# Observations of sodium chloride crystallisation on non-porous surfaces as a possible explanation for initial salt movement in unsaturated granular soils.

Abstract

# Introduction

Under laboratory conditions it has been found that sodium chloride can migrate upwards through columns of dry granular sand well below the natural capillary rise of the material when one end is when placed within a shallow container of supersaturated brine and with only dried air blown over the surface to maintain arid conditions (Figure 1). Furthermore, narrow vertical columns of spherical glass beads of 10mm diameter also have shown that salt will slowly ascend without the traditional capillary rise effect observed in less unsaturated particulate matter.



Figure 1: Salt crust above dry fine grained siliceous sand (300mm scale)

Sodium chloride, as halite, is one of the most abundant minerals on the earth surface and is encountered in both marine and terrestrial soils. It is particularly prevalent in arid environments where it originates from subterranean salt diapirs, relict deposits from sea level transgressions and from evaporation of underlying salt rich groundwater. Saline environments are also encountered in low lying areas formed though previous tectonic activity such as the Dead Sea and in current geothermal areas. Saline rich soils are often associated with coastal and inland arid soils which receive limited denudation and also hyper arid soils which are encountered where rainfall is virtually non-existent such as parts of the Atacama Desert in Chile (Nash, 2012).

Gradual upward movement of salt precipitate can also be observed on partially submerged nonporous objects placed into an open container of supersaturated sodium chloride solution. Such phenomena has been observed with glass, natural minerals such as gypsum, quartz and calcite and plastics such as nylon, PTFE, acrylic and polythene (Figure 2).



Figure 2: Dendritic crystallisation of sodium chloride in a plastic bowl

Repeated experiments using glass and plastic stirring rods placed within containers of supersaturated brine which were allowed to naturally evaporate at room temperature have revealed the following observations:

- 1) Initial nucleation of salt on the upper side of the rod at the brine-air interface
- 2) Precipitation of further salt crystals along the top and side of the rod which gradually ascends the sloping rod surface forming a frosted glass effect (Figure 3)
- 3) Absence of salt on the underside of the rod above the brine meniscus for at least 10mm
- 4) Salt initially remains semi-translucent before a secondary layer of opaque dendritic crystals form both horizontally and radially
- 5) Salt crust forms above and beyond extent of the evaporating source brine to distance between 30mm and 50mm.



Figure 3: Salt growth up glass rod

The observations promote the idea that the central core between the non-porous surface and salt acts as a conduit for fluid which to transport or wick solute to higher elevations. The wicking effect of salts, including sodium chloride, has been observed and measured in sedimentary rocks (Goudie, 1986) in relation to weathering, and in structural damage of natural stone masonry (Derluyen, 2012) though both studies were through the effects of wetting and drying porous material. The wicking

effect in porous materials can be attributed to capillary driven flow of salt solution, subsequent evaporation of water from the solution and diffusion of ions in the solution filled pore space (Zheng et al, 2009). In experiments involving sodium chloride in sealed glass capillary tubes, Bouzid et al, (2010) suggested the possibility of Young-Laplace capillary bridges in response to sodium chloride precipitation creating heterogeneous porosity in an 'initially irregular network'. Bouzid et al, (2010) were able to retain a liquid film between the precipitating salt and wall of the tube.

With non-porous materials, the central core of salt may explain how salt is able to move around unsaturated granular soil grains without the benefit of trapped, less concentrated fluid to act as a diffusive gradient. A plausible mechanism lies with the nature of the source brine and the evaporation rate of the brine rather than the ionic attractive nature of the substrate surface which the salt is deposited and this is demonstrated through simple experiments involving humidity sensors and electrical conductivity on hydrophobic surfaces.

# **Materials and Methods**

Two experiments were set up to determine the state and transport potential of the salt core created through salt precipitation upon a non-porous surface and whether the nature of the evaporating brine beneath the surface had an effect these properties.

Electrical charge can be carried by fluids containing ions and aqueous sodium chloride is a good conductor of electricity, whereas solid sodium chloride is a non-conductor. If the non-porous surface beneath the salt was found to carry electrical charge this would indicate that the salt was in solution as it was being wicked up to higher elevations. The distribution of the salt precipitate around the tube periphery could be determined through manual observation but the electrical conductivity would indicate whether any fluid remained in connection to the brine source. Electrical conductivity was determined using a pocket sized continuity meter to record whether a flow of electrons within a fluid resulted in an open circuit (no conductivity) or a closed circuit (conductivity). The resistivity of the fluid was not required in this experiment thought it may have been a useful addition to infer total dissolved salts. Rudimentary experiments with the continuity meter showed that when two probes placed 10mm apart in de-ionised water an open circuit resulted, but upon dissolving 0.18g sodium chloride reagent into 100 ml of deionised water a closed circuit was formed. Due potential errors with fluid films and rapid evaporation, the continuity condition was not determined for how much water would have to be added to solid sodium chloride to become an electrolyte.

