EPMA Methods Compilation

EPMA at Johnson Space Center (subset of Karoonda)

For apatite in the first seven analyses of Karoonda reported in Table S8, EPMA was conducted using a JEOL 8530 field emission electron microprobe housed in ARES at NASA JSC. Data were collected using PFE software from Probe Software, Inc. All apatite was analyzed using a 15 kV accelerating voltage and 20 nA beam current following previous procedures established by our group for the analysis of apatite in planetary materials (e.g., McCubbin et al., 2011; McCubbin et al., 2010). We analyzed the elements P, Si, Ce, Y, Fe, Mg, Ca, Na, F, and Cl. Fluorine was analyzed using a light-element LDE1 detector crystal, and Cl was analyzed using a PETL detector crystal. The standards used for calibration include: Durango apatite (Jarosewich et al., 1980) and fluourapatite (from SPI Supplies) for Ca and P, and a natural fluorapatite from India (Ap020 from McCubbin et al., 2012b) was used as secondary check on the standardization. A synthetic SrF_2 crystal was used as the primary F standard, and Ap020 was used as an additional check on the F standardization. Tugtupite (from SPI Supplies) was used as a primary Cl standard. Endmember REE-phosphates from Jarosewich and Boatner (1991) were used to standardize Ce ($CePO_4$) and Y (YPO_4). Albite (from SPI Supplies) was used as a primary standard for Na and Si. Ilmenite from the Smithsonian (USNM 96189) was used as a primary standard for Fe, and Springwater olivine (USNM 2566) was used as an Mg standard. In order to reduce or eliminate electron beam damage, we used a 10 µm spot for standardization and 1 to 10 µm diameter beams for analysis of apatite in Karoonda.

EPMA at Johnson Space Center (subset of Karoonda, DAV 92300, EET 87507, LAR 06872, Maralinga, subset of LAP 04840, subset of MIL 11207, LAP 03639, ALH 85151, PCA 91002, PRE 95410)

For apatite in the final 14 analyses of apatite in Karoonda from Table S8, the final 17 analyses of apatite in LAP 04840 from Table S2, the final 9 analyses of MIL 11207 from Table S3, and all the apatite in DAV 92300, EET 87507, LAR 06872, Maralinga, LAP 03639, ALH 85151, PCA 91002, PRE 95410, EPMA was conducted using a JEOL 8530 field emission electron microprobe housed in ARES at NASA JSC. Data were collected using the JEOL software. All apatite was analyzed using a 15 kV accelerating voltage and 20 nA beam current following previous procedures established by our group for the analysis of apatite in planetary materials (e.g., McCubbin et al., 2011). We analyzed the elements P, Si, Fe, Mn, Mg, Ca, Na, F, Cl, and S. Fluorine was analyzed using a light-element LDE1 detector crystal, and Cl was analyzed using a PETL detector crystal. The standards used for calibration include: fluourapatite (from SPI Supplies) for Ca and P, and a natural fluorapatite from India (Ap020 from McCubbin et al., 2012b) was used as secondary check on the standardization. A synthetic SrF_2 crystal was used as the primary F standard, and Ap020 was used as an additional check on the F standardization. Tugtupite (from SPI Supplies) was used as a primary Cl standard. Barite (from SPI Supplies) was used as the primary S standard, and spring water olivine (USNM 2566) was used as a standard for Mg. Albite (from SPI Supplies) was used as a primary standard for Na, and quartz (from SPI Supplies) was used as a primary standard for Si. Ilmenite from the Smithsonian (USNM 96189) was used as a primary standard for Fe, and Mn was standardized using rhodonite (from SPI Supplies). In order to reduce or eliminate electron beam damage, we used a 10 µm spot for standardization and 1 to 10 µm diameter beams for analysis of apatite grains in all samples.

