EXPOSURE AGES OF H-CHONDRITES AND PARENT BODY STRUCTURE.

Thomas Graf and Kurt Marti, Dept. of Chemistry, B-017, Univ. of Calif., San Diego, La Jolla, CA 92093

For the case of a simple exposure history, the exposure age of a meteorite measures the time between the separation of a meteoroid from its parent body and its capture by the Earth. Cosmic ray interactions in meteorites produce spallation and neutron capture products and the production rates depend on the chemical composition, the size of the meteoroid and the location of the sample within the meteoroid. Spallation He, Ne, and Ar were determined in a large number of meteorites (see 1), and clusterings of meteorite exposure ages were recognized by several workers and were interpreted as evidence for parent body break-ups (3-8). Some radioactive nuclides with half-lives shorter than meteorite exposure ages (in secular equilibrium) were used to determine production rates, and during the past few years, significant progress was made in the evaluation of production rates (9-11). Since recently far-reaching inferences were drawn regarding the structure, fragmentation and possible reassembly histories of asteroids (12,13), we considered it important to carefully reevaluate the cosmic ray records in meteorites. We selected the H-chondrites as the first class of meteorites in this effort, and we present here the exposure age distribution obtained for the H6 group. Studies of other H-chondrites are currently in progress. We shall first discuss selection criteria applied to the updated data compilation of Schultz and Kruse (1,2):

Cosmic-ray produced ^{21}Ne, ^{22}Ne, and ^{38}Ar are determined assuming atmospheric isotopic composition for the trapped component. Whenever possible, ^{22}Ne/^{21}Ne ratios are used to correct for shielding differences. If the ^{20}Ne/^{22}Ne ratio is larger than 1.2, the uncertainty of cosmogenic $(^{22}\mathrm{Ne}/^{21}\mathrm{Ne})_c$ is larger than $\pm 1\%$ causing an error of the ^{21}Ne shielding correction of about 20%. Therefore, mean production rates (i.e. production rates corresponding to a shielding described by $(^{22}\mathrm{Ne}/^{21}\mathrm{Ne})_c = 1.11$) are used for all samples with $^{20}\mathrm{Ne}/^{22}\mathrm{Ne} > 1.2$ as well as for samples with $(^{22}\mathrm{Ne}/^{21}\mathrm{Ne})_c < 1.06$ or $(^{22}\mathrm{Ne}/^{21}\mathrm{Ne})_c > 1.25$. ^{3}He concentrations are also corrected for a trapped component assuming $(^{4}\mathrm{He}/^{3}\mathrm{He})_{tr} = 3500$, only if the amount of ^{4}He is larger than 1700 x 10^{-8} cm^3 STP/g. In cases were loss of ^{3}He is possible ($^{4}\mathrm{He} < 1000 \times 10^{-8}$ cm^3 STP/g), no ^{3}He age is computed. Spallation data are rejected if the uncertainties caused by the correction for trapped components exceed 20%. Shielding corrections were carried out following Eugster (10) who used the procedure of Nishiizumi et al. (9). Calculated ages derived from ^{38}Ar concentrations are systematically lower by about 10% than ^{21}Ne and ^{3}He ages. Since this is true for H, L, and LL chondrites, we reduce by 10% the ^{38}Ar production rate proposed by Eugster. Our tests show that in most cases (70%), the shielding corrected production rates reduce the scatter in calculated exposure ages derived from ^{3}He, ^{21}Ne, and ^{38}Ar concentrations which indicates that our procedure is reasonable.

Next, we classify the meteorite data into three classes of differing quality: Class A data meet one of the following criteria: i) All three shielding corrected ^{3}He, ^{21}Ne, and ^{38}Ar exposure ages agree within $\pm$12% and the ^{22}Ne/^{21}Ne ratio is larger than 1.08; the latter is required because of limits on the preatmospheric size of the meteoroids where the above shielding corrections apply (11). Averages of the ages T_3, T_{21}, and T_{38} are used. ii) At least two of the three ages agree within $\pm$8% and the ^{22}Ne/^{21}Ne ratio is larger than 1.08. In addition, there has to be an explanation for the discrepancy in the third age (e.g. diffusion loss of ^{3}He indicated by $^{4}\mathrm{He} < 1000 \times 10^{-8}$ cm^3 STP/g, large abundance of the trapped component). Averages of the two ages are used. iii) All three ages agree within $\pm$10% when no shielding correction is applied; an average is used. Class B data meet one of the following criteria: i) For samples with $^{22}\mathrm{Ne}/^{21}\mathrm{Ne} > 1.08$, all three ages agree within $\pm$20%, or if two ages are available and agree within $\pm$15%. If the ^{22}Ne/^{21}Ne ratio is smaller than 1.08, the ages have to agree within $\pm$12% and $\pm$8%, respectively. ii) If only ^{21}Ne exposure ages are available, only meteorites with ^{22}Ne/^{21}Ne ratios larger than 1.09 and smaller than 1.13 are included. iii) All three ages agree within $\pm$20% or two ages agree within $\pm$8% when no shielding correction is applied. The remaining data belong to class C. When more than one analysis is available for a given meteorite, the exposure age of the highest class is used. We estimate that the uncertainties of the exposure ages are less than $\pm$10% for meteorites in class A, about $\pm$15% for meteorites in class B and $\pm$25% for class C, although some of the class C data may have much smaller error limits.

