COSMIC RAY PRODUCTS IN THE GHUBARA (L5) REGOLITH BRECCIA. T. E. Ferko[1], M. E. Lipschutz[1], N. Bhandari[2], A. K. Singhvi[2], R. Hutchison[3], P. H. Benoit[4], D. W. G. Sears[4], L. Franke[5], P. Scherer[5], and L. Schultz[5], [1]Purdue University Department of Chemistry (1393 Brown Building West Lafayette, IN 47907-1393 ferko@purdue.edu), [2]Physical Research Laboratory (Ahmedabad, India), [3]British Museum of Natural History (London, England), [4]University of Arkansas Department of Chemistry and Biochemistry (Fayetteville, AR), [5]Max-Planck-Institut für Chemie (Mainz, Germany).

Introduction: As part of a consortium study we have measured noble gases, cosmogenic radionuclides nuclear tracks, and thermoluminescence in samples obtained from three orthogonal cores of a 101.6 kg complete stone of the Ghubara L5 chondrite (sample 1958,805 from the British Museum of Natural History's Collection) [1]. Over 226 kg of the Ghubara meteorite have been recovered from desert surface in Oman since 1954 and this stone represents nearly 50% of recovered material. Our results indicate that this sample experienced a heating history that varies greatly from other Ghubara stones previously studied.

Samples and Measurements: Three orthogonal cores, all between 41 and 46 cm long were taken at the British Museum of Natural History using a rotary diamond drill cooled with distilled water. Cores were cut in half lengthwise with half being retained in London for archival purposes. From the other half, we measured various cosmic ray products from samples at various depths. Sections from the ends of each core (0.8-3.2 cm long) were analyzed for nuclear tracks at PRL. Based on descriptions of matrix and two different xenoliths in Ghubara [2], sample materials of various identity were isolated from one another during further sampling. Where host and xenolith materials were able to be isolated in close proximity, paired samples were removed for thermoluminescence measurement at the University of Arkansas. Aliquots of sections approximately 1cm in length (~1g) from various depths throughout the remainder of each core were measured for noble gases at MPI and for cosmogenic radionuclides ^{10}Be, ^{26}Al, and ^{36}Cl at Purdue University. Several follow-up measurements of thermoluminescence were also made at PRL to place constraints on the heating history.

Results:

Noble Gases. Previous noble gas measurements of Ghubara [3-5] indicated a regolith breccia with high levels of solar gases with ^{4}He, as an example, ranging from ~3000-14000 ($\times 10^{-8}$ cm^3 STP/g). He and Ne isotopes for a representative core sample of BM 1958,805 (a sample from near the center of the "A" core) and second stone (BM 1954,207) are shown in Table 1. Ratios of ^{4}He/^{20}Ne in these two samples indicates significant removal of ^{4}He in the cored stone.

Radionuclides. ^{10}Be activities range between 15 and 18.7 dpm/kg and ^{26}Al activities range from 57 to 64 dpm/kg. ^{36}Cl in magnetic separates average 15.5 dpm/kg metal. While ^{26}Al agrees with average production rates for L-chondrites (60 dpm/kg) both ^{10}Be and ^{36}Cl are less than average production rates of 22.1 and 22.8 dpm/kg respectively [6]. No previous measurements of these radionuclides in Ghubara are known.

Tracks. Samples were etched both for olivines and pyroxenes but did not show appreciable cosmic ray tracks in either mineral, even for near-surface grains. The upper limit of track density in two olivine samples was $\leq 10^4$/cm^2. Nuclear track densities in olivines of another sample, (BM 1954,207), were appreciably higher, ranging from 3.2×10^4/cm^2 to 3.4×10^5/cm^2.

Thermoluminescence. Thermoluminescence measurements at the University of Arkansas (on core samples) and PRL (on both a core end fragment and a sample of BM 1954,207) indicate that the low temperature (<270 °C) natural TL in Ghubara is absent. This suggests that samples were heated to ~250°C momentarily or at lower temperatures for longer times. Consistent with this, the equivalent dose of the high temperature natural TL (~330 °C) is ~50 krad, somewhat lower than typical values (~100 krad).

The induced TL measured throughout the Ghubara cores at the University of Arkansas indicates a regolith breccia of moderate maturity, comparable to St. Mesmin and less mature than Leighton [7].

Discussion: Based on the formalism of Eugster [8], an exposure age of 12 to 13 Ma is calculated from cosmogenic ^{21}Ne. For this time of exposure all cosmogenic radionuclides should have been at saturation at the time of fall. Assuming a cosmogenic ^{22}Ne/^{21}Ne ratio of 1.08, radionuclide activities suggest sample depths of approximately 20 cm in objects of 70-90 and 100-150 cm radii respectively for ^{26}Al (Fig. 1) and ^{10}Be based on the model of Graf et al. [9]. With Ghubara being a regolith breccia we are not able to use measured ^{22}Ne/^{21}Ne as relative depth indicators so the use of this model for Ghubara is only an estimate. However, the low track densities in end samples of the cores also suggest depths of 10-20 cm in a meteoroid with a radius larger than 40 cm.

