FLUID INCLUSION-BEARING HALITE AND SOLAR GASES IN THE MONAHANS 1998 H5 CHONDRITE. M.E. Zolensky[1], R.J. Bodnar[2], D.D. Bogard[1], D. H. Garrison[3], E.K. Gibson[1], M. Gounelle[4], L.E. Nyquist[1], Y. Reese[3], C.-Y. Shih[3], H. Wiesmann[3]; [1]SN2, NASA, Johnson Space Center, Houston, TX 77058 USA, [2]Department of Geological Sciences, Virginia Tech, Blacksburg, VA 24061 USA, [3]Lockheed Martin SMSS Company, Houston, TX 77058 USA; [4]Centre Spectrometrie de Nucleaire et de Spectrometrie de Masse, Bâtiment 104, Orsay, France.

Monahans 1998 fell on March 22, 1998. One of the stones was broken open at JSC less that 72 hours later and was found to consist of Light, Grey and Dark lithologies, with purple halite (NaCl) in the Gray [1]. All Monahans lithologies are H5, with the shock level increasing from S2 (Light) to S4 (Dark). Crystals of sylvite (KCl) are present within the larger halite crystals, similar to their occurrence in terrestrial evaporites. The purple color of the halite is probably due either to exposure to solar and galactic cosmic rays, or (more likely) by exposure to beta decaying ^{40}K in the sylvite. The presence of halite/sylvite solely within one breccia component shows that it formed before final aggregation of the meteorite. We describe here noble gas analyses, Rb/Sr systematics of halite separates, and aqueous fluid inclusions present within the halite.

Noble Gas Analysis The three lithologies of Monahans were analyzed for noble gases (Figure 1). Relative amounts of He, ^{20}Ne, and ^{36}Ar in the Gray and Dark samples indicate a major contribution of solar-wind-implanted gases, but these are only ~5-10% as large as those in Pesyanoe and Fayetteville, meteorites with the largest known concentrations of solar wind gases. However, Ar/Xe ratios for the Gray and Dark clasts suggest that much of the Xe in these two samples is indigenous and occurs in concentrations similar to that for many ordinary chondrites [2]. Surprisingly, the Dark lithology contains less solar gas than does the Gray sample, but has Xe concentrations similar to the Gray sample. This supports the suggestion that the darkening of this clast was caused by shock, and not by solar irradiation or the presence of carbonaceous material.

Neon in the three samples indicate the presence of three components, of which two derive from the sun. The first temperature extraction of the Gray sample gave ^{20}Ne/^{22}Ne =13.38, which approaches the solar wind value of ~13.8 [3&4]. The 1600°C extraction of the Light sample released pure cosmogenic neon. All other extractions fall below a two-component, solar wind and cosmogenic mixing line. This suggests the significant presence of an implanted energetic solar component, or SEP-neon, having a ^{20}Ne/^{22}Ne ratio of ~11.3 [4]. The solar wind and SEP Ne components occur in comparable abundances.

Most ^{4}He and ^{40}Ar in Monahans Light were produced by radioactive decay and essentially all ^{3}He, ^{21}Ne, and ^{38}Ar were produced by cosmic ray interactions. The cosmogenic ^{21}Ne/^{22}Ne ratio of 0.928 indicates space irradiation as a moderately large object [5]. If we assume noble gas production rates for H-chondrites [6], the calculated space exposure ages are ^{3}He =5.8 Myr, ^{21}Ne =5.0 Myr, and ^{38}Ar =5.4 Myr, comparable to other H chondrites [7].

We used noble gas concentrations for the Light sample to correct for cosmogenic and radiogenic components in the Gray sample, assuming that trapped ^{21}Ne/^{22}Ne has either the solar wind or SEP value [4]. The calculated concentration of cosmogenic ^{21}Ne in the Gray sample is 2.98 or 3.04x10^{-8} cm^{3}STP/g, respectively. Similarly, if trapped Ar has ^{36}Ar/^{38}Ar between the terrestrial value of 5.32 and a solar wind value of ~5.5 [4], then the concentration of cosmogenic ^{38}Ar in the Gray sample is 3.4-4.2 x10^{-9} cm^{3}STP/g. These concentrations of ^{21}Ne$_{cos}$ and ^{38}Ar$_{cos}$ are ~90% and ~60-100% larger, respectively than ^{21}Ne$_{cos}$ and ^{38}Ar$_{cos}$ calculated for the Light sample. We interpret this difference to indicate that the solar-irradiated phase of Monahans was preirradiated for a few Myr in the regolith of its parent body prior to its ejection as a meteorite. The excess ^{21}Ne and ^{38}Ar in the Gray phase represents a cosmogenic component produced prior to formation of the Monahans breccia. Similar regolith irradiations have been observed for other solar gas-rich meteorites [8&9].

The ^{4}He/^{3}He ratio in Monahans also seems consistent with a preirradiation of the Gray phase. If we assume concentrations of ^{3}He$_{cos}$ and radiogenic ^{4}He in the Light sample also occur in the Gray sample, then the calculated ^{4}He/^{3}He ratio for the solar component is ~2025. This value is slightly less than measurements of the recent solar wind He [3&4], and is considerably less than that measured in very gas- rich meteorites such as Fayetteville and Kapoeta [9&10]. If, in comparison to cosmogenic ^{21}Ne and ^{38}Ar, we assume that the concentration of cosmogenic ^{3}He in Monahans Gray is 90% larger than that of Monahans Light, then the corrected solar ^{4}He/^{3}He becomes ~3800. The reason why gas rich meteorites apparently have larger trapped ^{4}He/^{3}He compared to the recent solar wind is not completely understood.

