The examination and characterization of a previously unknown mineral from Alcaparrosa, Chile

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ENSC 501
2014

Abstract

In the summer of 2013 while working with Jennifer Day, Dr. Ron Peterson encountered a mineral with an unknown X-ray diffraction pattern. This mineral is pale yellow in colour, fibrous, very light, with a texture similar to cotton candy. With examination of the mineral in Dr. Peterson’s accommodations at the research site the XRD signature of the mineral changed from unknown to that of copiapite. Peterson attributed this to the difference in relative humidity between the location of the mineral discovery and his accommodations where the relative humidity was higher. At Queen’s, experiments were conducted with the mineral using the FEI Quanta 650 FEG ESEM and Fourier transform infrared spectroscopy (FT-IR) in the Avatar 320 detector, as well as an attempt to determine the relative humidity at which the mineral is stable. Several methods of sample preparation were attempted using the Avatar 320 including a diamond press, DRIFT, and transmission methods with varying degrees of success. The experiments did show that the mineral does react when it is exposed to an increased relative humidity, in the range of 5 to 22.5%, and results in a shift of the structure of the sulfate group as seen through a shift in the peaks due to sulfur-oxygen bond adsorption detected with the Avatar 320. The FEI Quanta 650 FEG ESEM also showed a significant change in the physical structure
of the mineral when exposed to an increased relative humidity that is not observed with the naked eye. The ESEM also allowed for identification of the chemical composition of the mineral whose main components are S, Si, O, and Fe, with smaller amounts of Mg, Al, and K. The mineral also appears to create sulfuric acid when dissolved in fluids as indicated by respiratory distress of those who handled the mineral at the discovery site. This release of sulfuric acid was noted due the mineral’s light and fibrous characteristics that allowed it to become suspended in the air when disturbed and interact with people in the area. The atomic structure and specific chemical composition of this potentially new mineral is still undetermined.
Table of Contents

Abstract .......................................................................................................................... 1
Table of Figures ............................................................................................................. 4
Introduction ..................................................................................................................... 5
Methods .......................................................................................................................... 7
  Diamond Press ............................................................................................................. 8
  DRIFT unmixed .......................................................................................................... 8
  DRIFT mineral/KBr mixture ....................................................................................... 9
  Transmission in KBr disk ............................................................................................ 10
  Determining the relative humidity to initiate hydration reaction .................................. 11
  Electron microscope .................................................................................................. 12
Results and Discussion ................................................................................................. 13
Conclusion ...................................................................................................................... 32
Summary ......................................................................................................................... 34
Acknowledgements ......................................................................................................... 35
References ...................................................................................................................... 36
Table of Figures

Figure 1 - Unknown mineral at Discovery Site in Alcaparrosa Chile. The mineral encased the opening to the mine and is exceptionally soft allowing for the sample container and scale cards to be pushed into the mine. The texture and appearance are very similar to spray foam insulation that has been applied to the entry of the mine. ................................................................. 6

Figure 2 - Non Hydrated Sample. Focused on the sulfate region showing the various peaks for the mineral after 11 days of exposure to air with a relative humidity of 35%. The Peaks of interest are near 1040 cm$^{-1}$ and 1220 to 1260 cm$^{-1}$ which indicated a structural change in the sulfate group. .................................................................................. 15

Figure 3 - Hydrated Sample. Focused on the sulfate region showing the various peaks for the mineral after exposure to air with a relative humidity of 35%. The Peaks of interest are near 1040 cm$^{-1}$ and 1220 to 1260 cm$^{-1}$ which indicated a structural change in the sulfate group. ................................................................. 15

Figure 4 - Hydrated and Non Hydrated Sample Comparison. Focused on the sulfate region showing the various peaks for the mineral both before and after exposure to air with a relative humidity of 35%. The comparison clearly shows the change in peaks around 1040 cm$^{-1}$ and 1220 to 1260 cm$^{-1}$ which indicated a structural change in the sulfide group. ................................................................. 16

