NSCG Newsletter

Title: Ammonia: A practical guide to the treatment and storage of minerals

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Source: Irving, J. (2001). Ammonia: A practical guide to the treatment and storage of minerals. *NSCG Newsletter*, *Issue 17*, 18 - 32.

URL: http://www.natsca.org/article/635

Ammonia
A practical guide to the treatment and storage of minerals

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This is aimed at non-specialist curators with small geological collections and limited resources who do not have access to specialized conservatorial help.

1. Rationale for the use of ammonia as a conservation treatment.
Oxidation of pyrite or marcasite, dimorphs of FeS_2, commonly cause destruction of geological material. Conditions that favour high rates of oxidation include fine grain size of the reactive material, and high RH and high temperature. But even at room temperature and moderate RH (>30%), some oxidation will occur in susceptible specimens. Neutralization by ammonia is important because the oxidation of pyrite leads to products such as ferrous sulphate and sulphuric acid.

Sulphuric acid acts as a solvent for removing passive oxide coatings, or tarnishes, thus exposing fresh surfaces for further oxidation, and it acts as an electrolyte to support any electrochemical oxidation that might occur. Ferrous sulphate will exist as any one of 3 hydrates at room temperature; but at about 60% RH the 1 to 7 hydrate transition occurs, resulting in a huge 256% volume expansion. This 7 hydrate, melanterite $FeSO4.7H_2O$, is the main cause of specimens cracking and falling apart. However, sulphuric acid and ferrous sulphate are both deliquescent, which will further accelerate oxidation above 30%RH. Thus any treatment which either removes or neutralizes the oxidation products is an essential part of conservation treatment for the specimens.

2. The treatment process used at OUMNH.
I shall briefly describe the process we use at OUMNH for treating pyritic specimens. This is based on Robert Waller's 1987 paper ' An Experimental Ammonia Gas Treatment Method for Oxidized Pyritic Mineral Specimens.'[1]. Prior to treatment, oxidation products can be removed carefully either by brushing or by means of sodium bicarbonate air abrasive, provided this is not going to threaten the integrity of the specimen. The importance of treating specimens early in the decay process before oxidation products become too widespread, cannot be stressed enough.

It is not necessary to spend a lot of money getting started. Because ammonia, as a gas, is all pervasive one can treat many specimens at the same time, in whatever size of container seems appropriate, and because the chemicals used are in small quantities and can often be recycled, the process is relatively cheap. For many years, we used two old fish tanks with draught-proofing around the top as a seal, together with a glass sheet as a lid, weighted down by heavy rocks spread out on a wooden tray. The shelves were made out of open-mesh plastic rescued from a skip, separated by glass jars as supports. We still use it for treating specimens that are too large for the current treatment desiccator. This desiccator is now kept in a fume cupboard which means that an ammonia filter gas mask and gas-proof goggles need not be used.

Together with the specimens, accompanying old pyrite-damaged labels can also be treated (to neutralize any attached acidic oxidation products), and also attached specimen labels, which will usually remain in place, though old varnish may react slightly with ammonia to give a brownish tinge.

At the bottom of a desiccator (30 x 30 x 45cm.) a bowl is placed, containing 35% ammonia solution together with polyethylene glycol (PEG) 400, the proportions being 0.2ml. of ammonium hydroxide to 1gm. of PEG 400 [1]. Because PEG 400 is a liquid, it is necessary to weigh out 1gm. of PEG, and measure the volume. This results in a ratio of 4.4ml. PEG to 1 ml. ammonium hydroxide, which can then be scaled up to suit the size of container. This has involved a certain amount of experimentation, initially resulting in specimens having to be re-treated. But for a desiccator of size 30 x 30 x 45cm., a working ratio of 330ml. of PEG to 75ml. of ammonia solution works for most small and medium sizes of specimen. Obviously, for larger specimens, more ammonia and PEG 400, in the same proportions, are required.

