R.C., silt

A.R. Tice, Zhu Yuanlin and J.L. Oliphant

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Phase composition curves are presented for a typical saline silt from Lanzhou, P.R.C., and compared to some silts from Alaska. The unfrozen water content of the Chinese silt is much higher than that of the Alaskan silts due to the large amount of soluble salts present in the silts from China, which are not present in silt from interior Alaska. When the salt is removed, the unfrozen water content is then similar for both the Chinese and Alaskan silt. Here we introduce a technique for correcting the unfrozen water content of partially frozen soils due to high salt concentrations. We calculate the equivalent molality of the salts in the unfrozen water at various temperatures from a measurement of the electrical conductivity of the extract from saturated paste.

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PREFACE

This report was prepared by A.R. Tice, Physical Science Technician, and Dr. J.L. Oliphant of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory and Zhu Yuanlin, on leave from Lanzhou Institute of Glaciology and Cryopedology, Lanzhou, P.R.C. Funding for this research was provided by DA Project 4A161102AT24, *Research in Snow, Ice and Frozen Ground*, Task A, *Properties of Cold Regions Materials*, Work Unit 002, *Properties of Frozen Soil.*

James Cragin of CRREL and Valerie Thurmond of the University of Miami technically reviewed the manuscript of this report.

The authors wish to thank Dr. Jerry Brown of CRREL and Professor Troy L. Péwé, Arizona State University, for providing samples of the Lanzhou silt. The cooperation of various indivduals at the Northwest Institute, Academy of Railway Sciences, in Lanzhou, P.R.C., who aided Dr. Jerry Brown and Dr. Péwé is also acknowledged.

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ILLUSTRATIONS

TABLES

THE EFFECTS OF SOLUBLE SALTS ON THE UNFROZEN WATER CONTENTS OF THE LANZHOU, P.R.C., SILT

A.R. Tice, Zhu Yuanlin and J.L. Oliphant

INTRODUCTION

Loess, or wind-deposited silt, is extremely widespread in the People's Republic of China (P.R.C.) and in Alaska. In China, loess covers 6.6% of the country and attains thicknesses of over 200 meters. The landforms, stratigraphy, composition, and utilization of loess are illustrated and described in Wang and Zhang (1980). Soils of the loess regions in China were reported on by Zhu et al. (1983). The Fairbanks silts (loess) have been well characterized by Anderson and Tice (1973) and Tice et al. (1978a,b).

The Chinese have devoted considerable research and engineering to the management of loess. Lin and Liang (1982) discussed the distribution of loessic soils in China, concentrating on the effects of building on these potentially collapsible soils. Groundwater that exists in loess deposits is used for irrigation. Technical designs have been developed to prevent the collapse of road cuts, tunnels, and slopes of reservoirs on loess landforms, and techniques to prevent water loss and soil erosion are used.

The physical and chemical properties of loess are of considerable scientific and engineering interest. Loess consists of particles less than 0.25 mm in diameter. Silt (0.05–0.005 mm) composes over 60% of Chinese loess. The clay minerals ($<$ 0.001 mm) most common in loess are illite, montmorillonite, and kaolinite. Calcium carbonate is the most common soluble salt (10–16% dry weight).

Dr. J. Brown and Dr. Y.C. Yen of CRREL obtained a sample of loess taken along the Yellow River (hereafter referred to as Lanzhou silt A) from the Northwest Institute, Academy of Railway Sciences, in Lanzhou (Brown and Yen 1982). In this area the loess reaches 200 m in thickness and is under extensive investigation.

Later in 1982, Professor T.L. Péwé, Arizona State University, and Professor Guoqing Qiu, Lanzhou Institute of Glaciology and Cryopedology,collected a second sample of loess from Lanzhou (Lanzhou silt B). This sample was taken 3 m below the surface at the summit of White Pagoda Mountain (600 m above sea level), which is located 200 m north of the Yellow River.

Unfrozen water content is a parameter of common interest to engineers and scientists in both the U.S.A. and the P.R.C. In light of this, we determined unfrozen water content and related characteristics of the two samples of Lanzhou silt for comparison. This paper compares the results of the analyses of the Lanzhou silt with some well-characterized Alaskan deposits.

BACKGROUND

When a soil-water mixture is cooled below 0 °C, not all of the pore water freezes. The fact that unfrozen water (the amount depending on temperature) exists in frozen soil has been demonstrated by numerous investigators. They have employed a number of techniques that have yielded results that compare favorably. Review articles by Anderson and Morgenstern (1973), Anderson and Tice (1973) and Anderson et al. (1978) report the various techniques and discuss the advantages and limitations of each. Recently, Tice et al. (1978a, b, 1981) introduced nuclear magnetic resonance (NMR) as a new method to measure the liquid water in partially frozen soils. NMR appears to circumvent the limitations of previous methods by allowing rapid, non-destructive measurements that are attainable on both undisturbed and remolded specimens.

Many factors contribute to the unfrozen water in frozen soils. Bouyoucos' (1917) early work related unfrozen water contents to the general classification of soil water which was known to be related to soil particle size. Nersesova and Tsytovich (1963) listed the main factors that determine the phase composition of frozen soil: a) temperature; b) pressure; c) specific surface area of the soil solids; d) chemical and mineralogical composition of the soil; e) other physical chemical characteristics, especially the nature of the exchangeable cations; and f) solute content and composition. Of these, temperature was established as the dominant factor for a given soil. Dillon and Andersland (1966) constructed a prediction equation that involved the specific surface area of the soil matrix, the plasticity index and a defined "activity ratio." The latter two parameters are related to the specific surface area. Anderson and Tice (1972) listed the primary factors that govern a soil's phase composition as (in order of importance): specific surface area, temperature, overburden pressure and osmotic potential of the soil solution. They also mentioned secondary factors that should be considered: nature of the fine pore geometry of the mineral grains, particle packing geometry, surface charge density, and the suite of exchangeable adsorbed ions. Pusch (1979) reports that the specific surface area is less influential in governing the amount of unfrozen water (reported by Anderson and Tice 1972) than a term he calls "effective surface area." He identifies this term as a measure of the degree of particle aggregation or the distribution and arrangement of soil particle aggregates and void spaces which compose a soil's microstructure.

