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Abstract:

The formation of craters involves the interaction of forces with the material present in the surface. All planets and moons in our solar system have been shaped by craters. Based on observed characteristics of Martian craters inferences can be made about the ambient conditions at the time of crater formation. Recent data from NASA's Mars Exploration Rovers confirmed the presence of past long-standing bodies of Mars surface and the presence of salts in the soil. To determine if crater characteristics differ depending on how the salts came to be in the surface – left over from evaporated standing bodies of water or merely deposited by the wind – experimental craters were made using soil samples prepared using salt evaporated out of solution and then soil with powdered salts.

Three salts were chosen: NaCl, $CaCl_2$ and $MgSO_4$. Kuzmin R.O. and E.V. Zabaluevaon, in a recent study on the Martian regolith assert that NaCl, $MgCl_2$, and $CaCl_2$ are likely present on Mars. Additionally, chemical analysis by the Mars Exploration rover *Opportunity* indicates the presence of Cl and $MgSO_4$. In my experiment, the fine Martian dust is simulated using commercially available "Crusher fines." Two projectile methods were used: the Crater Making Machine and a .22 caliber rifle.

The trials with evaporated salts display similar characteristics to craters on the Martian surface thought to be formed in the presence of sub-surface ice. Observations and photographic data indicate that the presence of powdered salts in the soil accentuates the movement of ejecta as compared to a control sample. Future experimentation is necessary to draw more definite conclusions.

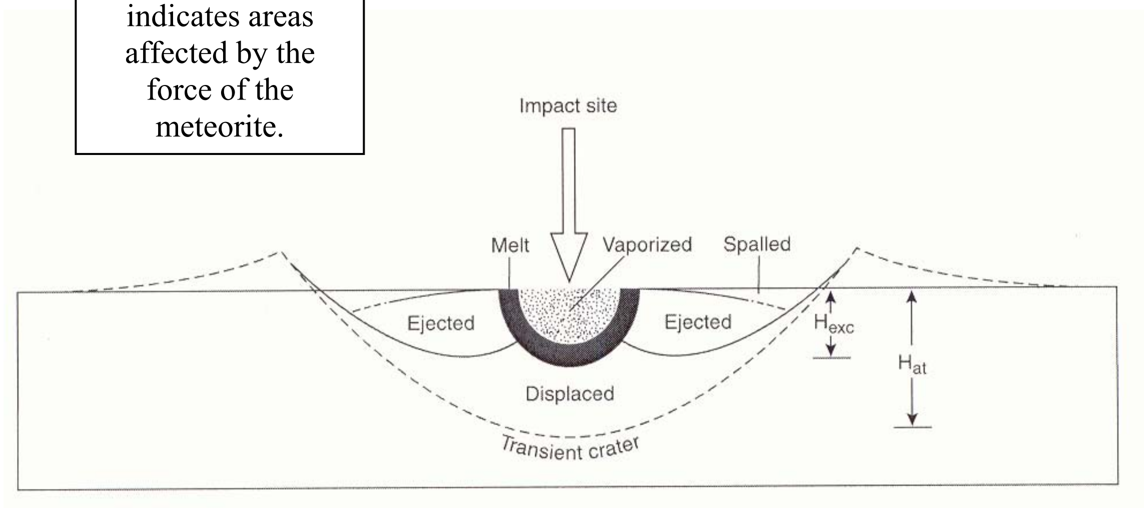
Introduction:

A high-velocity meteor plummets towards the unprotected surface of the earth. If large enough, it will not be slowed significantly or melted by the friction caused by the atmosphere and the projectile will ultimately impact the surface at supersonic velocity. The transfer of momentum from the projectile to the surface beneath it will be dissipated as heat, sound and the evacuation of the surrounding material. The inertia of the projectile will continue downward throwing subsurface material upward and outward disfiguring the surrounding area leaving a hole scarred in the surface –a crater has been formed.

The main difference in the formation of craters occurs from the velocity of projectile impact. Penetration craters occur with low-velocity impacts when projectiles have been relatively slowed by the presence of a thick atmosphere. The projectile penetrates only a short distance into the target. The momentum excavates a pit slightly larger than the projectile itself and the projectile remains intact at the bottom of the crater pit. Contrarily, a hypervelocity impact crater forms when the projectile retains most of its original cosmic velocity >11 km/s.[1] Since the impact velocities exceed the speed of sound the crater is produced by shock waves. As the intense, high pressure stress waves (shock wave) expand they interact with the original ground surface and set large volumes of surrounding rock in motion, which in turn excavates the crater. Immediately following the initial excavation, rock mechanics and gravity determine the final shape and ejecta of the crater.[2]

[1] French, Bevan M. Traces of Catastrophe. . A handbook of Shock-Metamorphic Effects in Terrestrial Meteorite Impact Structures. Houston: Lunar and Planetary Institute, 1998.
[2] French, Bevan M. Traces of Catastrophe. After the initial impact, which is affected by size and velocity of the projectile, the composition of the rock as well as the force holding the rock downward (gravity) will cause the final shape of the crater.

The diagram indicates areas affected by the force of the meteorite.



Since crater formation is affected by the medium in which it is formed, the characteristics observed in craters can be used to deduce the ambient conditions present at the time of formation. Craters act as a storybook into the past as meteorites dig holes and expose layers in the ground revealing the area's geological history. Can the study of craters give us clues about the geological history of Mars and even inform us about the possible existence of significant surface water on our closest planetary neighbor?

