MARTIAN METEORITE RAIN: PETROLOGY, ELEMENTAL AND ISOTOPIC COMPOSITION OF TEN RECENTLY RECOVERED SHERGOTTITES.

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Introduction: The number of unpaired Martian meteorites has increased remarkably in recent years, especially because of finds in northwest African countries. Within just the past year numerous new specimens have been recovered, such that the present total has reached 127, of which 111 are various sorts of shergottites. We have been conducting systematic petrologic and chemical studies of these specimens, and here we give a summary report about our latest findings.

Enriched Mafic Shergottites NWA 11866, NWA 11955, NWA 12262 and NWA 12269: These four different (and unpaired) aphyric olivine-free shergottite stones vary in grainsize, and texturally range from fine intersertal to diabasic to gabbroic. All are composed predominantly of clinopyroxene and maskelynite ($An_{50.9-55.0}Or_{2.1-0.9}$) with accessory phosphates (merrillite, chlorapatite), ilmenite, Ti-chromite and pyrrhotite.

Pyroxenes in all of these specimens exhibit similarly extensive compositional zoning (see Figure 1), and range from pigeonite ($Fs_{31.1}Wo_{14.0}$, FeO/MnO = 50) to subcalcic augite ($Fs_{25.9-71.4}Wo_{28.6-23.1}$, FeO/MnO = 50-75) to augite ($Fs_{23.2}Wo_{39.7}$, FeO/MnO = 49) to ferropigeonite on rims ($Fs_{80.1}Wo_{19.5}$, FeO/MnO).

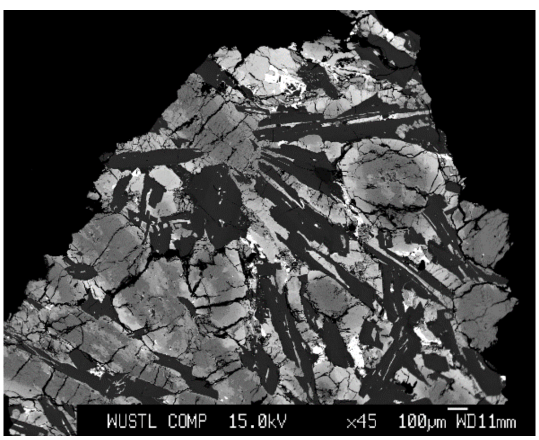


Figure 1. *BSE image of NWA 11269*

Enriched Poikilitic Shergottite NWA 12210: Large pyroxene oikocrysts (up to 6 mm across) enclose olivine chadacrysts, and are set in a relatively coarse grained groundmass containing olivine, pyroxenes, lath-like maskelynite ($An_{53.8-54.4}Or_{2.1-2.2}$), abundant phosphates (both merrillite and chlorapatite), Ti-poor chromite and pyrrhotite. Mafic silicates exhibit very limited compositional zoning: olivine ($Fa_{38.1-40.7}$, FeO/MnO = 49-51), low-Ca pyroxene core ($Fs_{24.7}Wo_{4.1}$, FeO/MnO = 30), pigeonite ($Fs_{26.4-30.8}Wo_{11.0-7.5}$; $Fs_{28.1}Wo_{16.3}$; FeO/MnO = 25-29), subcalcic augite ($Fs_{16.8-18.5}Wo_{33.7-36.6}$, FeO/MnO = 23-25).

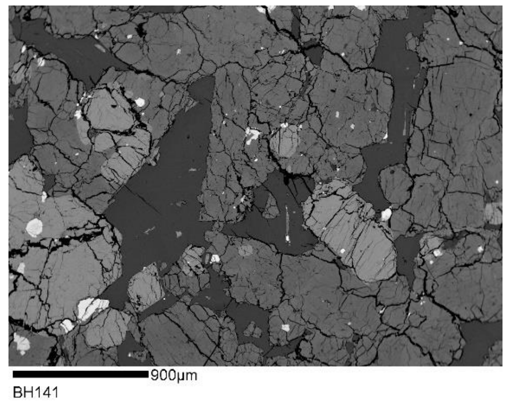


Figure 2. *BSE image of NWA 12210*

Intermediate Olivine-Phyric Shergottite NWA 2424: Following initial petrologic and INAA studies by Warren [1], we have obtained further elemental and isotopic data on a representative whole rock powder.

Intermediate Olivine Gabbroic Cumulate Shergottite NWA 12241 (*with birefringent plagioclase*): This fresh specimen has an orthocumulate texture with ~15 vol.% lath-like, birefringent plagioclase ($An_{43.0-57.8}Or_{2.4-1.3}$) occurring interstitially to more abundant and coarser grained (0.2-1.6 mm, mean 0.7 mm) mafic silicate grains. Olivine exhibits very limited compositional variation ($Fa_{32.7-34.3}$, FeO/MnO = 47-48), and clinopyroxenes consist of pigeonite ($Fs_{25.0-30.4}Wo_{5.5-10.0}$, FeO/MnO = 28-30) and subcalcic augite ($Fs_{17.1-18.1}Wo_{32.7-32.4}$, FeO/MnO = 23-25). Accessory phases include Mg-merrillite, chlorapatite, ilmenite, Ti-rich chromite, Cr-rich chromite and pyrrhotite (some associated with minor pentlandite).

Levels of shock are judged to be low, based on the absence of optical effects in plagioclase and the complete lack of any conversion to maskelynite. The presence of widespread microcracks in mafic silicates is the only clear evidence of shock. Among Martian meteorites, NWA 12241 joins NWA 4480 [2] and nakhlites as rare examples which are maskelynite-free.