All of the factors previously mentioned have influence on a soil's phase composition. An important factor, and one that is often neglected, is the effect of solutes (Banin and Anderson 1974). Solutes affect the phase composition curves by shifting the unfrozen water content—temperature curves toward lower temperatures. The freezing temperatures are lowered depending on the amount and nature of the solutes present.

In coastal polar regions where perennially frozen ground predominates, ionic concentrations in uplifted marine sediments generally increase with depth (Brown 1969).

Page and Iskandar (1978) reported high solute concentrations in cores recovered from the 1976 and 1977 Beaufort Sea drilling program. The widespread occurrence of surface salt incrustations in polar desert soils has been reported by Tedrow (1966) and Kumai et al. (1978).

In these and other cold regions where engineering activities are contemplated, the effect of solutes on the low temperature behavior of soils must be assessed.

MATERIALS

Samples of Lanzhou silts A and B were taken in the vicinity of Lanzhou, P.R.C. The samples of Chena Hot Springs silt and Northwest Alaska Pipeline silt were taken from sites around Fairbanks, Alaska. A sample of Kotzebue silt was taken from Kotzebue, Alaska.

Lanzhou silts A and B were wind-deposited saline soils (described previously). Both the Chena Hot Springs silt and the Northwest Alaska Pipeline silt are also wind-deposited (but non-saline) silts similar to those that cover much of the interior of Alaska. The Kotzebue silt is similar in texture to the silts from Fairbanks except that it contains large concentrations of soluble salts, which is typical of soils found in low-lying coastal regions.

METHODS

Sample preparation

Distilled water was added to 16 g of six specimens of the Lanzhou silts A and B in progressively larger amounts. Following thorough mixing, each sample was sealed and stored for one week to al-low for moisture equilibration. A specially designed mold was used to compact each sample in three equal layers. Once compacted, the samples were leveled to a uniform height of 3.2 cm with a diameter of 1.56 cm. To accommodate copper/constantan thermocouples for temperature measurement, a hole 0.5 mm in diameter was hand-drilled about half the core length into the center of each sample. With the thermocouples in place, the samples were placed in glass test tubes (19 mm OD × 150 mm high) and sealed with stoppers to prevent moisture changes. Following sample preparation, the test tubes containing Lanzhou silt A were placed in a precision temperature bath containing an ethylene glycol–water mixture and allowed to equilibrate at the first test temperature of +22.5 °C.

Nuclear magnetic resonance

The pulsed NMR used in this investigation was a Praxis model PR-103 operated in the 90° mode, 0.2-s clock, and fast scan speed. First pulse amplitudes (signal intensities) were measured for each sample, starting at the first test temperature. This instrument was factory-tuned to detect only hydrogen. The operating frequency was 10.72 MHz. The sample probe contained a 2.51-kilogauss permanent magnet. The 90° pulse length was 12 μs, followed by a dead time of 24 μs. We selected this mode of operation over other available modes because of the non-adjustable dead time of 24 μs. Signals from hydrogens associated with ice and those associated with soil ($T_2 < 24$ μs) would be lost in the recovery time between the 90° pulses.

We performed the following tests to ensure that we were measuring hydrogens associated with liquid water only. Large single crystals of pure ice were machined to fit into glass tubes. We selected single crystals of ice as opposed to polycrystalline ice to guard against any signal contributions which might be observed from liquid films between ice grain boundaries. The crystals of ice were placed in a constant temperature bath maintained at -0.3 °C. We saw no signal above the background level when the crystals of ice at -0.3 °C were inserted in the NMR. Similarly, we rarely see a signal from oven-dry (105 °C) soils. If a signal is observed in the oven-dry soils, we subtract this value from all readings prior to calculating unfrozen water contents.

After thermal equilibrium was reached at the first test temperature, NMR signal intensity vs temperature data were obtained from +22.5 °C to -24 °C for each sample of Lanzhou silt A according to the procedure reported by Tice et al. (1982). Unfrozen water content vs temperature data are shown in Table A2, Appendix A, for the cooling run only.

Following the last cooling determination, the samples were progressively warmed. Complete warming curves for each sample were determined and are shown in Table A1. The raw data for these curves are shown in Figure 1.

Samples of Lanzhou silt B were prepared in the manner mentioned above. The analysis, however, was started at the low temperature end and at a much lower temperature. A refrigerated bath filled with l-propanol was preset to a temperature of -57 °C. NMR readings were taken at different temperatures until a temperature of +25 °C was attained. Then a cooling curve was determined for all samples.

A portion of Lanzhou silt A was washed with distilled, deionized water six times to remove the soluble salts to determine the effect of salt in the naturally occurring soil on the phase composition curves.

The complete procedure for and the accuracy of

Table 1. Values of specific surface area and salinity for the various soils.

	Specific surface area (m^2/g)	*Electrical conductivity (mhos/cm)*	*Equivalent molality (moles KCl/L)*
Lanzhou silt A	34	2.1253×10^{-2}	0.1474
Lanzhou silt B	—	2.3895×10^{-2}	0.1658
Chena Hot Springs silt	40	8.0326×10^{-4}	0.0056
Northwest Alaska Pipeline silt	35	1.3932×10^{-3}	0.0097
Kotzebue silt	17	1.2088×10^{-2}	0.0839
KCl, 0.01 *N*	—	1.4415×10^{-3}	0.0100

The equivalent molality of the soil extract is calculated by dividing the electrical conductivity of the soil extract by that of the 0.01 *N* KCl standard solution and multiplying by 0.01.

