LUNAR METEORITE NORTHWEST AFRICA 13531: CHIP OFF OF A DIFFERENT KIND OF BLOCK.

A. M. Ruzicka[1] , M. L. Hutson[1] and K. Ziegler[2], [1]Dept. of Geology, Cascadia Meteorite Laboratory, Portland State University, Portland, OR 97207 U.S.A., ruzickaa@pdx.edu, [2]Institute of New Mexico, Albuquerque NM 87131, U.S.A., kziegler@unm.edu).

Introduction: Lunar meteorites provide a more global and comprehensive perspective of lunar rock types and geologic history than Apollo and Luna mission samples from geographically limited nearside areas [e.g., 1, 2]. Northwest Africa (NWA) 13531 is a newly-classified lunar feldspathic breccia that differs in important ways from other lunar meteorites.

Methods: Data were obtained using optical microscopy, scanning electron microscopy (SEM, including BSE imaging and EDS methods), and laser fluorination and mass spectrometry of acid-washed samples.

Oxygen isotope composition: Oxygen isotope composition relative to V-SMOW linearized values is $\delta^{17}O'=3.083\pm0.031$, $\delta^{18}O'=5.933\pm0.052$, and $\Delta^{17}O'= -0.050\pm0.005$ (N=3), typical of the Moon.

Petrography: Cut faces of the meteorite show a light-colored interior beneath black fusion crust, with white to light grey lithic and mineral clasts typically <1 mm across set in a finer-grained, light-toned matrix. A network of narrow black veins (shock veins) cross the specimen and occasionally lead to dark pockets or grade into or parallel wider light-colored (feldspathic) bands. Thin section observation shows that NWA 13531 is a crystalline melt breccia, with igneous interclast areas and two texturally distinct lithologies (Fig. 1). *Lithology 1* comprises over two-thirds of the section and contains one of the larger (~2 mm) clasts (Clast 1A complex), numerous feldspathic bands, and a dark pocket, which contains glass with schlieren. Interclast (interstitial) material is a mix of occasional olivine and larger (≥100 µm) plagioclase grains amidst finer-grained (<50 µm) portions with subophitic texture (Fig. 1a). *Lithology 2* contains clasts set in interstices that vary from having an intergranular texture (olivine and subequal pigeonite between plagioclase) to areas with more subophitic texture (<50 µm grains of plagioclase and pigeonite) interspersed with some larger (50-100 µm) plagioclase grains (Fig. 1b). Lithic clasts in both lithologies are dominated by fine-grained (<100 µm) feldspar (anorthosite), and the Clast 1A complex is a breccia with troctolite and fine-grained anorthosite subclasts. Other phases include accessory ilmenite and phosphate, minor carbonate (terrestrial weathering) in cracks, and rare troilite, metal, and spinel. Plagioclase in both clasts and interstices is largely crystalline (often cracked in BSE images), but some maskelynite (smooth) is present in the feldspathic bands and on the edges and in the interiors of clasts.

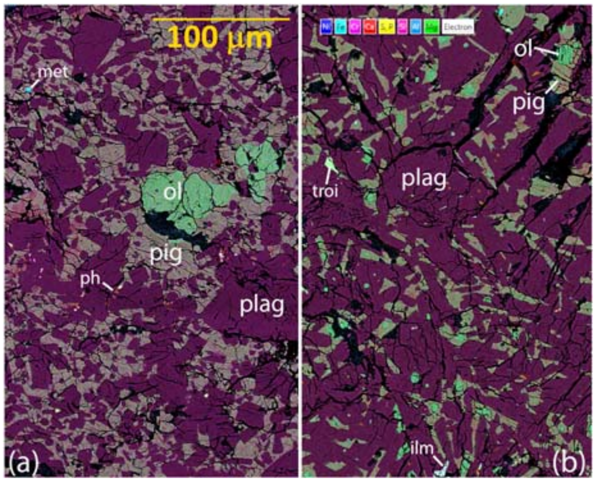

Fig. 1. False color EDS+BSE images showing textures of interstitial areas in (a) Lithology 1 and (b) Lithology 2 at the same scale. plag = plagioclase (dark purple), pig = pigeonite (tan to tan-red), ol = olivine (green), ilm = ilmenite (white-blue), ph = phosphate (orange), met = metal (light blue), troi = troilite (green-yellow), black = cracks.

Mineral chemistry: Average compositions of plagioclase, low-Ca pyroxene, and olivine mineral pairs in clasts and interstices are shown in Fig. 2. Compositions range between ferroan anorthosite (FAN) and the Mg-rich suite (Mg-suite) as defined by Apollo highland samples [3]. Good evidence for Mg-suite affinity is provided by Clasts 1A, 1AB, and 1AC (1A complex) in Lithology 1, and by Clast 2B from Lithology 2; and good evidence for FAN affinity is provided by Clasts 2A, 2E, and 2L from Lithology 2 as well as Clast 1C from Lithology 1 (Fig. 2). Interstitial minerals from interclast regions have more intermediate compositions between the two fields, but partly overlap Mg-suite (Lithology 1) or FAN (Lithology 2) (Fig. 2). These data imply that interstitial material from both lithologies was created by mixture and melting of Mg-suite and FAN sources, with a higher proportion of FAN being melted to make Lithology 2 and a higher proportion of Mg-suite being melted to make Lithology 1.

