

FURTHER EVIDENCE FOR CHONDRULE PRE-EXPOSURE TO COSMIC RAYS IN THE SOLAR NEBULA.E. Polnau¹, O. Eugster¹, and U. Krähenbühl². ¹Physikalisches Institut, University of Bern, 3012 Bern, Switzerland.²Departement für Chemie und Biochemie, University of Bern, 3012 Bern, Switzerland.

Summary: Our systematic study of the cosmic-ray exposure ages of chondrules separated from ordinary chondrites was continued. In a previous work [1] we reported a 0.9 Ma pre-exposure of a spherical chondrule-like inclusion from the H6-chondrite ALH76008 relative to the matrix material. We now present noble gas data and the chemical composition of chondrule and matrix samples from Bjurbole (LL4) Bern collection number BE-168, Bowesmont (L6) BE-191, Kalvesta (H4) BE-599 and BE-601, Kress (L6) BE-422, and St.Germain du Pinel (H6) BE-600. All chondrule separates, if compared with the respective matrix material, show an excess in the range of 0.2-3 Ma for their cosmic-ray exposure. This excess, however, is outside experimental uncertainties only in the case of Kalvesta.

Introduction: All meteorites are exposed to cosmic rays after break-up of their parent body. This exposure, T_{recent} , occurred recently for chondrites during up to 100 Ma [2]. If chondrules were formed and resided in a nebular environment before the matrix material solidified into which they were incorporated, they must exhibit an excess, represented by the pre-exposure time, T_{excess} , of cosmic irradiation.

The chondrites used for the study of a possible chondrule pre-exposure were selected according to the following criteria: (i) Chondrule material must be present in sufficient quantity for noble gas isotope analyses. (ii) T_{recent} must be brief enough to allow the determination of T_{excess} . (iii) The cosmic-ray produced gases must have been stored since chondrule solidification. Thus, the K-Ar gas retention age should be relatively high.

Results of the noble gas analyses: The noble gas abundances and isotopic ratios are given in Table 1. In addition to the meteorites mentioned above we analysed a bulk sample of the LL5 chondrite Hunter (BE-457). This meteorite contains numerous easily recognizable chondrules. Noble gases have not been studied before. Our results show extremely low concentrations of cosmic-ray produced gases. Noble gases in Kress (L6) were also analyzed for the first time. We found large concentrations of cosmogenic gases making a detection of a possible brief pre-exposure difficult. For St. Germain Schultz et al. [3] list one sample with relatively low and several ones with high concentrations of cosmogenic gases. The sample that we analyzed yielded large concentrations; consequently this meteorite does not fulfill criterion (ii).

Results of the chemical analyses: The concentrations of some elements obtained by ICP-mass spectrometry relevant for the calculation of the noble gas production rates are given in Table 2. Considering all elements analyzed in this work and the data on ALH76008 [1] the following trends are observed: the chondrule samples in Bowesmont, Kalvesta, and St. Germain are depleted but in ALH76008 enriched in Fe, Co, and Ni relative to the matrix. Generally,

in all four meteorites enrichments for the following elements in chondrules relative to matrix are found: the alkaline elements Na, K, and Rb, the alkaline earth elements Mg, Ca, Ba, and Sr, as well as Ti, Sc, Y, and Zr. Based on the specific chemical composition we derived the production rates using the method given by Eugster [4].

Exposure ages: Table 3 gives the cosmic-ray exposure ages and the K-Ar gas retention ages. Where several methods were applied for deriving exposure ages an average value, T_{av} , was calculated. In some cases chemical analyses are still in progress and T_{21} and T_{38} were not derived. T_3 is quite insensitive to variations in chemical composition and average chondritic abundances were adopted for the matrix samples. For the chondrules we used $P_3=1.69 \times 10^{-8} \text{ cm}^3 \text{STP/gMa}$, as obtained for the Bowesmont, Kalvesta, and St. Germain chondrule chemistry. For Hunter we obtain the lowest exposure age, $T_{\text{av}}=0.50 \text{ Ma}$, of all LL chondrites dated till now [2]. Thus, this meteorite is an excellent candidate for the present study. Chondrule and matrix measurements are in progress.