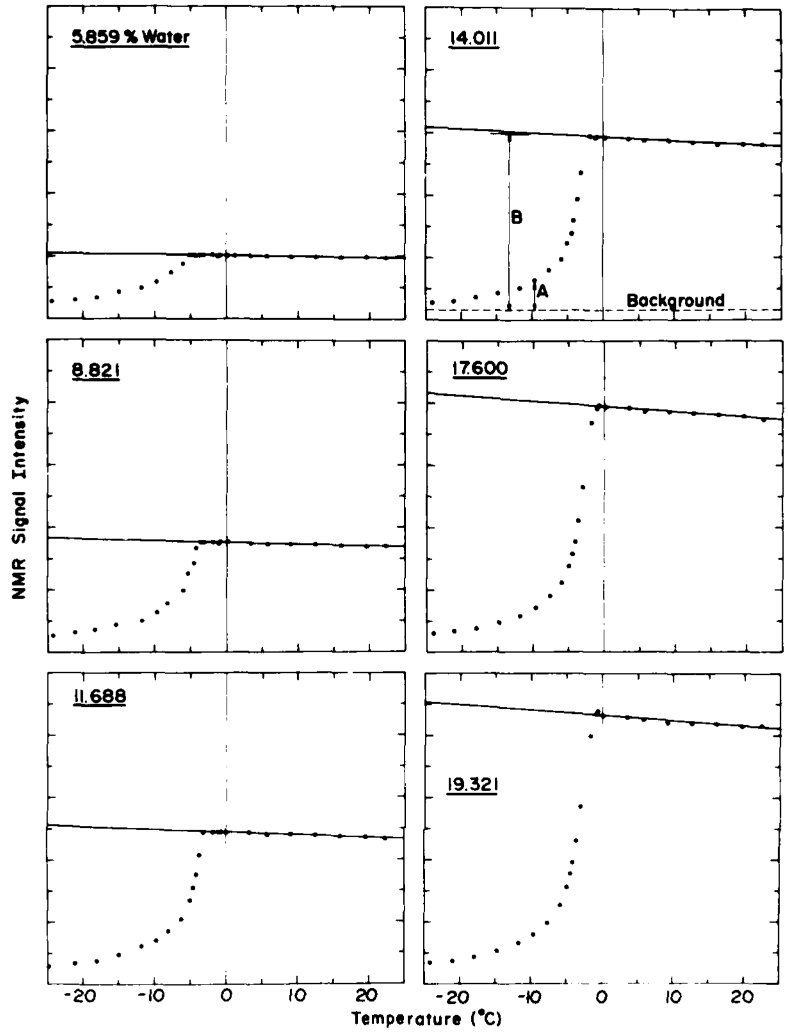

Figure 1. Raw NMR data vs temperature for Lanzhou silt A with natural solutes (warming).

measuring unfrozen water content in partially frozen soil by NMR have been reported previously by Tice et al. (1982) and Oliphant and Tice (1982). To reiterate, however, the unfrozen water content is calculated by extending the line drawn through the data points with no ice present down to low temperature by linear regression (see the raw data plots, Figure 1). The unfrozen water content is then calculated as the total water content (determined gravimetrically) multiplied by the distance from the experimental measurement to the background amplitude (A in the figure), and then divided by the distance from the regression line to the background amplitude reading (B in the figure).

Specific surface area

Specific surface areas were determined by the weight retention of ethylene glycol monoethyl ether. This method is described by Carter et al. (1965). The values are presented in Table 1.

Electrical conductivity

The electrical conductivity measurements and calculations for solute concentration were determined by the technique reported by Bower and Wilcox (1965). See Table 1 for these results.

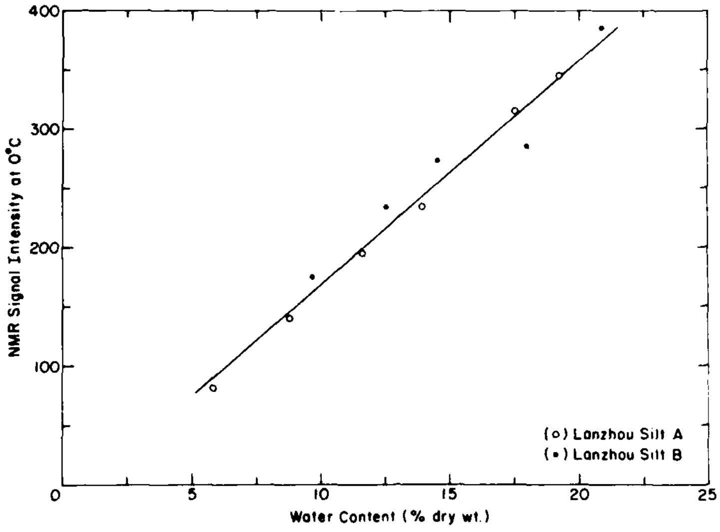

Figure 2. Relationship between sample water content and NMR signal intensity for Lanzhou silts A and B with natural solutes. Temperature is 0°C and silt is ice-free.

RESULTS AND DISCUSSION

Shown in Table 1 are some of the characteristics of the soils used in this study. The measurements show that the specific surface areas are similar for all the soils. According to Anderson and Tice (1972), the unfrozen water contents should also be similar if specific surface area is the only soil characteristic considered. We note, however, that the Lanzhou silts (A and B) have electrical conductivities which indicate large amounts of soluble salts. These high electrical conductivities suggest that only a few very salt-tolerant crops will yield satisfactory harvests when grown on these sites (Bower and Wilcox 1965). This high salt content would also influence the low temperature behavior by shifting the melting points to lower temperatures and thus increasing the amount of unfrozen water at a given temperature.