Figure 5 - Hydrated and Dehydrated Sample Compared with the Non Hydrated Sample. The comparison of the two samples almost perfectly parallel each other indicating that the structure of the sulfate group has returned to its non hydrated state in respect to IR signal after dehydration of the mineral. ....................... 17

Figure 6 – SEM Image of partially exposed mineral. Bright spots are the isolated grains and appeared scattered throughout the sample, but appear most frequently in the fibrous material. The fibrous material dominates the samples and overlays both the groups of platy material and isolated grains. Black areas are the carbon adhesive that were not covered by the sample ................................................................. 19

Figure 7 - SEM of the fiber that make up the unknown mineral. This image shows significant variation in the size range of the fibers and distribution of sizes. ............................................................................................... 20

Figure 8 - SEM showing the complex and generally curving orientations of the fibers.................. 21

Figure 9 -SEM of Platy material showing the variability of crystal sizes and similarity to copiapite....... 22

Figure 10 – ESM Grains. The bright areas are the isolated grains held within the fibers of the unknown mineral. ................................................................................................................................. 23

Figure 11 - SEM EDS scan of Fibrous with Ti .................................................................................. 24

Figure 12 - ESM EDS scan of Platy and Fibrous comparison. Green is Platy ................................ 25

Figure 13 - ESM EDS scan grain with Pb ...................................................................................... 25

Figure 14 - SEM EDS scan grain with Cu ...................................................................................... 26

Figure 15 SEM before Exposer. This image shows the unexposed area with fibrous, platy, and grainy material that is returned to after 15 minutes of exposure in Figure 16 ................................................................. 27

Figure 16 SEM after 15 Minutes Exposure. The dark gray area was occupied by the fibrous material and only some fibers are still visible. The light gray area that is highly fractured was the area covered by a cluster of platy material. See Figure 15 for comparison. The images are from the same location before and after exposure to the air with a humidity of 22.5%. ................................................................................. 28

Figure 17 - SEM Large Fibers and Plats After 15 Minutes of Exposure. The large fibers are relatively intact while a few smaller fibers are still visible in the dark gray area that was completely covered with small fibers before exposure. The plates in this image are more fracture than before exposure but less fractured then those in Figure 16. ........................................................................................................ 31
Introduction

The discovery of the unknown mineral in 2013 by Dr. Ron Peterson at the Alcaparrosa mine site in Chile, (Lat 22° 38’ 22.561” S Long 69° 9’ 3.123” W) a sulfate mine that has been closed since the 1920, has resulted in a quest to determine its characteristics (Figure 1). One of the key characteristics of the mineral is its hydration reaction with atmospheric humidity. The hydration reaction occurs at relatively low levels of atmospheric humidity, in the range of 5-22.5% and results in the mineral changing to copiapite. This was first noted by Dr. Peterson when he took the unknown mineral into his accommodation at the research site to conduct further tests on and discovered that after a shower the minerals X-ray diffraction signature had changed to that of copiapite from the unknown signature that had been first measured in an area of lower relative humidity. Further experiments have been conducted in Kingston Ontario with the mineral. Unfortunately the atmospheric humidity in Kingston is significantly high than Alcaparrosa Chile. This difference in humidity has made experimentation of this unknown mineral in its unaltered state very difficult as it reacts within tens of seconds of being exposed to the air in Kingston. Lacking the ability to directly control the humidity in the rooms where the equipment is housed has made it nearly impossible to prepare and test the mineral before it reacts with most standard equipment and it must be assumed that at least a partial reaction has occurred with the experiments that have been conducted which have showed the unreacted mineral.

Continued research of the mineral to identify its properties is important to clearly classify and define this material so it can be recognised as a new mineral species by the International Mineralogical Association. The true importance of the mineral is currently unknown due lack of information, but it is a potential environmental and health hazard due to its highly reactive
nature. Further definition of the minerals characteristics will help to develop safe methods to handle the mineral, especially with regard to unintentional inhalation.