From the brecciated nature of this meteorite it is expected that the track production rate during exposure on the surface of the parent body must have been significant but no traces of high density VH tracks (>10^7/cm^2) or steep track gradients, characteristic of solar cosmic rays, is found. This indicates that during the ultimate ejection event of the meteorite from the parent body, or later, the body was heated to a temperature high enough to anneal all the tracks barring some possible VVH tracks which now appear as "ghost" tracks.

Likewise, noble gases in Ghubara core samples indicate the loss of ^{4}He and ^{3}He, probably by late heating. While both core samples and prior measurements indicate ^{3}He loss (from low ^{3}He/^{21}Ne ratios) the core samples are depleted >87% in ^{4}He relative to these previous measurements (Table 1). To check this, a sample of a different Ghubara stone (BM 1954,207) was analyzed in a similar manner and contents of He and Ne isotopes agreed with prior data [5] and disagreed markedly with those in 1958,805 (Table 1), and in another recently recovered sample. Based on heating experiments on the Fayetteville regolith breccia [10], a single heating episode at 750-1000^{o}C would reduce ^{4}He to levels seen in the cored stone. Such time-temperatures would not be present in the hot desert where Ghubara was found but weathering over a long time period (ka) would also cause He loss.

The loss of natural TL suggest that the meteorite was heated to at least 250^{o}C for some time, confirming that the heating occurred late in the history of the meteorite after most of the cosmic ray exposure was over, either in orbit during perihelion or afterwards. An interpretation of the natural TL data is that Ghubara experienced a perihelion of ~0.6 AU <10^5 years prior to reaching Earth. While the most likely reason for loss of He in meteorites is elevated temperatures experienced during solar heating, it seems extremely unlikely that part of the preatmospheric Ghubara was degassed from depths in excess of 20 cm while other parts remained at elevated levels.

The other possibility is differences in terrestrial history. The cooling of the coring device with distilled water prevented significant heating during this process. Another recently recovered sample of Ghubara, which was not cored, also shows significant ^{4}He loss. In terms of terrestrial age, ^{36}Cl being under saturation suggests a long terrestrial age (160 ka) but saturation for this stone is not known and preliminary ^{14}C measurements performed at Purdue University indicate ^{14}C activities comparable to a recent fall, eliminating the possibility for such a long terrestrial age. Further efforts are needed to reconcile these unprecedented differences between multiple stones of the same fall.

Different fragments of Ghubara obviously experienced various degrees of heating. In summary, Ghubara is a regolith breccia of moderate maturity based on both induced TL and noble gases. However, while all prior measurements of noble gases in Ghubara show high levels of solar ^{4}He the cored stone (BM 1958,805) shows little ^{4}He. A late heating hypothesis for the cored stone is supported by the loss of both natural TL and tracks. BM 1954,207 also shows late heating in the loss of TL and nuclear tracks (although track levels are not as low as in the cored stone) but ^{4}He remains at elevated levels.

References: [1] Graham A. L. et al. (1985) *Catalogue of Meteorites* 4th ed. London, British Museum (Natural History), 460 p. [2] Binns R. A. (1968) *Geochim. Cosmochim. Acta., 32,* 299-317. [3] Levsky L. K. (1979) *Meteoritika, 38,* 27-36. [4] Scherer P. (1993) Ph.D. Thesis, Univ. Mainz. [5] Vinogradov A. P. and Zadorozhnyi I. K. *Geokhimiya, 1,* 587-600. [6] Vogt S. et al. (1990) *Rev. Geophys., 28,* 253-275. [7] Benoit P. H. and Sears D. W. G. (1998) *Meteorit. Planet. Sci., 33,* A14. [8] Eugster O. (1988) *Geochim. Cosmochim. Acta, 52,* 1649-1662. [9] Graf T. et al. (1990) *Geochim. Cosmochim. Acta, 54,* 2511-2520. [10] Wieler R. et al. (1989) *Geochim. Cosmochim. Acta., 53,* 1441-1448.

sample	**^{3}He**	**^{4}He**	**^{20}Ne**	**^{21}Ne**	**^{22}Ne**
1958,805	12.45	251	262	5.37	25.00
1954,207	14.06	12860	1045	6.66	86.60

Table 1: Helium and neon isotopes (10^{-8} cm^3 STP/g) in two stones of the Ghubara regolith breccia.

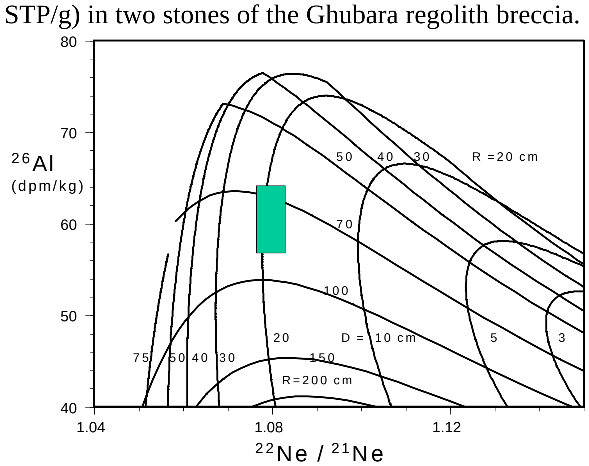

Figure 1: Aluminum-26 range in Ghubara (box) shown at a calculated (^{22}Ne/^{21}Ne)c value of 1.08. This suggests samples originated ~20cm deep (vertical lines) in an object with a radius of 70-90 cm [9].