We elected to evaluate the effects of the naturally occurring salts by comparing the unfrozen water contents of the Lanzhou silts with salt and without salt (leached). Only Lanzhou silt A was leached because of the similarity between the two samples. Figure 2 shows that the signal amplitude is about the same for both silts. Figures 3 and 4 and Tables A1-A4, Appendix A, contain the unfrozen water content vs temperature data for the Lanzhou silts A and B respectively. The two soils appear similar. A further comparison can be seen in the unfrozen water contents of Figure 5.

The unfrozen water content of the Lanzhou silt is compared to those of some typical Alaskan silts in Figures 6-8. The Northwest Alaska Pipeline silt and Chena Hot Springs silt are similar in most respects and are relatively salt-free. The differences between the unfrozen water contents of these two soils and the Lanzhou silts are due to the amount of salt contained in each (Fig. 6 and 7). When the salts are removed from the Lanzhou silt, the unfrozen water content of the leached silt then compares favorably to that of the two Alaskan silts mentioned above (Fig. 10). The data points for the salt-free Lanzhou silt A are shown in Table A3, Appendix A. Figure 8 compares the unfrozen water content of the Lanzhou silt A and the third Alaskan soil, Kotzebue silt. The unfrozen water contents are similar for these two soils which are both salt-rich.

The effect of the naturally occurring salt is apparent when the unfrozen water content vs temperature data are examined (Fig. 9). This figure shows large differences between the salt-rich and salt-free soils, especially around the melting points. The differences become smaller as the temperature is reduced and salts are precipitated. When precipitated, the salt would have a negligible effect on the amount of unfrozen water.

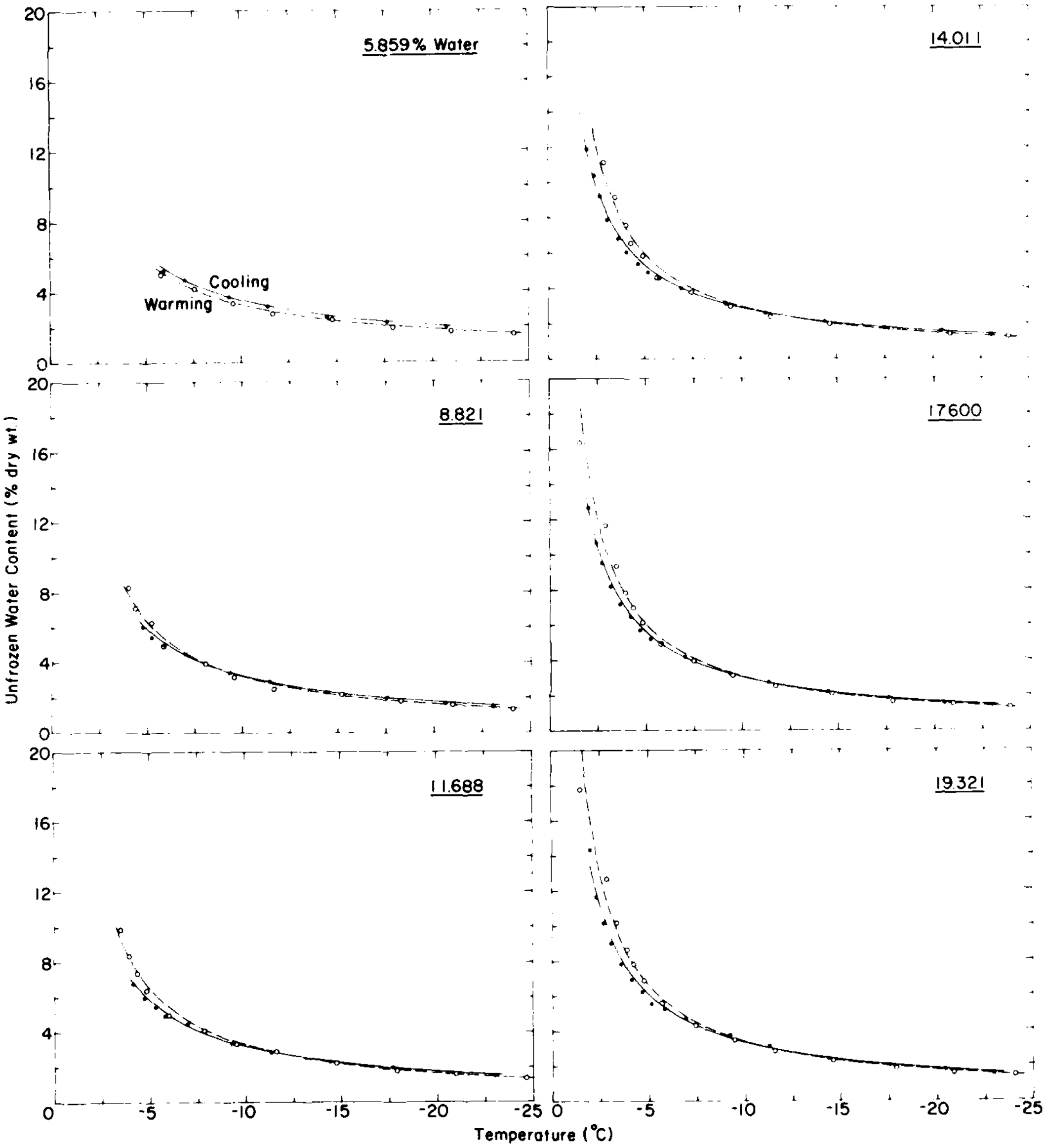

Figure 3. Unfrozen water content vs temperature for Lanzhou silt A with natural solutes.

