SPECTRAL PROPERITES OF SELECTED DOMINANT SALT CRUSTS

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ABSTRACT

The presence of salt crusts can provide information on soil salinization. Spectroscopy and remote sensing of salt crusts are useful for assessing the distribution of salt crusts in barren landscapes of arid regions as well as to evaporite accumulation in playa basins. The study reported here was conducted for examining spectral reflectance of gypsum, halite, calcium carbonate and sodium bicarbonate and their mixtures. Spectral reflectance was measured with a GER 3700 spectroradiometer in the visible and near infrared region (400-2500 nm), and was compared with the USGS and NASA spectral libraries. Spectral analyses have shown that the studied samples have diagnostic absorption features between 1000 to 2500 nm which are consistent with the reported values in the libraries. The positions of the absorption bands were not affected significantly by the size of gypsum and halite particles or with their quantities per unit area. However, reflectivites increased with reducing particle sizes or with increasing the weight fraction of evaporite present. The reflectivity of evaporite was related to the mixing ratios in a non-linear fashion. At certain mixing ratios, the spectral reflectance data from evaporites were similar to those of the endmembers. However, the halite spectral pattern eclipses the spectral features of the gypsum in a nonlinear fashion when the mass fraction of gypsum is reduced to about 75 % in mixed salt. It is interpreted that this is due to coating of gypsum with halite crystals. The reflectivity of the mixed calcium carbonate and sodium bicarbonate decrease by increasing the sodium bicarbonate fraction, due to the coating of calcium carbonate by sodium bicarbonate. The data of this study point to a possibility that the presence of gypsum, halite, calcium carbonate, sodium bicarbonate, and their mixtures in salt crusts can be assessed quantitatively by examining the position and intensity of the absorption features. The presence of soil particles may affect these results, and this subject is currently being evaluated.

1. INTRODUCTION:

Man relies on agriculture for most of his sustenance. The rapidly increasing population of the world is putting increased demand and stress on agricultural regions. Irrigation in arid and semi-arid agricultural regions results in saline soils. Salts of different composition precipitate on soil particles during evaporation of surface and near surface water, resulting in crusts, or efflorescences of usually white and transparent salts. The consistent identification and accurate mapping of these crusts have been a problem. Agricultural scientists and engineers have attempted to solve this problem by a variety of methods such as electrical resistivity, electromagnetic, and other methods. The present work will test groundbased multispectral techniques, which is a relatively new method that may have great promise in mapping salt crusts and salt affected soils. This paper is the first report of comprehensive studies of the spectral behavior of the common salts found in arid soils.

Presently there is no clear understanding of the spectral responses of the physicochemical properties of the land surface salinity, due to the complexity of the problem (Csillag, 1993). Hence, the problem must be broken down into simpler parts and analyzed. Gypsum, halite, calcium carbonate, sodium sulphate and their mixtures are very common in the soil solutions of arid and semi-arid regions (El Ashry, et al. 1985; Ghassemi et al., 1995; Tanji, 1996). In the act of breaking the problem down, this study will deal with the spectral characteristics of only halite, gypsum, calcium

carbonate, sodium bicarbonate, and their mixtures. Grain size, weight fraction, type of mixing, and mixing ratios are the variables of major concern to this study. These variables are interlinked in a complex manner and this study will test their spectral impacts. In the present study laboratory experiments under controlled conditions were used to isolate the variables that affect the spectral responses of the surface soil salinity. The purpose is to relate reflectance spectroscopy to the chemical and physical properties of gypsum, halite, calcium carbonate, sodium bicarbonate and their mixtures, as dominant salt crusts.

This study has evolved from a series of different mental steps to understand and predict real time physico-chemical processes of salinity build up. In the first attempt satellite based multispectral mapping has been evaluated to directly investigate the salt crusts in the field, however the pixel spatial and spectral resolution were major problems that faced this effort. The second attempt was based on satellite images and focused on the indirect investigations of the salt crusts based on the physiological and morphological responses of the vegetation cover to salinity. The difficulties of the field differentiation between the responses of the vegetation cover to salinity and to other environmental factors such as light, humidity, temperature, aeration, and temporal variations were the major limitations of this line of thought. These efforts led this study to consider the reflectance spectroscopy.

The advantages of reflectance spectroscopy (Hunt and Salisbury, 1970; Hunt, 1982; Crowley, 1991; Csillage, 1993; Drake, 1995; Clark, 1999) make it a quantitative and potentially real time method to directly link the spectral observations and the physico-chemical characteristics of the salt crusts. Establishing such linkages requires a basic understanding of 1) the geochemical processes that control the surface salinity build up (Carter, 1975; Poljakoff and Gale, 1975; El Ashry, et al. 1985; Ghassemi et al., 1995; Tanji, 1996), 2) the scattering, and absorption of the electromagnetic energy from different pure and mixed salts. It is the vibrational processes that are important for investigating salts and evaporate minerals. Vibrational absorption features are caused by streching and bending of bonds between anion groups of the molecular species such as water, sulphate, carbonate, and other anion groups (Hunt and Salisbury, 1970; Hunt, 1982; Crowley, 1991; Csilllage, 1993; Drake, 1995; Clark, 1999). Many of the spectral features of evaporate minerals can be explained by vibrational absorption due to water molecules chemically bound as a part of the chemical structure, or adsorbed on these minerals, as well as to the vibrational features of sulphate and carbonate (Crowley, 1991). Gupta, 1991, stated that the vibrational spectral features could be distinguished as fundamentals, overtones, and combinations. The fundamental tones occur in the middle-infrared region (> 3500 nm) and combinations and overtones in short wave infrared (SWIR) region (1000-3000 nm).