EPMA at University of New Mexico (NWA 8186)

For apatite in NWA 8186, EPMA was conducted using a JEOL 8530 field emission electron microprobe housed in ARES at NASA JSC. Data were collected using PFE software from Probe Software, Inc. All apatite was analyzed using a 15 kV accelerating voltage and 20 nA beam current following previous procedures established by our group for the analysis of apatite in planetary materials (e.g., McCubbin et al., 2010b, 2011). We analyzed the elements P, Si, Fe, Mg, Ca, Na, F, and Cl. Fluorine was analyzed using a light-element LDE1 detector crystal, and Cl was analyzed using a PETL detector crystal. The standards used for calibration include: Durango apatite (Jarosewich et al., 1980) for Ca and P, and a natural fluorapatite from India (Ap020 from McCubbin et al., 2012b) was used as secondary check on the standardization. A synthetic SrF_2 crystal was used as the primary F standard, and Ap020 was used as an additional check on the F standardization. Synthetic sodalite from Sharp et al. (1989) was used as a primary Cl standard. Albite (from Taylor multi element standard mount) was used as a primary standard for Na, and SiO_2 (from Taylor multi element standard mount) was used as a primary standard for Si. Ilmenite was used as a primary standard for Fe, and Mn was standardized using spessartine. Olivine (from Taylor multi element standard mount) was used as a standard for Mg. In order to reduce or eliminate electron beam damage, we used a 10 µm spot for standardization and 1 to 10 µm diameter beams for analysis of apatite in NWA 8186.

EPMA at The University of New Mexico (Parnallee)

For apatite in Parnallee, EPMA was conducted using a JEOL JXA 8200 electron microprobe equipped with 5 wavelength dispersive spectrometers in the IOM at UNM. Data were collected using both the JEOL manufacturer's software and the Probe for EPMA (PFE) software from Probe Software, Inc. All apatite was analyzed using a 15 kV accelerating voltage and 20 nA beam current using the methods reported in Lewis and Jones (2016). We analyzed the elements P, Ce, Y, Fe, Mg, Ca, Na, F, and Cl. Fluorine was analyzed using a light-element LDE1 detector crystal, and Cl was analyzed using a PET detector crystal. The standards used for calibration include: Wilberforce apatite (from the Taylor multi element standard mount from C.M. Taylor) for Ca, P, and F, and a natural fluorapatite from India (Ap020 from McCubbin et al., 2012b) was used as a secondary check on the standardization. Taylor Olivine was used as a standard for Mg and Fe, and synthetic sodalite crystal (from Sharp et al., 1989) was used as a standard for Cl and Na. Cerium and Y were standardized using their respective synthetic orthophosphate endmembers from Jarosewich and Boatner (1991). In order to reduce or eliminate electron beam damage, we used a 5 µm diameter beam for analysis of apatite grains in Parnallee.

EPMA at Johnson Space Center (subset of LAP 04840)

For apatite in the first 25 analyses of LAP 04840 reported in Table S2, EPMA was conducted using a CAMECA SX-100 electron microprobe housed in ARES at NASA JSC. All apatite was analyzed using a 15 kV accelerating voltage and 5 nA beam current (McCanta et al., 2008). We analyzed the elements P, Si, Fe, Mg, Ca, Na, F, Cl, and S. Fluorine was analyzed using a light-element PC1 detector crystal. The standards used for calibration include: Durango apatite (Jarosewich et al., 1980) for Ca, P, and F. Tugtupite was used as a Cl standard, and troilite was used as an S standard. Kaersutite was used as a standard for Fe, Mg, Si, and Na. In order to reduce or eliminate electron beam damage, we used a 5 µm spot for analysis of apatite in LAP 04840.

EPMA at American Museum of Natural History (subset of MIL 11207)

For apatite in the first 30 analyses of MIL 11207 reported in Table S3, EPMA was conducted using a CAMECA SX-100 electron microprobe housed in the American Museum of

Natural History. All apatite was analyzed using a 15 kV accelerating voltage and 15-20 nA beam current (Gross et al., 2023; Gross et al., 2013b). In order to reduce or eliminate electron beam damage, we used a 10 µm spot for analysis of apatite in MIL 11207. We analyzed the elements P, Si, Fe, Mn Mg, Ca, Na, F, Cl, and S. Fluorine was analyzed using a light-element PC0 detector crystal. The method described in Goldoff et al. (2012) and Webster et al. (2009) for apatite analyses was used to obtain proper abundances of F, Cl and Na. Standards included well characterized natural and synthetic materials, including: diopside, (Si, Ca, Mg), olivine (Si, Mg, Fe), jadeite (Na, Al), hematite (Fe), rutile (Ti), chromite (Cr), Ni-diopside (Ni), rhodonite (Mn), orthoclase (K), troilite (Fe, S), MgF_2 (F), scapolite (Cl), berlinite (P), and apatite (P). Data quality was ensured by analyzing standard materials as unknowns.

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