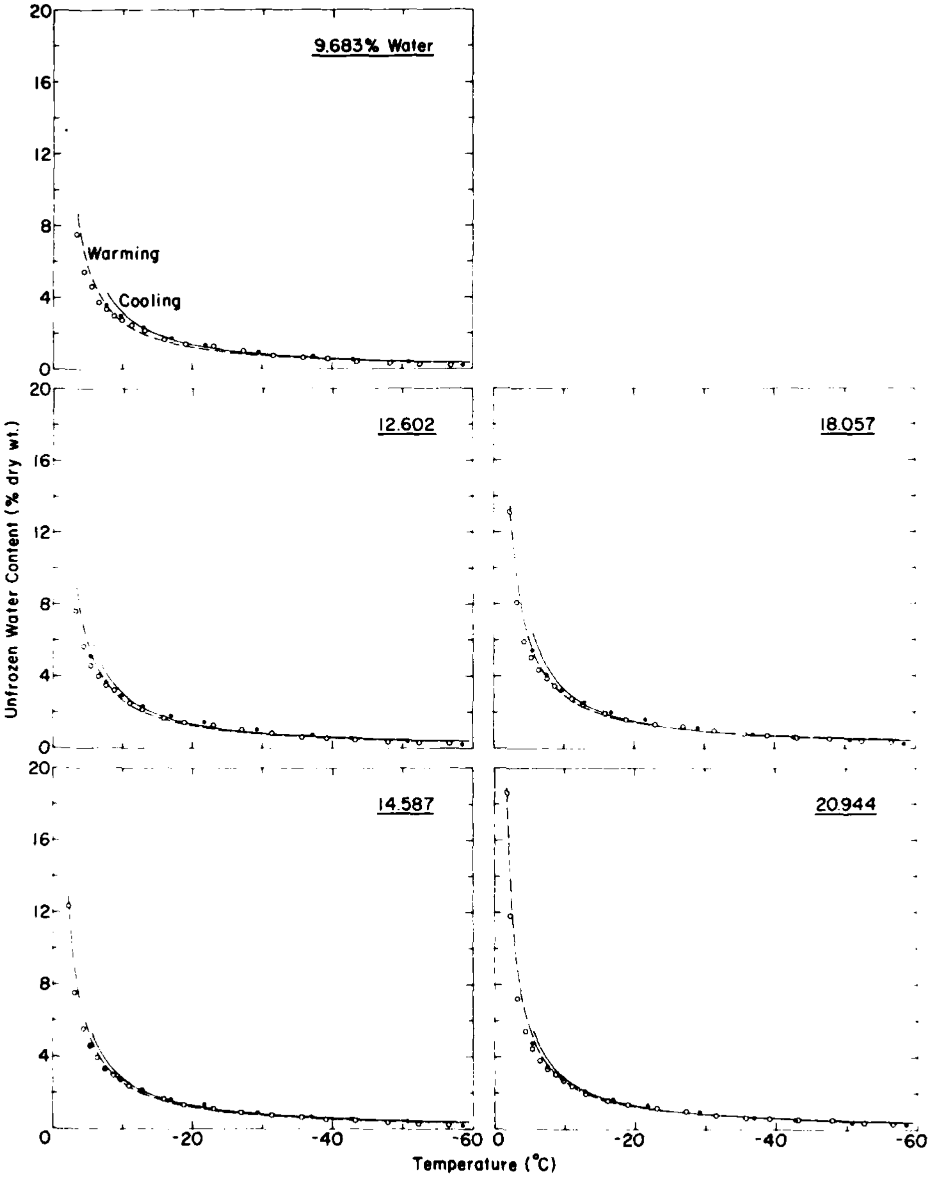

Figure 4. Unfrozen water content vs temperature for Lanzhou silt B with natural solutes.

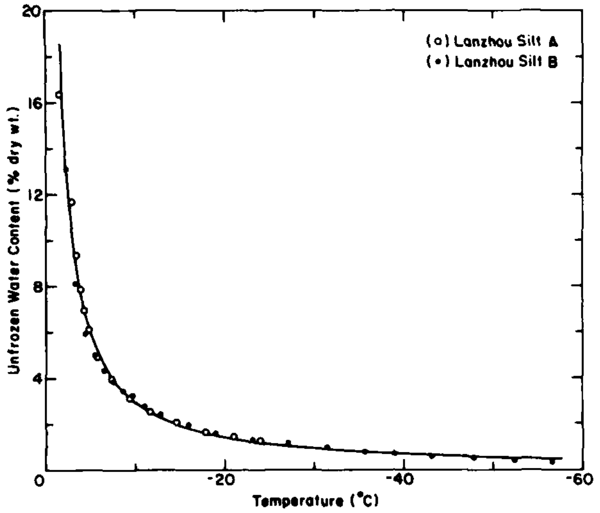

Figure 5. Comparison between unfrozen water content vs temperature for Lanzhou silts A and B at 18% water (warming).

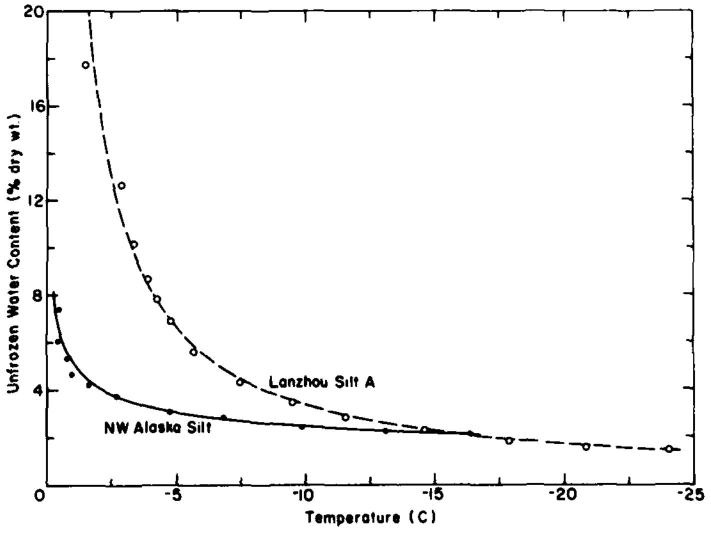

Figure 6. Comparison between unfrozen water content vs temperature for Lanzhou silt A and Northwest Alaska silt. Soils contain natural solutes (warming curves).

