A NEW MARTIAN GABBROIC SHERGOTTITE, NORTHWEST AFRICA (NWA) 13134.

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Introduction: The majority of Martian igneous meteorites with the exception of unique samples such as a breccias and an orthopyroxenite are categorized into three groups; Shergottite, Nakhlite, and Chasignite (SNCs) [1,2]. All of the SNCs are basaltic to ultra-mafic in nature but their textures and predominant minerals vary [1]. Shergottites, as the most common type of martian meteorite are subdivided either based on texture and mineralogy (olivine-phyric, poikilitic, augite, basaltic, and gabboric shergottite [1]) or bulk geochemical data (enriched, intermediate, and depleted) [2,3]. The distinction between basaltic and gabbroic shergottite is mainly pyroxene grain size [1]. Some previously named basaltic shergottite meteorites could actually be classified as gabbroic given their grain sizes, including >1 to 5 mm [1].

The meteorite NWA 13134 was a find purchased in 2013 in Morocco and had an original mass of 15 g. Here we provide a detailed petrology and geochemistry study of this sample, demonstrating it as an enriched gabbroic shergottite.

Methods: Imaging was conducted using a Zeiss 1550VP Field Emission Scanning Electron Microscope

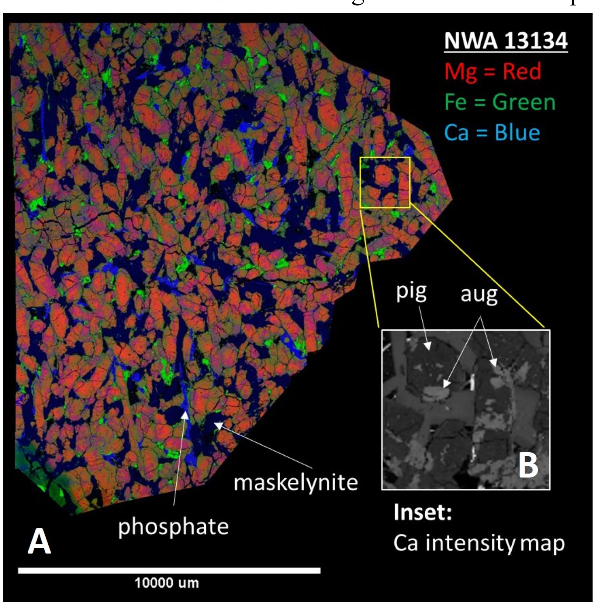

Figure 1: (A) A false color image combining Mg-Fe-Ca elemental intensities in NWA 13134. Mg = Red, Fe = Green, and Ca = Blue.(B): A Ca X-ray intensity map showing the intergrowth of low-Ca and high-Ca pyroxenes.

and quantitative mineral chemistry was measured using a JOEL JXA-8200 electron probe at the Division Analytical Facility in the California Institute of Technology (Caltech). Whole-rock major and trace element analyses were carried out at the Isotoparium (Caltech). Whole-rock powders (~0.5 g) were digested with HF-HNO_3 and aqua regia acid attacks on hot plates, after an initial isopropanol leaching step to remove surface contamination. Analyses were conducted on an iCAP RQ ICP-MS (Thermo Fisher) and data was reduced via external calibration using gravimetric multi-elemental standard solutions.

Petrography: NWA 13134 is composed of predominantly anhedral to subhedral pyroxenes that are up to 3 mm in length (57.1 vol%) and maskelynite of up to 3 mm in length (37.4 vol %) in the polished section studied (**Fig. 1**). The coarse grains of NWA 13134 resemble gabbroic shergottite. Minor phases include ulvöspinel, $Fe_{1-x}S$, merrillite (main phosphate), apatite, and mesostasis. Impact melt pockets are also present within NWA 13134 and range from 10's to 100's of µm across. Pyroxenes are normally zoned from Mg-rich interior to more Fe-rich rims (**Figs. 1&2**). Merrillite tends to occur at grain boundaries together with mesostasis and often contains rounded high-Si and high-K glassy inclusions.

Textural Analyses: Crystal size distributions (CSDs) were determined for pyroxenes. Pyroxene was chosen as (i) it is the most abundant phase and the early crystallized phase, and (ii) the shocked nature of maskelynite has obscured the crystalline boundaries necessary for a

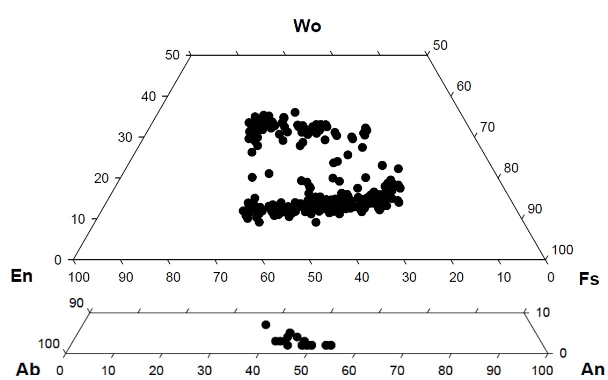

Figure 2: The compositions of pyroxene (top) and maskelynite (bottom) within NWA 13134.