The specimens all rest on polyethylene foam pieces in the desiccator for two reasons. First, it allows better flow of ammonia around the specimens, since they do not then block the holes in the desiccator shelves. Second, it cushions them, as the crumbly orange reaction products of the treatment, ammonium sulphate and ferrous hydroxide, tend to make the specimens a little friable. Friability is reduced by the use of PEG 400 as a humectant, which depresses the water vapour pressure to the equivalent of about 50% RH, which should prevent condensation in fractures. (If ammonia solution only is used, then 100% RH is likely to be reached [2], and condensation, aided by deliquescence of the oxidation and reaction products, could then occur in fractures in the specimen, which may then disintegrate [1].).

Obviously it is necessary to know when the ammonia has been depleted, and consequently how long to leave the specimens in for. The standard indicating tube is about 5mm. wide, and is filled with a mixture that reflects the density and constituent compounds of typical pyritized specimens, such as ferrous sulphate (representing the powdery sulphates) and glass beads, representing the fine granular material such as quartz and euhedral pyrite. A 1:1 ratio of glass beads and ferrous sulphate is tamped into the tube, and this is cello taped to the upper part of the door, where the top shelf of specimens reside. This is to indicate that the ammonia has penetrated the uppermost specimens.

As the reaction proceeds, a blackish brown colour will progress down the tube, so it is easy to measure the daily progress. When it stops, the ammonia is, to all intents and purposes, depleted. This can take up to 10 days. [N.B. Chris Collins recommends no more than 5 days, even if the reaction front is still progressing. The reason for this is that PEG 400 absorbs water and binds it in rather than buffering the environment in the way that silica gel does [2]. Thus after a few days the PEG 400 will have absorbed as much water as it can, and the RH in the treatment desiccator will start to rise to unacceptably high levels [2].] The reaction front will usually travel approximately 30mm. down the tube, which is usually enough to penetrate, via microcracks, all the way to the centre of each specimen. It may also be necessary to replace the PEG 400 and ammonia solution, if, after 5 days, the reaction front has not progressed as far as is necessary to ensure complete penetration of the largest specimens.

PEG 400 can be recycled, and according to Waller, you should heat the solution to 150 deg. C, to drive off the water, and it can only be recycled so long as the solution remains colourless. But I find that if the temperature rises above 120 deg. C then it turns yellow, which means that it has degraded into PEG's with higher vapour pressures, and then should definitely NOT be recycled. I have found that the PEG 400 can only be recycled successfully no more than twice, even though Waller states that four times should be possible. [N.B. Chris Collins recommends that only fresh dry PEG 400 should be used, as even Rob Waller finds recycling tricky and has had problems with breakdown of PEG 400 [2].].

After completion of the treatment process, the specimens are then placed in another desiccator for a week, at the bottom of which is a tray full of conditioned silica gel. This is where the specimens are conditioned to their final storage RH% of 30-33% and also to allow the ammonia to dissipate. It is useful to keep a thermohygrometer in the desiccator to check that the RH never rises above 33%, as occasionally desiccator seals are not as airtight as they should be.

The indicating silica gel turns a beautiful shade of opaque cobalt blue, as ammonia is sorbed. This cobalt-ammonia complex is known as *cis* tetraamminedichlorocobalt(III) chloride ($[Co(NH_3)_4Cl_2]^+Cl^-$). After a couple of uses, this is replaced with more conditioned silica gel, having stirred it after the first use in order to expose more silica gel for ammonia sorption on the next occasion.

3. Conditioning the silica gel.

The method for conditioning small quantities of silica gel to a specific relative humidity, and hence equilibrium moisture content, is to allow them to equilibrate with a saturated salt solution which reliably enforces a known relative humidity. In the case of pyritic specimens, the silica gel is conditioned using magnesium chloride, which will enforce an ERH of 33%. 33% RH is a compromise between not allowing specimens to become too dry (particularly where clay minerals are present in the matrix) and the less than 30% recommended for the storage of pyritic specimens. In practise, the silica gel often is conditioned to about 30%, due to lack of time spent in the desiccator.

