COSMOGENIC SAMARIUM-150 AND CALCIUM-41 IN NORTON COUNTY: D. Fink[1], J. Klein[2], R. Middleton[2], A. Albrecht[3], P. Ma[3], G. F. Herzog[3], D. D. Bogard[4], L. E. Nyquist[4], C.-Y. Shih[5], Y. Reese[6], and D. H. Garrison[5], J. Masarik[7], R. C. Reedy[8], G. Rugel[9], T. Faestermann[9], and G. Korschinek[9], [1]Institute for Environmental Research, ANSTO. PMB 1, Menai NSW 2234, Australia, [2]Dept. of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19104, [3]Dept. Chemistry & Chem. Biology, Rutgers University, 610 Taylor Road, Piscataway, NJ 08854-8087, [4]Johnson Space Center, Houston, TX 77058, [5]ESCG, Jacobs-Sverdrup, Houston, TX 77058, [6]Mail Code JE-23, ESCG/Muniz Engineering, Houston, TX, 77058, [7]Nuclear Physics Dept., Comenius University, SK-842 15 Bratislava, Slovakia, [8]Planetary Science Institute, Los Alamos, NM 87544 USA, [9]Fakultät für Physik, TU-München, D-85748, Garching, Germany.

Introduction: Though brecciated [1], the Norton County (NC) aubrite contains little or no trapped noble gas and has been widely assumed to have a simple if unusually long cosmic ray exposure (CRE), 115 Ma [2]. One goal of this ongoing study of NC [3,4] has been to search for signs of pre-irradiation as proposed by [5] and [6]. One may test for multiple stages of CRE by comparing thermal neutron fluences inferred from ^{41}Ca ($t_{1/2}$=0.1 Ma) activities, which reflect irradiation conditions over the last ~0.3 Ma, with those inferred from (stable) Sm isotope abundances, which integrate over the entire CRE history. In the case of a one-stage exposure the fluences should agree. We focus on these particular comparisons because the properties of NC - its long CRE exposure, relatively large size, and low iron concentration - all promised high production rates and ease of measurement. Previously, we reported on several cosmogenic nuclides in NC [3,4]. Here we present new ^{41}Ca data, Sm isotope measurements, and comparisons with model calculations of cosmic-ray production.

Experimental methods: Dr. E. Scott provided samples of Norton County from locations close to material analyzed for tracks [7] and ^{53}Mn [8]. After addition of Ca carrier, dissolution in $HF/HClO_4$, and fuming with $HClO_4$, we separated Ca by cation exchange (Dowex, 50WX8), precipitating the oxalate, and converting it to CaF_2. Accelerator mass spectrometry of ^{41}Ca was performed at the tandem accelerator of the Technische Universität and Ludwig-Maximilians Universität, Munich [9]. All concentrations were corrected for background and normalized to a ^{41}Ca standard prepared from the primary standards of [10]. Two procedural blanks gave $^{41}Ca/^{40}Ca$ ratios of $(3\text{-}8\pm4)\times10^{-14}$. Ca concentrations in the samples were measured in three different ways (see Table 1, note c).

Our methods for Sm analysis followed [11]. After dissolution, rare earth elements (REE) were eluted as a group in 6N HCl from a cation exchange column. Sm was separated from the other REE on a second cation column by elution with α-hydoxyisobutyric acid. Sample masses of 392, 299, and 255 mg yielded respectively 98, 75, and 64 ng of Sm for NC3C, NC102, and NC5. Sm isotopes were analyzed on a Finnigan-MAT 262 multicollector mass spectrometer in static multicollector mode. Sm blanks, ~5-10 pg, were negligible.

Results: Our average measured Ca concentrations excluding NC102 range from 1.1 to 3.6 wt% (Table 1) and are systematically higher than literature values (0.5-1.2 wt%) for other samples. Norton County is known to be coarse-grained (e.g., [1]) and to contain some Ca-rich diopside [12], so sample heterogeneity can explain the differences.

The Sm isotope ratios (Table 2) were measured in two ways, as Sm^+ for all three samples and as SmO^+ for NC102 and NC3C. The results for NC102 agree within the calculated uncertainties; those for NC3C agree within twice the calculated uncertainties.

Discussion: We modeled production rates in aubritic meteoroids with pre-atmospheric radii greater than 40 cm by using the recently compiled cross sections of [13] and the Los Alamos High Energy Transport (LAHET) Code System (LCS) [14]. The LCS model combines the LAHET code for interactions of nucleons above 20 MeV with the Monte Carlo N-Particle (MCNP) code for interactions of low-energy neutrons. For meteoroid orbits, the LCS model uses an effective flux of primary GCR particles of 4.8 nucleons cm^{-2} s^{-1} for energies great than 10 MeV. This model is known to overestimate the lunar capture rate of thermal neutrons by ^{149}Sm.

The depth profiles of ^{10}Be, ^{26}Al [4], and ^{41}Ca follow most closely the model predictions for a meteoroid radius of about 50 cm [4]. Differences between modeled and measured profiles at smaller depths may indicate the effects of space erosion. Bhandari et al. [7] estimated the preatmospheric mass as 3600 kg, which corresponds to a radius of 65 cm, somewhat larger than the one estimated from the depth profiles.