CSD. The results of the CSD analysis are a concave-up shape which is chracteristic of crystal ripening or possibly crystal accumulation [4]. This indicates that the larger crystals grew at the expense of the smaller crystals or that larger crystals settled into the melt prior to cooling. Slow cooling produces this texture and the framework of pyroxenes touching each other means that NWA 13134 is likely the result of an intrusive or thick flow-hosted cumulate [2,5]. This analysis has also shown a preferred mineral orientation which is further evidence of a cumulate nature of formation [4]

Results and Discussion:

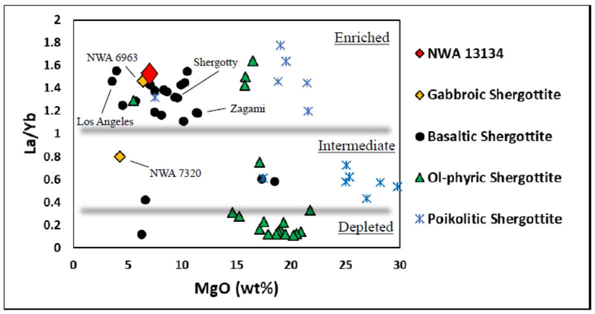

Figure 3: MgO (wt%) vs La/Yb (wt./wt.) showing different geochemical groups of shergottites. NWA 13134 shows an enriched REE signature, similar to NWA 6963 and other basaltic shergottites.

Whole-Rock Composition: The whole-rock trace element data show that NWA 13134 contain enriched rare earth elements (REEs), specifically light rare earth elements (La - Nd). The enrichment or depletion of the REEs is represented by the ratio of the light REEs (La) to the heavy REEs (Yb). Low light REEs represent depleted samples while higher light REEs is a more enriched signature. The La/Yb signature reveals the REE relationships and shows which samples are enriched and which are depleted. Based on the MgO vs La/Yb correlations, NWA 13134 plots in the enriched shergottite field, similar to another enriched gabboric shergottite, NWA 6963 [5,6] and to many basaltic sherogottite meteorites **(Fig 3).**

Pyroxenes: Pyroxene grains display normal zonation with respect to Mg and Fe (En = 20-58, Mg# = 25-69) (**Fig 2**). However, the Ca map shows that pyroxene grains are made of intergorwn pigeonite and augite (Wo = 9-36) with augite often appearing in the core of pigeonite (**Fig 2b**). Both pigeonite and augite show similar trends in Al and Ti as Mg# decreased. Both phases show an inflection at Mg# of ~40 where Al begins to decrease with increasing Ti after plagioclase begins to crystallize (**Fig 4**). These observations suggest pigeonite and augite co-crystallized as plagioclase became stable and began to crystallize. The intergrowth of augite and pigeonite in NWA 13134 appears to differ from that in NWA 6963, in which high Ca-pyroxene appears to

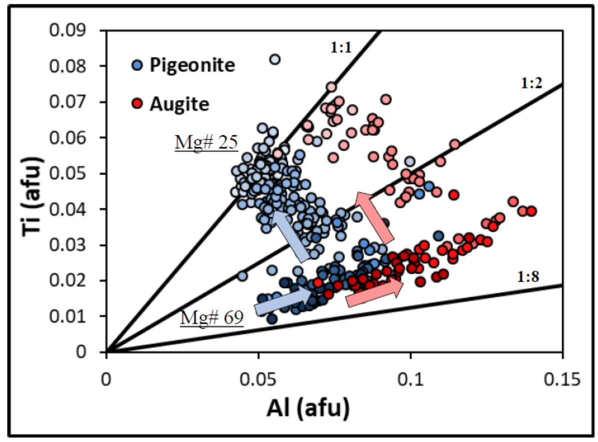

Figure 4: The Al vs Ti in atomic formula units (afu) in pigeonite and augite. The darkest shades represent an Mg# of 65-69 while the lightest an Mg# of 25-30. The Al and Ti correlate positively in both augite and pigeonite until ~ Mg# 40, after which Al decreases with increasing Ti. This inflection in the slope of Al-Ti trends indicates the onset of plagioclase crystallization and the inflection occurring at Mg# 40 for both pigeonite and augite.

form discrete grains at the same time with the low-Ca pyroxene [5]. Similar intergrowth of pigeonite and augite is was previously reported in coarse-grained basaltic shergottites (e.g., Shergotty, Queen Alexandra Range 94201, and Los Angeles) [6,7]. The different pyroxene textures between NWA 13134 and NWA 6963 suggest they are not from the same meteor impacting Earth, with NWA 13134 possibly representing a unique flow.

References:

[1] Udry, A. et al., (2020) *JGR, 125.* [2] Day, J.M.D. et al., (2018) *Nat. Com., 9(1),* 1-8. [3] Sarbadhikari, A.B. et al., (2009) *GCA, 73, 2190-2214*. [4] Higgins, M.D. (2006) *Cambridge University Press.* [5] Filiberto, J. et al., (2018) *JGR, 123, 1823-1841.* [6] Dann, J.C. et al., (2001) *MaPS, 36, 793-806.* [7] McSween Jr., H.Y. et al., (1996) *GCA, 60, 4563-4569.*