Potassium carbonate enforces an ERH of 43%. This is mostly used for the storage of vulnerable palaeontological material that is not pyritic, but which will suffer damage due to daily fluctuations in temperature / RH.

To condition the silica gel for pyritic specimens, make up a saturated solution of magnesium chloride, leaving an excess of about 1 cm. of precipitated salt in each container used. This minimizes concentration gradients in the solution, and ensures that whatever the atmospheric temperature, the solution will remain saturated. It has been found that for the size of desiccator used (30 x 30 x 45cm.), it is necessary to mix up about 2 litres of saturated magnesium chloride. This is to keep maintenance of the magnesium chloride to a minimum (it will evaporate). To minimize salt creep, containers used should always be made of plastic, and straight-sided, and the solution should only take up half the volume of each. The containers are then placed on the bottom and about half way up the desiccator to allow for a more even circulation.

The silica gel to be conditioned should be spread thinly in several 1cm. deep polystyrene trays, together with, but not on the same shelf as, the saturated magnesium chloride solution. These polystyrene trays are supported on polyethylene foam blocks, so as not to impede the circulation around the desiccator. About 800gm. of dry silica gel can be conditioned to 33% RH in 3-4 weeks. If more silica gel is put in, it just takes longer to condition. Therefore it is useful to have 2 or 3 desiccators conditioning the silica gel, according to need.

To re-condition used silica gel, which is at ambient RH, just place in a **very** low oven for a few hours with a thermohygrometer, to dry it to about 25 % RH, before placing it in the desiccator with the magnesium chloride to finish conditioning. If silica gel is to be used to enforce an RH **below** the average ambient RH, it should first be conditioned to too low an RH, then conditioned upward to the required RH. This will enforce the conditioned RH for longer, as it minimizes problems with hysteresis. (Hysteresis in silica gel results in a reduced capability to enforce the conditioned RH, i.e., the desorption curve is offset from the adsorption curve, and the RH drifts towards the ambient.) [3]

4. Storage and monitoring.

After the specimens have been conditioned for a week, they are stored in Stewart box microclimates with a humidity strip and a measured quantity of conditioned silica gel dependent upon the size of Stewart box.

Specimens can be a little friable after treatment, and so they are either placed in 2 cm. high polystyrene boxes lined with 1mm. thick 'Jiffy foam', or are surrounded by 'nests' of this inert polyethylene foam, depending on the size of the specimens. The specimens are then placed in the Stewart box. Old labels must be stored away from any **direct** contact with the specimen in case of further decay of the pyrite, preferably in an attached polyester wallet on the outside of the Stewart box.

To allow the conditioned silica gel maximum exposure inside the Stewart box, combinations of three sizes of the same 2 cm. high transparent polystyrene container (also obtainable from The Stewart Company) are again used. Measuring a specified amount into a polystyrene box causes minimal disturbance when changing the silica gel annually. Spreading silica gel across the bottom of the Stewart box underneath a layer of 'Jiffy foam' would cause undue disturbance to the specimens in these circumstances.

The amount of silica gel in each box is loosely based on the 20 kg. m^{-3} recommended by Gary Thomson in his 1977 paper 'Stabilization of RH in Exhibition Cases : Hygrometric Half-time' [4]. This was used as a starting point, taking into account the fact that the smaller the volume of a container, the greater will be the relative leakage from its lid seal, and hence more silica gel will be required than Thomson suggests. So, being constrained by (a) the size of the silica gel containers, (b) the need to have room for the specimen(s), and (c) the need to ensure that the silica gel will enforce the 33% RH for **at least** a year, workable amounts of silica gel that I use as standard for particular Stewart box sizes have been arrived at by experimentation. Since these boxes are fairly common in the Museum world, the following are examples of these workable amounts.