Figure 1 - Unknown mineral at Discovery Site in Alcaparrosa Chile. The mineral encased the opening to the mine and is exceptionally soft allowing for the sample container and scale cards to be pushed into mineral. The texture and appearance are very similar to spray foam insulation that has been applied to the entry of the mine.
Methods

The initial experiments of the unidentified mineral were conducted by Dr. Ron Peterson using the portable Terra X-ray diffractometer which displayed an unrecognised diffraction pattern. Samples of the mineral were studied in the ambient air and additional scans of the material were done in his accommodation after a shower had increased the relative humidity of the room. These additional scans of the mineral resulted in the diffraction signature for copiapite. Dr. Peterson returned to the discovery site and collected more samples to further study the mineral. At this point it was noted that interaction of the mineral with moisture on the hands or the mucus membranes of the body resulted in irritation and the conclusion that as part of the hydration reaction sulfuric acid was produced.

IR measurement

The first set of experiments that were conducted in Kingston were using the Avatar 320 DTSG infrared spectrometer operating at 32 scans 4 wave point resolution with a 4000 cm⁻¹ range, with KRS5 window. Several methods were used including: diamond press, DRIFT, and Transmission modes. The Diamond press method was conducted using just the sample mineral, the DRIFT method was conducted with the pure sample of the mineral and a mix of the mineral with KBr at approximately 5% mineral to 95% KBr. The Transmission method was conducted with only a mixture of the mineral and KBr at approximately 5% mineral to 95% KBr. For all experiments the room temperature and relative humidity were recorded and were all ranging from 22 to 26 degrees Celsius with a relative humidity in the room ranging from 22.5% to 35%.
Diamond Press

The first method conducted used the diamond press on the Avatar 320. The mineral was collected in an airtight container at the field site. This was opened and a metal tool used to scoop out a small portion of the mineral. This sample of the mineral was placed on the panel and compressed with the diamond press. This step took approximately 30 seconds to complete. The sample was then scanned which required approximately 30 seconds to complete. Scans of the sample were repeated for the next 10-15 minutes until no changes of the spectra were observed. It is likely the compression of the mineral and isolation by the diamond surface reduced the minerals absorption rate of moisture from the air.

DRIFT unmixed

The next method attempted was using the DRIFT attachment of the Avatar 320. In this method both the mineral and the control (KBr) are continually exposed to the air and used pure samples of both the mineral and KBr. Both the KBr and mineral are placed into indents on a metal tray which is then inserted into the Avatar 320. The KBr in the first tray which is used to calibrate the Avatar 320 and the mineral is placed in the second tray. The KBr was added to the tray first and leveled off, followed by the mineral. A level surface of both samples is required and took approximately 2 minutes to complete with the mineral being portion taking approximately 1 minute. The tray was then placed in the Avatar 320. The calibration scan with KBr required approximately 30 seconds to complete and then the tray needed to be repositioned for the mineral sample. The scan of the sample mineral took approximately 30 seconds to complete.
Additional scans were completed to determine if any change occurs over the next 10 minutes. The sample mineral was exposed for at least 1 minute and 45 seconds before it was scanned.

The DRIFT scanning module for the Avatar 320 also allowed for the use of a silica disc onto which the mineral is applied to as a scanning medium instead of placing of the powder sample directly in the indents of the tray. The discs were placed in the glove box at less than 5% relative humidity for 24 hours before application of the mineral. The unmixed mineral was pressed onto the disc and the lose material shaken off leaving a fine powder on the disk. Another disc also had the mineral pressed into it to create a coating on the disc. The discs were then placed in glass containers and sealed for transport. The advantage to the disc method was that it allowed for calibration of the Avatar 320 before exposing the samples to the air. Once the Avatar 320 was calibrated the silica disc with the unmixed mineral was placed on the tray and positioned, taking approximately 30 seconds, and then the scan was conducted. Additional scans were conducted to determine if any change in the mineral occurred.