Human interest in water is intrinsically linked to the question: "are we alone?" This question permeates human history's study of the cosmos. Evidence of human use of the observations of the night skies date back to at least 2500 B.C. when the Egyptian pyramids erected in Giza were aligned to read the seasons based on the pyramid's shadow and the spacing of the three pyramids mimic the stars of Orion's belt.[4] Human fascination with the universe leads us to question the possibility of life elsewhere. A fundamental part of the study for extraterrestrial life is the search for water; for life as we know it exists only in the presence of liquid water. The most logical search for extra-terrestrial life focuses on our "sister planet"

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[3] French, Bevan M. Traces of Catastrophe. A handbook of Shock-Metamorphic Effects in Terrestrial Meteorite Impact Structures. Diagram utilized from Chapter 3 page 22.
[4] Caidin, Martin and Jay Barbree. Destination Mars. In Art, Myth, and Science. New York: Penguin Studio, 1997. p.17.

Mars. Although we now know that the surface of Mars is cold and dry, was there a time when long standing surface water existed on Mars? Humans, past and present, devote hours and lifetimes towards the observation of Mars. Christiann Huygens, in 1659, observed dark markings on the surface of Mars.[5] In the 1882, Schiaparelli drew up a map of Mars showing "canals" and this view was championed by Percival Lowell as late as 1916.[6] With the belief that intelligent beings built "canals," life was greatly anticipated on Mars.

The possibility of a grand civilization and abundance of water was seriously discussed until Mariner 9, but the images sent back revealed a dusty, barren, dry, and lifeless surface. However, NASA's latest Mars endeavor at "Meridiani [Planum] demonstrate[d] unequivocally that a body of water was once present there for a significant time."[7] The landing site of the second of the twin Mars Exploration Rovers, *Opportunity*, indicates "a bedded sequence of salts"[8] confirmed through chemical analysis of the rocks and soil. Previous theories for water were supported solely by geomorphic evidence from studying images of landforms. *Opportunity* provided the geological and chemical evidence of salts, deposits of blue hematite spherules and cross bedding. Since similar occurrences on Earth are found only in the presence of large, standing bodies of water this allowed scientists to conclude that water also existed on Mars.[9]

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[5] Hartmann, William K. A Traveler's Guide to Mars. The Mysterious Landscapes of the Red Planet. New York: Workman Publishing, 2003. p. 7. The Dutch observer, Huygens, was the first to show recognizable marking on Mars, which included a dark triangle believed to be Syrtis Major and polar ice caps.

[6] Hartmann. A Traveler's Guide to Mars. p. 44. Lowell drew a map containing many symmetrical formations which he named cannels. The leading hypothesis was that the complex system had to be created by intelligent beings. Caidin. Destination Mars. p.83-85. Besides being known for his public popularity and strong adhesion to his beliefs Lowell made Martian studies an acceptable scientific discipline.

[7] Carr, Michael H. "The Proof is in: Ancient Water on Mars."

[8] Carr, Michael, H. "The Proof is in: Ancient Water on Mars."

[9] Carr, Michael H.. "The Proof is in: Ancient Water on Mars." *Opportunity's* landing site, an old dried up lake bed, provided ample proof of water. The spherules are composed of hematite indicating that they were deposited and saturated with water. Narrow, roughly rectangular depressions in the rock are common in evaporates on Earth. Cross-bedding indicates a sequence of sediments through a process of deposition. The waviness of the deposits is a result from ripples, indicating the beds were deposited in water.

Opportunity's chemical analysis, besides establishing the plausibility of long standing water on Mars, also demonstrated the presence of salts in the soil.

A remaining question is how the salts present on Mars came to be in the soil. The Martian surface often endures long lasting dust storms. The salts could have either been weathered off of rock and blown into the top layer of the soil or they could have been deposited by the evaporation of standing bodies of water. Because we cannot view how the salts were deposited on Mars, we observe the effect of different types of deposits on the surrounding geological features. One of the most prominent features on Mars is the abundance of craters. Martian craters look different than those found on the Moon and Mercury due to the different process of ejecta emplacement. It should also be noted that Mars' gravity differs from that of the Earth, Mercury, or the Moon. The final stage of emplacement of ejecta on Mars is thought to be an outward moving debris flow instead of the simple ballistic deposition that occurs on the Moon and Mercury.[10] Therefore, since crater formation involves interaction with the soil, the composition of the soil will affect the final outcome of the crater.

Purpose:

The purpose of this investigation is to distinguish characteristics of craters formed in soil containing blown salts versus evaporated salts. As it may be possible to observe some of these characteristics in actual Martian craters, it will then be possible to infer the means by which salt was deposited on the Martian surface and thus imply whether or not standing surface water was present at some time.

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[10] <http://history.nasa.gov/SP-441/ch7.htm>. Most ejecta on Mars has a pushed outward look rather than a thrown outward appearance that is prominent on the Moon and Mercury. This could be a result of different gravities.

Hypothesis/Rational:

I hypothesize that crater characteristics are affected by the different types of adhesion in the soil. Based on previous observations where marbles and BBs shot into wet and dry sand I noticed that the slightly wet samples caused the sand to "peel." If the sample was too wet the projectile produced no crater effect. Dry soil produced very symmetrical craters that were not as well defined as those that were wet. Was soil adhesion only a physical function of dampness or could there be a chemical function as well? Could salt concentrations have an effect? Or is it a combination of the salts' presence and the means by which it was deposited? The means of salt deposit should affect adhesion. Evaporated salts should form crystals with stronger adhesion forces among sand particles and the resulting craters formed after an impact should closely resemble the wet craters. The samples containing dry, powered salts should be slightly more adhesive than the control sample containing no added salts. Without the evaporation and resulting crystallization, there should be no method to facilitate the creation of strong adhesion forces between the powdered salt and sand so only slight restriction on ejecta should be noticed.