Workable weights of conditioned silica gel per Stewart box size to ensure 33%RH for at least one year

Stewart box size	Weight of silica gel used	G. Thomson recommended wt. (20 kg. / m-3)
0.5 litre (Butter Storer)	45gm.	4.5 times rec. wt.
1.0 litre (Lunch Pack)	70gm.	3.5 times rec. wt.
2.25 litre (Popular Pack)	90gm.	2.0 times rec. wt.
3.5 litre (Pizza Storer)	125gm.	approx. 1.75 times rec. wt.

The above weight used in Pizza boxes will actually enforce the 33% RH for 2 years, though it is important to check annually (now that the Stewart boxes are transparent) to see if the cobalt chloride has discoloured due to pollutants generated by oxidizing pyrite. Occasionally it happens that you may have to re-treat a specimen, but experience suggests that this happens in less than 5% of specimens treated. All smaller boxes must have their conditioned silica gel changed annually.

Though you do have to wear a dust mask and plastic gloves for Health and Safety reasons [5] when mixing the two sorts of silica gel, the biggest advantage of using indicating silica gel is that the cobalt chloride is very useful as a pollutant indicator, becoming, most commonly, yellowish brown (when the indicating silica gel is pink) or dirty greyish blue (when the indicating silica gel is blue), if the specimen needs re-treating (assuming there are no other pollutant generators in the box). This happens even before a sulphurous smell can be detected. This is obviously a reaction of gaseous oxidation products with the cobalt chloride.

Artsorb can be used in Stewart boxes in place of silica gel, but conditioning and any re-conditioning must be done by the manufacturers, which tends to make it expensive. Artsorb also lacks any pollution indicator.

The Stewart boxes must then be stored in a suitably stable environment, such as within wooden drawers inside wooden cabinets with doors, where our specimens are normally stored. Stability can be ascertained by regular

monitoring. There are many methods of monitoring, from the expensive radiometric systems to the inexpensive spot checks using thermohygrometers. But however monitoring is done, it is necessary to know the extent of any problem to decide how it can best be resolved. The buffering effect of our wooden cabinets and drawers appears to result in only a 10% variability in RH annually, between about 37% and 47%. (See Appendix 1). This is low enough for stability of conditioned micro-environments in the Stewart boxes, in that drift towards the average ambient RH will be slower, but RH is still too high to prevent some pyrite decay outside those microclimates.

This data was produced, not from the expensive radiometric system, but from weekly spot checks done with thermohygrometers. It is slightly more time-consuming, but for the internal drawer readings, because wood is such a good buffer, it is as accurate as the radiometric system, with which it has been checked for comparison.

All information about the specimen, including any conservation notes, appear on a conservation database which can generate the conservation labels attached to the lids of the Stewart boxes, and annual checking reports, so that one knows exactly which specimens to check and when, where they are stored in the Museum, and which ones need re-treating.

5. Problems encountered whilst treating minerals.

When treating minerals for pyrite decay, one has to take into account the associated minerals on the specimen. Each case must be assessed individually, since other sulphides may be present, such as chalcopyrite and chalcocite, which are not only sensitive to the presence of acids, but to alkalis such as ammonia. Frank Howie's chapter on 'Sulphides and allied minerals in collections' in 'The Care & Conservation of Geological Material' [3] is invaluable as a starting point in this respect.

There are two types of low temperature instability in sulphides and allied minerals: tarnishing, which is a self-limiting and non-destructive surface effect and is **generally** not influenced by crystal size and shape; while oxidation reactions which occur in the presence of water vapour in air are predominantly influenced by the surface area available for oxidation, and are normally destructive. Because hydrated oxidation products are formed in

both cases, if *d*-block transition metal ions are present, reaction with ammonia will often be accompanied by colour changes, which may be undesirable.