The outcome from this study will test and demonstrate the potential application of multispectral data in mapping and detecting gypsum, halite, and their mixtures. In the future and combined with other data, this may lead to the delineation of areas where progressive salinization occurs, and can be used to assess the effectiveness of mitigation measures. In the future this study will also be expanded to include other evaporite mineralogies. This study will provide foundations to better map and quantify this problem on a large scale. On the other hand crusts of gypsum, halite, calcium carbonate, sodium bicarbonate and their mixtures in agricultural and adjacent riparian areas of river systems are a global problem (Ghassemi et al., 1995). The results from this study could lead to better understanding, and better methods for prediction of the problem based on cost effective ground and airborne based spectroscopic data.

2. STATEMENT OF THE PROBLEM:

Gypsum, halite, sodium bicarbonate and calcium carbonate are dominant salt crusts in the arid and semi-arid regions (Carter, 1975; Tanji, 1993). The excess of some of theses salts especially gypsum and halite in the soil has significant adverse impacts, restricting soil use for both agricultural and engineering purposes (Ghassemi et al., 1995). In most agricultural areas, the result of the salinity build up is the covering of soil surfaces with an efflorescent crust. Consistent identification and accurate mapping of this crust over an area is difficult to achieve and has been a problem. Remote spectroscopy is the recommended method for this mapping (Csillage, 1993; Clark, 1999; Ben Dore et al., 1999). The utility of remote spectroscopy techniques for discriminating among the salts is based on the potential differences that exist among their spectral properties (Hunt et al., 1971; Hunt, 1982; Csillage, 1993; Clark, 1999).

On the other hand, in order to use remote sensing in the study of gypsum and halite, it is necessary to determine and demonstrate in advance that these salts can be distinguishable from each other and remotely identified (Crowley, 1991; Csillage, 1993; Drake, 1995). Thus, it is vital to understand better the fundamental concepts behind the spectral detection capabilities of gypsum, halite, calcium carbonate, sodium bicarbonate and their mixtures. That is, what are the controlling factors and the characteristics of the optimum bands for detection. In this study a laboratory-based approach has been used to increase the understanding of the fundamental concepts of the spectral detection of the mentioned salts.

3. PREVIOUS LITERATURE:

During the last two decades several studies have employed remote sensing data to identify or monitor various conditions of salts and surface salinity status of soils, including the study of gypsum, halite, calcium carbonate, and sodium bicarbonate (Tuller, 1987; Price, 1990; Mougenot, et al., 1993; Csillage et al., 1993, Verma, 1994; Drake, 1994; Metternicht and Zinck, 1997; Dwiviedi and Sreenivas, 1998). The results have demonstrated the value of spectral techniques in efflorescences and evaporite deposit studies. However most studies and others have used digital image interpretation, image transformation and other image processing techniques in order to map the salt occurrences. Tuller (1987) reviewed the application of field remote sensing in arid land studies, and he stated that it is evident that there is need for additional careful scientific research into field remote sensing methodologies and land spectral signatures before the potential can be realized. Price (1990) concluded that four broad band spectral measurements at 930-1130 nm, 2030-2310 nm, 630-740 nm and 1600-1800 nm are sufficient to describe more than 90 % of the spectral variability of the soil spectra. Mougenot and Pouget (1993) concluded that bands in the middle infrared region of the electromagnetic spectrum provide information on the differences of the salt content. Csillage et al., (1993) studied the reflectance spectra of salt affected soil samples collected from California and Hungary. The study identified key spectral ranges for detecting the salts in the visible (550-770 nm), near infrared (900-1030 nm, and 1270-1570 nm) and the middle infrared (1940-2150 nm, 2150-230 nm, and 2330-2400 nm) portion of the spectrum. Drake (1995) reviewed the applications of spectroscopy in evaporate deposits. Verma et al. (1994) used satellite based remote sensing data for mapping salt affected soils; the study found that the dull white tone of salt affected soils have posed a problem in the discrimination. The study of Metternicht and Zinck, 1997 suggested the need for further research to isolate and determine sensitive spectral curves to surface salinity status. Numerous other researchers have shown in general that spectral matching techniques applied to image spectroscopy data can be used to identify minerals (Hunt and Salisbury, 1970; Hunt et al., 1971; Hunt, 1982; Clark, et al, 1991; Csillage, 1993; Metternicht, 1997). These published studies have not used laboratory-controlled conditions to study both the salt crusts and evaporite deposits in conjunction with multispectral examination, except Drake (1995). Drake used laboratory-based approach to show the effect of evaporite dehydration on the spectral responses. Several spectral catalogues are present on the World Wide Web (Salisbury, 1991; Vincent 1997; Clark, 1999) and growing volumes of studies are related to the problem at hand. Review of this literature reveals that currently there is no comprehensive spectral guide or integrated information of the spectral behavior of gypsum, halite calcium carbonate, sodium bicarbonate and their mixtures that can be used in remote sensing applications.