Method:

Choosing a salt:

For my experiment the effects of salt deposition are observed by using three different salts. In choosing a salt, previous chemical analysis data was considered. A chemical analysis of the outcrop in *Opportunity's* landing crater indicates 20-30 percent sulfate and a prominence of chlorine.[11] In addition, a recent study, conducted by Kuzmin R.O. and E.V. Zabaluevaon, on the effects of water soluble salts affecting the phase state of ice containing regolith, asserts that the most probable candidate for salts in the Martian regolith are such salts as $NaCl$, $MgCl_2$, and

[11] Carr, Michael. "The Proof is in: Ancient Water on Mars."

$CaCl_2$.[12] The cations (metals) in the ionic compound suggested in Kuzmin's study are used in my experiment but due to limited availability of $MgCl_2$, $MgSO_4$ is used instead. The use of a sulfate (SO_4^-) and chlorine (Cl) allows the testing of the chemicals confirmed at *Opportunity's* landing site.[13] The final three water-soluble salts chosen were NaCl (table salt), $MgSO_4$ (Epsom salt) and $CaCl_2$. The two application methods were powdered dust and evaporate deposits as salts crystallized out of solution. The salts were powdered in a mortar and pestle and mixed with the upper layer of sand to simulate blown dust. The solution was made using 167 gram of solute (salt) in 500 grams solvent (water) to make a 25 % solution which is near the solubility saturation of NaCl.

Soil preparation:

Seven soil samples were prepared –one control and six salt combinations. For each sample it was also necessary to provide a base of high-density foam in the bottom of the container to limit ricochet occurrences when using the crater formation machine at the Denver Museum of Nature and Science.[14] The fine Martian soil was simulated using "breeze" or

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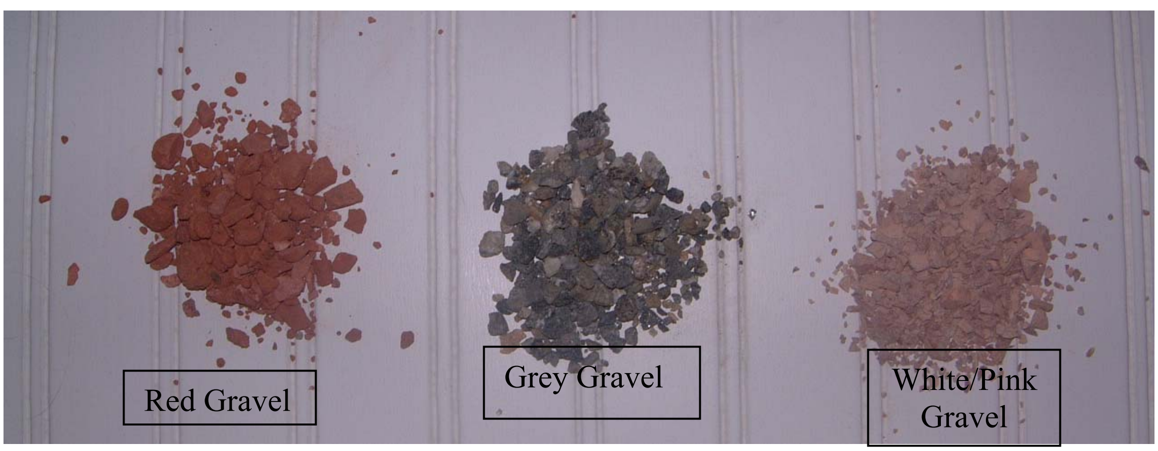
[12] R., Kuzmin O. and E.V. Zabalueva. "Seasonal Salts Could Rub Mars Raw." <http://www.spacedaily.com/news/mars-water-science-00a.html.>
[13] Carr, Micheal. "The Proof is in: Ancient Water on Mars." Chemical analysis of the outcrop in the crater where *Opportunity* landed indicates presence of sulfates and chlorine. These elements and compounds become concentrated in lakes and seas that are undergoing evaporation. Once the water evaporates the evaporate deposits are left behind. The presence of these elements and compounds is also indicative of a past lake bed.
[14] Schoemer, Jodi; Space Odyssey and Planetarium Project Manager at the Denver Museum of Nature and Science. Phone and email interview with Kristyn Rodzinyak.

"crusher fines" soils. Three separate layers of gravel were piled on top of foam –1.5 cm of gray gravel, 1.5 cm white gravel, and 1.3 cm red gravel. The sand layer followed the same color pattern –4.5 cm gray sand, 2 cm white sand and 1.5 cm red sand. In the top layer 167 grams of salt dust was mixed into each of 3 samples. Three additional samples were created by spraying the 25 % solution on evenly and left to evaporate at room temperature in a dry location. The 7th contains no salts. The samples were left to evaporate until completely dry.

Red soil before shifting

Separating the fine dust from the gravel



Red Gravel

Grey Gravel

White/Pink Gravel

Crater Formation:

Crater Simulation Machine:

The Crater Simulation Machine in the Space Odyssey exhibit of the Denver Museum of Nature and Science was used to simulate a heavy impact. The 2.54 cm diameter steel balls were shot, with a pressure of 765.32 kPa (111 psi), using the default position, which was approximately vertical. The pressure and angle of entry remained as constant as possible for all trials.[15] The museum staff figured that 90% of the ejecta would fall within 12.7 cm of the impact site; however, a board surrounds the sample container to collect escaping ejecta material. The height from the bottom of the "launch pipe" to the bottom of the medium is 86.36 cm. The height of the medium ~ 8.89 cm. Videos were taken of the screen displaying images from the high-speed camera (250 frames a second). Along with measurements and observation regarding crater diameter and ejecta characteristics, still photographs were also taken.