A hydrophobic surface was chosen because salt nucleation was observed to be quicker than a hydrophilic surface such as glass. Shahidzadeh-Bonn et al, (2011) experimentally determined that sodium chloride crystals preferentially form in contact with a non-polar surface including air or hydrophobic materials. This was due to the fact that a hydrophobic surface was more efficient at purifying a single sodium chloride crystal through solution and precipitation cycling than a hydrophilic surface. A single pure crystal grows above the meniscus and forms separate crystals which ascend outward (see Figure 2).

Two experiments were conducted to determine the nature of the central salt core using electrodes to measure the continuity and thus whether the salt along the surface of each plastic probe remained in solution. Each probe was constructed from 25mm OD acrylic tubes, sealed at one end

and with and 0.6mm holes drilled along one side where single strand, tinned copper wires were placed which were then sealed inside the tube using an epoxy resin. The wires on the exterior of the tube were painted with silver conducting paint to ensure conductivity and surface integrity.

The first experiment acrylic tube comprised a single alignment of 10mm spaced electrodes along the base of the tube at which to observe the effect of water evaporation from the brine-air interface. The second tube comprised four alignments of electrodes placed at 20mm spacing along each tube, though each adjacent set of electrodes were offset by 10mm such that each opposite electrode alignment had the same electrode interval. This was to determine the nature of the salt as it evolves on the non-porous surface along 4 sides of the tube. The electrode orientation (Figure 4) and position above the evaporating brine solution was to ensure that the two horizontal electrode alignments (OT and OB) were not at the same level, thus to observe a different spread of potential data when comparing adjacent electrode continuity.

A large, almost vertical walled polythene bowl of height 130mm and internal diameter of 205mm and 100mm at the top and bottom respectively was used for holding the brine in the first experiment. The electrode was placed at an inclined angle of 42° so that part of the upper section (electrode 20) rested on the bowl side and protruded 100mm beyond the rim of the container (Figure 5a). The second multi element probe was held in a rectangular acrylic box of internal dimensions, 275mm x 125mm x 90mm, at an inclination of 36° by means of a clamp (Figure 5b).



Figure 4: Alignment of electrodes used in the experiments

In the first experiment brine made up of 525g of sodium chloride dissolved into one and a half litres of water and the second experiment 900g of sodium chloride was dissolved into two and a half litres of water at room temperature in a separate container. In both cases the sodium chloride used was reagent grade supplied by Sigma Aldrich ( $\geq$ 99.8% purity) dissolved into deionised water with an electrical conductivity of 13.44µS. The electrolyte was carefully added to each vessel without splashing. The brine in each container containing the electrodes was then left to evaporate at room temperature to reach a supersaturated state. The distribution of relative humidity around the electrode and evaporating container was also determined for the first experiment using capacitance type sensors (Sensiron SHT21) connected to a logging unit. It took 4 days for the brine solution to reach a supersaturated state to begin to nucleate crystals. As water molecules left the brine-air interface, proto-crystals forms on the surface of the brine as a response to sodium and chloride molecules being pulled together. Some crystals were observed to fall to the base of the bowl, others developed dendroid shaped branches whilst others attached either to the wall of the container or the plastic rod. As water vapour condensed as tiny droplets on the side of the plastic rod, solute flows from the brine through diffusion. Nielsen, (1984), found that very soluble electrolytes crystallise from aqueous solution by means of the linear rate law where the rate is controlled by the transport of ions in the bulk solution or by the adsorption process. The development of a dominant crystal at the brine meniscus-probe interface resulted in a nucleation point for further crystals to develop but where air was sufficiently humid, deliquescence took place (Desarnaud and Shahidzadeh-Bonn, 2011). The movement of salt beyond the nucleation point at the brine-air-rod surface was observed to be different between hydrophilic and hydrophobic surfaces, the latter attaining an initial frosted coating of translucent partially saturated salt. Observation of a glass surface under microscope revealed an ascending diagonal front of fine cubic crystals appearing in response to droplets of water vapour condensing on the rod surface. In the case of the acrylic probes, salt growth was more prolonged leading to individual cubic crystals later forming secondary lateral and radial dendroid structures. Dendritic salt formation was also encountered by Zhang, et al (2009) when observing the wicking of salt solution onto porous nanoparticle coatings.