4. METHODOLOGY:

Laboratory experiments under controlled conditions have been carried out in order to prepare crusts of pure gypsum, halite calcium carbonate, sodium bicarbonate and their mixtures. Analytical grade compounds of NaCl (halite), and $CaSO_4$. $2H_2O$ (gypsum), $CaCO_3$ (calcium carbonate), and $NaHCO_3$ (sodium bicarbonate) were used in this study. These salts have been selected because they are very common problems in the soil solutions of arid and semi-arid regions (Carter, 1975; El-Ashry, 1985; Ghasemi et al., 1995; Tanji, 1996). The variable of major concern is the weight fraction or mixing ratios of the mixed salts. In developing the procedure to test the spectral effect of this variable, different masses of salts, different grain sizes as well as different mixing ratios were prepared and studied. In these experiments the salts were dissolved in sterilized distilled water (DI H_2O) in different weight fractions (10, 20, 30 and 40 grams) according to the following steps:

4.1 The salts were dissolved in water in 1000-ml volumetric flasks;
4.2 Total quantity of 200 ml of each solution were removed and placed in glass Petri dishes;
4.3 The water was removed from the Petri dishes by evaporation at 40 C^o in an electric oven for 12 hours, then the samples were removed from the oven;
4.4. Immediately following the removal from the oven, the samples were placed in a desicator, after which the reflectance readings were made;
4.5 A GER 3700 spectroradiometer was used to obtain the reflectance readings, replicate of the samples and the measurements were considered.

Most of salts encountered in soils are a mixture of two or more type of salts. Sets of chemically mixed salt samples were prepared from the 10 g/l solution fraction from which the pure salts were made using the same steps as described above. The mixing proportions are in 1 : 0, 0.75 : 0.25, 0.5 : 0.5, 0.25 : 0.75, and 0 : 1 weight mixing ratios. The spectra of the mixed samples were compared with the spectra of the pure samples of the 20 g/l solution fraction. The masses of salt (g) in the Petri dishes were divided by the area (cm^2) of the Petri dishes. All of the pure and mixed samples were examined under petroghraphic and binocular microscopes for crystal size and morphology observations.

In this study different approaches of data processing and digestion were considered. The traditional method of graphing the spectral data (Hunt and Salisbury, 1970; 1971 and Hunt et al., 1971, a, b, 1972, 1973; Salisbury,1991; Clark, 1999) was used. This method is to plot the percent of reflectance versus wavelengths for the entire spectral region. Another method is the continuum removal which is of particular significance in the study of the absorption features (Clark, 1999). The continuum is the background absorption onto which the absorption feature is superimposed. The continuum removal method implies the removal of the absorption features in the spectra, by plotting the intensities or band depths of the absorption features versus the associated wavelengths. This technique of spectral reconstruction can isolate the spectral features and put them on a level so that they can compared with each other (Clark, 1999).

5. RESULTS AND DISCUSSION:

5.1. Halite (NaCl)

Halite, sodium chloride (NaCl), is the most abundant evaporite mineral in soils (Carter, 1975; Ghasemi et al., 1995). The halite samples are white to colourless, isometric or cubic crystals, with average sizes that range from 638 µm to 1850 µm (Figure 1). In most of the halite samples prepared for this study, small crystals adhere to the larger ones. About 50% to 70% of larger size crystals (2mm) are covered with small crystal sizes that average 500 µm.

In the region of 500 nm to 1850 nm, the spectra of halite are almost featureless. In this region the spectra has a plateau shape with high reflection values that ranges from 80% to 90 % (Figure 2 ; Table 1). Two weak absorption features were observed in this region, at 994 and 1151 nm (Figure 2). As can be seen in Figure 3a, halite has two major absorption features that appear at 1457 nm (P6) and 1958 nm (P11) (Figure 2, Table 1). Table 1 gives all the possible positions of the main absorption features of halite that might appear in the full range spectra. The reflectivity of halite spectra is high with an average value of 85%. According to Mougenot et al., 1993, halite is a transparent salt, and its chemical composition and cubic crystal system (Figure 1) do not induce strong absorption bands in the visible and near to thermal infrared. Hunt, 1972, concluded that halide ions possess no internal vibration modes, and the absorption features all occur in the far infrared. However, the absorption features in halite spectra are attributed to the water in fluid inclusions of halite (Hunt et al, 1970, 71; Mulders, 1987; Mougenot et al., 1993)

5.2 Gypsum ($CaSO_4.2H_2O$):

Gypsum is a hydrated calcium sulphate mineral, mostly found in nature as a prismatic, curved or twisting monoclinic crystals of vitreous luster, and as earthy, foliated or granular masses (Cole, 1974). The structure of gypsum consists of layers of SO_4^{-2} strongly bonded to Ca^{+2}. Successive layers of this type of structure are separated by sheets of H_2O molecules (Cole, 1974; Klien and Hurlbut, 1993). The gypsum crystals prepared here have fine particle size; the average crystal size was 470 µm (Figure 1). The samples are white to colorless with monoclinic crystals