Tarnishing.
Tarnishing occurs with a number of sulphides and sulphosalts including most of those containing iron, lead, iron-copper mixtures, copper, nickel and cobalt. Often the reason appears to be due to the presence of 'impurities' such as other metal sulphides, for instance, the tarnishing of galena is likely to be due to the presence of a silver sulphide, with which galena is almost always associated. Most commonly, in the context of pyrite decay, is the presence of iron and its destabilizing effect on copper sulphides. Thus with chalcopyrite ($CuFeS_2$), very often found in association with oxidizing pyrite, a series of complex oxidation and transformation reactions occur in which iron is transported to the surface of the mineral, where it is oxidized, electrochemically, to a hydrated ferric oxide, probably complexed with water of hydration or hydroxyl ions (brown-red colours). The remaining sulphur-enriched copper sulphide underneath is oxidized slowly to copper sulphate (iridescent blue).

Oxidation reactions which occur in the presence of water vapour in air.
Oxidation reactions which occur in the presence of water vapour in air take place generally above 30% RH, hence the necessity of storage in a low RH environment after treatment. Typically, this type of reaction involves the oxidation of a sulphide to a sulphate species and the retention of H^+ ions in the reactive aqueous film on the surface of the mineral. Thus oxidizing pyrite will often cause appreciable oxidation of accompanying sulphides, even those that are normally very stable. One particularly common mineral assemblage found in intimate association with oxidizing pyrite are the sulphides sphalerite (ZnS) and galena (PbS). Under normal situations sphalerite is extremely stable, doesn't tarnish or react in air, but is **extremely** sensitive to the presence of acids, and will rapidly decompose when associated with oxidizing pyrite, as will galena.

Transition metal complexing.
In both types of low temperature instability, ammonia will react with the **hydrated** oxidation products of most *d*-block transition metal ions to produce a typical ammine complex, often, but not always, with accompanying colour changes; for instance, $[V(NH_3)_6]^{3+}$, $[Co(NH_3)_6]^{3+}$, $[Co(NH_3)_6]^{2+}$, $[Cr(NH_3)_6]^{3+}$, $[Ni(NH_3)_6]^{2+}$, $[Cu(NH_3)_4]^{2+}$, $[Co(NH_3)_4Cl_2]^+$, $[Cr(NH_3)_2Cl_4]^-$, $[Ag(NH_3)_2]^+$ and $[Zn(NH_3)_4]^{2+}$, the last two of which are colourless. Iron forms aqua complexes but **not** ammine complexes in the presence of ammonia. Transition metal compounds are usually coloured because the energy difference between the orbitals is very small, which means that the transition elements can absorb energy in the visible region of the electromagnetic spectrum to promote the electrons in their outer shell from a low energy to a higher one, i.e., **unpaired** *d*-electrons rise from a lower to a higher energy state. When this happens a wavelength for a colour is emitted. Ions which have the electronic configuration $3d^{10}$ such as the Cu^+ ion or Zn^{2+} ion are colourless, because they do not have any unpaired *d*-electrons.

As an example: pre-treatment condition of a decaying pyritic specimen showed accompanying chalcopyrite altered to velvety dark bluish-black minerals, likely to be a mixture of mostly copper sulphides slowly oxidizing to hydrated sulphates. After treatment with partially-dried ammonia, there were many patches of different blues and violet colours, where the dark-bluish black minerals were. The likely reasons for this are (a) the initial reaction of water molecules or hydroxyl ions to form complex ions such as tetra aqua copper $[Cu(H_2O)_4]^{2+}$ (pale blue), or di hydroxo tetra aqua copper $[Cu(OH)_2(H_2O)_4]$ (pale blue), and then (b) excess ammonia giving deep blue cuprammine complexes such as di ammine tetra aqua copper $[Cu(NH_3)_2(H_2O)_4]^{2+}$ (blue-violet), or tetra ammine copper $[Cu(NH_3)_4]^{2+}$ (bright blue), whose composition depends on the amount of ammonia present.

Pharmacosiderite.
So far, transition metal complex formation with ammonia has been the problem, but the reaction of **pharmacosiderite,** $KFe^{3+}_4(AsO_4)_3(OH)_4.6$-$7H_2O$, with ammonia was unexpected, since iron does not form ammine complexes with ammonia. Originally, the crystals of the specimen were dark green in colour, but because of the decaying pyritic state of the matrix it became necessary to treat the specimen using ammonia gas. The results of this were quite dramatic, in that while the specimen was sur-

rounded by an atmosphere of ammonia the crystals turned a bright red. However, when removed from the ammonia, and placed in a much drier environment, the crystals again changed colour gradually over the course of the next week ultimately to a dark reddish brown.

