

SALT – A CRITICAL MATERIAL TO CONSIDER WHEN EXPLORING THE SOLAR SYSTEM.

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Introduction: Salts, including sulfates, halides and (bi)carbonates, are likely a component of planetary bodies. For example, salts are found in meteorite falls [e.g., 1]; salts coat lunar glass spheres [2], salts are abundant on Mars as cements, veins and coatings and occur in Martian meteorites [e.g., 3]; and infrared (IR) spectroscopy shows salts on some asteroids [4], the moons of Jupiter [5-6], and Enceladus [7].

It is important to recognize and identify extraterrestrial salts in both meteorites and planetary bodies for several reasons. First, salts may increase the cohesion and reduce the density of planetary bodies, allowing them to survive impact events and impeding dust levitation. Second, salts may provide a record of leaching and aqueous processes on other planetary bodies related to their surface history [3] and, for Mars, past climate. Third, salts may influence our choices of targets in the search for life beyond Earth [8].

Despite the importance of salts, many are difficult to detect unequivocally with our current techniques, both in the laboratory and remotely. Laboratory identification of salt suffers from the fact that salt may vaporize during transit through the atmosphere (e.g., Na, Mg, Ca and Fe emission in meteor light trails [9]) and many salts are easily remobilized [e.g., sulfates; 3], change phase as a function of relative humidity and temperature [10], and may not be stable during analysis. Remote techniques like rover-based instruments (e.g., Mars Exploration Rover spectrometers) may provide insight into salt identity, but give limited information on very light element contents and specific crystallography. The other major remote technique uses visible to thermal (mid-) IR spectroscopy; previous work shows that sulfate cements affect IR spectra [11].

Here, we examine the effect of IR-transmissive salt (halides) on reflectance thermal IR (R-TIR) spectra. Addition of halides changes R-TIR spectra [12] and may affect interpretations of asteroid spectra [13]. Also, newer TIR instrumentation (e.g., Kuiper Airborne Observatory, Spitzer, and SpeX telescopes) make it an opportune time to closely examine lab TIR spectra.

Methods: To simulate the effects of nominally IR-transmissive salt (or void space) on R-TIR spectra we prepared salt:enstatite and salt:meteorite mixtures using KBr (similar to NaCl). We call the samples mixtures because they were not pressed (cemented). We chose to examine enstatite to better understand the result of salt dilution on E-chondrites [12]. Also, we examined a

suite of ground ordinary chondrites [Table, from 14] from a range of H, L and LL meteorite classes, petrographic grades, shock levels, and olivine / (olivine + orthopyroxene) values [from XRD in 15]. Shock effects on the TIR spectra are likely indistinguishable from annealing effects [12]. We analyzed falls (mostly) to minimize weathering effects. We attempted to retain metal and sulfides during grinding, although they mainly contribute a 'red slope' in the TIR.

Minerals or rocks were ground to <30 µm to be representative of regolith. Powders were weighed and ground with dried KBr. Enstatite:KBr mixtures were made with salt contents of 0%, 24.7%, 43.0%, 51.1%, 90.0%, 95.1%, and 97.7%. Ordinary chondrite:KBr mixtures were made with salt contents of 0%, ~17%, ~46% and ~97.6%. Lower salt contents may mimic those found on other planetary bodies, while higher contents may mimic evaporite deposits, or salty, dirty oceans or surfaces on the moons of Jupiter and Saturn.

Class	Sample	ol/(ol+opx)#	Shock	Fall/Find
H3	Dhajala	0.778	S1	Fall
H4	Kabo	0.529	?	Fall
H6	Chiang Khan	0.581	?	Fall
L3	Mesö-Madaras	0.738	S3	Fall
L4	Rio Negro	0.625	?	Fall
L6	Kyushu	0.683	?	Fall
LL3	Bishunpur	0.591	S2	Fall
LL4	Greenwell Springs	0.697	?	Find*
LL6	Saint-Séverin	0.718	S2	Fall
LL6	Bandong	0.730	<S3	Fall

* meteorite found within a week of the fall. # from [15]

R-TIR analyses were done at UNM using a Pike Auto-Diff biconical reflectance attachment on a Nicolet Nexus 670 spectrometer with a Global source, KBr beam splitter and DTGS detector (spectra are similar to RELAB [12]). Samples were purged with dry air for >2 hrs before analysis and a polished Al disc was used to collect the background. Spectra were collected for 500 scans, at 4 cm⁻¹ resolution over ~1.8-25 µm.

Results: *Enstatite.* As salt is added to enstatite, the spectra become progressively less reflective and more transmissive (Fig. 1). With increasing salt, the ~8.5 µm principle Christensen feature is diminished, the spectral contrast of the reststrahlen bands increases, and the spectra show stronger transmission features. At enstatite:salt ~ 50:50, there appears to be a transition between dominantly reflective and transmissive spectra.