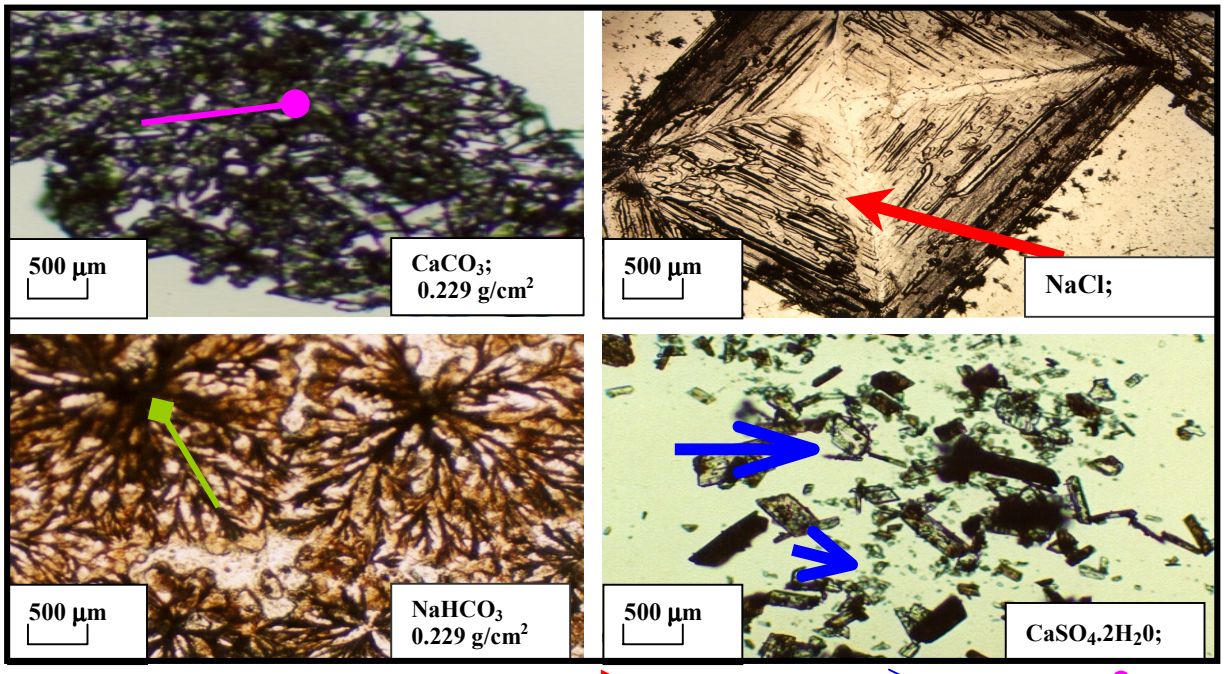

Figure 1: Different micrographs of NaCl ( ) and $CaSO_{4.2}H_2O$ ( ), CaCO3 ( ), and NaHCO3 ( ).

(Figure 1).

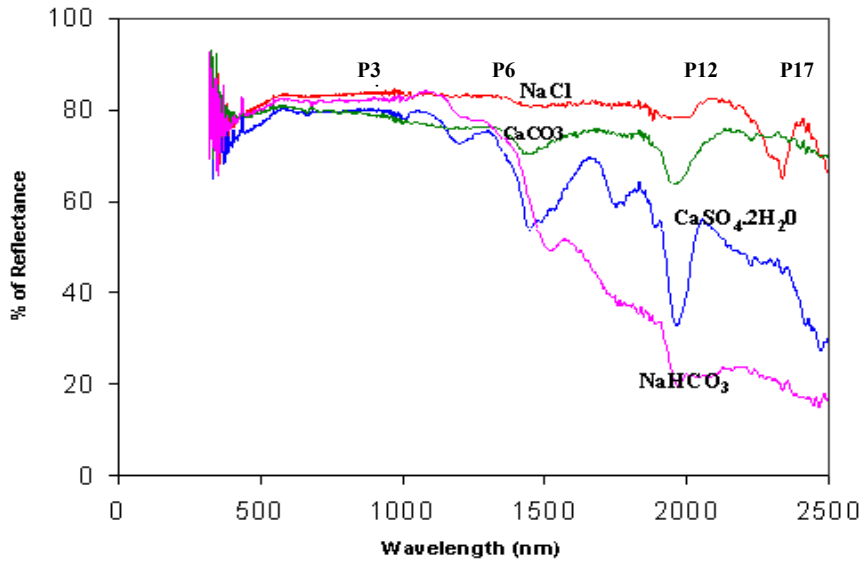

Figure 2: Comparison among the spectra of NaCl, $CaCO_3$, $CaSO_4.2H_2O$ and $NaHCO_3$

Between 500 nm and 1883 nm, gypsum has a reflection value of 87 to 80 %. Beyond 1883 nm, the reflectivity values of gypsum spectra decrease sharply from 87 % (2179 nm) to 35% (1978 nm) (Figure 2). The spectra of gypsum shows four major absorption features at different positions and reflection values (Table 1 and 2). Hunt et. al., 1977, reviewed all the possible positions of gypsum absorption features and they have been complied in Table 2. The spectrum of gypsum displays very prominent water bands characterizing gypsum in the near-infrared region beginning at 1400 nm and continuing out to 2500 nm. Sulphate can be divided into four groups in relation to their spectral responses (1) hydroxylated (2) hydrated (-OH) (3) hydrated, H_2O trapped in the lattice (4) hydroxylated and hydrated (5) not hydroxylated and not hydrated (Hunt and Salisbury, 1970; Hunt et al., 1971, 1972; Moungnot and Pouget, 1993; Clark, 1999). These produce a series of bands affecting the infrared spectrum between 1000 and 2500 nm, particularly at 1450 nm (P6), 1550, 1750 nm (P8) and 2300 nm. These bands can be seen in the spectra of gypsum (Figure 3 b, Table 1, Table 2). Figure 3 illustrates the changes produced in the spectrum of $CaSO_4.2H_2O$ as it is transformed to $CaSO_4.1/2H_2O$ (bassinite), and $CaSO_4$ (anhydrite), which are related by differences in water content. The purpose of this figure is to show the positions of the absorption features of the water molecule in these minerals. In the spectrum of $CaSO_4.1/2H_2O$ (bassinite), the major water bands are still present, but they are narrower and less structured. In the spectrum of anhydrite ($CaSO_4$), the major water bands disappear and the absorption features at 1487 nm (P6), and 1940 nm (P11) (Table 1) are related to the vibrational responses of the water inclusions within the samples.