Measurements at each of the electrodes were delayed until sufficient salt had accumulated on each rod so that electrodes had been covered. Electrical continuity readings were determined between each adjacent electrode and between the brine and each electrode. The latter case was determined by inserting a tin electrode in the brine solution whilst the electrode on the tube was measured with the continuity meter.



Figure 5: Salt encrusted electrode: Single probe (left) and multi electrode probe (right)

#### **Results and Discussion**

#### Single electrode

The first experiment comprising a single orientation of electrodes represents the underside of the tube in direct contact with evaporating water.

Relative humidity and temperature measurements were undertaken within the container for specific durations to determine the average conditions taking place. Prior to conductivity measurements,

sensors were placed at between 5mm and 10mm, 10mm and 20mm and mid-height of the probe at 50mm above the brine surface. One sensor also monitored ambient room conditions

Figure 6a shows slightly lower temperature readings compared to ambient temperature as one proceeds to the brine surface which is related to vapour density. Likewise the relative humidity in Figure 6b is markedly higher towards the brine surface where water molecules activity is most intense. But the variation of both temperature and relative humidity appears to be largely controlled to the ambient conditions in which the container is placed.



Figure 6a and 6b: Initial temperature and Relative humidity variation

Figures 7a and 7b present the temperature and relative humidity conditions around the probe once the salt had begun to precipitate on the acrylic probe and up until desiccation of the brine. A sensor was positioned beneath the probe close to the brine-air surface to determine conditions which prevent salt from accumulating. In previous experiments, salt was observed to accumulate beyond the influence of water vapour from the evaporating source brine so a sensor was placed at the edge of the bowl to record humidity readings. It can be seen from plots that temperature is at least 2°C near the brine meniscus under the inclined probe, through fluctuations are in line with ambient condition measurements. However, the relative humidity at this point above the brine meniscus is unaffected by the ambient variation showing a range of between 71°C and 75°C.





Figure 7a and 7b: Temperature and Relative humidity variation around the salt encrusted probe

This concurs with results presented by Derluyen, (2012) who found that salt deliquescence in porous limestone had a relative humidity is about 75% RH and was slightly temperature dependant. The variations of the humidity and temperature relate to the reducing level of brine in the container and slight adjustment to the sensor height throughout the experiment. The sensor placed at the

container edge followed a similar variation with the ambient conditions but with a higher relative vapour density indicating convection up the side of the container by evaporating water molecules.

# **Electrical Continuity**

Figures 8a and 8b present the data for the single electrode. 0 indicates no conductivity and 1 indicates a closed circuit or conductivity. The blue areas indicate where the electrode remains submerged in the brine solution, no colour shows where the electrode is above the brine but with no salt accumulations and shaded areas show salt accumulation.

	Day 0 Day 11		Day 17	Day 23	Day 27	Day 28	Day 32	Day 36	Day 40	Day 41		Lay 4	Day 42
Electrode											AM	PM	
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	0	0	1	1	1
4	1	1	1	1	1	1	1	1	0	0	1	1	0
5	1	1	1	1	1	1	1	1	0	0	1	1	1
6	1	1	1	1	1	1	1	0	0	0	1	1	1
7	1	1	1	1	1	1	0	0	0	0	1	1	1
8	1	1	1	1	1	1	0	0	0	0	1	0	0
9	1	1	1	1	0	0	1	1	0	0	0	0	0
10	1	1	1	0	1	1	1	1	0	0	0	0	0
11	1	1	0	1	1	1	1	1	0	0	0	0	0
12	0	0	0	1	1	1	1	1	0	0	0	0	0
13	0	0	0	1	1	1	1	1	0	0	0	0	0
14	0	0	0	1	1	1	0	0	0	0	0	0	0
15	0	0	0	1	1	1	1	1	0	0	0	0	0
16	0	0	0	1	1	1	1	1	0	0	0	0	0
17	0	0	0	1	1	1	1	1	0	0	0	0	0
18	0	0	0	1	1	1	1	0	0	0	0	0	0
19	0	0	0	1	1	0	0	0	0	0	0	0	0
20	0	0	0	1	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0



Figure 8a – Single Electrode Probe: Continuity between brine and electrodes

Electrode 20 marks the position at the edge of the container, where the probe rests. Electrodes 21 to 25 are not influenced by the evaporating brine in the container and are subjected to ambient conditions. Salt was observed to accumulate beyond the edge of the container by approximately 50mm and continuity measurements determined:

- 1. There was no continuity between the source brine and electrode 21
- 2. Continuity between adjacent electrodes extends beyond electrode 20 at least 9 days after brine source is cut off from the main salt capillary.

