EFFECTS OF SUBSAMPLE HETEROGENEITY AND DIFFUSION KINETICS ON THE COSMIC RAY EXPOSURE AGES OF ENSTATITE (E) CHONDRITES

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Introduction: Cosmic ray exposure (CRE) ages provide information about the parent bodies and source regions of meteorite classes [1]. The CRE age distribution of enstatite (E) chondrites is of particular interest because E chondrites have an oxygen isotopic composition similar to Earth [2]. Using the E chondrite CRE age distribution to identify potential parent bodies could therefore provide insight into the building blocks of an early Earth. At present, several factors inhibit us from inferring the E chondrite source region from the CRE age distribution. First, there are significant discrepancies between ^{21}Ne and ^{3}He CRE ages of E chondrites: 86% of ^{3}He CRE ages are younger than the ^{21}Ne CRE ages measured in the same meteorite [3]. It has been hypothesized that these discrepancies are the result of diffusive loss of ^{3}He due to solar heating during orbit [1,3,4], but evidence of diffusive loss has yet to be validated with information about ^{3}He diffusion kinetics. Second, uncertainties in E chondrite ^{21}Ne CRE ages are nearly double that of other meteorite classes [3]. These large uncertainties are linked to uncertainties in cosmogenic noble gas production rates, which are controlled by chemical composition. Historically, an average chemical composition for an entire meteorite class or subgroup was used to calculate production rates [5,6]. However, at the scale necessitated for noble gas measurements, E chondrites can have heterogeneous mineral abundances. This suggests that production rates may vary significantly between subsamples of the same meteorite.

To determine whether anomalously young ^{3}He CRE ages can be attributed to thermally-activated diffusion, we perform diffusion experiments on proton irradiated pyroxene and metal (the most dominant phases in E chondrites). We also demonstrate an approach for determining subsample-specific cosmogenic noble gas production rates using micro-computed x-ray tomography (μCT). We then measure the noble gas concentrations in distinct chips of the same meteorite to evaluate whether they have distinct noble gas concentrations and calculate their CRE ages.

Methods: We analyzed 4 E chondrites for this study: Caleta el Cobre (CEC) 024 (EL), CEC 025 (EH), CEC 028 (EL), and North West Africa (NWA) 974 (EL). We performed μCT analyses at the Smithsonian National Museum of Natural History (NMNH), segmented the μCT data, and quantified the volumetric abundance of metal, sulfide, silicate, and weathering products (if present) within each subsample. We also prepared polished epoxy mounts of each meteorite for electron microprobe (EPMA) analyses at NMNH, to quantify the elemental composition of different mineral phases. The abundance of cosmogenic ^{21}Ne in meteorite subsamples and diffusion experiments on kamacite and pyroxene were carried out in the noble gas mass spectrometry facilities at Purdue University and Lawrence Livermore National Lab.

Expected Results: Both the metal and sulfide abundances in E chondrite subsamples have significant effects on calculated cosmogenic nuclide production rates. We found the volumetric abundance of metal can vary by over 10% between subsamples of the same meteorite. This yields a nearly 20% difference in cosmogenic nuclide production rates, which would be proportional to the differences in calculated exposure ages. Due to the observed heterogeneity in metal abundance between subsamples of the same meteorite, we expect to observe measurable differences in the abundance of cosmogenic ^{21}Ne in our subsamples. We will also quantify the diffusion kinetics of ^{3}He and ^{21}Ne in pyroxene and metal. This will provide insight into what thermal histories are necessary to explain the anomalously young ^{3}He-derived CRE ages observed in E chondrites. We expect to demonstrate that pairing μCT scans with noble gas measurements enables recovery of the same CRE age of each meteorite subsample, despite variations in cosmogenic noble gas abundance. This will demonstrate the more general need for subsample-specific production rates for meteorite classes that exhibit spatial heterogeneity in mineral abundances at the scale necessitated for cosmogenic noble gas measurements.

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