Peak name	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17
1 CaSO4.2H20 (G)	994	1173		1435		1785			1940		2113		2310		
0.75 G : 0.25 H		1124	1217	1435	1650	1795	1800	1870	1968	2049	2183				2449
0.50 G : 0.50 H		1125	1217	1435	1650	1795	1800		1968	2049	2183				
0.25 G : 0.75 H		1145	1217	1435	1650	1795	1800		1968	2049	2183				
1NaCl (H)		1181		1457					1958			2284			
CaCO3 (Ca)				1486					1988		2123		2338		2428
0.75 C: 0.25 S			1225	1479					1978		2113		2356		
0.50 C: 0.50 S			1225	1473					1968		2123		2356		
0.25 C: 0.75 S			1220	1464					1970		2126		2356		
NaHCO3 (S)		1109	1243	1498		1768			1988				2356		

Table 1: The location of the absorption features of NaCl, $CaCO_3$, $CaSO_4.2H_2O$, $NaHCO_3$ and their mixtures.

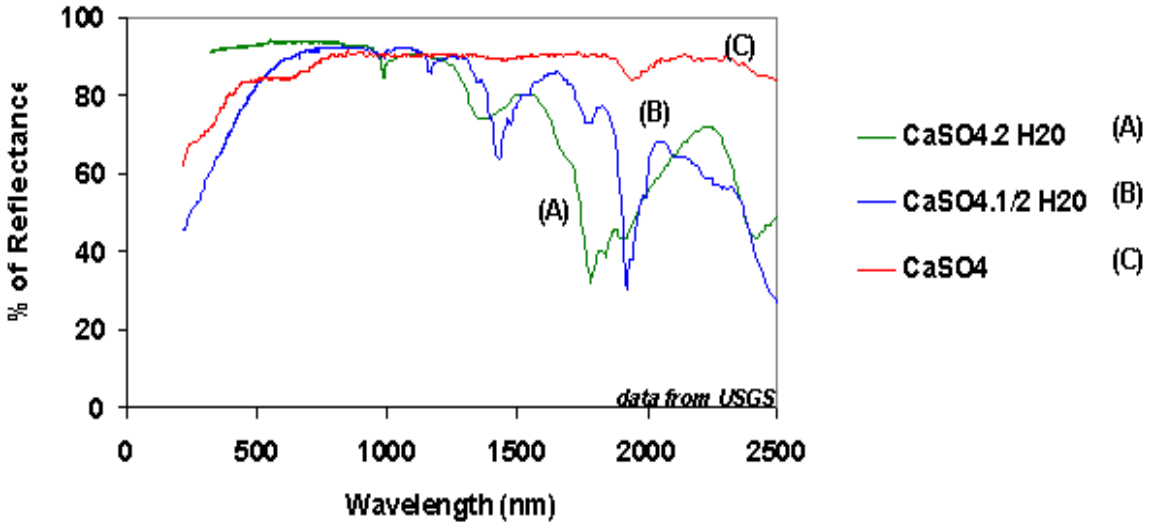

Figure 3: Spectral comparasion among the spectra of gypsum ($CaSO_4.2H_2O$), bassanite ($CaSO_4.1/2H_2O$) and anhydrite ($CaSO_4$).

POSITION OF ABSORPTION FEATURES (NM)	RELATIVE STRENGTH
1443 (P6)	Vvs
1486 (P6)	Vs
1575	Sh
1533	S
1745 (P8)	Vs
1772 (P8)	Sh
2075 (P12)	Vs
2125 (P13)	W- Sh
2176 (P13)	Sh
2215 (P13)	M
2265 (P14)	M-w

Code: S, Strong; M, medium; W: weak; V, very; Sh: shoulder.

Table 2: The possible positions of $CaSO_4.2H_2O$ absorption features (Hunt, 1977)

5.3 Calcium carbonate ($CaCO_3$):

Calcium carbonate is one of the most common minerals on the face of the Earth. It comprises about 4% by weight of the Earth's crust and is formed in many different geological environments. Of major concern to this study is the accumulation of calcium carbonate at or near the surface of the soil which is very common on the arid and semi-arid environment.

The prepared calcium carbonate crystals of this study were white with very fine aggregate of crystals; their average crystal size is 400 µm (Figure 1). The spectra of calcium carbonate usually has several absorption features at wavelength in excess of 1498 (P6) due to vibrations of the carbonate radical; these absorption features are situated near 1763 (P8), 1876, 1990 (P8), 2167, 2333 (P13) and 2500 nm (P17) (Gaffery, 1989, Drake, 1995, Clark, 1999). The observed spectrum of calcium carbonate of this study displays carbonate bands in the range of at 1988 nm (P11), 2123 nm (P13), and 2338 nm (P15), and 2428 (P17) (Figure 2 and Table 1). The spectral profiles of calcium carbonate shows the highest reflection values occur between P13 and P15. These absorption features are due to the vibrational modes of $CO3^{-2}$ ion.

5.4 Nahcolite ($NaHCO_3$):

Nahcolite ($NaHCO_3$), is a naturally occurring sodium bicarbonate. Its structure consists of planar chains of carbonate groups linked with hydrogen bonds; planes are linked together by sodium in six-fold coordination with oxygen (Klein and Hurlbut, 1993). NaHCO3 is also known chemically as "baking soda" and geochemically as nahcolite. In this study the sodium bicarbonate samples have white, very fine rosy crystals that range from 290 µm to 1100 µm with an average crystal size of 850 µm (Figure 1). The spectra of sodium bicarbonate exhibit a large diagnostic slope from 1243 nm (P5) to 2356 nm (P15) (Figure 3). The spectrum of sodium bicarbonate shows the higher reflection value around the 1109 nm (P4) (Fig. 3). Several absorption features can be seen in the spectra of sodium bicarbonate. These absorption features appear at 1243 (P5), 1498 (P6), 1790 (P8), 1988 (P11) and 2356 nm (P15) (Figure 3 and Table 1). Crowley, 1991 suggests that the broad nature of this salt could be due to the network of symmetrical H-bands between the carbonate ions, however, among the salts, sodium bicarbonate has the most diagnostic spectral pattern (Figure 2).

