PRIMITIVE OLIVINE-PHYRIC SHERGOTTITE NWA 5789: PETROGRAPHY, MINERAL CHEMISTRY AND COOLING HISTORY IMPLY A MAGMA SIMILAR TO YAMATO 980459.

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Introduction: Knowledge of martian igneous and mantle composition is crucial for understanding mantle evolution including early differentiation, mantle convection and the chemical alteration of the surface. Primitive magmas provide critical information on their mantle source regions but most Martian meteorites crystallized from fractionated melts [1]. The new martian meteorite NWA 5789, discovered in North West Africa, is an olivine-pheric shergottite. NWA 5789 may have special significance among the martian meteorites because it appears to have the most primitive magnesian martian magma yet found besides Yamato 980459. With NWA 5789 potentially being a primitive melt it will help elucidate igneous geology and geochemistry of Mars.

Sample and method: A chip of 5.6g of NWA 5789 was split and two thick sections (each 1.5-2.0mm thick) were cut, doubly polished and analyzed. Mineral analyses were obtained using the electron microprobe (Cameca SX100) at NASA JSC. Operating conditions were: 15kV accelerating voltage, 20nA beam current, focused beam and measurement times of 20-40s per element. Standards included well characterized natural and synthetic materials.

Petrography and Mineralogy: NWA 5789 is an igneous rock with a porphyritic texture of olivine megacrysts and smaller grained phenocrysts (pyroxene, olivine, spinel) in a crystalline mesostasis. The mesostasis itself is composed of radiating sprays of plagioclase, clinopyroxene, spinel and silica. The volume proportions of minerals are: 19% olivine, (14% megacrysts), 38% pyroxene, 1-2% chromite, and 41% mesostasis.

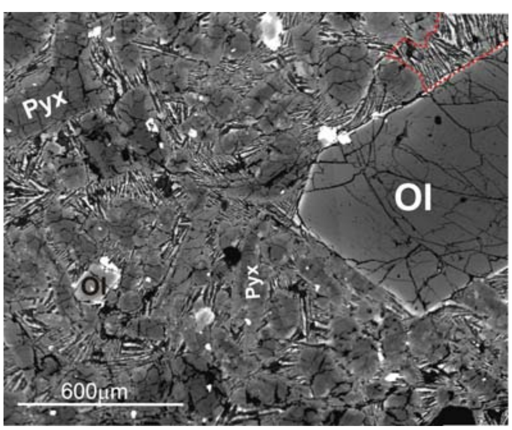

Figure 1: BSE image of NWA 5789. Upper right corner: typical radiating texture of the mesostasis (red dotted outline).

Olivine: Olivine megacrysts are euhedral to subhedral, and up to several mm in length. Olivine phenocrysts are subhedral to anheuhedral, and have grain sizes from tens up to 600µm in length. The cores of olivine megacrysts are as magnesian as Fo_{84} (Fig. 2), and are surrounded by a wide 'mantle' of Fo_{73-71} which overlaps with the core compositions of the phenocryst olivine (Fo_{75-71}). The mantle compostion of the phenocrsysts rages from Fo_{70-60}. Both types of olivine have thin Fe-rich rims of Fo_{45-30} and contain inclusions of pyroxene and of melt (partially crystallized).

Pyroxene: Pyroxene phenocrysts are prismatic euhedral to subhedral grains typically <600µm. The cores are Mg-rich orthopyroxene ($En_{81}Fs_{17}Wo_2$) which zone outward continuously to intermediate composition augite ($En_{42}Fs_{29}Wo_{29}$) (Fig. 2). Some grains have irregular Ca-rich patches. Edges of the phenocrysts have the same composition as those in the mesostasis which are Fe-rich pigeonites (En_{33-21} $Fs_{51-65}Wo_{16-14}$) (Fig. 2).

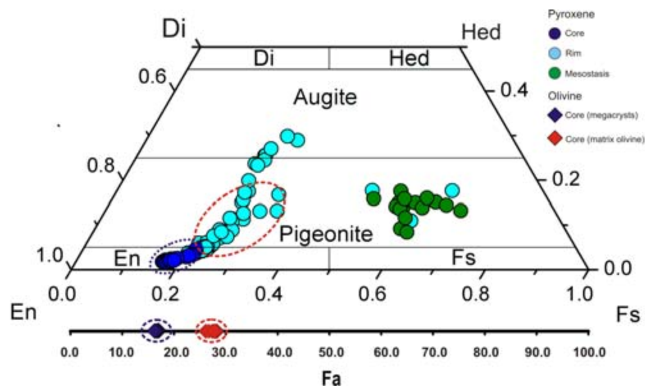

Figure 2*: Composition of pyroxene and olivine in NWA 5789. Olivine megacrysts have the same Mg# as the core pyroxene (blue dotted circles); olivine phenocrysts have similar Mg# to intermediate pyroxene composition (red dotted circles).*

Other phases: Cr-Al spinel is present as phenocrysts, in mesostasis and as inclusions in olivine and pyroxene.

Plagioclase controls the texture of the mesostasis with its radiating sprays of laths (An_{65-58}). Among these laths are: silica (up to 3 wt% Al_2O_3), Cr-Al spinel, ilmenite and iron sulfide. Silica-rich glass is found only in magmatic inclusions in olivine and pyroxene.