.22 caliber long rifle:

The rifle was used to simulate a higher velocity impact. Aguila no gunpowder bullets were used to safely imitate a high velocity impact. Each bullet was shot from a height of 24 cm

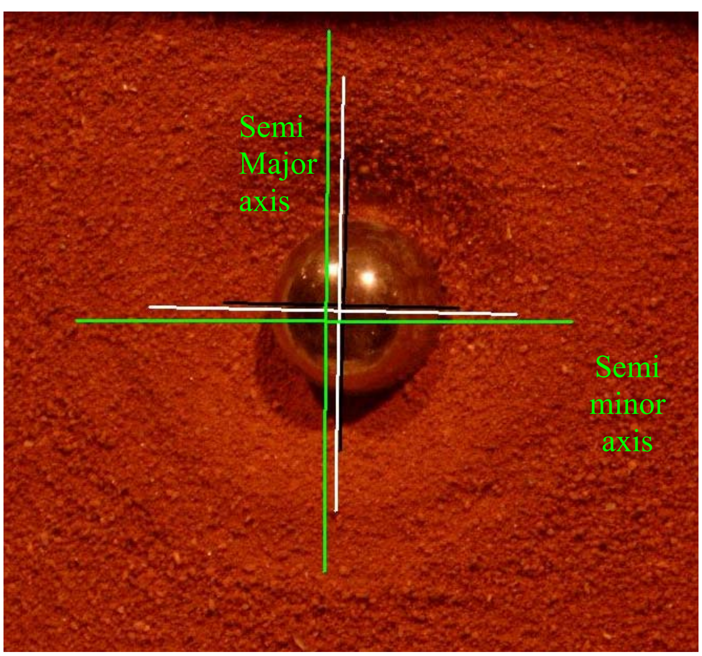
[15] The pressure and angle of entry are kept constant for all trials by leaving the machine in default position.

with a vertical angle of entry. Two tests were completed for each sample. Using the bullet specs the velocity is given to be 114 m/s with a weight of 20 grams.[16]

Analysis:

Evaporated versus powdered salt:

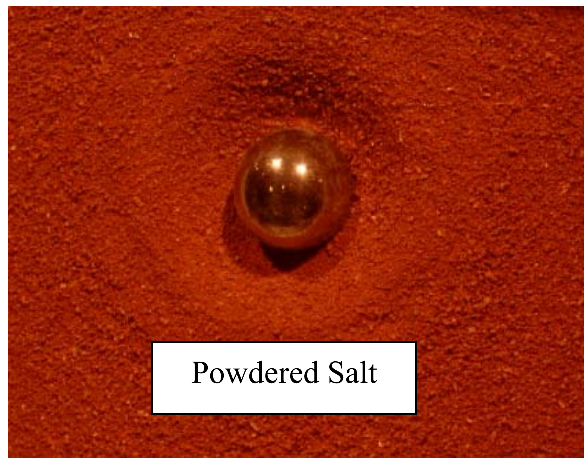
A noticeable difference occurred between trials with evaporated vice powered salts. To begin with, crater diameter is compared between craters. The average crater diameter is found. When a crater was formed in solution the average crater diameter of 3 cm by 3.2 cm was less then the control at 5.3 by 5.0. Contrarily, the powered samples had crater diameters that exceeded that of the control 5.67 cm by 5.67 cm. This demonstrates that the adhesion forces caused by the crystallization of the salts as they were deposited out of solution caused the material to stick together rather than be sprayed out. The powdered salt in the soil seemed to increase the mobility of the soil as it was pushed outward more easily from the initial impact. The increased mobility of the soil due to the powered salt is evident in the more wide spread ejecta.



Legend
Outer shell of the double ejecta
Inner shell of the double ejecta
Crater bed

[16] Aquila Ammunition. .22 Rimfire. <http://www.aguilaammo.com/rimfire.pdf> 28 Nov 2004

The physical appearance of the craters differs based on the application of the salt. Apart from the double ejecta, the powered salt samples closely resembled the control. Each had the evidence of a shock wave from the video data collected immediately following the initial impact. The ejecta spewed in all directions. The crater bed itself was not well defined. Once the projectile was removed there was evidence of filling in. The crater bed itself was difficult to distinguish due to its ill defined nature.

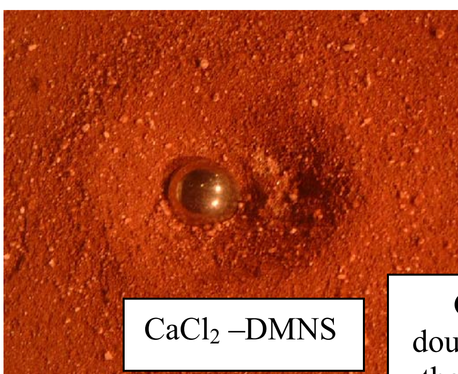


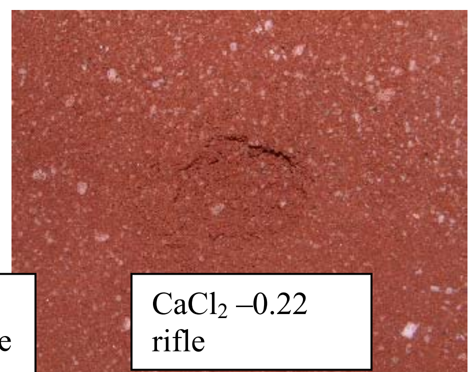
Contrarily, the craters formed from the samples containing evaporated salts showed evidence of cracking and peeling. These craters had well defined crater beds. The walls were tightly packed and there was no filling in. The ejecta was pushed up and held solid. The force of the impact affected the surrounding area by creating cracks. Evidence of crystallization was found because rather than eject pieces of dust, large chunks were thrown. Also on the underside of the $MgSO_4$ "boulder" ejecta small white crystals were observed extending perpendicularly out from the boulder. It is reasonable to deduce that strong adhesion forces, facilitated by the formation of crystals as water evaporated, caused the soil to stick together even with impact. Whereas, the powdered salt seems to disrupt the adhesion forces as it separates the molecules of sand causing it to be thrown and displaced with greater ease.