This study also investigated the reflectivity of different grain sizes and amount of NaCl, $CaCO_3$, $CaSO_4.2H_2O$, $NaHCO_3$. It was found that the positions of the absorption bands were not affected significantly by the size of gypsum and halite particles or with their quantities per unit area (Appendix 1; http://www.geo.utep.edu/Faculty_Staff/goodell.html). However, reflectivites increased with reducing particle sizes or with increasing the weight fraction of evaporite present.

5.5 Mixture analyses or weight fraction:

5.5.1 NaCl (H) - $CaSO_4.2H_20$ (G): The traditional method of plotting the percent of reflectance for the entire spectral region versus the wavelength (Hunt and Salisbury 1970; 1971; Hunt et al., 1972, 1973, 1979; Grove et al., 1992; Clark 1999) were used to graph the spectra of gypsum, halite and their mixtures (Figure 4). This figure shows that the spectra of the chemically mixed samples are different from the pure spectra of gypsum and halite. Most of the peak intensities, especially P4, P10, P14, and P16, vary according to the mixing ratios. Using the continuum removal method, this variation is expressed graphically in Figure 5. The peak intensity of the mixed samples decreases by decreasing the gypsum fraction, and 80% of the investigated peaks follow this pattern. A non-linear relation was found between the reflectivity of the chemically mixed gypsum and halite, and the mass fractions or the mixing ratios of the samples (Figure 4 and 5). When the mass fraction of gypsum decreases, the spectral contribution of halite eclipses the spectral features of the gypsum. Lindberg and Smith 1973, indicated that when gypsum is mixed with other evaporite salts, some bands disappear and the intensity and sharpness of the strong peaks decrease. This could be attributed to the spectral interferences between gypsum and halite in the mixed samples and/ or the coating of one salt over the other.

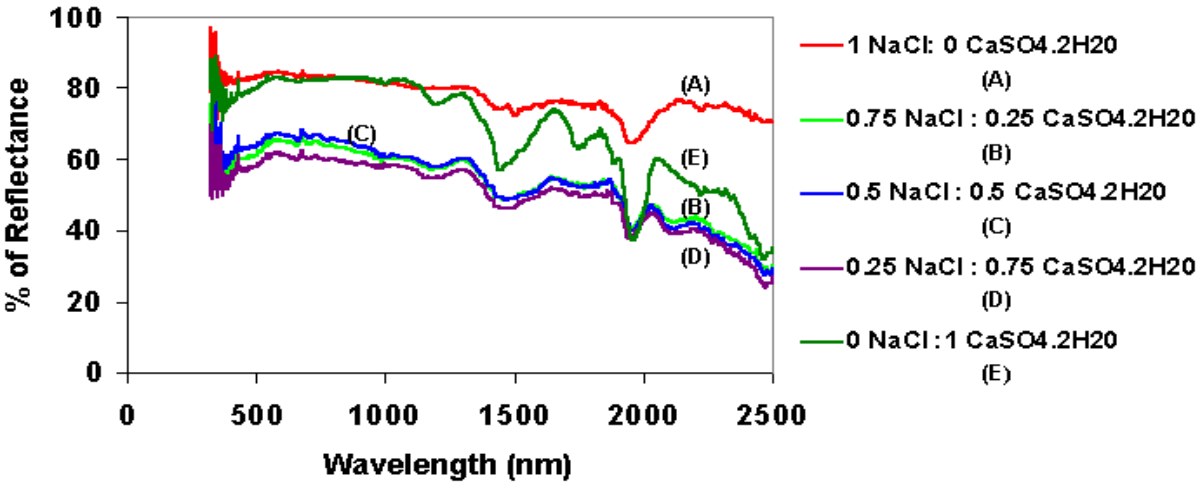

Figure 4: Comparasion among the spectra of NaCl, $CaSO_4.2H_2O$ and their chemical mixtures.

By inspecting the mixed and pure samples (MS and PS) under the optical and plain microscopes, crystal overgrowth was observed in the mixed samples. This could be due to the fact that the nucleation and the growth rate of the PS and MS are different from each other. The first is homogeneous, and the second is relatively a heterogeneous system. This causes differences between the sizes and habits of the crystals among the PS and MS. Gypsum has white milky color, and halite has glassy transparent color. The colors of the mixed samples are different from the colors of gypsum and halite, they are less transparent. Photons have a high probability of encountering less transparent grains (Clark 1999). According to Clark, 1999, this can drastically reduce the reflectance values much more than the weight fraction and

less than or equal to the effects due to grain size. This result in lower reflectivity of the spectra of the mixed samples. The spectral interferances between gypsum and halite crystals in the mixed samples are another cause of their lower reflectivities. The causes and effects of the spectral interferances is discussed in detail in Gupta, 1991; Vincent, 1997; Gaffey, 1989; Asrar, 1989 and others.

