PETROGRAPHY, MINERAL CHEMISTRY, AND CRYSTALLIZATION HISTORY OF OLIVINE-PHYRIC SHERGOTTITE NWA 6234: A NEW INTERMEDIATE MELT COMPOSITION J. Gross[1], J. Filiberto[2], A.H. Treiman[3], C.D.K. Herd[4], M. Melwani Daswani[5], S.P. Schwenzer[5] . [1]American Museum of Natural History, New York, NY 10024; [2]Southern Illinois University Carbondale, Carbondale, Il 62901; [3]Lunar and Planetary Institute, Houston, TX 77058; [4]University of Alberta, Edmonton, Alberta T6G 2E3, Canada; [5]The Open University,CEPSAR, Milton Keynes MK7 6AA, UK; Gross@lpi.usra.edu

Introduction: Knowledge of martian igneous and mantle composition is crucial for understanding Mars' mantle evolution, including early differentiation, mantle convection and the chemical alteration at the surface. Primitive magmas provide the most critical information on their mantle source regions but most Martian meteorites crystallized from fractionated melts [1]. The new martian meteorite NWA 6234, discovered in North West Africa, Mali, is an olivine-phyric shergottite. NWA 6234 may have special significance because it appears to represent a magma composition[10] and new group of shergottites [2] that is neither depleted nor enriched in incompatible trace elements. With NWA 6234 being a melt composition and representing a new group of shergottites, it will help elucidate igneous geology and geochemistry of Mars.

Sample and method: A piece of the thicksection of NWA 6234 was doubly polished and analyzed. Mineral analyses were obtained using the electron microprobe (Cameca SX100) at the American Museum of Natural Histroy, NY. 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 sythetic materials.

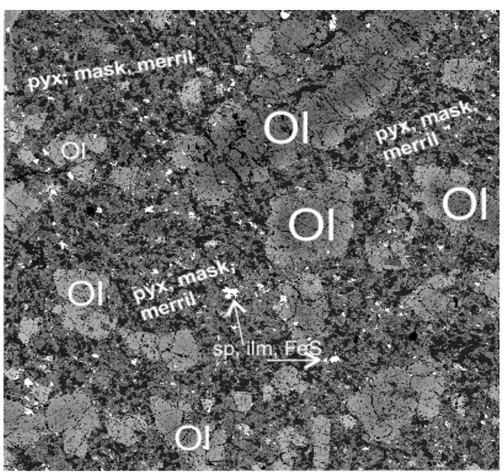

***Fig. 1**: BSE image of NWA 6234. Ol=olivine, pyx=pyroxene, mask=maskelynite, merril=merrillite, sp=spinel, ilm=ilmenite.*

Petrography and Mineralogy: NWA 6234 is an igneous rock with a fine grained texture of olivine crystals set in a finer-grained groundmass of pyroxene, maskelynite, olivine, merrellite, ilmentite, spinel, and FeS. The volume proportions of minerals in the whole rock are roughly: 23% olivine, 46% pyroxene + merrillite, 30% maskelynite, 1-2% spinel and ilmentite ± FeS,.

A thin (<200µm) melt vein crosses through the rock. In some areas, it consists of pockets of glass and crystals, while in other areas the vein is completely crystalline with fractured crystals but no glass.

Olivine: The larger olivine crystals are euhedral to subhedral, and up to 1.5 mm in length. Olivine crystals in the groundmass are subhedral to anhedral, and have grain sizes from tens up to 500µm in length. The cores of the larger olivines are as magnesian as Fo_{78} (Table 1; Fig. 2), and their Fo content decreases monotonically outward to Fo_{60}. The compositions of the groundmass olivine range from Fo_{47-40}. Both types of olivine contain inclusions of spinel, and of melt (partially crystallized).

Pyroxene: Pyroxene crystals are subhedral to anhedral prismatic grains and are typically <250µm in length. Commonly, pyroxenes are found as clusters of anhedral grains. Pyroxene cores are Mg-rich orthopyroxene ($En_{69}Fs_{27}Wo_4$) and zone outward continuously to a more ferroan pigeonite composition ($En_{62}Fs_{31}Wo_7$) (Table 1; Fig. 2). Clusters of pyroxene have compositions ranging from pigeonite to augite (En_{36-51} $Fs_{30-44}Wo_{11-30}$) (Fig. 2).

Other phases: Cr-Al spinel is present in the groundmass and as inclusions in olivine. The groundmass also includes grains of merrillite, plagioclase/maskelynite (An_{65-58}), ilmenite and iron sulfide.

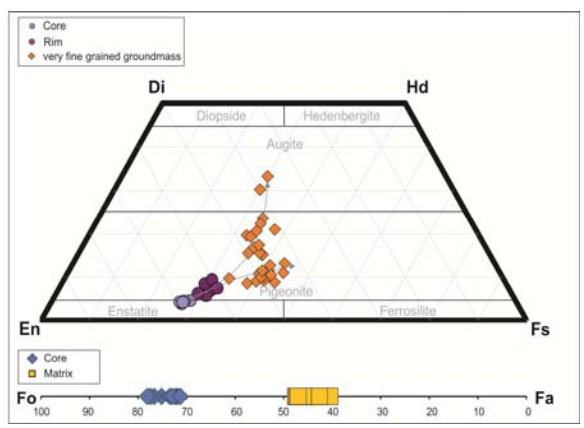

***Fig. 2**: Composition of pyroxene and olivine in NWA 6234. Olivine cores(blue diamonds)have the same to slightly higher Mg# as the cores of pyroxene (purple circles); groundmass olivine have similar Mg# to groundmass pyroxene composition (orange diamonds).*

Is NWA 6234 a melt composition? For any igneous rock, it is important to know whether its bulk composition is that of a pure magma, or instead includes excess material such as cumulus crystals, xenocrysts, or assimilated material. True magma compositions are required to derive constraints on Martian mantle compositions and magma generation [4,5,10].