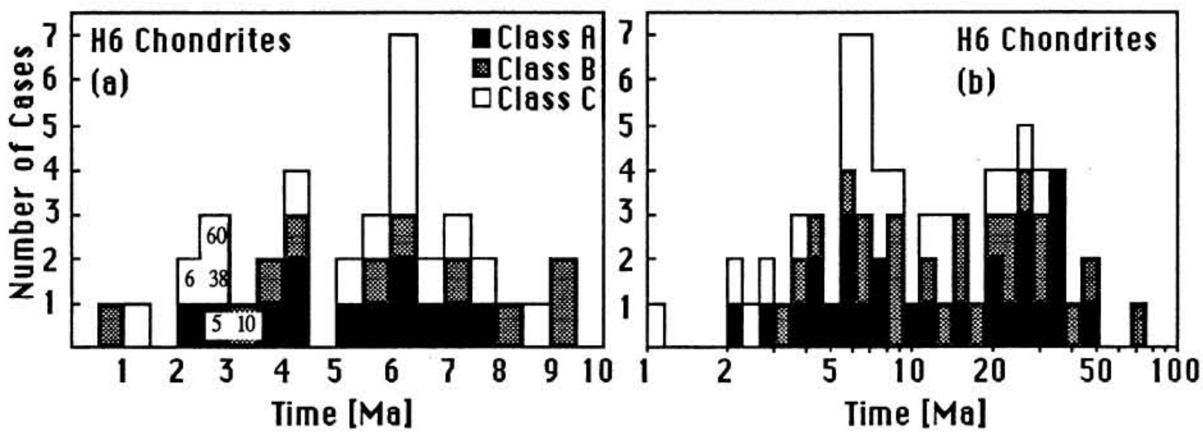

Figure 1: Exposure age distribution of H6 chondrites on (a) a linear scale for 0-10 Ma and (b) a logarithmic scale for 1-100 Ma. The resolution is 0.5 Ma in (a) and 10% of the age in (b).

The exposure age distribution of the H6 chondrites is shown in Figures 1a and 1b. There are 111 measurements from 73 different H6 chondrites available. Note, that there is no significant change in the distribution if only ^{21}Ne ages are plotted. The distribution shows a peak at about 6.2 Ma and another peak at about 4.2 Ma. Both peaks appear in the individual distributions of each quality group. The 4.2 Ma peak is asymmetric with a tail towards lower exposure ages. Numbers in the histogram indicate the low but almost identical percentages of retained ^{4}He and ^{40}Ar in these meteorites (assuming totals of $^{4}He = 1700 \times 10^{-8}$ cm^3 STP/g and $^{40}Ar = 6000 \times 10^{-8}$ cm^3 STP/g to be 100%). ^{4}He and ^{40}Ar concentrations are strongly and similarly depleted in 4 out of 6 meteorites with exposure ages between 2 and 3.5 Ma. This is in sharp contrast to ^{4}He and ^{40}Ar retention close to 100% for meteorites with exposure ages belonging to the 4.2 and 6.2 Ma peaks. Unfortunately, it is not possible to determine reliable $(^{22}Ne/^{21}Ne)_c$ ratios for these meteorites. Therefore, it is unknown wether the respective data points would fall below the correlation line in a $^{3}He/^{21}Ne$ vs $^{22}Ne/^{21}Ne$ diagram. However, at least one of the meteorites (Doroni) lost not only radiogenic ^{4}He and ^{40}Ar, but also cosmogenic gases ($^{3}He/^{21}Ne < 1.8$), indicating that its true exposure age is higher than 2.8 Ma. There are clusters of exposure ages between 20 and 35 Ma, but the number of distinct peaks is unclear at present because of poor statistics. The results for meteorites of different petrographical type will help to improve the statistics if the distribution is the same.

References: (1) Schultz, L. and Kruse, H. (1983) Special publication of the MPI, Mainz. (2) Schultz, L. and Kruse, H. (1988) pers. comm. (3) Anders, E. (1964) Space Sci. Rev. 3, 583-714. (4) Hintenberger, H., Konig, H., Schultz, L. and Wanke, H. (1964) Z. Naturforsch., 19A, 327-341. (5) Eberhardt, P. and Geiss, J. (1964) in: Isotopic and Cosmic Chemistry (eds H. Craig, S. L. Miller, and G. J. Wasserburg), 452-470. (6) Wanke, H. (1966) Fortschr. Chem. Forsch., 7, 322-408. (7) Tannenbaum, A.S. (1967) Earth Planet. Sci. Lett., 2, 33-35. (8) Schultz, L. and Crabb, J. (1981) Geochim. Cosmochim. Acta, 45, 2151-2160. (9) Nishiizumi, K., Regnier, S. and Marti, K. (1980) Earth Planet. Sci. Lett., 50, 156-170. (10) Eugster, O. (1988) Geochim. Cosmochim. Acta, 52, 1649-1662. (11) Graf, Th., Signer, P. and Wieler, R. (1989) in prep. (12) Taylor, G. J., Maggiore, P., Scott, E. R. D., Rubin, A. E. and Keil, K. (1987) Icarus, 69, 1-13. (13) Lipschutz, M. E., Gaffey, M. J. and Pellas, P. (1989) submitted to Asteroids II.