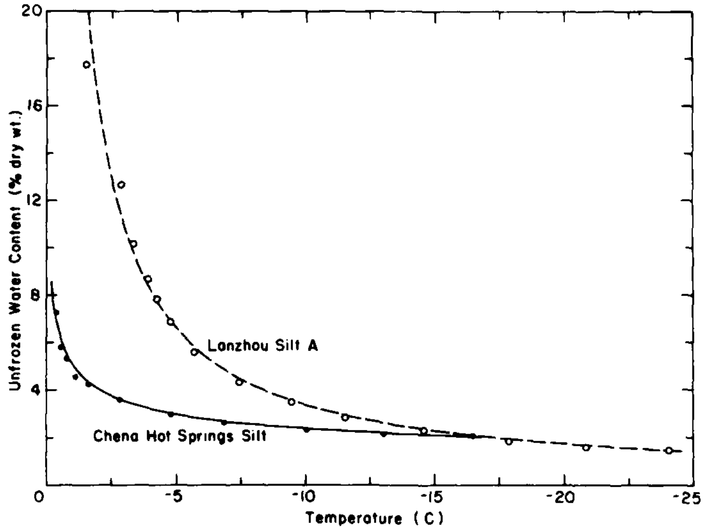

Figure 7. Comparison between unfrozen water content vs temperature for Lanzhou silt A and Chena Hot Springs silt. Soils contain natural solutes (warming curves).

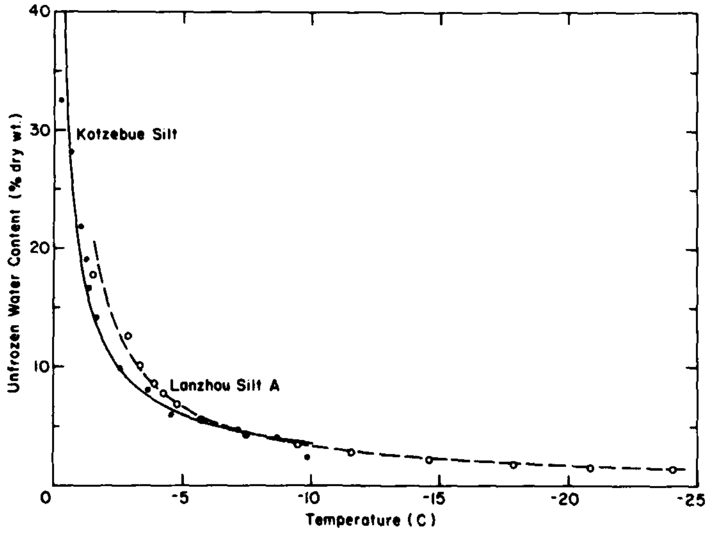

Figure 8. Comparison between unfrozen water content vs temperature of Lanzhou silt A and Kotzebue silt, both containing solutes (warming).

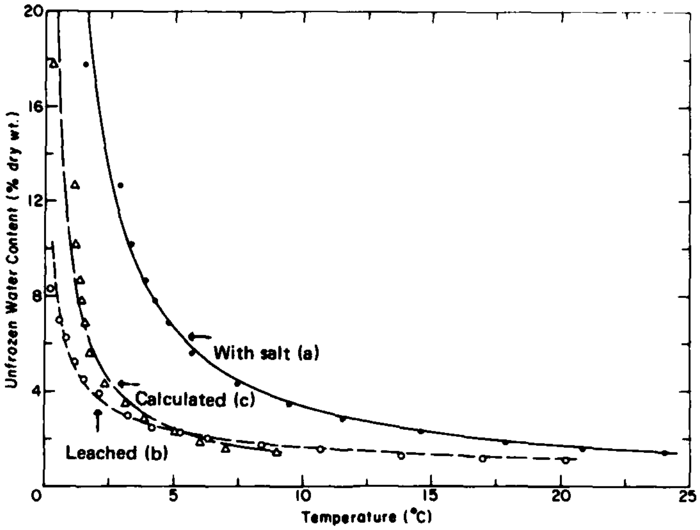

Figure 9. Unfrozen water content vs temperature for Lanzhou silt A.

a. With natural solutes.

b. Solutes leached.

c. Calculated from solute concentration.

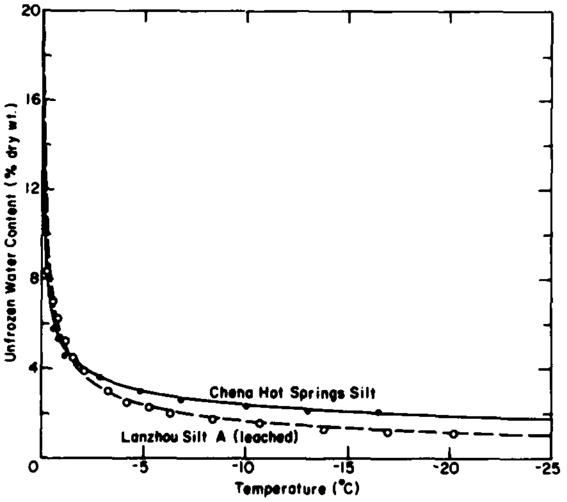

Figure 10. Comparison of unfrozen water content vs temperature for Lanzhou silt A (leached) and Chena Hot Springs silt (warming).