Ordinary chondrites. Within each chondrite group, the R-TIR spectra are generally muted as ol/(ol+opx) increases (left side of Fig. 2), except for Bishnupur. However, these are subtle effects compared to adding salt (or increasing transmissivity). Addition of salt results in similar changes to the addition of salt to the enstatite: the reststrahlen band decreases and the spectra become more transmission-like (right side, Fig. 2).

Discussion: Our results indicate that salt can have a significant effect on R-TIR spectra. Specifically, salt changes the ratio of surface scattering (where photons are scattered from surfaces of particles) relative to volume scattering (where photons travel through the interior of particles and are scattered back out). These changes mimic changes observed in reflectance and emission spectra with decreasing grain size [e.g., 16-17]. Our results may be used to model the effect of adding salt (or void space) or to simulate decreasing grain size. These spectra may be helpful when modeling very fine-grained regolith surfaces [13], evaporite deposits, or salty, dirty (icy) oceans or surfaces.

Interestingly, if salts coat surfaces rather than is mixed with them, the resulting spectral features differ because coatings obscure the substrate [Fig. 3B, 18]. Continuous coatings produce R-TIR spectra typical of thin coatings with some interference fringing [18]. Discontinuous coatings cause the R-TIR signal to decrease as a function of coating thickness [18].

For the Tagish Lake meteorite, with high C content, undiluted samples produced noisy R-TIR spectra, whereas KBr-diluted samples produce smoother spectra, without noticeable transmissive features [19]. Therefore, dark meteorite:salt mixes need further study.

Conclusions: Salts are likely important materials in the solar system. Models for the physical and chemical properties of planetary bodies need to account for salts. IR-transmissive salts significantly affect R-TIR spectra.

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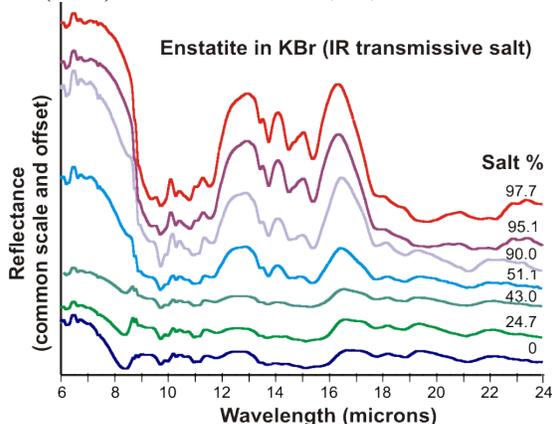


Fig. 1: R-TIR spectra of enstatite mineral-KBr mixes.

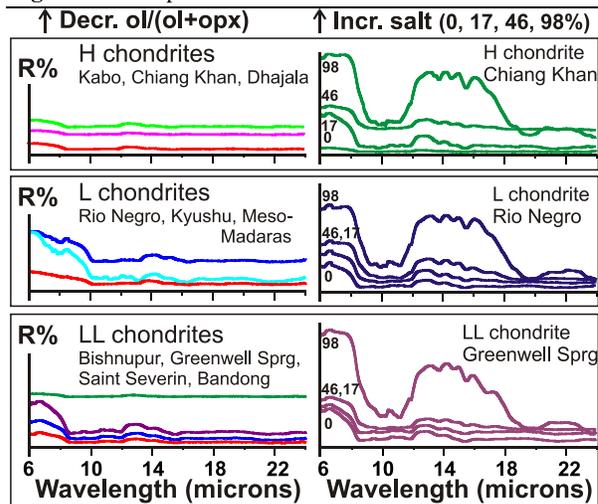


Fig. 2: R-TIR spectra. Left column shows the effects of decreasing ol/(ol+opx) in non-diluted ordinary chondrites (labeled top to bottom). Right column (same scale as left) shows the effect of adding salt to a single ordinary chondrite.

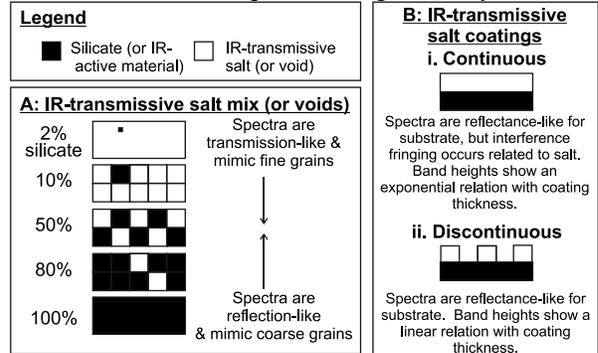


Fig. 3: A: schematic model for the effect of IR transmissive salt (or voids) on R-TIR spectra. B: Models for the effects of salt coatings on R-TIR spectra [18].