Additionally, the evaporated salt samples demonstrated similar characteristics to those observed when the soil was wet. The elliptical crater defined by an ejecta ring was observed with the powdered salt but not with evaporated salts. The evaporated salt trials demonstrated cracking, uplifted material and overturned surface material. Whereas the powdered salt trials showed very symmetrical characteristics with no unequally disturbed surface area. The observed surface material was pushed observably equally in all directions.

Powered salts comparison:

Two of the craters formed in the powered solution formed prominent double ejecta. The control had only a light double ejecta that was separated by several mm. Interestingly, the trial using $CaCl_2$ did not form a double ejecta in any of the trials. Although NaCl and $CaCl_2$ possessed the same anion, Cl^-; $MgSO_4$ and NaCl behaved more similarly with regards to ejecta. This seems to demonstrate that the physical properties of the salt and the geometry affect the resulting crater more than the chemical composition of the molecule.



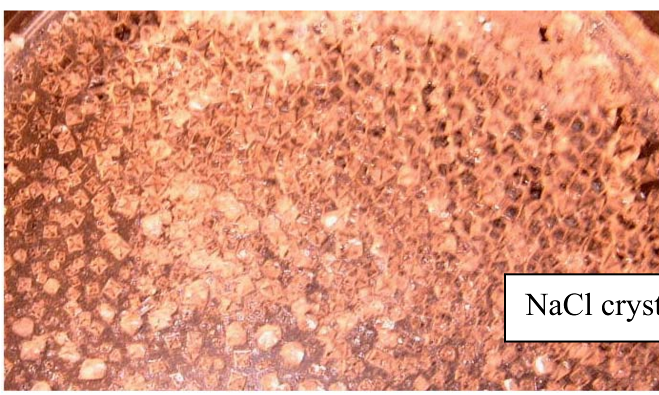


Craters with double ejecta were the control, NaCl and $MgSO_4$. $CaCl_2$ did not produce a double ejecta.

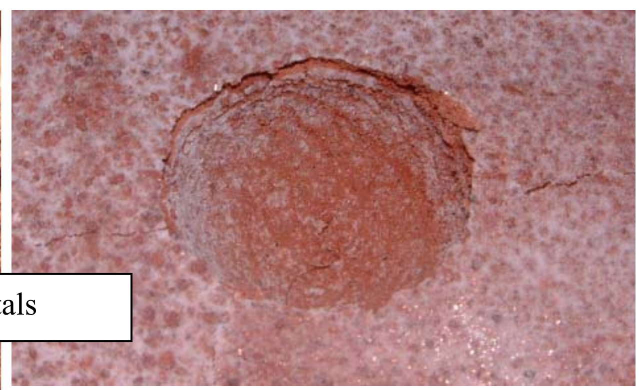
$CaCl_2$ is hygroscopic and even in the dry Colorado air could absorb water out of the air. This property caused the powered salt in the soil to form into clumps. These thicker particles restricted the movement of the surface material resulting in a single ejecta ring and a smaller average ejecta distance. The measured control displaced material out to 87.8 cm , NaCl had an average ejecta distance of 91.7[17], and $MgSO_4$ displayed an average ejecta displacement of 92.6 cm. Compared this to $CaCl_2$, which only had an ejecta displacement average of 63 cm. A similar trend is observed in the ejecta diameter. The general trend was that NaCl and $MgSO_4$ had greater movement of surface material than the control while $CaCl_2$ had the least surface material movement. In $CaCl_2$ there was a larger concentration of water. Thus, if water was present in the soil the resulting crystallization caused greater adhesion forces restricting ejecta movement.

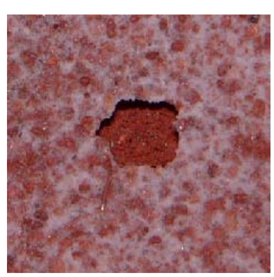
Comparing crystal geometry to crater characteristics:

In petri dishes a sample of each of the salts is dissolved in water and left to evaporate. The resulting crystals formed are compared to the crater formed.