Bulk rock composition: The bulk rock composititon is an average of 95 EMP point analyses of the fusion crust (Table 1). This composition is nearly identical to the bulk rock analysis from [2], Table 1. The fusion crust has a slightly lower Na content which could represent loss during formation or EMP spot analysis.

Is NWA 5789 Martian? NWA 5789 is classified as Martian based on chemistry and oxygen isotopes [2]. With the FeO-MnO ratio of our bulk rock (35) and olivine (40) as well as the intermediate composition plagioclase [6] we confirm this classification.

Table 1: *Bulk Chemical Compositions of NWA 5789 and Y 980459*

	NWA 5789 Fusion crust (this study)	NWA 5789 Bulk rock [2]	Y98 [3]	Y98 [4]
Na_2O	0.43	0.69	0.80	0.48
MgO	17.74	19.20	18.10	19.64
Al_2O_3	5.65	5.30	6.00	5.27
SiO_2	49.24	48.60	49.40	48.70
P_2O_5	0.38	0.34	0.31	0.29
K_2O	0.02	-	0.02	0.02
CaO	6.48	6.50	7.20	6.37
TiO_2	0.48	0.45	0.48	0.54
Cr_2O_3	0.46	0.73	0.71	0.71
MnO	0.47	0.45	0.43	0.52
FeO	16.61	17.60	15.80	17.32
Total	97.96	99.86	99.35	99.89
Mg#	65.6	66.0	67.1	66.9

Comparison to Yamato 980459: NWA 5789 is very similar in most respects to Yamoto 980459 (Y98).

Petrography and Mineral Chemistry: NWA 5789 and Y98 are nearly identical in petrography, mineralogy and chemistry [1]. Both contain mm-sized megacrysts of olivine with cores of the highest known Mg# among martian meteorites (NWA: Fo_{84}; Y98: Fo_{84-86}) and smaller phenocrysts of olivine and pyroxene of identical composition. The bulk rock chemistries of both shergottites are nearly the same especially in Mg# (Table 1). Yet, the mesostasis of the two rocks has rather different textures. NWA 5789 has a crystalline mesostasis defined by lath-like crystals of plagioclase, while Y98 has a glassy mesostasis which contains no crystalline plagioclase. This difference suggests that the meteorites had different cooling histories.

Cooling history: The compositional relationships between olivine and pyroxene of NWA 5789 are shown in Fig. 2. It seems that the pyroxenes began crystallizing while or shortly after the olivine megacrysts formed, since the core compositions are in Fe-Mg equilibrium. The core compositions of the phenocryst olivines seem to be in equilibrium with the intermediate pyroxene compositions and hence crystallized at approximately the same time. The mesostasis texture indicates that the rock cooled rapidly but not quickly enough as to produce glass. Therefore it cooled slower than Y98.

The Al/Ti ratio of the groundmass pyroxene compared to the mesostasis pyroxene suggests that the magma started to crystallize at higher pressures and was emplaced and finished cooling in a late stage on or near the surface (i.e. very low pressure) [5].

Is NWA5789 a primitive melt? Olivine is often the first phase to crystallize from a magma and as such its chemistry records important information about the bulk rock's igneous history (e.g., [6, 7]). By comparing the chemistry of olivine to the bulk rock composition, one can determine if the olivine could have been in equilibrium with a magma of bulk rock composition, and thus have been true phenocrysts. In Fig. 3 the Mg# of the cores of the olivine megacrysts are compared with the bulk rock Mg# and with the theoretical olivine-basalt equilibrium lines [5,7,9]. It is clear that the NWA 5789 megacryst cores are in [5,9] or close to [7] Mg# equilibrium with the melt from which it crystallized. They are very similar to Y98, which is primitive liquid [8]. Hence it is plausible that NWA5789 also represents a primitive melt.

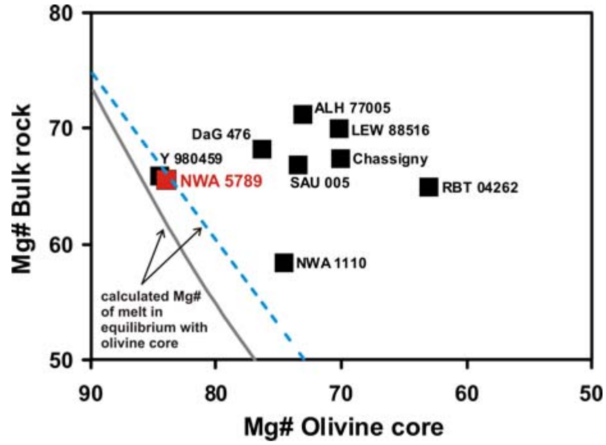

Figure 3: *Mg# [Mg/(Mg+Fe)] in olivine cores versus Mg# of bulk rock for selected Martian meteorites (after [7]). Grey solid line [7]; Blue dotted line [9,5].*

Conclusions: NWA 5789 and Y98 are similar in mineralogy, chemistry and bulk compositions and slightly different in texture. These strong similarities suggest that both rocks derived from the same type of magma, perhaps even the same magma. Y98 is thought to have cooled in a thin lava flow so as to form quench crystals within a glass-matrix [1,10]. NWA 5789 could have crystallized from the same magma, but cooled more slowly (e.g., in a thicker flow), so as to produce plagioclase and high Ca-pyroxene whiskers as mesostasis and ferroan rims around olivine and pyroxene.

We expect to obtain more complete understanding of the crystallization history and conditions by undertaking crystallization experiments on the bulk chemistry of NWA 5789.

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