The structure of pharmacosiderite consists of an open zeolitic-like framework $[Fe_4(OH)_4(AsO_4)_3]^-$ with channels filled with alkalis, alkaline earths and water molecules [6]. Like zeolites, the water content can vary considerably and the cations are easily exchangeable accompanied by typical colour changes [7] as described. Zeolites are used for ion-exchange in the chemical industry as molecular sieves and catalysts, and because of their structure, there is ongoing research into pharmacosiderites for this purpose. Since the framework is unlikely to have been altered [7], merely the channel fillings, it would probably be appropriate to call the specimen ammonium pharmacosiderite for reasons given below.

Initially [8], it was thought that the cause of the colour change was due to the K^+ in the formula having been replaced by NH_4^+ in a one to one ratio. But having researched the literature further, it appears not to be this simple, as only a trace of potassium or other alkali metals have been found by previous investigators [7] in the pharmacosiderite crystal structure, green or brown. Neither does it appear to be that the colour change is produced by Fe^{2+} to Fe^{3+} [9]. Mutter et al [6], have 'proved definitely the **absence** of Fe^{2+}' in both a green and brown specimen tested. So Fe^{3+} appears to be the correct ionic state in pharmacosiderite.

Whilst totally surrounded by ammonia (as partially dried gas) the bright red colour persists, so sorption of ammonia on the surface of the crystal and / or within the channels is likely to be taking place. Since **all** ion-exchange with alkalis produces bright red coloration [7], this suggests that it is the effects of these trace cations upon the Fe^{3+} ion (see explanation in paragraph below), possibly by the replacement of hydrogen (or hydronium) ions in the channels, that is the cause of the colour change. There are two sorts of water molecules found within the channels. Certain water molecules are too widely separated to be hydrogen bonded to each other, but are probably bonded to the hydroxyl oxygen atoms of the framework by relatively strong hydrogen bonds. Other water molecules appear to be too far from the framework to be bonded to it, but are probably

weakly bonded to the previous water molecules [7]. This allows for ammonia to have a possible indirect effect upon Fe via the hydroxyl oxygen of the framework.

The underlying mechanism for the colour changes noticed in the specimen of treated pharmacosiderite is likely to be transitions involving ligand field effects, which can be related to the incompletely filled 3*d* orbitals. If Fe is written thus: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$, denoting the arrangements of electrons in orbitals within shells, Fe^{2+} is: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$, and Fe^{3+} is: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5$. Absorption of light, and hence the coloured appearance of the specimen, is explained by electron transitions ***within*** the set of five 3*d* orbitals. All five 3*d* orbitals would normally have exactly the same energy level in the Fe^{3+} ion, but when this is surrounded by ligands (such as water), the 3*d* orbitals are no longer symmetrically arranged. Orbitals closer to the ligands are pushed to a slightly higher energy level than those further away. The 3*d* orbitals are split into two or more slightly different energy levels. The promotion of an electron from the lower to the higher of these *d* orbitals just happens to require energies within the range of visible light [10], and thus colour changes may occur. Complexing reactions involve competitions between different ligands for metal cations. The exchange of ions within the channels of the pharmacosiderite framework is thus likely to produce ligand orientation changes, causing the frequency, and hence colour, of the light absorbed to shift.

When removed from the gaseous ammonia, the colour of the crystals changed gradually from red to brown. There is likely to have been some ammonia desorption (though FT-IR results show at least some ammonia retention [11]), but the specimen was subjected to drier conditions than in the treatment desiccator where the PEG 400 only dries the ammonia to about 50% ERH [1]. It is likely then that the dark reddish brown that the specimen eventually became is due to further changes in the symmetry of 3*d* orbitals in the Fe^{3+} ion, brought about by different bonding arrangements due to loss of water and some ammonia from the channels.