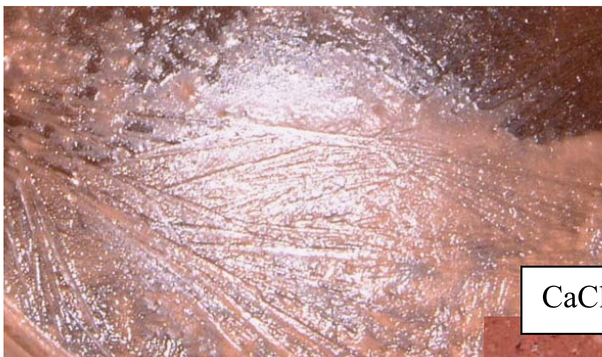
NaCl crystals





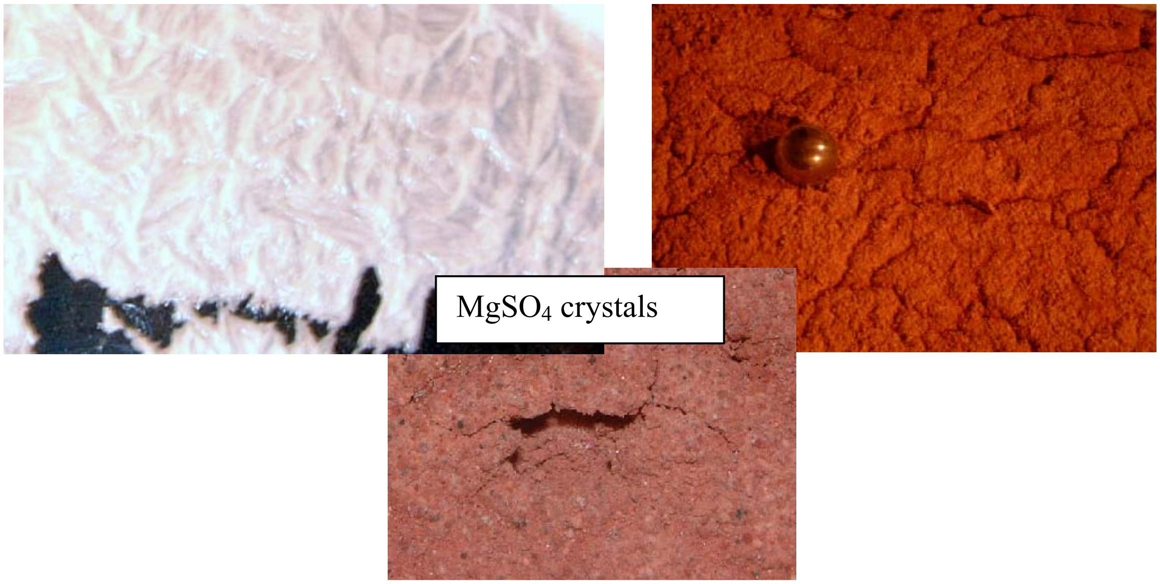
[17] The measurement of 52 cm was deemed an outlier and was excluded from average calculations.

The NaCl crystals are small and square. There is also space between each crystal. The crater formed in the trial using NaCl evaporated salts reflects the characteristics of the salt crystals. Space between the crystals allowed the soil to compress upon impact, resulting in well defined crater walls and a relatively uninterrupted surface surrounding the crater. The lip that was upturned in the upper right corner is very rectangular in shape reflecting the general geometry of the NaCl crystals.



$CaCl_2$ crystals

The $CaCl_2$ crystals demonstrate a long, narrow, interlocking crystal. The resulting crater is influenced by the long and interlocking nature of the crystals. Rather than having the room to be compressed, upon impact the surface is disrupted causing a circular uplifted area surrounding the impact site. This uplift may be a result of the connected crystals. The crystal formation also appeared very shallow; thus, upon impact the top layer was easily disrupted resulting in the peeling and upturning of large chunks of the immediate surface. The $CaCl_2$ craters were the only craters that exhibited peeling. This peeling can be attributed to the long shape of the crystals – rather then completely breaking the crystals are bent backwards.



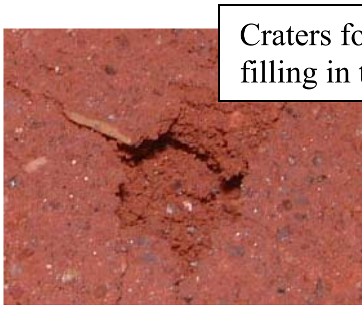
The contours of the soil surface of the sample reflect that of the pure crystal. The ridges present in the pure crystals are accentuated in the soil. In addition, the crystal depth is much greater than the other two. In the crater this increased depth results in very little impact distance. The crystals in the soil must have also formed in greater depth extending the overlapping, interconnecting crystal structure to greater depth within the soil. Several chunks were ejected but they were not as square as those found in $CaCl_2$. This difference in geometry is reflected in the formation of the crystals. The crystals of $CaCl_2$ follow a very linear path whereas the $MgSO_4$ crystals appear more random. The shape of the crater formed by the rifle also reflects the distinct crystal pattern.

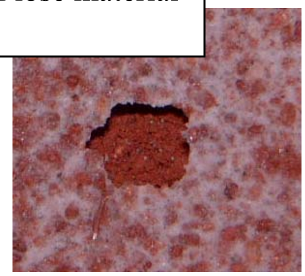
Although the similarities between crystal geometry and crater characteristics may be merely coincidental it is possible that the adhesion properties produced a matrix in the soil and when fractured the pieces retained the crystal form.

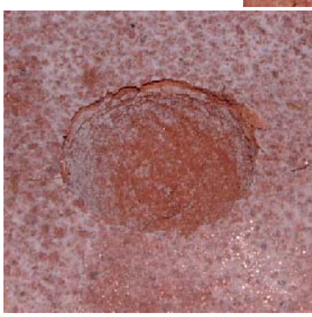
Crater Simulation Machine versus .22 caliber long rifle:

The characteristics observed with the Denver Museum Crater Simulation Machine and the rifle were very similar.

Craters formed with the .22 –evidence of lose material filling in the crater bed floor.



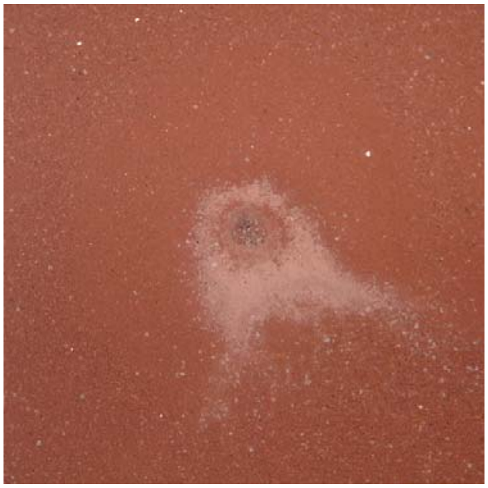




Crater formed at the Denver Museum –no evidence of filling in after the projectile has been removed.

