

**COSMOGENIC NOBLE GASES,  $^{10}\text{Be}$ , AND  $^{26}\text{Al}$  IN CORES OF THE CHICO L6 CHONDRITE.** D.H. Garrison, D.D. Bogard (Code SN, NASA Johnson Space Center, Houston, TX 77058), A. Albrecht, G.F. Herzog (Dept. Chemistry, Rutgers Univ., New Brunswick, NJ 08903), J. Klein, and R. Middleton (Dept. Physics, Univ. Pennsylvania, Philadelphia, PA 19104).

The Chico L6 chondrite (105 kg, approx. 27x37x42 cm, found in New Mexico; 1) is interesting in two respects. First, more than half of its mass is impact melt apparently formed by the same  $\sim 0.5\text{Ga}$  shock event observed in several other chondrites (2). Secondly, Chico has a very old exposure age for a chondrite (calculated here to be  $\sim 63\text{ My}$ ) and gives evidence of having been irradiated with cosmic rays under high shielding. To gain access to interior samples to study this cosmic ray exposure, we cut the meteorite in half and bored small diameter cores into its six orthogonal surfaces (called (T)op, (B)ottom, (N)orth, (S)outh, (E)ast, and (W)est) and into both interior faces exposed after cutting (called IS and IN). Samples from the T, E, W, N, & IN faces were melt; samples from the B & S faces were chondritic; both melt (ISM) and chondritic (IS) samples were measured from the IS face. Isotopic abundances of cosmogenic He, Ne and Ar (measured by mass spectrometry) and  $^{10}\text{Be}$  and  $^{26}\text{Al}$  (measured by AMS) were measured on interior, relatively unweathered samples taken from these cores. Data are given in Table 1. We also analyzed exterior, much more weathered samples taken from the north and south ends of the specimen.

Determinations in documented depth samples of cosmogenic nuclides produced by cosmic ray interactions previously have been made in a few stone meteorites, e.g., Keyes, St. Severin, ALHA78084, Jilin, and Knyahinya. These data have been utilized, along with cross section data and nuclear systematics, to develop models that predict production rates of cosmogenic nuclides as a function of shielding depth (e.g., 3, 4, 5, 6, 7). The cosmogenic  $^{22}\text{Ne}/^{21}\text{Ne}$  ratio is sensitive to shielding depth and commonly is used to correct production rates and exposure ages for shielding differences. The various models differ, however, in their predictions of the  $^{22}\text{Ne}/^{21}\text{Ne}$  ratio expected at high shielding; lower limit values from 1.09 to less than 1.00 have been predicted. The models also differ in the predicted production rates as a function of meteorite size, in part because experimental data for conditions of large shielding have been sparse. In this regard, Chico apparently extends the cosmogenic nuclide data for documented depth samples and a simple irradiation history to greater shielding depths than previous data.

Fig. 1 reproduces the recent production rate model of Graf et al (7) for  $^{10}\text{Be}$  in L-chondrites as a function of the  $^{22}\text{Ne}/^{21}\text{Ne}$  shielding parameter. Data for Chico core samples are also shown. The average  $^{10}\text{Be}$  value of 21 dpm/kg and the  $^{22}\text{Ne}/^{21}\text{Ne}$  range of 1.06-1.08 plot near the model curve for a 70cm radius chondrite at depths between approximately 20cm and 60cm. The older model of Reedy (5), now under revision, would predict a substantially smaller radius. Similarity in the range of values for  $^{10}\text{Be}$  ( $\sim 22\%$ ) and for  $^{21}\text{Ne}$  (19%) for samples dispersed over such large relative distances (Table 1) are consistent with irradiation near the top of a production rate profile. A similar range of  $^{22}\text{Na}$  data ( $\sim 17\%$ ) was seen in samples from the main mass of the Jilin H-chondrite (8). The relative constancy of the  $^{10}\text{Be}/^{21}\text{Ne}$  and  $^{10}\text{Be}/^{26}\text{Al}$  ratios for Chico suggest a single stage irradiation by cosmic rays, unlike the case for Jilin (8, 9, 10).

From a model curve for  $^{21}\text{Ne}$  that is very similar to the one for  $^{10}\text{Be}$  (7), a production rate for  $^{21}\text{Ne}$  of approximately  $0.3 \times 10^{-8}$  ccSTP/g-Ma is indicated for Chico. (The model of (6) would give a slightly higher  $^{21}\text{Ne}$  production rate for a 70cm radius object.) With an average  $^{21}\text{Ne}$  concentration of  $19 \times 10^{-8}$  ccSTP/g (Table 1), the exposure age for Chico is ca. 63 Ma. This exposure age is unusually old for an ordinary chondrite, but cannot be as old as the impact event that caused Ar degassing at  $\sim 0.5\text{ Ga}$ . In a plot of  $3\text{He}/^{21}\text{Ne}$  against  $^{22}\text{Ne}/^{21}\text{Ne}$ , the Chico data fall near the so-called Bern line, which is the overall trend of data for many chondrites, and indicate that Chico has not lost much cosmogenic gas.