**DRIFT mineral/KBr mixture**

The KBr and an opened container holding the mineral were both placed into a glove box at 23°C with a relative humidity of less than 5% for a 24 hour period to stabilize the samples temperature and humidity. The KBr and mineral were added to a mortar and pestle at an approximate mixture of 95% KBr and 5% mineral and then ground together to create a fine well-mixed powder. The mixture and KBr were then placed into the indents on the metal tray and covered with a glass slide (held in place with a clip). The tray was covered with a glass slide and then placed in a Tupperware container with silica gel for transport to be scanned. As with the pervious DRIFT
method, the KBr sample is in the indent of the first tray used to calibrate the Avatar 320 and the KBr/mineral mixture (95% KBr/ 5% mineral) is in the second indent. The tray was removed from the Tupperware container, the glass slide removed, then it was inserted into the Avatar 320. This method reduced exposure time of the mineral to approximately 15 seconds while positioning the tray. The Avatar 320 was then calibrated with the KBr, approximately 30 seconds, and the tray was moved to position KBr/mineral sample and the scan completed, approximately 35 seconds. This reduced the exposure time of the mineral before scanning to approximately 50 seconds. Additional scans were run to determine if any change occurred over the next 10 minutes.

A portion of the exposed KBr/mineral mixture was than pressed into KBr disk to determine if the mineral could be scanned with this method. The results were positive so the transmission through a KBr disk method was conducted.

Transmission in KBr disk

The KBr and mineral were both placed into a glove box at 23°C with a relative humidity of less than 5% for a 24 hour period to stabilize the samples temperature and humidity. The KBr and mineral were added to a mortar and pestle at an approximate mixture of 95% KBr and 5% mineral and then ground together to create a fine well-mixed powered. The mixture was then placed into the press die and sealed with the washer and a plug. The sealed die was then placed in a Tupperware container with silica gel to maintain humidity during transport to press. The die was placed in the press and placed under 10 tons of pressure in a vacuum for 1 min to form a disc. The newly formed disk was placed into the holder of the Avatar 320 transmission scanner.
and the scan completed. The exposure time for the disk to the air was approximately 50 seconds until the scan was completed. Additional scans were run to determine if any change to the mineral would occurred. Since the mineral had not reacted at all after 45 minutes, the disc was left exposed to the room air with a relative humidity of at least 35% and addition scans were conducted until the mineral stabilized.

An additional experiment was conducted using this method with an unmixed sample of the mineral that had been exposed to the air for at least 5 minutes in a room with a relative humidity of 35%. A portion of hydrated sample was then placed in the glove box for 24 hours at less than 5% relative humidity to dehydrate. The sample was then mixed with KBr in a mortar and pestle at approximately 95% KBr and 5% mineral and placed in the die for compression into a KBr disc. This sample was also transported in a Tupperware container with silica gel to be pressed into a disc and scanned.

Determining the relative humidity to initiate hydration reaction

A glove box was constructed using a large clear Tupperware container, two 5 inch plumbing fixtures with gloves attached, and 3 inch plumbing fixtures with screw in caps as an airlock. The NIR detector was inserted into the top of the box and all gaps sealed with silicon to create an airtight container. Silica gel in closable container was used to reduce relative humidity to less than 5% in the chamber. A stand was constructed to position the mineral directly below the NIR with less than 1 cm clearance. Once the chamber had reached less than 5% humidity the first scan of the mineral would be completed and the silica gel containers would be sealed. Water was released onto paper towels from a syringe, 1ml at a time, and monitor relative humidity in glove
box conducting IR scans of the mineral at every 0.5% increase in relative humidity until a
change in the IR spectra was observed.

Electron microscope
The data was collected using the FEI Quanta 650 FEG ESEM. Room temperature and relative
humidity were recorded at 22 degrees Celsius and 22.5% relative humidity. The sample pin was
prepared with double-sided carbon sticky paper to allow for the mineral to adhere to the pin
surface. The mineral was then put directly on the carbon tape from an unopened sample tube of
the mineral using a metal tool. The pin was then placed on the stage in the microscope and sealed
under a vacuum at 1 Torr. Total exposure time of the mineral was approximately 45 seconds
before pumping began.