Figure 9 also contains a curve which is calculated from the electrical conductivity of the extract of a saturated paste of Lanzhou silt A. Calculated values are shown in Table 2. The molality at each temperature is calculated by [E.C. SP/E.C. STD × W_c SP]/W_u at T. In this expression, E.C. SP is the electrical conductivity of the saturated paste in mhos/cm. E.C. STD is the electrical conductivity of the 0.01 N KCl standard solution in mhos/cm. W_c SP is the saturated paste water content which is equal to 41.4% for the Lanzhou silt A sample. The freezing point depression of the soil water is calculated by multiplying the molality at each value of T by 3.71, which is the molal freezing point-depression constant of an ideal salt solution in water. From Table 2 one sees a large change in the freezing point depression with temperature. This is due to the gradual freezing of the soil water, which excludes the solutes, creating an increasingly concentrated solution of the remaining unfrozen water.

Table 2. Calculated freezing point depression for Lanzhou silt A at 19.3% water.

T	W_u	*Molality*	T_1	$T-T_1$
0	19.321	0.3158	- 1.17	
- 1.55	17.8	0.3427	- 1.27	-0.28
- 2.91	12.7	0.4804	- 1.78	-1.13
- 3.38	10.2	0.5981	- 2.22	-1.16
- 3.94	8.7	0.7012	- 2.60	-1.34
- 4.28	7.86	0.7762	- 2.88	-1.40
- 4.80	6.91	0.8829	- 3.28	-1.52
- 5.72	5.63	1.0836	- 4.02	-1.70
- 7.47	4.35	1.4025	- 5.20	-2.27
- 9.49	3.51	1.7142	- 6.36	-3.13
-11.59	2.89	2.1110	- 7.83	-3.76
-14.63	2.33	2.6184	- 9.71	-4.92
-17.90	1.88	3.2451	-12.04	-5.86
-20.88	1.61	3.7894	-14.06	-6.82
-24.07	1.48	4.1222	-15.29	-8.78

T = temperature °C.
W_u = unfrozen water content at T.
T_1 = freezing point depression.

SUMMARY

Phase composition curves are presented for a typical saline silt from Lanzhou, P.R.C., and compared to curves for some silts from Alaska. The unfrozen water content of the Chinese silt is much higher than that of the Alaskan silts. This higher amount is due to the large amount of soluble salts present in the silts from Lanzhou which are not present in the silts from interior Alaska. When the salts are removed, the unfrozen water contents of the Chinese and Alaskan silts are similar.

We have introduced a technique for correcting the unfrozen water content of partially frozen soils due to high salt concentrations. This correction is made possible by calculating the equivalent molality of the salts in the unfrozen water at each temperature from a measurement of the electrical conductivity of the extract of a saturated paste.

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APPENDIX A: UNFROZEN WATER CONTENT VS TEMPERATURE DATA FOR LANZHOU SILT.

Table A1. Unfrozen water content vs temperature data for Lanzhou silt A with natural solutes (warming).

Temperature (°C)	Unfrozen water (% dry wt)
5.859% water	
-24.26	1.60
-20.99	1.75
-17.98	1.97
-14.82	2.47
-11.7	2.83
-9.62	3.41
-7.57	4.27
-5.86	5.06
8.821% water	
-24.15	1.32
-21.04	1.57
-18.34	1.82
-15.28	2.19
-11.7	2.51
- 9.59	3.20
- 8.08	3.95
- 5.88	4.96
- 5.3	6.33
- 4.43	7.14
- 4.07	8.33
11.688% water	
-24.67	1.36
-20.99	1.60
-17.93	1.79
-14.79	2.26
-11.65	2.91
- 9.54	3.34
- 7.87	4.11
- 5.99	5.01
- 4.86	6.44
- 4.38	7.39
- 3.94	8.40
- 3.52	9.89
14.011% water	
-23.98	1.30
-20.96	1.42
-17.88	1.72
-14.71	2.02
-11.62	2.44
- 9.54	3.03
- 7.5	3.83
- 5.72	4.65
- 4.99	5.89
- 4.36	6.61
- 4.12	7.62
- 3.52	9.22
- 2.97	11.2
17.600% water	
-23.98	1.32
-21.01	1.49
-17.88	1.66
-14.68	2.10
-11.73	2.55
- 9.49	3.16
- 7.47	3.99
- 5.78	4.94
- 4.86	6.16
- 4.36	7.00
- 3.94	7.88
- 3.49	9.38
- 2.96	11.7
- 1.61	16.4
19.321% water	
-24.07	1.49
-20.88	1.61
-17.9	1.88
-14.63	2.33
-11.59	2.89
- 9.49	3.51
- 7.47	4.35
- 5.72	5.63
- 4.8	6.91
- 4.28	7.86
- 3.94	8.70
- 3.38	10.2
- 2.91	12.7
- 1.55	17.8

Table A2. Unfrozen water content vs temperature data for Lanzhou silt A with natural solutes (cooling).

Temperature (°C)	Unfrozen water (% dry wt)
5.859% water	
- 5.99	5.28
- 7.12	4.78
- 9.41	3.84
-11.46	3.26
-14.55	2.62
-17.68	2.32
-20.77	2.04
8.821% water	
- 4.83	6.10
- 5.3	5.48
- 5.94	5.10
- 7.05	4.54
- 9.35	3.48
-11.43	2.98
-14.44	2.35
-17.6	2.04
-20.66	1.67
-23.13	1.48
11.688% water	
- 4.2	6.81
- 4.8	6.04
- 5.33	5.50
- 5.86	4.97
- 7.05	4.55
- 9.33	3.42
-11.38	2.89
-14.47	2.35
-17.74	1.99
-20.57	1.70
-23.07	1.52
14.011% water	
- 2.08	11.95
- 2.47	10.45
- 2.73	9.26
- 3.12	7.95
- 3.7	6.87
- 4.12	6.09
- 4.72	5.44
- 5.25	4.96
- 5.83	4.60
- 6.94	4.06
- 9.3	3.16
-11.35	2.62
-14.47	2.14
-17.52	1.78
-20.52	1.60
-23.1	1.36
17.600% water	
- 2.05	12.7
- 2.47	10.7
- 2.73	9.54
- 3.17	8.21
- 3.67	7.21
- 4.22	6.49
- 4.72	5.71
- 5.25	5.21
- 5.83	4.98
- 7.02	4.20
- 9.33	3.26
-11.35	2.76
-14.44	2.20
-17.63	1.86
-20.55	1.53
-23.02	1.42

Table A2. Continued.