Specimens of green pharmacosiderite from certain localities (Burdell Gill) have been known to change to brown naturally over a period of time [9]. Desorption of water is perhaps the likely reason, since this happens without the addition of alkalis. However, this does not explain why some

specimens from the same locality remain mostly green, as is the case at OUMNH. It is possible that they have a much higher water content, possibly reflecting different storage conditions, and / or a more acidic matrix, both contributing to a higher H^+ ion content. This needs further looking into.

It has been shown that treating with acidic solution causes the colour of brown specimens to return to green possibly by flooding the specimen again with H^+ (or H_3O^+) ions [7]. I feel it is probably not advisable to reverse the colour change of ammonium pharmacosiderite as this would mean undoing the neutralization of the pyrite decay, and the possibility of introducing instability into the specimen by means of micro-cracks which get worse with every ion-exchange process, i.e., crystals have been known to explode [6].

6. Conclusion.

When contemplating the treatment of pyritic mineral specimens, knowing which minerals are present makes it possible to predict which specimens are likely to produce coloured complexes in the presence of ammonia. These include the hydrated oxidation products of most *d*-block transition metal ions with unpaired *d* electrons, i.e., usually those with more than one important oxidation state, such as Ti, V, Cr, Mn, Fe, Co, Ni, Cu. Pharmacosiderite, with its hydrated open zeolitic-type framework and microchannels where ion-exchange may easily take place, with hindsight seems an obvious candidate for reaction with ammonia, but since knowledge of structural chemistry is not always in the forefront of one's mind, it is likely that other problems with ammonia may yet surface. It is not that this knowledge is unknown, but that conservators / curators with very little time to search literature are sometimes unaware of it and / or do not have the time to make it available to others. I hope therefore that this will help to promote further exchange of information on this matter.

Assessing specimens in a systematic way for any conservation needs upon acquisition makes sure of detecting all specimens with pyrite decay before unsightly oxidation products become too widespread. This can be followed by treatment if necessary, and most importantly, **correct storage**. Despite the problems that I've encountered with certain mineral specimens, most have been saved from their ultimate fate by following the

above regime. Even if specimens do fall apart after treatment it is not always a disaster, as the mineral assemblage that is important to the collections may have been saved, even though in several pieces. One also has to assess whether it really matters if treating with ammonia causes the formation of coloured complexes, since by not treating, one is possibly hastening the end of the specimen. This will obviously depend upon the importance of the specimen to the collection, and how much or how little of the specimen is likely to be affected. Putting it all in perspective, out of all the hundreds of specimens that I have treated, only about 5% have needed retreating, and one can count on the fingers of two hands those that have produced coloured complexes with ammonia. Ammonia is a successful treatment, and will remain important until we can **reliably** exclude water vapour and / or oxygen from vulnerable pyritic specimens.