The main observed difference was the occurrence of filling in on the evaporated samples. With the craters formed at the museum, the crater beds were well defined for the evaporated salt craters. On the other hand, the craters formed with the rifle appear as if the bullet exploded upon impact beneath the surface causing the soil to be ejected. However, the hard surface restricted the soil from being ejected so the soil fell back into the hole. The increased movement of subsurface material may have been inadvertently caused by transportation of the samples to and from the museum, which may have resulted in the breakage of a quantity of crystals, decreasing the amount of adhesion forces keeping them together. The higher velocity of the .22 shell resulted in deeper craters as shown by the increase in different colored material from the different depth of the soil sample.

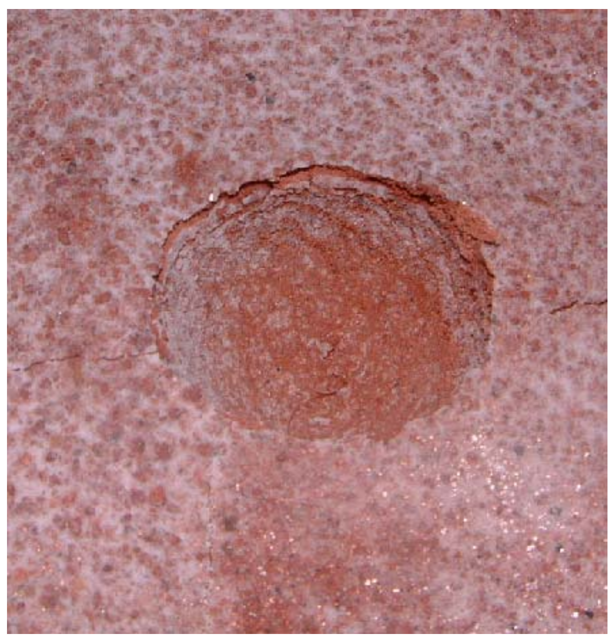
The powered salt craters also demonstrated an indent in the side of the ejecta ring. Part of the ejecta ring looked to be depressed from the surrounding ground area. This could be a result of the line of entry of the projectile not being exactly vertical.



The lower right ejecta area surrounded by the wings of white ejecta is depressed from the surrounding area. This lower elevation could be caused by the increased shock of impact resulting from the higher velocity projectile.

Applying Observed Characteristics to Real Martian Craters:

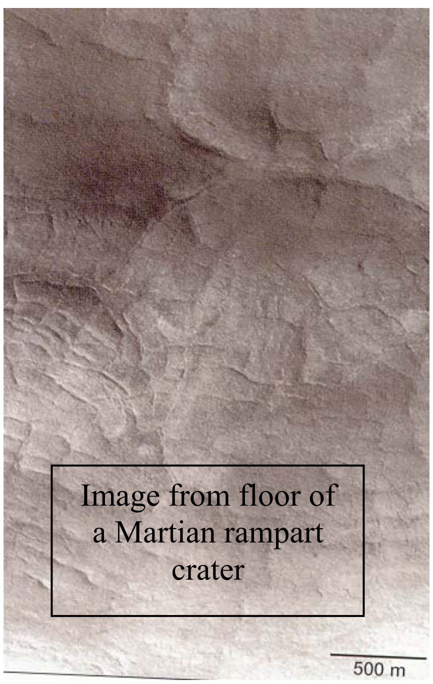
[18]



The M03-01141 crater on Mars has some distinct properties. On the southern portion of the rim the crater retains the original sharp-crested rim. However, the north side exhibits the phenomenon deemed by scientists to be "terrain softening" which is characterized by wearing

[18] Hartmann, William A Traveler's Guide to Mars. Image page 106

away the rim to result in a smoother, rounder rim. It is theorized that these were formed in ice-rich soil as topographic features can "relax" into softened forms if formed in icy soil. Deep craters penetrating the ice layer tend to retain their form but if the ice-rich material is piled on top of the surface as ejecta, it will tend to flatten. Thus the presence of sub-surface ice explains the "terrain softening" phenomena; however, the southern ridge closely resembles the characteristics observed in the presence of evaporated NaCl crystals.[19] The presence of evaporated salts causes similar characteristics to those resulting from sub-surface ice. It is inconclusive as to which (if not both) factors are causing the observed phenomena. The experimental data from the evaporated NaCl trial supports the argument that it is a result of evaporated salts.



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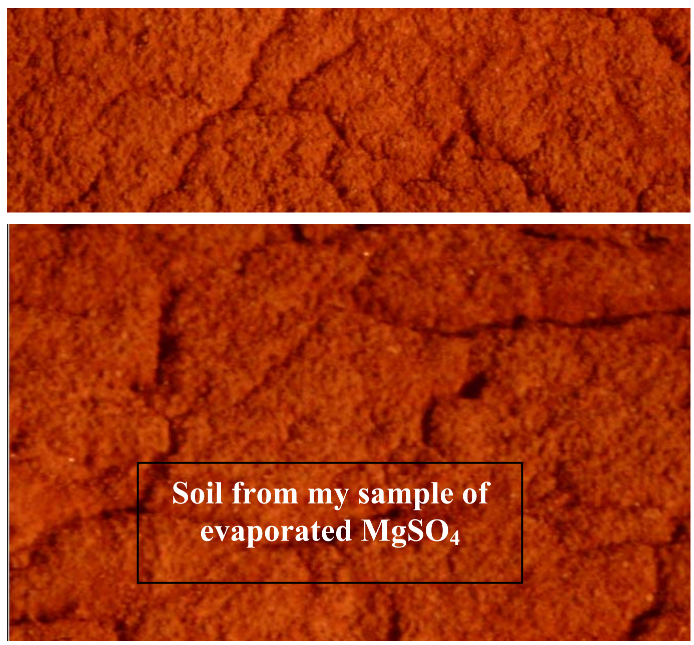