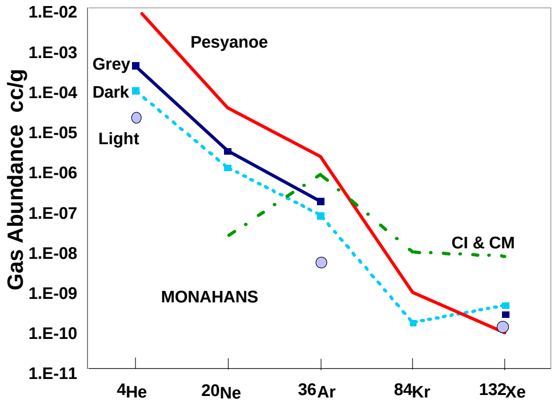

Figure 1 Noble gas results for Monahans

Rb/Sr analysis One mg of halite/sylvite was consumed by Rb/Sr analysis by mass spectrometry. This halite/sylvite contains 3.75 +/-0.08 ppm Rb and 0.257 +/-0.006 ppm Sr. ^{87}Rb/^{86}Sr = 43.3 +/-1.6, ^{87}Sr/^{86}Sr = 3.59 +/-0.07. Using a ^{87}Rb decay constant of 0.01402 Ga^{-1}[11], and initial ^{87}Sr/^{86}Sr = 0.698972 [12], the calculated Rb-Sr model age for the halite is 4.7 +/- 0.2 Ga. Because the isotopic composition of Sr in the halite/sylvite is extremely radiogenic, the model age must be a very good approximation of the formation age of the halite; it formed very early in the history of the Monahans 1998 parent asteroid.

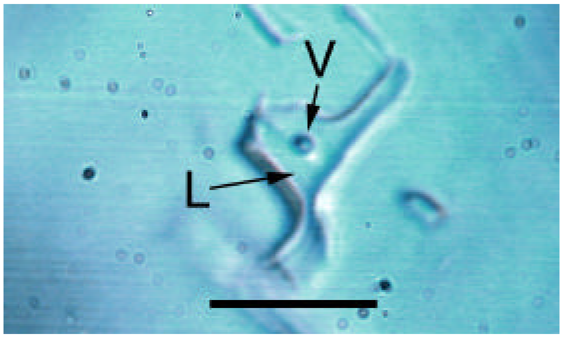

Figure 2. Isolated (primary) inclusion in halite. The inclusion contains a liquid (L) and a small vapor bubble (V). The scale bar measures 10μm.

Fluid Inclusions Primary and secondary aqueous fluid inclusions are present in the halite. The inclusions range up to 15μm in longest dimension. At room temperature, a few of the inclusions contain vapor bubbles that are in constant Brownian motion (Figure 2), proving that the inclusions contain both liquid and vapor. Microthermometric analysis of the inclusions indicates that, in addition to Na^{+} and K^{+}, the aqueous liquid in the inclusions must contain additional divalent cations such as Ca^{2+} or Mg^{2+}. Most of the inclusions do not contain a vapor bubble at room temperature, suggesting a low formation temperature (less than 100°C, and probably less than 50°C), assuming that the formation pressure was low - a few 10s of bars at most. The halite precipitated relatively rapidly, based on its polycrystalline texture.

Most of the inclusions occur along healed fractures in the halite and are demonstrably secondary in nature. Other inclusions are isolated and represent primary inclusions trapped during initial halite deposition. The presence of both primary and secondary inclusions in the halite could indicate prolonged or episodic introduction of aqueous fluids into the halite depositional environment.

Implications for Asteroid Evolution The surprising presence of evaporites within an H5 chondrite, containing actual samples of the aqueous mineralizing fluid, is very exciting. These are the first aqueous fluid inclusions found in an extraterrestrial sample which are clearly not artifacts of sample preparation or fluids introduced after the sample arrived on earth. Measurement of the fluid composition (in progress) will permit realistic modeling of asteroid alteration; in the past we have always had to "make up" the fluid composition. Measurement of the oxygen and hydrogen isotopic composition of the fluid will shed light on the source of water in the early solar system. Apparently, water was more common on asteroids than we realized, and chondrite metamorphism paths should be reconsidered. It should be possible to more precisely date the sylvite/halite by the ^{39}Ar/^{40}Ar laser ablation technique.

Halite was noticed in Monahans 1998 because of its attractive purple color and large grain size, and this permitted special sampling and thin-sectioning procedures to be employed which preserved the halides. It is possible that halite is commonly present in chondrites, but has been overlooked, resulting in errors in bulk Cl determinations for chondrites. It is also possible that a fraction of the sulfate/halide efflorescence noted on Antarctic meteorites is derived from halite, rather than from indigenous contaminants in the ice.

References [1] Gibson et al. (1998) *MATS* **33**, A57; [2] Zahringer (1968) *GCA* **32**, 209; [3] Geiss et al. (1972) *NASA Spec. Publ. SP-315*, 14.1; [4] Benkert et al. (1993) *JGR*. **98**, 147; [5] Graf et al. (1990) *GCA* **54**, 2521; [6] Eugster (1988) *GCA* **52**, 1649; [7] Graf and Marti (1995) *GCA* **54**, 2521; [8] Rao et al. (1997) *Meteoritics* **32**, 531; [9] Wieler et al., 1989; [10] Rao et al. (1993) *JGR* **98**, 7827; [11] Minster et al. (1982). *Nature* **300**, 414; [12] Nyquist et al. (1994) *Meteoritics* **29**, 872.