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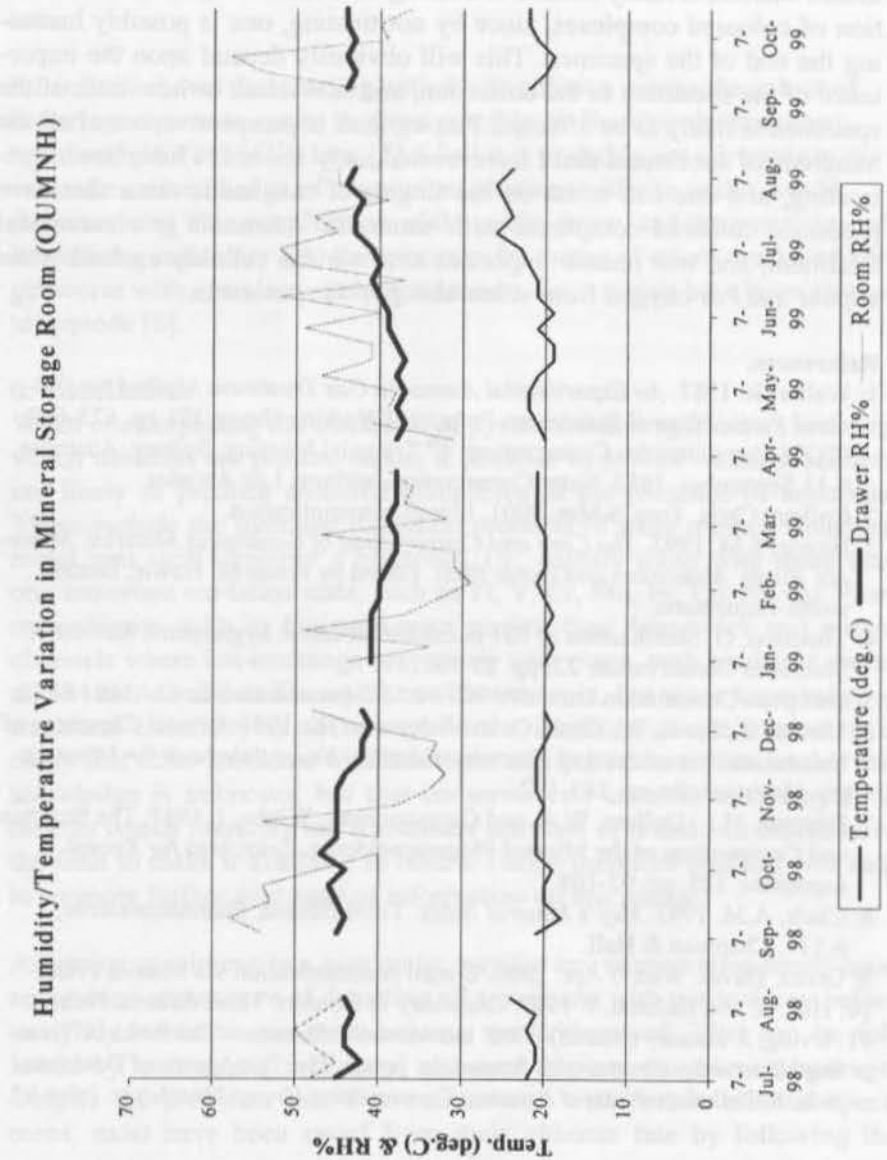
Appendix 1



SOCIETY FOR THE PRESERVATION OF NATURAL HISTORY COLLECTIONS

15th Annual Meeting, 8th-14th July 2000, Halifax, Nova Scotia, Canada.

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This year's SPNHC meeting, themed on Marine Biology, was held in the scenic city of Halifax, Nova Scotia, and hosted jointly by the Nova Scotia Museum of Natural History and the Geological Survey of Canada (Atlantic). In total, 115 delegates attended, including a Cuban, a Bermudan, two Dutch and four Brits. (Rob Huxley, William Lindsay, Julian Carter & Paul Brown), the rest being Canadians and Americans. Many delegates stayed at Shirreff Hall, part of Dalhousie University student accommodation.

The first official activities of the week consisted of field trips; whale watching in the Bay of Fundy, Nova Scotia's south shore, and the Joggins and Parrsboro Geology Tour. This delegate went on the latter, a coach ride through the forests and lakes of the glaciated Cambrian and Ordovician slates and greywackes of the central area, to the more agricultural Carboniferous red sandstones to the North. We visited the Fundy Geological Museum, Parrsboro, where we were guided round the small but well equipped fossil preparation laboratory by Tim Fedak, who showed us dinosaur fossil preparations currently being worked on. The public galleries had a good mix of real specimens and interactive models, with views over the Parrsboro Creek, just yards away. The Bay of Fundy reputedly has the highest tides in the world, so one hopes that this museum is built where it will not be inundated by abnormal tide and weather conditions! We then moved to the coastal cliff exposure of Carboniferous sandstones and coal seams, to see where the best of the reptile remains have been found. We were provided with a free Nova Scotia geology map and a series of papers on the local geology.