TERRESTRIAL AGES OF METEORITES DETERMINED BY ^{14}C AND ^{14}C/^{10}Be USING ACCELERATOR MASS SPECTROMETRY.

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Introduction: Large concentrations of meteorites can be recovered from areas of the Earth's surface where weathering rates are lower, such as in deserts, or in polar regions, where concentration of the meteorites can occur due to ice flow, such as in Antarctica. Abundant recovery locations for meteorites are arid and semi-arid regions. These include Antarctica, the Sahara Desert, Atacama, Namib and Arabian deserts, the Nullarbor Plain of Australia, areas in the southwestern USA and similar recovery locations. Cosmogenic radionuclides (such as ^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl and ^{41}Ca) 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 [1-3]. We find that exposure times of meteorites reflect the time since the breakup of the larger parent object, which is typically in the range of 1-50Ma. The terrestrial-residence time (or terrestrial age) depends on the environment where a meteorite lands. This age can range from zero (a recent fall) to over 40ka in desert environments and can be hundreds of thousands of years in cold, polar environments. Radionuclides such as ^{14}C have also been used to distinguish between terrestrial and extraterrestrial sources of carbon by using the very different levels expected.

Material in space and on the earth is subject to irradiation by cosmic rays. The result is the production of secondary nuclides, known as "cosmogenic nuclides". We know that meteorites and lunar material contain significant radioactivity produced by the action of cosmic radiation in space [1,2]. Since radionuclides decay, they give us "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 or exposure age, 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 Eugster et al. [1] and Herzog et al. [2]. Jull [3] has summarized data for terrestrial ages. It has also been recognized that small amount of cosmogenic nuclides can be produced on the Earth's surface as well, although the atmosphere shields this production substantially [4]. The radionuclides ^{14}C (half-life: 5.7ka), ^{10}Be (1.38Ma), ^{36}Cl(301ka) ^{26}Al (700ka), and ^{129}I (15.7Ma) can all be measured with accelerator mass spectrometry (AMS). This suite of cosmogenic radionuclides provides a useful range for potential exposure age studies, from thousands to millions of years. The distinct and varied chemical properties of each of these elements also make them well-suited to geochemical studies. For stable cosmogenic nuclide the units of concentration are expressed as atoms g^{-1}, however for radionuclides the most widely used units are given as activities(dpm/kg = decays minute^{-1} kg^{-1}). 60 dpm/kg is equivalent to 1 Bq/kg.

Secondary neutrons and protons produced by GCR reactions have a characteristic depth dependence. The time for a target to become saturated with a particular cosmogenic radioisotope is a function of the half-life of the radionuclide. A maximum saturation level for a radionuclide occurs within about 5-6 half-lives, since the radioactivity builds up according to the build-up relation:

$$N = \frac{P}{\lambda}(1 - \mathrm{e}^{-\lambda t}) \qquad [1]$$

Where P is the production rate (at a given location), λ is the half-life of the radionuclide of interest, and t is the build-up time. The production rate P depends on a complex function of the particle flux at the depth of the sample in the body, the energy distribution of nuclear particles at this depth, the excitation function for ^{14}C production from oxygen (and other elements) as a function of energy, and the chemical composition of the sample [5]. In the case of ^{14}C, we can calculate the terrestrial age if we know the production rate, since we can assume that the ^{14}C saturated during the meteorite's exposure in space. The ^{14}C terrestrial age is then calculated from the equation:

$$T_{terr} = -\frac{1}{\lambda_{14}} \ln \left(\frac{N_m}{N_{sat}}\right) \qquad [2]$$

Where λ_{14} is the decay constant for ^{14}C of 1.21 X 10^{-4}, N_m is the measured amount of ^{14}C (in activity, dpm/kg; or atoms/g) and N_{sat} is the saturated activity, which is P_{14}/λ [3,6].

We previously also investigated the ratio ^{14}C/^{10}Be for dating on the assumption that this production ratio should be reasonably constant at ~2.5 to 2.6 [7,8].

Since ^{10}Be and ^{14}C are produced by similar nuclear spallation reactions, we expect that the production ratio of these two nuclides is relatively constant and this is a way of correcting for the depth effects. In this case, we can calculate the terrestrial age from the ratio of ^{14}C/^{10}Be, according to the following equation. The terrestrial age is then calculated from the equation:

$$T_{age} = -\frac{1}{\lambda_{10} - \lambda_{14}} \ln\left(\frac{{}^{14}C/{}^{10}Be_{m}}{{}^{14}C/{}^{10}Be_{sat}} \right) \qquad [3]$$

This assumes that the exposure age of the meteorite in space was long enough to saturate ^{10}Be.

Meteorites have been recovered since prehistoric times. The length of time they survive on the surface of the Earth has always been of considerable interest. Meteorites appear to fall equally all over the world and have be recovered from all parts of the globe [9]. In general, the infall rate can been described as a function of mass where:

$$\log N = a \log M + b \qquad [4]$$

where N is the number of meteorites which fall per 10^6 km^2 per year, of greater than mass M in grams. Halliday et al [9] determined the constants a and b to be -0.49 and -2.41 for M<1030g, and -0.82 and -3.41 for M>1030g, based on observations of meteoroids. This would result in an infall rate of M>10g of 83 events per 10^6km^2/yr, or roughly one event per km^2 in 10,000 yr. Bland et al. [10] estimated an infall rate of 36-116 events per 10^6km^2/yr based on meteorite weathering and recovery. The total mass of infalling material from cosmic dust to large objects averages about 40,000 tons/yr [11]. Despite the apparently uniform infall rate, meteorites are easier to locate in some places than in others.

Methods: We extracted ^{14}C from samples using an RF induction system, as described earlier [6]. Sample gas is extracted, cleaned and reduced to graphite for AMS measurement without adding a carrier. Graphites are pressed into a target holder and were measured using the NEC machine at the University of Arizona running at 2.5MV. Recently, we also have experimented with using an AMS gas ion source attached to the 200kV MICADAS AMS in Debrecen for meteorite ^{14}C measurements.

In this paper, we present measurements of terrestrial ages on a number of meteorites from different environments and compare the differences due to various factors. We highlight some recent results on meteorites from central and eastern Europe.

Acknowledgements: This research was supported by the European Union and the State of Hungary, co-financed by the European Regional Development Fund in the project GINOP-2.3.2.-15-2016-00009 'ICER'. We also acknowledge support for IK from an IAEA training fellowship and AG for a Fulbright fellowship from the Hungarian-American Fulbright Commission.

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