**Introduction:** Cosmic ray exposure (CRE) ages can 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 CRE age distribution to identify potential parent bodies could therefore provide insight into the building blocks of an early Earth. CRE ages have been determined for only a small number of E chondrites using cosmogenic noble gases, and these CRE ages have high uncertainties relative to other meteorite classes, making interpreting the E chondrite CRE age distribution difficult [3]. The large uncertainties in E chondrite CRE ages are linked to uncertainties in cosmogenic noble gas production rates. Cosmogenic noble gas production rates are controlled by chemical composition. Historically, an average chemical composition for an entire meteorite class or subgroup was used to calculate production rates [4,5]. However, at the scale necessary 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.

Here, we demonstrate an approach for determining subsample-specific cosmogenic production rates using micro-computed tomography (μCT). We show production rates can differ by > 10% for subsamples of the same E chondrite, particularly for cosmogenic 21Ne. By applying this method to more E chondrite subsamples and refining the E chondrite CRE age distribution, we may begin to address whether the EH and EL subgroups share an impact history, and whether peaks in the age distribution are attributable to distinct impact events.

**Methods:** We analyzed six E chondrites for this study: Caleta el Cobre (CEC) 024 (EL), CEC 025 (EH), CEC 028 (EL), North West Africa (NWA) 974 (EL), Indarch (EH), and Ufana (EL). For CEC 024, CEC 025, CEC 028, and NWA 974, which are all meteorite finds, we cut two subsamples (~100-500 mg) from each meteorite for μCT analyses, referred to as either (A) or (B). We also analyzed individual subsamples of Indarch and Ufana, which are both meteorite falls and therefore expected to exhibit minimal weathering compared to the meteorite finds.

We performed μCT analyses at the Smithsonian National Museum of Natural History (NMNH) using the GE Phoenix Dual Tube μCT scanner. We used Dragonfly Object Research Systems (ORS) software to segment the μCT data and quantify the volumetric abundance of metal, sulfide, silicate, and weathering products (if present) within each subsample. We also prepared polished epoxy mounts of CEC 024, CEC 025, CEC 028, and NWA 974 for electron microprobe (EPMA) analyses using the JXA-8530F+ Hyper Probe Electron Microanalyzer at NMNH. We used existing microprobe data on Indarch and Ufana mineral compositions [6].

**Production Rate Calculations.** We use the model of Leya and Masarik [7] to calculate composition-dependent production rates of cosmogenic noble gases. Both the metal and sulfide abundances have significant effects on calculated cosmogenic nuclide production rates: production rates are ~3-5 orders of magnitude lower in metal than in silicate minerals [8], and 21Ne production rates in troilite is higher compared to metal because of the presence of S [9]. We determined normalized elemental weight percent of each E chondrite subsample using the mineral composition from the EPMA data, volumetric abundances from the μCT data, and phase densities from Keil [6]. We then used those weight percentages to calculate depth dependent cosmogenic noble gas production rate in each E chondrite subsample.

**Results:** Volumetric abundances of metal, sulfide, silicate, and weathering products in the E chondrite subsamples from our μCT analyses are shown in Figure 1. Only NWA 974 contained volumetrically significant weathering products. For the purposes of calculating cosmogenic noble gas production rates in NWA 974, we assume there is either no retention of cosmogenic noble gases in the weathering products (Fig. 2, NWA 974), or complete retention. If we assume complete retention, we assume the terrestrial weathering products were either initially fully metal (Fig. 2, NWA 974*), or some average of the subsample composition (Fig. 2, NWA 974**). Using these criteria, we calculate the percent difference in depth-dependent production rates in subsample (A) relative to subsample (B) (Fig. 2).

**Discussion:** We found that differences in mineral abundances result in > 10% difference in the 21Ne production rate in subsamples of the same meteorite in most cases (Figure 2). Model production rates of 20-, 40-, and
Figure 1: Volumetric abundances of metals, sulfides, silicates, and weathering products (if applicable) in E chondrite subsamples.

Figure 2: Percent difference in production rate between subsamples of the same E chondrite as a function of depth below the meteoroid surface for $^3$He (dashed) and $^{21}$Ne (solid) in different sized meteoroids, assuming $2\pi$ geometry.

50-cm sized bodies show similar patterns, with $^{21}$Ne displaying higher production rate differences than $^3$He because $^3$He production is less sensitive to chemical composition. Subsample production rate differences in NWA 974 are small when we assume the weathering products were initially metal (Fig. 2, NWA 974*). This is because NWA 974 (A) had a much lower weathering volume % relative to NWA 974 (B), but (A) also had a much higher metal volume percent relative to (B) (Fig. 1). When we re-allocate the weathered portion to the metal, their compositions are nearly identical.

Overall, we calculated mineral abundances that are within the average range for EL and EH meteorites [6], so we are confident we have correctly identified phases using the $\mu$CT approach. The EL meteorites were easier to segment than the EH meteorites, as they generally exhibit large grain sizes and consist predominantly of kamacite, troilite, and enstatite. The exception is that weathering products in NWA 974 were difficult to quantify, particularly because their grayscale values overlapped with sulfides. The EH meteorites CEC 025 and Indarch were both more difficult to segment due to abundant fine grained minerals of varying composition.

Conclusions: Spatial heterogeneity in mineral abundance within E chondrites causes significant cosmogenic noble gas production rate differences between subsamples, particularly for cosmogenic $^{21}$Ne. Production rates are directly proportional to CRE ages; therefore when integrated over million year timescales, CRE ages can change by several million years when subsample-specific production rates are accounted for. We suggest that the nondestructive approach used here to determine subsample mineral abundances can be utilized to determine cosmogenic production rates for E chondrites and other meteorite classes before carrying out destructive noble gas analyses on the same subsamples.

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