Electrodes	Day 0	Day 11	Day 17	Day 23	Day 27	Day 28	Day 30	Day 32	Day 36	Day 40	Day 41	AM	Day 42	
1-2	1	1	1	1	1	1	1	1	0	0	0	0	1	1
2-3	1	1	1	1	1	1	1	0	1	1	0	0	0	1
3-4	1	1	1	0	1	1	1	0	1	0	0	0	0	1
4-5	1	1	1	1	1	1	1	1	1	0	0	0	1	0
5-6	1	1	1	1	0	0	1	1	0	0	0	1	1	1
6-7	1	1	1	1	1	1	1	0	0	0	0	0	1	1
7-8	1	1	1	1	1	1	0	0	1	0	0	0	0	0
8-9	1	1	1	1	0	0	1	1	1	0	0	1	0	0
9-10	1	1	0	0	0	0	0	1	1	0	0	1	0	0
10-11	1	1	0	0	1	1	1	1	1	0	0	0	0	0
11-12	1	0	0	1	1	1	1	1	1	0	0	0	0	0
12-13	0	0	0	1	1	1	1	1	1	0	0	0	0	0
13-14	0	0	0	1	1	1	1	1	0	0	0	0	0	0
14-15	0	0	0	1	1	1	1	0	0	0	0	0	0	0
15-16	0	0	0	1	1	1	1	1	1	0	0	0	0	0
16-17	0	0	0	1	1	1	1	1	1	0	0	0	0	0
17-18	0	0	0	1	1	1	1	1	1	0	0	0	0	0
18-19	0	0	0	1	1	1	1	1	1	0	0	0	0	0
19- <b>20</b>	0	0	0	0	1	1	1	1	1	0	0	0	0	0
<b>20</b> -21	0	0	0	0	1	1	1	1	1	0	0	0	0	0
21-22	0	0	0	0	1	1	1	1	0	0	0	0	0	0
22-23	0	0	0	0	0	1	1	1	1	0	0	0	0	0
23-24	0	0	0	0	0	0	0	1	1	0	0	0	0	0
24-25	0	0	0	0	0	0	0	0	0	0	0	0	0	0

#### Figure 8b – Single Electrode Probe: Continuity between adjacent electrodes

Forty one days after the experiment had been setup, the brine source had completely desiccated and no further closed electrical continuity measurements could be made. 500ml of deionised water was then added to determine whether the salt capillary core can be recharged. Whilst some limited continuity between the brine solution and electrodes was restored (up to electrode 7), brine continuity between some adjacent electrodes was also detected up to electrode 10. This suggests that the central core may redundant once salt has precipitated along the single alignment of the electrodes but restored in another orientation perhaps relating to the dendritic structure of the salt on the acrylic rod surface.

#### Multi electrode

The main purpose of the multi electrode was to detect whether there was a radial distribution of electrolyte within the central core of the salt accumulation. Figures 9a and 9b present the continuity readings between brine and electrodes and between adjacent electrodes, respectively.

	Day 0				Day 7				Day 10				Day 17					Day	/ 20			Day	/ 23			Day 27			
Electrode	OB	OT	GT	GB	OB	OT	GT	GB	OB	OT	GT	GB	OB	OT	GT	GB	OB	OT	GT	GB	OB	OT	GT	GB	OB	OT	GT	GB	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	
6	1	1	0	1	1	1	1	0	1	1	1	0	1	1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	
7	0	1	0	1	1	1	0	0	1	1	1	0	1	1	1	0	1	0	1	0	0	0	0	0	1	1	1	1	
8	0	0	0	0	0	1	0	0	1	1	1	0	1	1	0	0	1	0	0	0	0	0	0	0	1	1	1	1	
9	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ō	0	0	0	Ō	0	0	
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
14	0	0			0	0			0	0			0	0			0	0			0	0			0	0			

# Figure 9a: Multi-electrode Probe: Continuity between brine and electrodes

Figure 9a shows limited continuity between the core of the salt deposit and the brine solution, though it should be reemphasised that the electrode spacing is double that of the first experiment between electrodes on the same alignment but half the distance between opposite pairs on the adjacent alignment. Also the electrode probe was immersed into a shallow sided container so that the evaporation of water vapour from the brine was not confined as for the case in the first experiment. Electrodes along OB and OT which are orientated along the side of the probe, generally showed good continuity between brine and electrodes suggesting salt capillaries remain open due to water vapour capture from evaporation. Figure 9b presents the continuity between adjacent electrodes along each alignment.