Scan sample taking images and energy dispersive analysis (EDS) measurements of the mineral in
the multiple forms recording data and images. The stage location was then recorded so that the
specific location could be returned to. The scanning electron microscope was then opened
exposing the mineral to the air with a relative humidity of 22.5% for 15min to allow for a
reaction to occur and then resealed and returned to 1 torr pressure. The stage was position to its
previous coordinates with EDS spot scans and images taken for comparison.
Results and Discussion

Diamond Press

The resulting scans over the period of the experiment were able to show a shift in one of the Sulfur-oxygen IR absorption peaks. These peaks around 1040 cm\(^{-1}\) and 1220 to 1260 cm\(^{-1}\) disappeared or shifted as the sample was allowed to react. This suggests a change in the atomic structure around the sulfate molecule likely due to the bonding of H\(_2\)O to the sulfate group. This reaction shows that the mineral does change from the state it was found in when exposed to air with a humidity above 5%. Unfortunately the results of the IR scan had a significant amount of noise and making it difficult to determine if other changes were occurring as well.

DRIFT unmixed

The results of the unmixed DRIFT scans did not show the peak around 1040 cm\(^{-1}\) that was seen in the diamond press method. It was determined that the exposure time to humid room air of the mineral was too long before the scan was conducted due to the requirements of positioning the mineral and run the calibration scan. This scan also had a significant amount of noise like the diamond press method.

The silica disc method failed to give any useable results from either application method. This was believed to be due to the difficulty of applying the very fluffy mineral to the silica disc in an even level that was required for the scan to function.
DRIFT mineral/KBr mixture

Due to the failure of the unmixed DRIFT experiment it was hoped that using a mixture with KBr would provide better results as it was believed that the KBr would preferentially absorb the water in the air over the mineral. Unfortunately this method also failed to show the sulfate absorption peaks around 1040 cm\(^{-1}\) and 1220 to 1260 cm\(^{-1}\). This scan also had a significant amount of noise like the diamond press method.

A portion of this exposed and mixed sample was pressed into a KBr disk to determine if the mineral could be scanned in transmission through the disk. The scan results followed the previous curves with a significant reduction in noise creating a very clear signal and showed an additional peak, the absorption peak due to H\(_2\)O that could not be seen in the other scans. This method appeared promising and it was hoped that the compression in KBr would effectively seal the mineral from the humidity and allow an IR absorption measurement of the unaltered mineral.

Transmission in KBr disk

The resulting scan of the unexposed mineral in the KBr disk produced very good results which clearly showed the sulfate peaks around 1040 cm\(^{-1}\) and 1220 to 1260 cm\(^{-1}\) with almost no noise in the scan, see Figure 2. The compression in the KBr disk greatly reduced the rate of minerals hydration with no change in the absorption spectra being visible for more than hour of exposure to the air. In fact the hydration rate was slowed so significantly that it took 11 days in room air with RH of approximately 35% before it could be determined that the mineral had hydrated, see Figure 3. This method allowed for the first clear scan of the non-hydrated mineral and hydrated
mineral while clearly showing the structurally shift of the sulfate absorption peaks around 1040 cm\(^{-1}\) and 1220 to 1260 cm\(^{-1}\) see Figure 4.

*Figure 2 - Non Hydrated Sample. Focused on the sulfate region showing the various peaks for the mineral with little or no reaction to air. The Peaks of interest are near 1040 cm\(^{-1}\) and 1220 to 1260 cm\(^{-1}\) these are the peaks that shift with hydration of the mineral.*
Figure 3 - Hydrated Sample. Focused on the sulfate region showing the various peaks for the mineral after 11 days of exposure to air with a relative humidity of 35%. The Peaks of that shifted are near 1040 cm$^{-1}$ and 1220 to 1260 cm$^{-1}$ these are the peaks that shift with hydration of the mineral.