This section taken from the floor of a rampart crater found in the northern planes of Mars supports the theory that rampart ejecta is formed in water. These features are similar to those caused by underground ice in Earth's artic region. It is theorized that water ponded in the crater

[19] Hartmann, William. A Traveler's Guide to Mars. "Ground Ice Deposits: Key to terrain Softening" page 112

[20] Hartmann, William. A Traveler's Guide to Mars. "Rampart craters and Patterned Ground" page 141. Water is one of the few substances that expands when it freezes. In the artic tundra during the daily or seasonal freeze cycles the expansion lifts the ice-soil mixture causing faint patterns of ridges and grooves on the surface. The Martian regolith is hypothesized to be tundra-like and should demonstrate similar behaviours as observed in the artic tundra.

floor and soaked into the ground forming underground ice deposits. However, based on characteristics observed during my experiment the ridges and groves present in the Martian regolith could be caused from evaporated salts rather than the expansion of ice.

Conclusion/ Evaluation:

The experimental results obtained suggest that it is possible to distinguish characteristics of craters formed in soil containing blown salts versus evaporated salts. Further, it is also possible to apply these characteristics to actual Martian craters. Geological phenomena found in crater variance across Mars, generally attributed to sub-surface ice, could actually be a result of evaporated salts in the soil. The observed experimental characteristics from the evaporated salt trials had a strong resemblance to characteristics found in certain craters found on Mars. However, it is important to note that to allow the salts to evaporate, water would have had to be present at some time in Martian history. Future research comparing evaporated salts to sub-surface ice is needed to determine whether these similarities are due to the factors tested here or to sub-surface ice.

Crater formation in the experimental trials were more affected by the application method than by the salt sample used. The force of impact of a true meteorite was not duplicated under my experimental conditions so it must be understood that my crater experiment is on a much smaller scale then actual craters are formed and additional forces would come into play for impacts at supersonic speeds.

A significant difference was observed in the powdered salt samples versus the evaporated salt samples. The powdered salt samples demonstrated similar characteristics to the control containing no salts. The craters were circular to slightly oblique and often demonstrated a double ring of ejecta. These craters were very similar to the "traditional" craters generally viewed on Mars, the Moon or other interplanetary objects. Conversely, the evaporated salts did not have a basic circular ejecta that had been pushed out of the crater. Rather chunks were ejected and material was upturned and peeled from the site of impact. The craters formed in trials with evaporated salts were also better defined and did not fill in. Another measure of their persistence (and possibly their resistance to erosion) was demonstrated by the fact that they remained intact even after being transported.

The difference in salts used in the powdered solutions also had an effect on the crater formations – although to a lesser extent. For NaCl and $MgSO_4$ the presence of the salt in the soil affected the mobility of the ejecta. I argue that this increased mobility may be attributed to the fact that the salt was thoroughly mixed and evenly distributed throughout the top layer. However, during preparation, to simulate the fine Martian dust, all the sands were shifted so the additional stirring of the soil to mix the sand should not have had a great affect on ejecta mobility. Contrarily, the nature of $CaCl_2$ caused the salt to absorb water out of the atmosphere resulting in clumping of the sand. This increase in the concentration of water restricted the movement of the surface material upon impact.

In the experimental trials using evaporated salt crystals the soil characteristics; depth of projectile infiltration; and the shape of ejecta and crater; reflected the geometry of the pure crystals. The square, individual crystals of NaCl resulted in soil compression upon impact; rectangular uplift in the lip of the crater; and square indents in the crater rim lip. The long, interlocking crystals of $CaCl_2$ were imitated in the peeling of surrounding surface material and the circular uplifted sections surrounding the site of impact. Thirdly the thick, irregular crystals of $MgSO_4$ were mirrored by the shallow depth of infiltration and the oblong irregular ejected chunk for the Denver Museum Crater Machine and the oblong irregular crater bed with the .22.

The experimental craters remained true to previously observed characteristics for both the metal ball from the Crater Machine and the bullet from the .22. When the bullet was used there was an increase in the movement of ejected material. I expect this increase in ejected material was due to the increased velocity, and consequently the energy, of the impact. It is possible that the vibrational force from driving the samples to and from the museum could have broken some of the crystals up from their original form. The reduced amount of crystals would have decreased the adhesion forces restricting the movement of the subsurface material into ejecta.

In order to improve upon the experiment it would be beneficial to create multiple sample batches rather then using the same soil sample for each trial. This would decrease the breaking of crystals caused by transportation. A larger projectile from the crater machine was used to simulate the size of the meteorite while a bullet was used to simulate the high velocity of a meteorite. However, for more realism projectiles traveling at supersonic speeds would more closely replicate meteorite impacts.

For a future experiment it would be interesting to vary salt concentration as the control variable and see if the concentration affects crater formation. Other salts present in the Martian regolith should be tested and compared in order to expand the comparison of characteristics between experimental craters and real planetary craters. Additionally, the similarities observed in evaporated salt trials and sub-surface ice needs to be further tested to draw more definite conclusions.

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