The figure shows that all chondrule samples yield a lower exposure to cosmic rays than the respective matrix material, confirming the same conclusion obtained for ALH76008. The pre-exposure of the chondrules is of the order of one million years. The difference between chondrules and matrix is, however, not in all cases outside experimental errors. For Bjurbole, Bowesmont, Kress, and St.Germain the errors overlap. We now attempt to obtain ⁸¹Kr-Kr ages for samples for which sufficient chondrule material is available. In particular, we collaborate with colleagues of the University of Tennessee (K. Ocker and N. Thonnard) who apply resonance ionization mass spectrometry to Kr.

Conclusion: For two chondrites, Kalvesta and ALH76008, we observe a pre-exposure of the chondrules relative to the matrix of $0.21 \pm 0.09 \text{ Ma}$ and $0.9 \pm 0.4 \text{ Ma}$, respectively. For Bjurbole, Bowesmont, Kress, and St. Germain the chondrules show a pre-exposure that is in the present study not outside experimental uncertainty. A pre-exposure to cosmic rays of the chondrules not necessarily means that they are older in the sense of an earlier crystallization than the matrix material. In the model suggested by our results chondrules were pre-exposed in the solar nebula to cosmic rays for about one million years before they were incorporated into asteroidal material.

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References: [1] Polnau E. et al. (1997) LPS XXVIII, 1125. [2] Marti K. and Graf T. (1992) Annu. Rev. Earth Planet. Sci. **20**, 221. [3] Schultz L. et al. (1996) Helium, neon, and argon in meteorites. Max-Planck-Institut für Chemie, Mainz. [4] Eugster O. (1988) GCA **52**, 1649

FURTHER EVIDENCE FOR CHONDRULE PRE-EXPOSURE: E. Polnau et al.

Table 1. Noble gas concentrations and isotopic ratios (concentrations in 10^{-8} cc/g)

Meteorite		^4He	^{20}Ne	^{40}Ar	^4He	^{20}Ne	^{22}Ne	^{36}Ar	^{40}Ar	^3He	^{21}Ne	^{38}Ar	^{40}Ar
					^3He	^{22}Ne	^{21}Ne	^{38}Ar	^{36}Ar				
Bjurbole (LL4)	matrix	1494	3.70	7794	115.5	0.8636	1.068	3.90	1805	13.8	4.01	0.34	7794
	chond.	1991	4.22	7207	131.1	0.8267	1.099	2.37	4691	15.2	4.62	0.41	7207
Bowesmont (L6)	matrix	956	2.53	5737	107	0.8579	1.054	2.42	7482	8.94	2.80	0.30	5737
	chond.	888	3.29	7040	80.8	0.8577	1.057	2.27	4980	11.0	3.63	0.27	7039
Hunter (LL5)	bulk	1070	0.186	3910	1606	1.067	1.203	3.27	9159	0.67	0.156	0.055	3910
Kalvesta (H4)	matrix	935	0.643	4508	801	1.862	1.183	4.89	2102	1.17	0.30	0.042	4508
	chond.	1523	0.491	6840	945	1.057	1.115	3.80	5425	1.61	0.42	0.108	6840
Kress (L6)	bulk	635	9.54	3666	11.58	0.8362	1.114	1.10	2072	54.8	10.2	1.47	3666
	matrix	656	9.70	3851	12.19	0.8379	1.113	1.04	2428	53.8	10.4	1.42	3851
St. Germain (H6)	chond.	431	12.46	3395	6.98	0.8389	1.121	0.822	5352	61.8	13.3	0.78	3395
	matrix	1233	8.50	6430	23.76	0.8315	1.141	1.078	3189	51.9	8.96	1.70	6429
	chond.	1046	11.43	11330	19.55	0.8185	1.148	1.272	4228	53.5	12.17	1.83	11330
Exp. errors %, 2σ		3	3	5	1-2	1	1	4	4	4	4	6	5