Figure 4 - Hydrated and Non Hydrated Sample Comparison. Focused on the sulfate region showing the various peaks for the mineral both before and after exposure to air with a relative humidity of 35%. The comparison clearly shows the change in peaks around 1040 cm$^{-1}$ and 1220 to 1260 cm$^{-1}$ which indicated a structural change in the sulfide group.
The hydrated then dehydrated sample appeared to have reverted to its original state with the same sulfate peaks appearing around 1040 cm$^{-1}$ and 1220 to 1260 cm$^{-1}$ as the non-hydrated sample, see Figure 5. This suggest that the hydration reaction maybe reversible, with respect to the IR signal (but perhaps not XRD). It is also possible that the portion of the mineral sample that was used in the disc had not completely hydrated. If the hydration reaction is completely reversible than some tests could be conducted in equipment that can produce a vacuum if the mineral can be kept in place while the vacuum is established and not sucked out of position. More testing is needed to confirm if the minerals hydration reaction is reversible, with respect to the IR signal as well as XRD.

Figure 5 - Hydrated and Dehydrated Sample Compared with the Non Hydrated Sample. The comparison of the two samples almost perfectly parallel each other indicating that the structure of the sulfate group has returned to its non hydrated state in respect to IR signal after dehydration of the mineral.
Determining the relative humidity required to initiate hydration reaction

Unfortunately this experiment was a complete failure as the relative humidity within the chamber never dropped below 11% even though the silica gel was able to reduce the relative humidity below 5% in the glove box used to prepare the mineral for use with the Avatar 320 IR experiments. Despite the addition of more silica gel and resealing of areas that appeared to have not sealed properly a relative humidity of less than 5% was not attended. The main issue with the glove box appeared to be with the silicon used to seal the box was not properly adhering to the container allowing for air exchange with the outside.

Although the precise relative humidity required for hydration to initiate was not determined it was possible to determine a range of 5-22.5% from the recorded relative humidity in the rooms of the other experiments.
Scanning Electron Microscope

The Scanning Electron Microscope results showed three different materials in the mineral sample. Large sections of fibrous structures, clusters and individual platy structures and isolated

Figure 6 – SEM Image of partially exposed mineral. Bright spots are the isolated grains and appeared scattered throughout the sample, but appear most frequently in the fibrous material. The fibrous material dominates the samples and overlays both the groups of platy material and isolated grains. Black areas are the carbon adhesive that were not covered by the sample.
grains see Figure 6. The fibrous and platy structures were very similar in composition
determined from the EDS spot scans. They are made up of S, Fe, O, Si, Mg and Al with some
additions of Ti, C, K and Na in some areas see Figure 11 and Figure 12. The carbon that appears
in the scan may be from the adhesive used to attach the mineral to the pin and not part of the
mineral itself.

Figure 7 - SEM of the fiber that make up the unknown mineral. This image shows significant
variation in the size range of the fibers and distribution of sizes.
The fibrous material ranges in size from small fibers to relatively large fibers, see Figure 7. The fibers have not apparent preferred orientation generally overlaying each other see Figure 8.

Figure 8 - SEM showing the complex and generally curving orientations of the fibers.

The platy material has a large range, see Figure 9, in size but the platy material seemed to cluster together often surrounded by the fibrous material. This may suggest the platy material are inclusions within the fibrous material which acts similar to a matrix material. The platy areas generally had more S than the fibrous areas, see Figure 12. This higher sulfur content may be due
to the material being more compacted and presenting a better surface for taking EDS scans using the SEM. These platy structures are similar in morphology to copiapite, and the XRD pattern of the exposed mineral is copiapite (Majzlan & Michalkik, 2007). Therefore it is likely that the platy material is actually copiapite which is grouped within the unknown mineral which has the fibrous morphology.

Figure 9 -SEM of Platy material showing the variability of crystal sizes and similarity to copiapite
The isolated grains are generally scattered throughout the sample with no apparent relationship to each other but they do appear more commonly within the fibrous material as very bright spots in the ESEM images see Figure 10.