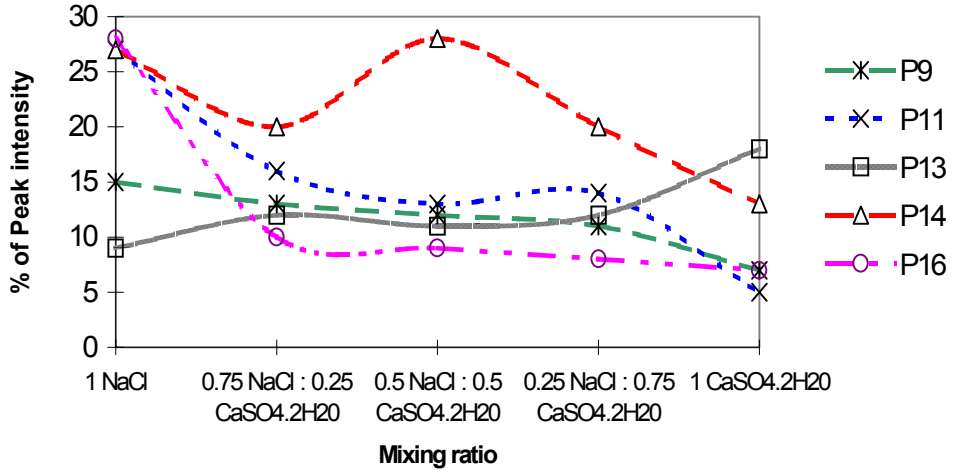

Figure 5: The behaviour of the peak intensity of selected absorption features of gypsum and halite *(Table 1 and Figure 4)* versus the chemical mixing ratios; using the continuum removal method.

Covering of one salt by another is controlled by the solubility product of the salts, based on the principal, the first to precipitate the last to dissolve (Tanji, 1996). The solubility of the NaCl (6108 meq/ litter) is higher than the solubility of $CaSO_4.2H_20$ (30 meq/l) and under certain conditions (Drever, 1982; Meybeck et al., 1990; Rosen, 1994; Tanji, 1996) is expected that after evaporation of the 81%, $CaSO_4.2H_20$ will be completely precipitated; then after evaporation of about 90.5% of the water, NaCl is precipitated. Therefore, halite will coat gypsum and prevent the detection of gypsum spectra if it has sufficient amount and thickness to cover the gypsum and fill the field of the view of the spectroradiometer.

1.2.1 $CaCO_3$ (C) - $NaHCO_3$ (S): In the range of 400 nm to 1450 nm, the mixed samples of CaCO3 and NaHCO3 reveals reflection values less than the reflection values of those of 1) calcium carbonate spectra, and 2) sodium bicarbonate spectra (Figure 6). This figure depict that in the range of 1464 (P6) to 2428 (P17) nm, the mixed samples has a reflection values in between those of the endmembers, calcium carbonate and sodium bicarbonate (Figure 6 and Table 1).

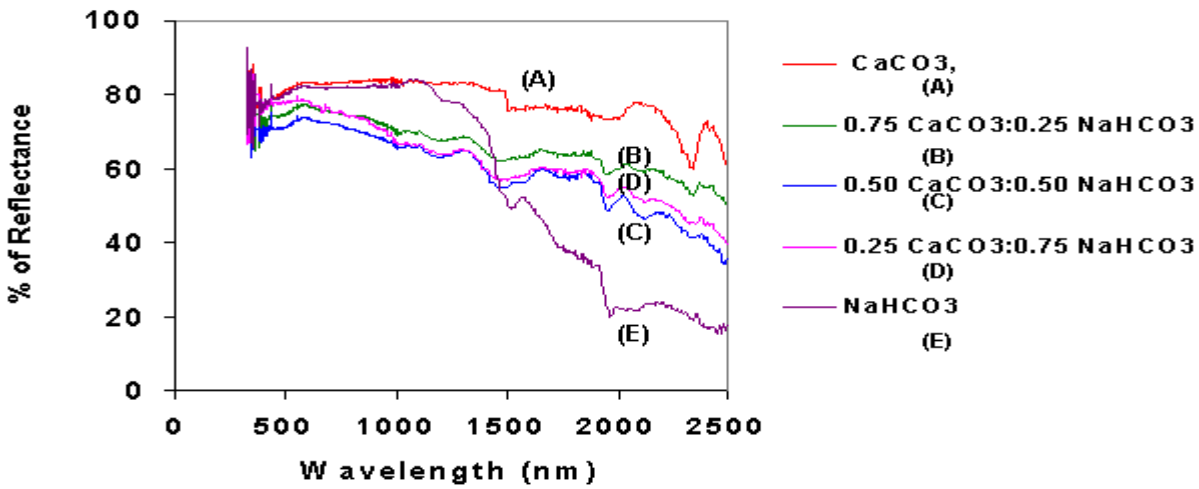

Figure 4: Comparison among the spectra of $CaCO_3$, $NaHCO_3$ and their chemical mixtures.

In the range of 450 to 2500 nm, the reflection values of the mixed samples are less than those of carbonate spectra and higher than those of the sodium bicarbonate spectra. As observed from Figure 6, the shape of the mixed spectra is different than the shape of the spectra of the endmembers. However, three absorption features can be traced between the mixed and pure samples. These absorption features are located at 1486 nm (P6), 1988 nm (P11) and 2338 nm (P15)

(Figure 86and Table 1). By applying the concept of the continuum removal method on selected absorption features, the study investigated the relation between the mixing ratio and the reflectiviy, it was found that the mixing ratio affect the detected spectra of the mixed samples in a nonlinear fashion. In this system of mixing the reflectivity of the absorption features of the mixed samples decrease by increasing the wavelength in different trends:

The study found that the slope of the decreasing trends increase by increasing the sodium bicarbonate fraction of the mixed samples. It is interpreted that this is due to coating of calcium carbonate with sodium bicarbonate crystals.