Table 1: *Chemical compositions of olivine and pyroxene.*

	Olivine core	Olivine in groundmass	Pyroxene core	Pyroxene ground-mass
Na_2O	0.00	0.00	0.02	0.17
MgO	41.84	19.37	24.92	14.45
Al_2O_3	0.23	0.38	0.81	1.49
SiO_2	38.74	34.38	53.93	51.79
P_2O_5	0.07	0.05	0.02	0.02
K_2O	0.00	0.00	0.00	0.01
CaO	0.12	0.15	2.13	11.91
TiO_2	0.02	0.00	0.17	0.55
Cr_2O_3	0.05	0.00	0.83	0.33
MnO	0.43	0.86	0.53	0.61
FeO	21.03	46.45	17.06	19.15
Total	102.53	101.55	100.42	100.50
Mg#	78	42.6	72.3	57.4

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, thus is a true phenocrysts. In Fig. 3 the Mg#, molar [Mg/(Mg+Fe)], of the cores of the olivine megacrysts are compared with the bulk rock Mg# [5,7,8,10]. It is clear that the NWA 6234 olivine cores are very close [5,8] to Mg# equilibrium with the melt from which it crystallized and thus are likely to be phenocrysts. Hence it is plausible that NWA 6234 represents a true melt composition.

Crystallization history: The compositional relationships between olivine and pyroxene of NWA 6234 are shown in Fig. 2. It seems that the pyroxenes began crystallizing while or shortly after the olivine crystals formed, since the core compositions are in Fe-Mg equilibrium. The core compositions of the olivine crystals in the groundmass seem to be in equilibrium with the compositions of the very fine grained pyroxene of the groundmass and hence crystallized at approximately the same time or shortly there after. Pyroxene in the fine grained groundmass show two distinct chemical trends: one that evolves towards augite and the other one that evolves towards ferroan pigeonite. The fine grained texture of the groundmass indicates that the rock cooled at a moderate rate, such as in a dike or a sub-volcanic intrusion, as no indications of glass or very fine matrix texture [1,9] is found.

Oxygen fugacity: Preliminary data on f_{O2} based on two sets of Fe-Ti oxide pairs in NWA 5960, gives QFM +0.3, with a standard deviation (n=2) of 0.1. This suggests that the later-stage oxides formed under quite oxidizing conditions (similar to NWA 1068 groundmass). This is interesting because geochemical NWA 6234 is an intermediate shergottite, while NWA 1068 is an enriched shergottite.

Comparison to other magma compositions: Olivine-phyric shergottites NWA 5789 and Y 980459 represent primitive melt compositions [1,9], with a Mg# = 65-67. NWA 6234 also most likely represents a melt composition but with a lower Mg#=59 [2]. NWA 6234 has an intermediate REE pattern [2], similar to those of the basaltic shergottites NWA 480, Shergotty , and Zagami, whereas NWA 5789 and Y 980459 are depleted in REE more similar to EET 79001B and QUE 94201.

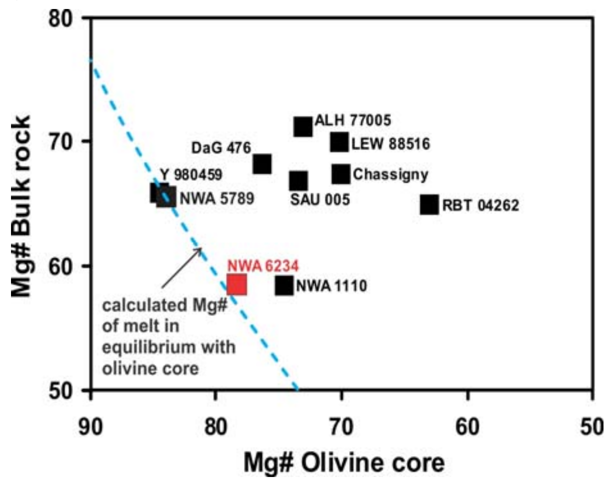

Figure 3: *Mg# in olivine cores versus Mg# of bulk rock for selected Martian meteorites (after [7]). Blue dashed line from [5,8,10].*

Conclusions: NWA 6234 is similar to NWA 5789 and Y 980459 in the sense that all three are olivine-phyric shergottites and represent magma compostitons. However, NWA 6234 is significantly less depleted in incompatible elements, and is distinct from any other olivine-phyric shergottite in being neither enriched nor deleted [2]. This suggests a unique source region for NWA 6234 with trace elemets similarities to the source region of basaltic shergottite NWA 480 and mineralogical similarities to the source regions of olivine-phyric shergottites, which has not previously been sampled by other ol-phyric shergottites.

Acknowledgments: Supported by NASA MFR grant NNX09AL25G.

References: [1] Usui T. et al. (2009) *GCA,72,* 1711-1730. [2] Filiberto J., et al. (2011) *MAPS.* in review. [3] Meteoritical Bulletin (2011) *MAPS. 46*; 99 [4] Musselwhite D. S., et al. (2006) *MAPS.* 41:1271-1290. [5] Filiberto J. et al. (2010) *GRL.*, 37, doi:10.1029/2010GL043999. [6] Shearer C.K. et al. (2008) *MAPS. 43,* 1241-1258. [7] Papike J.J. et al. (2009) *GCA,* 73, 7443–7485 [8] Filiberto J. et al. (2009*) AM*. 94, 256-261. [9] Gross et al. (2011) *MAPS.* 46, 116–133. [10] Filiberto J. & Dasgupta R. (2011): *EPSL.*, 304; 527-537.