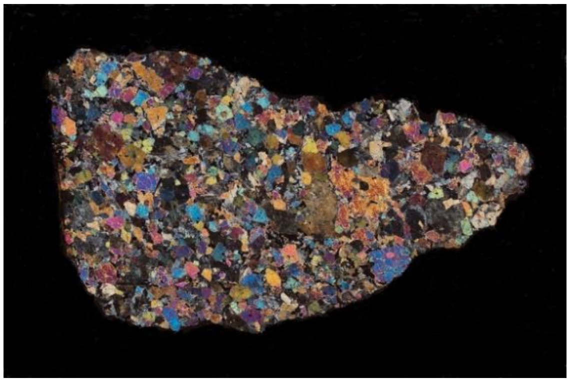


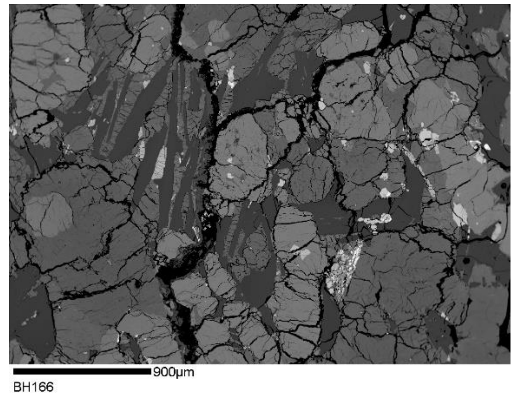
Figure 3. *Cross-polarized light optical thin section image of NWA 11241. Width = 20 mm.*

Intermediate Mafic Gabbroic Shergottite NWA 12323: This specimen (which is very similar to NWA 10761 and NWA 11300) is composed predominantly of prismatic, zoned and twinned grains of pyroxene (up to 3.6 mm long) and maskelynite ($An_{54.6-54.7}Or_{0.6-0.5}$, some as thin laths in subradial groups) with accessory merrillite, ilmenite, ulvöspinel and pyrrhotite, plus minor secondary barite and calcite. Pyroxenes have orthopyroxene cores ($Fs_{22.1}Wo_{3.1}$, FeO/MnO = 32), but are composed predominantly of pigeonite ($Fs_{29.9}Wo_{7.3}$; $Fs_{31.9-76.8}Wo_{13.7-15.7}$; FeO/MnO = 31-46) and subcalcic augite ($Fs_{28.9-39.3}Wo_{31.7-27.1}$, FeO/MnO = 33-37).

Figure 4. *Partially cross-polarized light optical thin section image of NWA 12323. Maskelynite is white. Note the shock glass veinlet. Width =18 mm.*

Unnamed Poikilitic Shergottite and Olivine-Phyric Shergottite: Studies of these two evidently unpaired specimens are in progress and will be reported. A 31.8 gram poikilitic specimen (see Figure 5) contains olivine ($Fa_{33.9-41.5}$, FeO/MnO = 50-52) and a variety of clinopyroxenes exhibiting limited Fe/Mg compositional zoning. Other phases are maskelynite ($An_{51.8-53.8}Or_{1.4-1.5}$), ilmenite, Ti-chromite, Mg-merrillite and pyrrhotite.

The second unnamed specimen (14.2 grams) found near Zbayra in southern Morocco contains essentially unzoned olivine phenocrysts (Fa_{33}) set in a groundmass of pigeonite and maskelynite with accessory Ti-chromite, merrillite and pyrrhotite. **Figure 5 (below)**.



Elemental and Nd-Hf Isotopic Compositions: Employing methods detailed previously [3, 4] we obtained the results shown in Figures 6 and 7.

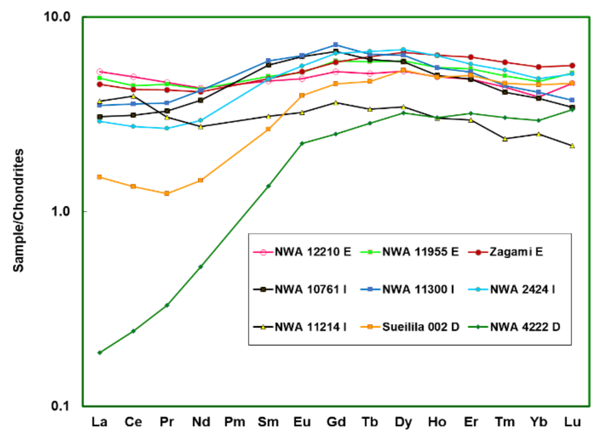


Figure 6. *Chondrite-normalized REE plot. NWA 11214 is intermediate (εHf 27.7) but has a flat pattern.*

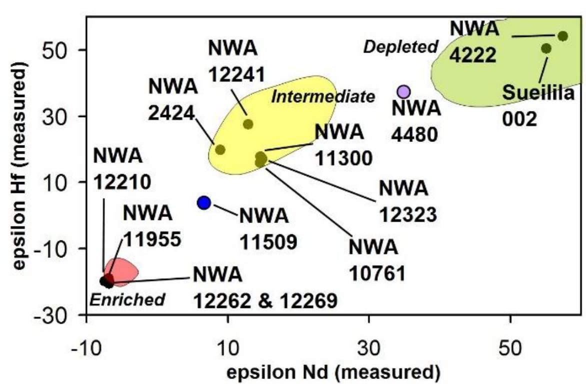


Figure 7. *Mantle isotopic domains for shergottites*

References: [1] *Meteorit. Bull.* **107** [2] Irving A. et al. (2016) *LPS* **XLVII**, #2330 [3] Lapen T. et al. (2017) *Science Advances* **3**, doi: 10.1126/ sciadv.1600922 [4] Lapen T. et al. (2018) *LPS* **XLIX**, #2773.