![Figure 10 – ESM Grains. The bright areas are the isolated grains held within the fibers of the unknown mineral.](image)

The isolated grains contained Cu and Pb with S, Fe, Na, Si, O, C, N and Mg see Figure 13 and Figure 14. These isolated grains are likely impurities that were trapped within the fibrous
structure of the unknown mineral as it formed or may even have been transported in after formation of the fibrous as the fibrous are highly porous. The porosity may have allowed small particles of other minerals to be blown into fibers after formation.

*Figure 11 - SEM EDS scan of Fibrous with Ti*
Figure 12 - ESM EDS scan of Platy and Fibrous comparison. Green is Platy

Figure 13 - ESM EDS scan grain with Pb
Figure 14 - SEM EDS scan grain with Cu
After exposure of the sample for 15 minutes to the room air there was a significant change in the sample see Figure 16. Most the smaller fibrous material disappeared leaving only very faint
traces in most areas. EDS spot scans of these areas showed significantly smaller or no peaks for the elements that were present previously.

It is unclear what happened to the elements that were previously present, they may have been released as a gaseous state or the hydration of the unknown mineral may have created some fluid
that allowed for the material to dissipate across the surface of the stand thus diluting the material and reducing the concentrations of the elements where the fibrous material initially was. It is also possible that the matrix effects raised the detection limits for these elements. The change in the peak intensity of the elements may also be a relic of the complex surface area of the fibrous causing anomalously high readings initially, although this seem unlikely. The most likely explanation is that the elements became mobilized during hydration in a solution and have spread out across the surface of the sample pin diluting the signal.

A few of the very large fibers were still visible and maintained their original elemental composition. Why these larger fibers were able to remain relatively intact after exposure for 15 minutes is unknown. Pervious experiments with the Avatar 320 showed a reaction time of less than 50 seconds. Therefore 15 minutes of exposure should have been more than sufficient to allow for the full reaction of the mineral. It is possible that the rate of reaction is related to the relative humidity and that the lower relative humidity of the room were the SEM scans were conducted, 22.5% compared to the 35% of the room where the Avatar 320 experiments were conducted, was sufficient to increase the reaction time of the mineral. It may also be possible that the size of the large fibers allowed for a crust to form around them as they reacted with the H$_2$O in the air preventing further reaction to occur at their core see Figure 17.

The platy material had also been affected during exposure to humid air, becoming significantly more fracture and segmented into smaller pieces but it did maintain its elemental composition. This change of the both the fibrous and platy mineral might suggest that both occur as natural forms of the unreacted mineral. It is also possible one form changes into the other and that with
continued exposure the fibrous portion, which were most greatly affected, might restructure into the platy portion. The morphology of the platy material is similar to copiapite and since the XRD pattern of the exposed mineral was copiapite it would appear that hydration of the unknown mineral results in copiapite. The copiapite may be formed from the unknown mineral when hydrated. This would mean that the portions of copiapite that were seen in the original SEM scans were the result of partial hydrations of the unknown mineral while preparing and placing it in the SEM. It is also possible that the copiapite is enclosed within the unknown mineral but is only detectable to XRD after the hydration reaction has broken down the small fibrous. More experiments and testing will be required to confirm if copiapite is in evidence with the unknown mineral before any reaction has occurred.

The segmentation of the platy portion, likely copiapite, might be a result of the production of sulfuric acid during hydration of the unknown mineral. A method to test whether the segmentation of the platy portion is a result of the sulfuric acid would be to place a sample of the non-hydrated unknown mineral in the SEM and while actively scanning the mineral adjust the chamber to atmospheric or near atmospheric conditions so that the reaction can be observed as it occurs. Unfortunately the production of sulfuric acid could potential harm the ESEM so some precautions must be undertaken before attempting this experiment.

