COSMOGENIC NUCLIES IN ANTARCTIC METEORITES: OPPORTUNITIES AND DIRECTIONS.

M. W. Caffee[1], G. F. Herzog[2], A. J. T. Jull[3,4], K. Nishiizumi[5], and K. C. Welten[5], [1]Dept. of Physics and Astronomy, Purdue University, West Lafayette, IN 47907-2036, USA (email:mcaffee@purdue.edu), [2]Dept.of Chemistry and Chemical Biology, Rutgers University, Piscataway, NJ 08854-8066, USA (Herzog@chem.rutgers.edu), [3]Depts. of Geosciences and Physics, University of Arizona, Tucson, AZ 85721, USA (jull@email.arizona.edu), [4]Institute for Nuclear Research, 4026 Debrecen, Hungary. [5]Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450, USA (kuni@ssl.berkeley.edu; kcwelten@ssl.berkeley.edu).

Introduction: For more than four decades researchers from numerous countries have been scouring ice-fields on the Antarctic continent for meteorites. ANSMET, in particular, has returned tens of thousands of the interplanetary interlopers [1]. These samples have, in some instances, revolutionized our view of the origin of the solar system and the processes, still ongoing, that dictate its dynamical evolution. The meteorites collected in Anarctica represent an archive for those studies that seek to reconstruct the history of a meteorite's exposure to cosmic rays. This exposure history consists of several epochs: the meteorite's most recent residence on Earth (terrestrial age); the meteorite's transit to Earth (most recent exposure); and in some instances an earlier period of exposure in a different physical setting (complex exposure). In addition to harboring the nuclear vestiges of exposure to galactic cosmic rays - the so-called cosmogenic nuclides - in some instances these samples retain records of exposure to energetic particles from the Sun. The solar particles may simply be implanted or, like galactic cosmic rays, may cause nuclear reactions that yield easily recognized products.

Methodology: The buildup of cosmogenic nuclides, both radioactive and stable, is a function of the duration of the exposure (exposure age) and parameters related to the geometry (size of meteoroid and location in relation to the surface). Energetic particle reactions between the primary particles, mainly though not exlusively protons, and secondary particles, mainly neutrons, produce a plethora of nuclides within the meteoroid. The most commonly measured radionuclides are ^{10}Be (1.36 Myr), ^{14}C (5,730 yr), ^{26}Al (0.705 Myr), and ^{36}Cl (0.301 Myr). The recovery of Antarctic meteorites fortuitously coincided with the advent of accelerator mass spectrometry, a mass spectrometric technique that vastly increased the sensitivity of long-lived radionuclide measurements. The most commonly measured stable cosmogenic nuclides are the least abundant isotopes of the noble gases – ^{3}He, ^{21}Ne, and ^{38}Ar – and are most often measured by more conventional forms of mass spectrometry. There are scores of other cosmogenic nuclides, which for various reasons have received little attention; they present opportunities for future work. To maximize the information extracted from a single sample multiple nuclides, both stable and radioactive, are measured.

Results and Discussions: The terrestrial ages of nearly 1,000 Antarctic meteorites have been determined [e.g., 2, 3]. Most of these terrestrial ages are less than 300 ka and many are less than 50 ka. Some locations with large blue ice areas, the Allan Hills main icefield, Frontier Mountains, Lewis Cliff, and MacAlpine Hills, for example, contain meteorites with terrestrial ages up to ~1 Myr, while a few outliers have ages up to 3 Myr [3,4]. Among the thousands of Antarctic meteorites are those from other planetary surfaces, most notably those of the Moon and Mars. The sum of the terrestrial age and the most recent exposure age yields the ejection age, which indicates the time at which the meteorite was launched from its parent body. Martian meteorites, in particular, have exposure ages that are in general younger than those of other stony meteorites, reflecting the dynamics of launching and transporting these objects into Earth-crossing orbits [5]. The exposure ages of Antarctic Martian meteorites have helped identify major launch events from Mars. Lunar meteorites have even shorter exposure ages, consistent with theoretical studies that indicate short transit times from the lunar surface to Earth [5,6]. Lunar meteorites are not the only Antarctic meteorites with short exposure ages. CM chondrites have surprisingly short exposure ages, perhaps indicating a source near Earth orbit [7]. Cosmogenic nuclide studies of Antarctic meteorites have allowed and will undoubtedly continue to contribute to a better understanding of the processes responsible for the delivery of planetary materials to Earth, as well as to the stability of blue ice fields, transient features whose existence depends strongly on changes in the thickness of the ice sheet. The oldest terrestrial ages may even guide the search for locations where old glacier ice is surfacing that is unrepresented by the deepest Antarctic ice cores [8].

Acknowledgements: Investigations of Antarctic meteorites would not have been possible without unflagging financial and technical support from the entire ANSMET team: NASA, NSF, and the Smithsonian.

References: [1] Herzog G.F. et al. (2015) in 35 Seasons of U.S. Antarctic Meteorites, edited by Righter, K., Corrigan, C. M., McCoy, T. J., Harvey, R. P, 153-172. [2] Nishiizumi K. et al. (1989) *Earth and Planetary Science Letters* 93:299-313. [3] Jull A. J. T. (2006) Terrestrial ages of meteorites. In "Meteorites and the Early Solar System II" (eds. D. Lauretta and H. Y. McSween, Jr.), University of Arizona Press, Tucson, pp. 889-905 [4] Welten K. C. et al. (2006) Meteoritics Planet. Sci. 41:1071-1094. [5] Gladman B. (1997) *Icarus* 130:228–246. [6] Gladman B. J. et al. (1995) *Icarus* 118:302–321. [7] Nishiizumi K. and Caffee M. W. (2012) *LPS XLIII,* Abstract #2758. [8] Spaulding N. E. et al. (2012) *J. Glaciology* 58:399-406.