Glass and reconstructed bulk composition: The glass pocket in Lithology 1 is feldspathic and straddles the boundary of the FAN field, whereas fusion crust glasses vary greatly in alumina and form an apparent mixing line between end member composition A in the

Mg-suite field, and composition B near the FAN field, with no obvious distinction between fusion glasses developed on the two lithologies (Fig. 3). Mixing line A-B describes a chemical mixture of pigeonite and plagioclase, the dominant minerals in the interstices of Lithology 1 and 2. This implies that fusion glasses were produced by localized melting of variable proportions of these minerals. The average composition of fusion glass could be taken to be an estimate of the bulk composition of NWA 13531, but we infer that the true bulk composition is displaced along the fusion glass mixing line from the average to composition B, as the texture of the fusion crust indicates preferential melting of pyroxene (pyroxene is decomposed before plagioclase as the surface is approached).

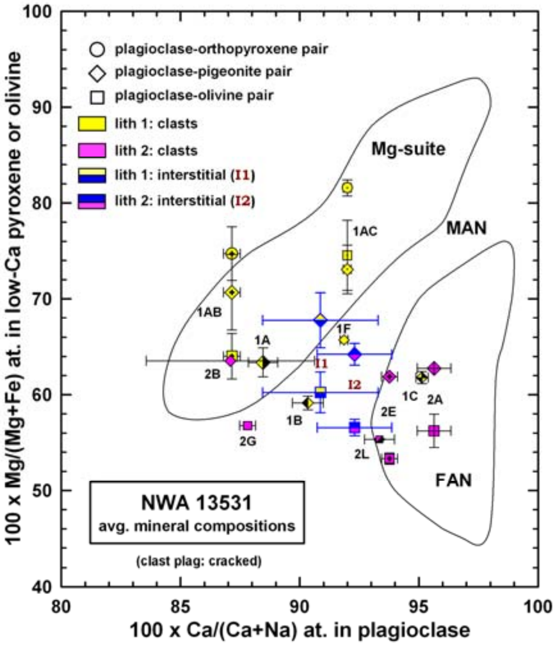

Fig. 2. Average mineral compositions (mean ± 1 standard deviation) in clasts and interstitial regions compared to pristine highland Apollo rocks of the Mg-suite and FAN [3] and magnesian anorthosite (MAN) often found in lunar meteorites [e.g., 4, 5].

A different method used to constrain the bulk composition of NWA 13531 is modal reconstruction of the interstitial regions of Lithology 1 and 2, as these make up the bulk of the rock and were themselves produced by mixing and melting of incorporated clasts. Reconstructed compositions for three interstitial areas in Lithology 2 approach that of FAN, the glassy pocket, and the B end member, whereas two areas in Lithology 1 approach that of the Mg-suite and the average composition of fusion glass (Fig. 3). Given that Lithology 1 is prevalent, the likely bulk composition of NWA 11351 straddles the A-B fusion glass mixing line and has ~22-25 wt% Al_2O_3 and Mg# ~59-65 (the green box in Fig. 3).

Summary: NWA 13531 is distinctive in: 1) being a crystalline melt breccia, which is uncommon for lunar meteorites [2, 6]; and 2) having an apparent mixture of Mg-suite and FAN, with no evidence for admixture of a mare component as in "mingled" lunar meteorites [1, 2] (Fig. 3), nor for magnesian anorthosite as is common in feldspathic lunar meteorites [e.g., 4, 5] (Fig. 2). The incorporation of much Mg-suite into NWA 13531 is especially notable, as this component is not prevalent in lunar meteorites [2] although a mafic KREEP component associated with is present [6]. NWA 13531 is a new type of lunar highlands meteorite that is more mafic than typical feldspathic lunar meteorites [1] (Fig. 3); reminiscent of Sayh al Uhaymir (SaU) 300 [6, 7] but unlike this meteorite in containing much Mg-suite and no magnesian anorthosite.

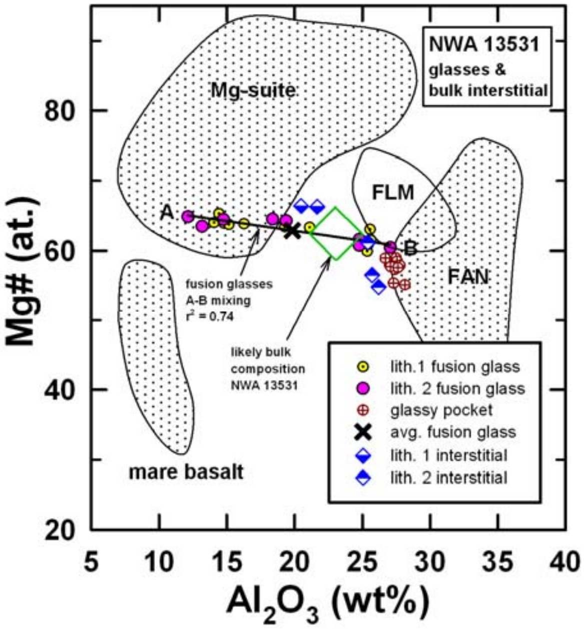

Fig. 3. Composition of fusion crust glass, the glassy pocket, and reconstructed bulk composition of interstitial areas, compared to the bulk compositions of FAN, Mg-suite, and mare basalt [8] and feldspathic lunar meteorites (FLM) [1, 2].

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References: [1] Korotev R.L. et al. (2003) *GCA* 67, 4895-4923. [2] Korotev R.L. (2005) *CdE* 65, 297-346. [3] Papike J.J. et al. (1998) *RevMin 36*, Ch. 5. [4] Gross J. et al. (2014) *EPSL* 388, 318-328. [5] Nagaoka H. et al. (2014) *EPS* 66:115. [6] Korotev R.L. et al. (2009) *MAPS* 44, 1287-1322. [7] Hsu W. et al. (2008) *MAPS* 1363-1381. [8] Taylor G.J. et al. (1991) Lunar Sourcebook, Ch. 6.