

**COMBINED IRON AND SILICON ISOTOPE COMPOSITIONS OF UNGROUPED ACHONDRITES:
EVALUATING THE ROLE OF DEGREE OF DIFFERENTIATION AND REDOX CONDITIONS**

S. Ray^{1*}, D. L. Schrader^{1,2}, V.K. Rai¹, M. Wadhwa¹, ¹School of Earth and Space Exploration, Arizona State University, USA, ²Buseck Center for Meteorite Studies, Arizona State University, USA, *Current Address: Department of Geology, University of Maryland College Park, USA.

Introduction: Ungrouped achondrites are achondrites that have been characterized well enough to determine that they cannot currently be categorized as belonging to any established group of meteorites. These achondrites sample parent bodies that have undergone different degrees of differentiation (primitive to evolved), formed under varied redox conditions, accreted and differentiated at different times relative to calcium-aluminum-rich inclusion (CAI) formation, and are thought to have originated both in the inner and outer Solar System [e.g., 1]. Therefore, the identification of numerous ungrouped achondrites provides an opportunity to understand the diversity of conditions and processes operating on distinct parent bodies in the early Solar System. In particular, ungrouped achondrites that record different degrees of differentiation and redox conditions have the potential to provide insights into factors controlling the stable isotope compositions of such achondrites. Here, we report the Fe and Si isotope compositions of ten ungrouped achondrites (GRA 06129, NWA 2976, NWA 5297, NWA 6926, NWA 6962, NWA 8486, NWA 8777, NWA 10503, NWA 11119, and Tafassasset) that are thought to have resulted from different degrees of differentiation occurring under varied redox conditions. The goal was to evaluate the roles of degree of differentiation and redox conditions in influencing their Fe and Si isotopic compositions.

Analytical Methods: Polished sections of a subset of these ungrouped achondrites (NWA 2976, NWA 5297, NWA 6962, NWA 8777, NWA 10503, and NWA 11119) were analyzed using the JEOL JXA-8530F electron microprobe in the Eyring Materials Center at Arizona State University (ASU). All sample handling and chemical processing for isotopic analyses were carried out under clean laboratory conditions in the Isotope Cosmochemistry and Geochronology Laboratory at ASU. A clean, interior piece (20–100 mg) of each of the ten achondrites was powdered using a clean boron carbide mortar and pestle. Thereafter, ~1 mg of the homogenized powdered sample of each meteorite was mixed with ~200 mg NaOH.H₂O flakes in a round-bottomed Teflon beaker. The 200:1 flux-sample mixture was heated on a hotplate at 250°C for ~96 hours to ensure complete digestion. Solutions containing ~15 ug of Si were loaded onto columns with 1.8 ml of AG50W-X8 (200–400 mesh) cation exchange resin and eluted with Milli-Q[®] water. Subsequently, Fe and other cations that were adsorbed on the cation exchange resin were eluted using 6N HCl onto a column containing 1ml of AG1-X8 (200–400 mesh) anion exchange resin. Finally, Fe was separated from the anion exchange resin according to methods modified after [2]. Silicon and Fe isotope compositions were measured on a Thermo Neptune multicollector inductively coupled plasma mass spectrometer (MC-ICPMS) in high- and medium-resolution mode, respectively. Details of the column chromatographic technique and isotopic measurements have been described in [3].

Results and Discussion: We determined the olivine-spinel and/or two-pyroxene equilibration temperatures and oxygen fugacities of six samples (i.e., NWA 2976, NWA 5297, NWA 6962, NWA 8777, NWA 10503, and NWA 11119) using the compositional data obtained with the electron microprobe for appropriate mineral assemblages according to methods described in [4–6]. For the remaining four achondrites studied here, i.e., GRA 06129, NWA 6926, NWA 8486, and Tafassasset, we used the equilibration temperature and oxygen fugacity values published in literature for these achondrites (or their paired samples) [4,7–10].

The Fe isotope compositions ($\delta^{56}\text{Fe}$) of the ten achondrites range between $-0.316 \pm 0.020\%$ and $0.077 \pm 0.013\%$ while the Si isotope compositions ($\delta^{30}\text{Si}$) range between $-0.213 \pm 0.052\%$ and $-0.552 \pm 0.018\%$. Their equilibration temperatures range between 673 ± 50 °C and 1190 ± 66 °C. Relative to the iron-wüstite (IW) buffer, these achondrites also record a wide range of redox conditions ranging from $\Delta\text{IW} - 3.4 \pm 0.1$ to $\Delta\text{IW} + 2 \pm 0.5$. The $\delta^{56}\text{Fe}$ and $\delta^{30}\text{Si}$ do not exhibit a correlation with their oxygen fugacities of formation. However, it seems likely that the mode of formation and degree of differentiation control the $\delta^{56}\text{Fe}$ and $\delta^{30}\text{Si}$ values of the ungrouped achondrites in this study, irrespective of their redox state. We conclude that the combined $\delta^{56}\text{Fe}$ and $\delta^{30}\text{Si}$ of the ungrouped achondrites, in combination with their mineralogy and chemical composition, can be used as a tracer of differentiation and mode of formation.

References: [1] Sanborn M. E. et al. (2019) *Geochimica et Cosmochimica Acta*, 245, 577–596. [2] Arnold G. L. et al. (2007) *Analytical Chemistry*, 76, 322–327. [3] Ray S. et al. (2020) *LPSC LI*, Abstract# 2558. [4] Gardner-Vandy K. et al. (2012) *Geochimica et Cosmochimica Acta*, 85, 142–159. [5] Gardner-Vandy K. et al. (2013) *Geochimica et Cosmochimica Acta*, 122, 36–57. [6] Schrader D. L. et al. (2017) *Geochimica et Cosmochimica Acta*, 205, 295–312. [7] Shearer C. K. et al. (2010) *Geochimica et Cosmochimica Acta*, 74, 1172–1199. [8] Hibiya Y. et al. (2019) *Geochimica et Cosmochimica Acta*, 245, 597–627. [9] Goodrich C. A. et al. (2017) *Geochimica et Cosmochimica Acta*, 203, 381–403. [10] Sutton S. R. et al. (2017) *Geochimica et Cosmochimica Acta*, 204, 313–330.