Fig. 2 shows  $^{21}\text{Ne}$  concentrations plotted against  $^{22}\text{Ne}/^{21}\text{Ne}$  for the Chico data. Portions of the  $^{21}\text{Ne}$  production rate curves for L-chondrites 70cm and 100cm in radius (7) have been normalized to these data. Samples from the North side of the meteorite indicate the least shielding (lowest  $^{22}\text{Ne}/^{21}\text{Ne}$ ), and samples from the South side the most shielding (highest  $^{22}\text{Ne}/^{21}\text{Ne}$ ). This trend indicates that a shielding gradient existed from the North to South sides of Chico, and its positive slope suggests that irradiation occurred at a shielding depth somewhat greater than the maximum in the production rate curves. Core samples from most chondrites previously analyzed show a negative slope on this plot (see 11), indicative of irradiation on the right side of the maxima in the production rate curves (e.g. Fig.1). Samples of Jilin show no clear slope, but interpretation of Jilin data are complicated by its 2-stage irradiation under different shielding. Although general agreement exists between the Chico core data and the model curves, there are discrepancies outside estimated analytical errors (shown for sample E). The dispersion shown by the IN, W, and IS data is unlikely to be a shielding trend, for the IN and IS samples were located only  $\sim 9\text{cm}$  apart and the IS and ISM samples  $< 2\text{cm}$  apart, all near the center of Chico. Specific position on Fig. 2 is very sensitive to possible variations in Mg concentration, the major target element for  $^{21}\text{Ne}$ . The vector from sample IS shows the magnitude this datum would move if it contained only 1 wt.% lower Mg than the other samples. Although [Mg] may not be expected to vary this

amount among small samples of a chondrite, large scale impact melting in Chico may have created some chemical fractionation. Core samples N, IN, W, and ISM are melt, whereas, IS and B are chondritic. Composition measurements are planned for our samples.

The production rate models of (7) for L-chondrites of ~70-100cm radius predict a uniform decrease in  $^{22}\text{Ne}/^{21}\text{Ne}$  with increasing shielding up to a maximum in production rates at a depth of ~20cm and  $^{22}\text{Ne}/^{21}\text{Ne}$  of ~1.08. The model by (6) makes similar predictions. With increasing shielding to depths of ~70-100cm, the model of (7) predicts very rapid decreases in production rates with very slow decreases in  $^{22}\text{Ne}/^{21}\text{Ne}$  to lower limits of ~1.05-1.06. Data from Knyahinya encompass an ~40cm shielding range and show  $^{22}\text{Ne}/^{21}\text{Ne}$  variation of 1.12-1.07. Chico data apparently also encompass an ~40cm shielding range and show  $^{22}\text{Ne}/^{21}\text{Ne}$  variations of only 1.08-1.06. Chico data appear consistent with the Graf model, as is the observation that essentially no verified examples apparently exist of ordinary chondrites with cosmogenic  $^{22}\text{Ne}/^{21}\text{Ne}$  less than ~1.05 (average L-chondrite normalized).

Table 1. Cosmogenic nuclides in samples from six orthogonal faces and two interior locations of Chico. Repeat gas analyses were made for 4 samples; both chondritic and melt phases were measured in the South-Interior core. Uncertainties in noble gas abundances are estimated at <2% based on variations in standard gas samples run in a "standard addition" mode. Typical uncertainties in  $^{22}/^{21}$  are 0.25%. Estimated uncertainties in  $^{10}\text{Be}$  and  $^{26}\text{Al}$  are 6-7%. Sample distances are N-S = 38cm, E-W = 31cm, T-B = 22cm. IN and IS are from the center of Chico. Gas abundances are e-8ccSTP/g; radionuclide abundances are dpm/kg.

CORE	$^3\text{He}$	$^{21}\text{Ne}$	$^{22}/^{21}$	$^3/^{21}$	$^{38}\text{Ar}$	$^{10}\text{Be}$	$^{26}\text{Al}$
Top	67.6	17.7	1.062	3.83	1.23	21.6	64.9
Bottom	81.5	19.2	1.073	4.24	1.85	21.2	66.5
East	71.1	18.1	1.066	3.93	1.58	21.2	74.3
West#1	75.7	20.0	1.062	3.79	1.49	23.5	69.7
West#2	77.1	20.3	1.065	3.80	1.56		
North	81.8	20.4	1.079	4.01	1.35	20.9	62.5
South#1	65.7	16.8	1.058	3.91	1.30	—	54.4
South#2	66.6	16.7	1.065	3.98	—		
Int-N#1	76.9	20.3	1.065	3.79	1.57	22.5	63.0
Int-N#2	78.7	20.2	1.062	3.90	1.43		
Int-S#1	70.8	17.8	1.084	3.99	1.55	20.2	62.9
Int-S#2	71.2	18.4	1.082	3.87	1.70		
Int-S-M	78.9	19.8	1.068	3.98	1.50		

References: (1) L. LaPaz, *Meteoritics* 1, p182, 1954; (2) Bogard et al, LPSC XXI, p103, 1990; (3) Nishiizumi et al, E.P.S.L. 50, p156, 1980; (4) Bhandari & Potdar, E.P.S.L. 58, p116, 1982; (5) R. Reedy, Proc. 15th LPSC, pC722, 1985; (6) McDowell & Nyquist, LPSC XVII, p528, 1986; (7) Graf et al, G.C.A. 54, p2521, 1990; (8) Heusser et al, E.P.S.L. 72, p263, 1985; (9) Pal et al, E.P.S.L. 72, p273, 1985; (10) Honda et al, E.P.S.L. 57, p101, 1982; (11) Graf et al, G.C.A. 54, p2511, 1990.

Fig.1 (Left): Model curves from (7) of  $^{10}\text{Be}$  production rates vs the  $^{22}\text{Ne}/^{21}\text{Ne}$  shielding parameter for L-chondrites with different radii, R. The loci of 20cm depths are also shown, as are experimental data for Chico core samples. Fig.2 (Right): Plot of cosmogenic  $^{21}\text{Ne}$  vs  $^{22}\text{Ne}/^{21}\text{Ne}$  for Chico core samples and three exterior samples. Typical analytical uncertainties for core data are shown on the E sample. The vector on the IS sample represents the magnitude of the normalization required if this sample had 1 wt.% lower [Mg] than the others. Portion of the normalized model curves for L-chondrites with 70cm and 100cm radii are shown (7).