6. EXPECTED APPLICATION:

The results reported here can be used to (1) identify and map selected salt crusts soil surfaces, and (2) evaporite accumulations of the playas. According to Tanji, 1996 and Drake, 1995, the presence of particular diagnostic minerals on the playa or soil surfaces give an indicator of those solutes that are common in the brine from which these evaporite or salts have been derived from (Figure 7). Gypsum is diagnostic mineral for Na-Ca-SO_4-Cl and Mg-Na-Ca-SO_4-Cl brines, and nahcolite is diagnostic for Na-CO_3-SO_4-Cl (Figure 8). Therefore this study add a link between spectroscopy and the evaporite and/ or salt crusts evolution. As mentioned earlier the results reported here is part of the first report of comprehensive studies (Table 3) of the spectral behavior of the common salts and evaporite, that is expected to have a wide range of applications (Table 3).

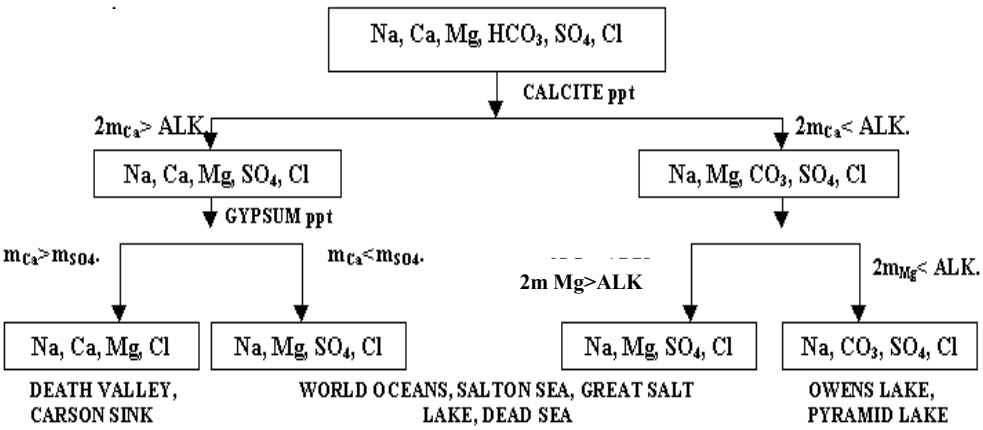

Figure 6: Flow diagram of Hardie-Eugster model of evaporative salinization of waters of continental brines and/ or salt crusts; m: morality, Alk: carbonate alkalinity
(Drever, 1982)

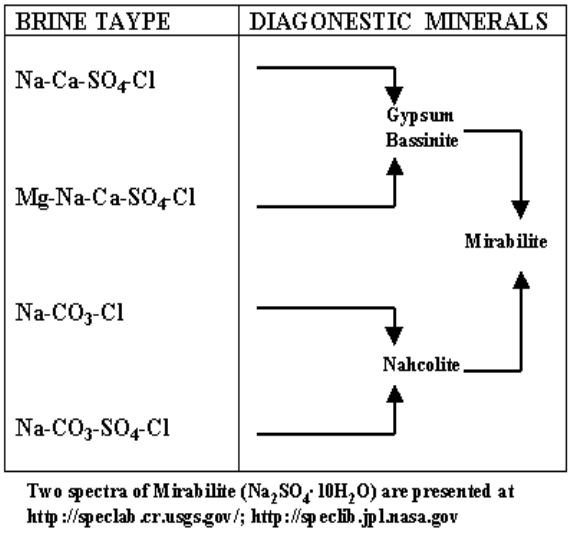

Figure 7: The minerals associated with each brine type. The left-hand columns show the four brine types. The right hand column outlines the diagnostic minerals that can be used for the discrimination between these brines (Modified after Drake, 1995)

Materials Studied	Natural phenomena applications	Area of potential influence	Progress
Pure salts	Evaporates, playa, lakes, river bed sediments	Limited	Done
Mixtures of salts	Mixed salts, evaporates, playa, lakes, river bed sediments	Limited	Done
Salt crusts onto soils	Soil suffering from salt crust formation, soil sever salinization	Extensive	Partially completed
Saline soils	Soil salinity in agricultural areas	Global	In planing and preparation phase

Table 3: Approaches, areas of potential influence and progresses of our studies of spectral behavior of the common salts and evaporite.

8. CONCLUSIONS:

The features in the studied spectra are sufficiently characteristic to be used for analytical purposes. Although any two pure or mixed gypsum and halite spectra may well have one or more of their absorption features in a similar position, the observed variations in the position, spacing, size and shape of these features means that their spectra can be diagnostic. Thus, the spectral differences of the salts appear to be significant to determine the identity and characteristics of gypsum, halite and their mixtures and/ or calcium carbonate and sodium bicarbonate and their mixtures. The positions of the absorption bands were not affected significantly by the size of gypsum and halite particles or with their quantities per unit area. However, the reflectivity increased with reducing particle sizes or with increasing the amount or the concentration of the salts. The reflectivity of both evaporate samples was related to the mixing ratios in a non-linear fashion. The mixing ratios affect the intensity and shape of the absorption features. The reflectivity of evaporite samples was related to the mixing ratios in a non-linear fashion. The study shows that halite spectral pattern eclipses the spectral features of the gypsum in a nonlinear fashion, when the mass fraction of gypsum is reduced to about 75 % in mixed salt evaporites.

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