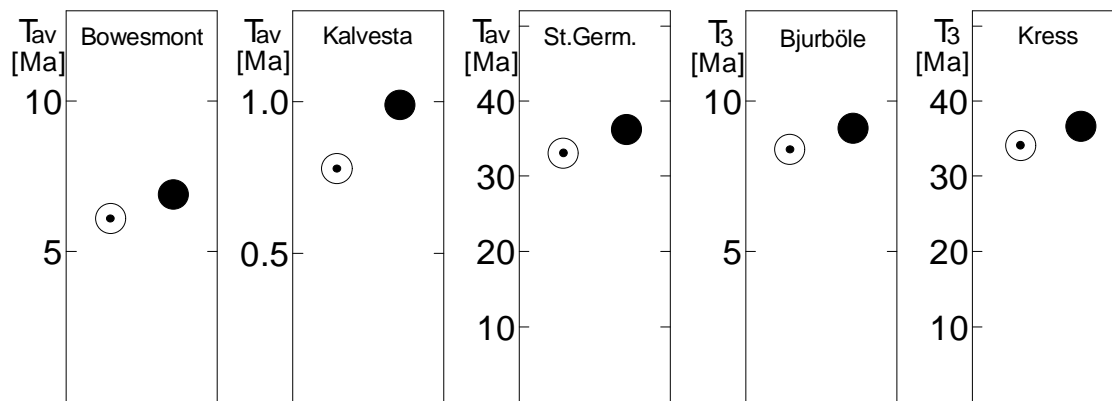
Table 2. Chemical abundances (weight %)

Meteorite		Na	Mg	K	Ca	Ti	Fe	Ni
Bowesmont	matrix	0.54	14.4	0.106	1.14	0.0485	18.0	1.3
	chondrules	0.75	18.7	0.092	0.99	0.0600	13.6	0.19
Kalvesta	matrix	0.39	11.7	0.064	0.81	0.0460	26.6	1.5
	chondrules	0.61	17.1	0.115	1.7	0.0790	11.5	0.42
St. Germain	matrix	0.57	14.1	0.098	1.16	0.0535	23.8	1.5
	chondrule	0.88	17.1	0.145	2.1	0.0670	7.9	0.04
Exp. errors %, 2σ		10	6	10	10	10	6	7

Table 3. Cosmic-ray- and K-Ar ages (Ma)

Meteorite		T_3	T_{21}	T_{38}	T_{av}	T_{40}
Bjurbole (LL4)	matrix	8.4 ¹⁾	²⁾	²⁾	-	²⁾
	chondrules	9.1 ³⁾	²⁾	²⁾	-	²⁾
Bowesmont (L6)	matrix	5.4	6.4	6.5	6.1±0.7	3910
	chondrules	6.5	6.9	7.3	6.9±0.5	4470
Hunter (LL5)	bulk	0.42 ¹⁾	0.58 ¹⁾	-	0.50±0.8	3640 ¹⁾
Kalvesta (H4)	matrix	0.72	0.83	-	0.78±0.05	4330
	chondrules	0.95	1.02	-	0.99±0.04	²⁾
Kress (L6)	bulk	33.4 ¹⁾	31.0 ¹⁾	30.7 ¹⁾	31.7±1.7	3540 ¹⁾
	matrix	34.1 ¹⁾	²⁾	²⁾	-	²⁾
	chondrule	36.6 ³⁾	²⁾	²⁾	-	²⁾
St. Germain (H6)	matrix	32.7	32.0	34.6	33.1±1.6	3500
	chondrule	31.6	38.6	38.5	36.2±4.6	4510
Exp. errors %, 2σ		5	7	10		12

¹⁾ Av. chondritic chemistry adopted. ²⁾ Chemical comp. unknown. ³⁾ Av. $P_3=1.69 \times 10^{-8}$ cc/g, Ma of chondrules from Bowesmont, Kalvesta, and St. Germain adopted.



C.-r. exp. ages of matrix (○) and chondrules (●)