Temperature (°C)	Unfrozen water (% dry wt)
19.321% water	
- 2.02	13.4
- 2.36	11.7
- 2.7	10.2
- 3.12	9.04
- 3.62	7.87
- 4.17	6.97
- 4.72	6.25
- 5.2	5.58
- 5.83	5.29
- 6.99	4.73
- 9.27	3.78
-11.33	3.16
-14.39	2.44
-17.58	2.04
-20.46	1.77
-22.99	1.54

Table A3. Unfrozen water content vs temperature data for Lanzhou silt A leached (warming).

Temperature (°C)	Unfrozen water (% dry wt)
21.061% water	
-20.25	1.15
-17.03	1.21
-13.87	1.33
-10.74	1.61
- 8.45	1.78
- 6.36	2.06
- 5.3	2.29
- 4.2	2.51
- 3.28	3.02
- 2.15	3.92
- 1.55	4.53
- 1.21	5.26
- 0.85	6.27
- 0.59	7.00
- 0.28	8.35

Table A4. Unfrozen water content vs temperature data for Lanzhou silt B with natural solutes (cooling).

Temperature (°C)	Unfrozen water (% dry wt)	Temperature (°C)	Unfrozen water (% dry wt)
9.683% water		18.057% water	
- 7.76	3.63	- 5.57	5.46
- 9.91	3.00	- 7.63	4.09
-13.09	2.37	- 9.81	3.27
-17.17	1.74	-12.85	2.58
-22	1.37	-16.90	2.03
-29.57	0.99	-21.75	1.62
-37.38	0.74	-29.21	1.15
-43.09	0.56	-37.1	0.81
-50.99	0.44	-42.88	0.61
-58.8	0.27	-50.87	0.48
		-58.5	0.29
12.602% water			
- 5.51	5.13	20.944% water	
- 7.65	3.71	- 5.49	4.82
- 9.81	2.94	- 7.65	3.49
-13.01	2.35	- 9.7	2.86
-17.09	1.82	-12.99	2.17
-21.84	1.46	-17.01	1.71
-29.37	1.05	-21.89	1.36
-37.3	0.76	-29.32	1.02
-42.83	0.59	-37.01	0.68
-50.84	0.42	-42.88	0.57
-58.6	0.26	-50.81	0.40
		-58.5	0.30
14.587% water			
- 5.59	4.62		
- 7.63	3.41		
- 9.83	2.82		
-12.96	2.19		
-17.03	1.67		
-21.86	1.37		
-29.43	0.92		
-37.15	0.69		
-42.83	0.57		
-50.81	0.46		
-58.6	0.25		

Table A5. Unfrozen water content vs temperature data for Lanzhou silt B with natural solutes (warming).

Temperature (°C)	Unfrozen water (% dry wt)	Temperature (°C)	Unfrozen water (% dry wt)
9.683% water		14.587% water	
-57.1	0.27	-56.7	0.30
-52.6	0.35	-52.4	0.36
-48.36	0.39	-48.03	0.41
-43.58	0.45	-43.41	0.52
-39.45	0.62	-39.24	0.58
-35.93	0.69	-35.75	0.69
-31.7	0.81	-31.51	0.81
-27.36	1.05	-27.06	0.98
-23.15	1.30	-23.15	1.15
-19.13	1.43	-18.94	1.38
-16.11	1.69	-16.11	1.67
-13.2	2.19	-12.93	2.14
-11.41	2.50	-11.11	2.43
- 9.99	2.75	- 9.81	2.77
- 8.87	3.01	- 8.79	3.01
- 7.73	3.39	- 7.65	3.36
- 6.65	3.77	- 6.54	3.99
- 5.65	4.64	- 5.51	4.63
- 4.57	5.46	- 4.49	5.56
- 3.41	7.53	- 3.3	9.59
		- 2.42	12.39
12.602% water			
-56.8	0.31	18.057% water	
-52.5	0.37	-56.7	0.36
-48.06	0.37	-52.5	0.42
-43.41	0.48	-47.94	0.55
-39.3	0.60	-43.29	0.62
-35.75	0.66	-39.1	0.75
-31.51	0.88	-35.81	0.82
-27.17	1.06	-31.51	1.01
-23.15	1.29	-27.11	1.22
-19.02	1.47	-23.13	1.34
-16.06	1.71	-18.99	1.63
-12.96	2.18	-16.03	1.97
-11.22	2.54	-12.96	2.45
- 9.86	2.95	-11.17	2.80
- 8.82	3.25	- 9.78	3.27
- 7.65	3.56	- 8.69	3.48
- 6.6	4.02	- 7.63	3.90
- 5.54	4.62	- 6.54	4.38
- 4.43	5.68	- 5.51	5.07
- 3.3	7.63	- 4.43	5.96
		- 3.36	8.15
		- 2.37	13.14

Table A5. Continued.

Temperature (°C)	Unfrozen water (% dry wt)
20.944% water	
-56.6	0.35
-52.5	0.41
-48.09	0.52
-43.29	0.57
-39.24	0.64
-35.81	0.69
-31.59	0.80
-27.31	1.03
-23.21	1.20
-19.05	1.43
-16.17	1.67
-13.07	2.01
-11.17	2.47
- 9.81	2.76
- 8.77	3.11
- 7.63	3.40
- 6.62	3.86
- 5.51	4.50
- 4.49	5.48
- 3.41	7.27
- 2.39	11.88
- 1.87	18.67

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