		Day	/ 17			Day	/ 20			Day	/ 23		Day 27					
Electrode	ОВ	от	GT	GB	ОВ	от	GT	GB	ОВ	от	GT	GB	ОВ	от	GT	GB		
1-2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
2-3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
3-4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
4-5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0		
5-6	1	1	1	1	1	1	1	0	1	0	1	0	1	0	1	0		
6-7	1	1	1	0	1	1	0	0	1	0	1	0	1	0	1	0		
7-8	1	1	1	0	0	1	1	0	1	1	1	0	1	1	1	0		
8-9	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0		
9-10	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0		
10-11	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0		
11-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
12-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		

#### Figure 9b – Multi-electrode Probe: Continuity between adjacent electrodes

The data set presented for the continuity between adjacent electrodes along the same alignment have been largely confined to the middle and later stages of the experiment when sufficient salt had collected on the electrode. Measurements show that electrodes along the base of the rod (GB) do not show continuity i.e. no electrolyte freely exists between adjacent electrodes as opposed to the top electrode (GT) which does. There is also good continuity between electrodes along the side of the probe (OT and OB). Radial measurements of continuity were also undertaken on two days; at first accumulation of salt and at the final stages of the experiment. Figure 9c presents continuity data between one or more electrodes on different alignments. Note that shaded cells with no "1" or "0" indicate no continuity measurements taken. Measurements show that there is good continuity between the electrodes along the probe sides (OB and OT) and along the top of the electrode (GT) but also with some continuity between the lower electrode (GB) and the nearest side (OB). Limited continuity was recorded between the two opposite sides (GB and GT) where measurements were restricted to close to the brine-salt interface. It should be noted that the bulk of the continuity measurements which showed closed circuit existed between electrode numbers 7 and 8 which represent the midpoint of the probe above the brine meniscus and where the majority of salt had accumulated.

The experiments detail herein point to a central core within the salt accumulation that contains electrolyte. The electrodes along the base of the probe in experiment 1 had larger continuity than those in the multi-electrode probe and this must therefore be related to the confining nature of the container retaining a larger water vapour density thus allowing partial deliquesce. However the continuation of the salt beyond the edge of the container points to the fact that the salt can act as a capillary between electrode points but the main capillary to the host brine solution is restricted. The multi electrode probe shows that the central core above the evaporating brine to also retains some fluid, though this appears to be restricted to between electrodes.

						D	ay 1	0					Day 27											
Electrode	GT-OT		GT-OT GT-GB		GT-GB GT-OB		OT-GB		OT-OB				GT-OT		GT-GB		GT-OB		OT-GR		00 F.O	OT-OB		a)-a)
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0	0	0	0	1
6	1	1		0	1	1	1	0	1	1	0	1	0	0	0	0	1	1	0	0	1	1	0	1
7	1	1			1	1	1		1	1			1	1	0	1	1	1	0	0	1	1	1	1
8	0	1			0	1			1	1			1	1	0	0	1	1	1	1	1	1	1	0
9	0	1	0		0	0			1	0		0	0	0	0	0	0	0	0	0	1	1	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0		0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

# Figure 9c – Multi-electrode Probe: Continuity between alternate electrodes

# Conclusions

This paper presents the observations and experimental data of salt accumulation on an inclined nonporous material above an evaporating super-saturated sodium chloride brine solution. Data supports the existence of a central salt core that remains in partial solution between the non-porous surface and a secondary salt precipitation phase. This core acts as a conduit to supply solute to higher elevations on the surface and radial dendritic fronds of secondary salt growth.

Deliquesce by brine evaporation may be key to the survival of the central core, but irregular dendritic crystal growth along the substrate and secondary salt accumulation may affect the porosity of the salt capillaries.

Salt accumulation on non-porous surfaces may provide an alternative mechanism of how salts are able to migrate up columns of dry soil without the addition or assistance of interstitial pore water.

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