Thermal neutron fluxes, ϕ (n cm^{-2} s^{-1}) were calculated by substituting 1) the ^{41}Ca activities, which equal production rates, $P(^{41}Ca)_n$, after small corrections for spallation of iron; 2) the Ca concentrations,

Table 1. Neutron-produced ^{41}Ca activities and production rates, Ca concentrations, and thermal neutron fluences.

Sample	Depth	^{41}Ca	Ca	P(^{41}Ca)$_n$	Φ	
	(a)	(b)	(c)	(d)	(e)	(f)
NC102	10	26.2[3]	12.3^g	0.21±0.3	0.50	0.22
		21±12	12.3	0.17±0.10		0.17
NC7	11	6.7[3]	1.7^g	0.36±0.04	0.55	0.37
		9±2	1.7	0.49±0.16		0.49
NC6	12	9.0[3]	1.5^g	0.58±0.06	0.59	0.59
NC6B7	12	4.3±1.4	1.1	0.36±0.14		0.37
NC1L	17	11±4	1.9	0.57±0.20	0.86	0.58
NC1U	17	10.5±2	1.6	0.64±0.15		0.65
NC5	17	9.5[3]	1.7^g	0.55±0.06		0.55
NC3E	25	16.0[3]	1.4^g	1.15±0.12	1.25	1.17
		16±5	1.4	1.18±0.41		1.20
NC3C	32	24.6[3]	1.9^g	1.25±0.13	1.44	1.27
		23±6	1.9	1.13±0.33		1.14
NC3A	33	46±10	3.6	1.26±0.32	1.59	1.27
		49±10	3.6	1.35±0.32		1.37
NC23-5	35	7±4	1.1	0.58±0.36	1.71	0.59

a) cm. **b)** Activities in dpm/kg corrected for spallogenic contributions from Fe. **c)** Averages (wt%) of 6 analyses by AA, powder XRF, and ICP-MS. **d)** Production rate of ^{41}Ca (dpm/[g Ca]) calculated from activities and Ca concentrations. Uncertainties of P(^{41}Ca)$_n$ from [3] do not include an unknown contribution from the uncertainty in the Ca concentration. **e)** Thermal neutron fluence (10^{16} n cm^{-2}) from modeling calculations for a radius of 50 cm, a density of 3.2 g/cm^3 and a CRE age of 115 Ma. **f)** $\Phi(\text{n cm}^{-2}) = P(^{41}\text{Ca})_n \times t_{exp}/(\sigma \times {}^{40}\text{Ca abundance})$; see text. **g)** Ca not analyzed and taken as result for another portion of the same specimen.

and 3) a thermal neutron cross section, σ=410 mb, into the relation $P(^{41}\text{Ca})_n=[^{40}\text{Ca}]\phi\sigma$. To convert fluxes, φ, to fluences, Φ, we multiplied by the CRE age of 115 Ma. Fluences based on the modeling calculations for ^{41}Ca generally agree with these results (Table 1). Thermal neutron fluences were also calculated from the Sm isotopic abundances using the relation $\sigma_{eff}\Phi = \left[\frac{^{150}\text{Sm}}{^{149}\text{Sm}} - \left(\frac{^{150}\text{Sm}}{^{149}\text{Sm}}\right)_{terr}\right] \Big/ \left[1+\frac{^{150}\text{Sm}}{^{149}\text{Sm}}\right]$ where $\sigma_{eff} = 6.1\times10^{-20}$ cm^2 was obtained following [15]. The fluences inferred from Sm are about 3× higher than those inferred from ^{41}Ca (Figure 1). The difference may indicate that up to half the ^{149}Sm neutron captures occurred at depths between 38 and 138 cm during earlier cosmic ray irradiation of Norton County in the parent body or a precursor meteoroid.

Table 2. Sm isotopic abundances.

	ε ^{149}Sm	ε ^{150}Sm	Φ^{149}Sm^a
SmO$^+$ measurements^b			
NC102	-11.05±0.97	17.88±1.36	1.88±0.13
NC5	-8.42±0.19	11.94±0.39	1.34±0.08
NC3C	-18.78±0.28	34.27±0.39	3.49±0.08
Hidaka06	-6.59	14.22	1.64
Sm$^+$ measurements			
NC102	-10.26±0.87	17.39±1.84	1.80±0.13
NC3C	-17.59±0.11	32.80±0.48	3.32±0.04
Average			
NC102	-10.66±0.97	17.63±1.84	1.84±0.09
NC5	-8.42±0.19	11.94±0.39	1.34±0.08
NC3C	-18.18±0.84	33.53±1.04	3.41±0.04

a) Φ^{149}Sm (10^{16}/cm^2) = ε ^{149}Sm/10,000 × σ_{eff}(^{149}Sm); σ_{eff}(^{149}Sm) = 6.1×10^{-20} cm^2 for Σ_{eff}=0.0018 cm^2/g. **b)** ^{149}Sm/^{152}Sm = 0.516852±0.000017; ^{150}Sm/^{152}Sm = 0.275983±0.000028. **c)** ^{149}Sm/^{152}Sm = 0.516837±0.000008; ^{150}Sm/^{152}Sm = 0.276065±0.000007.

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