The isolated grains seemed relatively unaffected by the hydration and are likely impurities in the sample and directly related to unknown mineral.
Figure 17 - SEM Large Fibers and Plats After 15 Minutes of Exposure. The large fibers are relatively intact while a few smaller fibers are still visible in the dark gray area that was completely covered with small fibers before exposure. The plates in this image are more fracture than before exposure but less fractured than those in Figure 16.
Conclusion

The resulting data showed that the unknown mineral does undergo a hydration reaction when exposed to atmospheric humidity greater than at least 22.5%, but potentially as low as 5%, and results in a change in the IR spectra caused by the change in bonding of H$_2$O with the sulfate groups. The shift of the structure at the sulfate group may be reversible as indicated in the hydration/dehydration experiment, but this may also be an anomaly and should be retested with a sample that has been confirmed to be fully hydrated. This reversibility of the IR spectra does not mean that it would be reversible for XRD as well, so experiments with XRD will also need to be conducted to determine how complete the reversal of hydration of the mineral is.

Additionally, the physical structure of the mineral changes as the fibrous and platy portions of the mineral appear to break down at the microscopic level when hydrated. Although not all of the fibrous or platy portions were broken down during the 15 minutes of exposure, this may be why the mineral does not appear to change significantly to the naked eye when exposed to elevated levels of humidity. With the large fiber remaining relatively intact after hydration, they may support most of the structure of the material even in the absence of the smaller fluffier fibers. From the experiments with the Avatar 320, it became clear the mineral completed reaction within 1 minute of exposure to a relative humidity of 35% but the largest fibres appear to have maintained their form after hydration. Why they do not change and break down like the smaller fibrous is unclear but it seems more likely that the hydration of the smaller fibers surrounds them, and their own surface, may create a coating that retards further reaction with the atmospheric H$_2$O. An experiment that might prove this hypothesis would be to dissolve the mineral in water.
and then scan to check for fibers with in the solution. If fibers are detectable this would indicate that they are either resistant to further reaction to H\textsubscript{2}O, or they are of a different structure to begin with that resist reaction with H\textsubscript{2}O.

The release of sulfuric acid when dissolved or deliquesces may place the mineral within a group of other sulfate minerals that produce sulfuric acid when hydrated but that has yet to be determined at this time. Further research is needed to clearly define the minerals characteristics. It would be best if the experiments could be conducted in a controlled environment where the relative atmospheric humidity can be maintained below 5\% as the mineral appears to be stable at this humidity. Working with the mineral in an environment where it is stable would greatly reduce the difficulty of conducting experiments on the unknown mineral. Experiments conducted in higher relative humidity levels means that it is impossible to say whether copiapite is naturally present with the unknown mineral, but for some reason undetectable or unrecognizable, or if the copiapite is the result of the hydration reaction of the unknown mineral when exposed to a humid atmosphere.
Summary

- The unknown mineral does react with atmospheric humidity
- The mineral is stable at less than 5% relative humidity
- The mineral starts to hydrate between 5 to 22.5% relative humidity
- Reaction at 35% relative humidity appears to complete in less than 50 seconds
- Inferred spectroscopy shows a change in the structure of the mineral at the sulfate group peaks around 1040 cm⁻¹ and 1220 to 1260 cm⁻¹
- The mineral hydration reaction may be reversible with respect to IR but XRD is unknown
- The mineral is composed of three material types
  - Fibrous material composed of S, Fe, O, Si, Mg and Al with occasional occurrences of Ti, C, K, and Na
  - Platy material composed of S, Fe, O, Si, Mg and Al with occasional occurrences of Ti, C, K, and Na, appears to have approximately double the S ratio of the Fibrous
  - Grain material composed of S, Fe, and O, with Cu and/or Pb, and occasional occurrences of Na, Mg, Si, N and C
- Small Fibrous and platy material reacted and fracture/dissolve
- Large fibrous and platy material appear to remain relatively intact
- Reason for larger material remaining relatively intact is unclear
- The reason for apparent disappearance of the smaller material is unclear but may be the result of migration of the elements during hydration.
Acknowledgements

Dr. Ron Peterson

Dr. Herbert F. (Gus) Shurvell for helping with IR

Mr. Michael Doutre for helping with IR

Miss. Agatha Dobosz for helping with SEM

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