Terrestrial Ages of Antarctic and Hot Desert Meteorites Using Carbon-14 and Other Cosmogenic Radionuclides

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Cosmogenic radionuclides (^{10}Be $t_{1/2}$ 1.38Myr, ^{14}C 5.73kyr, ^{26}Al 705kyr, ^{36}Cl 301kyr and ^{41}Ca 100kyr) provide important information on the exposure time of meteorites and planetary surfaces in space and also shorter-lived nuclides provide information on the terrestrial-residence time of meteorites on the surface of the Earth. The infall rate of meteorites and other extraterrestrial material is some 40,000 tons per year over the surface of the earth. Material in space is subject to irradiation by cosmic rays at a much higher level than on the Earth's surface. The result is the production of secondary nuclides, known as "cosmogenic nuclides". It has been known for a long time that meteorites and lunar material contain significant radioactivity produced by the action of cosmic radiation in space (e.g. Eugster et al. 2006; Masarik and Reedy 1994; Leya and Masarik 2009). Since radionuclides decay, we have clocks on various time-scales that help us to better understand the duration of the time during which they were exposed to cosmic rays, which we call the cosmic ray exposure time, and the length of their residence on the Earth's surface, which we call the terrestrial age. Cosmic ray exposure ages have been reviewed by Herzog and Caffee (2013). Jull (2006) has summarized data for terrestrial ages based on ^{14}C. For shorter time-scales <50kyr, ^{14}C is the most useful, and nuclides such as ^{36}Cl and ^{41}Ca can also be used to estimate longer-lived terrestrial residence times, particularly in Antarctica and for iron meteorites.

The production rate (P) of any nuclide depends on not only the cross section and the number of target atoms but on the energy (E), radius of the object R), depth in the object (d) and the total mass (M) of the irradiated object, integrated in three dimensions. This is because secondary neutrons and other particles (e.g. muons) produced have a characteristic depth dependence. Also, the size of the object determines if the irradiation is just from one direction (2π irradiation) of from all directions ($4\ \pi$). Since the mean depth of secondary neutrons at these energies of ~160g/cm^2 this means that objects larger than a few meters in size differ little from very large objects, such as the moon. For an object of smaller size, the production rate becomes less as less secondary particles are produced in the object. In the case of cosmogenic radionuclides, it is common to quote the activity (decay rate) of the nuclide instead of the number of atoms. For meteorites, we then quote the specific activity (activity per gram, or usually decays per minute per kilogram).

Terrestrial ages of meteorites from a wide variety of environments have been measured. Meteorites from temperate or tropical regions do not survive for more than a few thousand years, but it has been recognized since the 1990's that some meteorites can survive for tens of thousands of years in arid environments, and even longer in Antarctica (Jull et al. 1998, Jull 2006). Studies on US and Australian meteorites (e.g. Jull et al. 1993, 2010) are well established. Recently, there have been a significant number of studies which investigated terrestrial ages from Antarctica and concentration processes of meteorites (Folco et al. 2006; Zekollari et al. 2019). There are also terrestrial-age studies of the Atacama Desert (Hutzler et al. 2016; Gattacceca et al. 2011), where a very high concentration of meteorites has been observed, implying some concentration mechanism. Large numbers of meteorites have also been recovered from the Arabian peninsula (Hezel et al. 2011; Hofmann et al. 2018) and Morocco (Aboulahris et al. 2019). I have highlighted a number of these studies in the reference list. The distribution of terrestrial ages in these various arid environments will be contrasted with the cold Antarctic environment.

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