A LARGE IGNEOUS CLAST IN THE NORTHWEST AFRICA 092 CHONDRITE (L3.7): XENOLITH FROM A DIFFERENTIATED PARENT BODY OR PRODUCT OF AN ORDINARY CHONDRITE-RELATED MELT? C.A. Goodrich and D. A. Kring. Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058 USA. goodrich@lpi.usra.edu. kring@lpi.usra.edu

Introduction: Foreign clasts in meteoritic breccias are an important source of information about the collisional environment in which the host formed, and can reveal types of early solar system material not represented by individual meteorites [1]. For example, polymict ureilites contain foreign clasts of a wide variety of chondrite (OC, EC, RC, CC, unique) and achondrite types [2-5]. About 4% of ordinary chondrites (OC) contain large igneous-textured inclusions [6-10]. However, whether any of these clasts are truly foreign is unclear. Proposed models include: 1) impact melting of local or non-local OC materials [8,11-14]; 2) macrochondrule formation [8,15,16]; and 3) igneous differentiation within an OC- or other parent body [7,17-19]. We describe a new igneous-textured clast in L3.7 chondrite Northwest Africa (NWA) 092 and investigate its origin. Our objective is to determine whether OC contain truly foreign (not OC-related) achondritic clasts that could provide evidence for mixing over large radial distances in the early solar system, as inferred for polymict ureilites [5].

Sample and Methods: NWA 092 is an 88 g type L3.7 OC. It was classified with a shock stage S5, implying that olivine has mosaicism, planar fractures, and planar deformation features, and that plagioclase has been converted to maskelynite. We do not see those features in our split of the sample, suggesting a lower shock level. In addition, our aliquot contains a 1 cm sized light-colored clast, which is described here. This clast was studied by SEM and EMPA in the electron beam laboratories at ARES, JSC.

Results: The clast is ~1.1 × 0.9 cm in size and has irregular boundaries with the chondritic host (Fig. 1). It has a microphorphyric texture of euhedral to subhedral olivine phenocrysts (up to ~700 μm) in a groundmass of smaller, subhedral olivine grains (~40-100 μm), pyroxene grains (~50-200 μm long), and feldspathic mesostasis (Fig. 2). Modal abundances are 30-35% olivine, 45-55% pyroxene and 7-12% mesostasis, with trace Fe,Ni metal(s) and sulfide.

Olivine phenocrysts are commonly skeletal (Fig. 2), with crystallographically oriented melt inclusions. They are zoned with cores of Fo ~82 and rims of Fo ~70-80. Smaller olivine grains are homogeneous and more ferroan (Fo ~67-70). Average FeO/MnO (by wt.) in olivine = 62.8±7 (96 analyses).

Pyroxene grains (Fig. 3) typically have orthopyroxene (defined compositionally) cores (Wo ~1-3, mg# ~75-78) and CaO-, FeO-, TiO_2- and Al_2O_3-enriched rims (Wo up to ~32, mg# as low as 65). Core to rim zonation profiles commonly show oscillatory zoning of mg# in cores. Average FeO/MnO (by wt.) of pyroxenes = 25.6±2.1 (109 analyses).

Mesostasis areas consist of feldspathic glass containing numerous crystallites of calcic pyroxene (Fig. 3). A "clean" analysis of the glass could not be obtained, but bulk analyses of glass + dendrites indicate that the glass is Na_2O and K_2O-rich (An <20 and Or >2). Rare opaque grains consist of troilite, kamacite (~5% Ni, 1% Co), and taenite (~43% Ni, 0.2% Co). No other trace phases were observed.

Along some boundaries of the clast with the host there is a rim of what appears to be clast-rich glass and/or very fine-grained (≤ 1μm) olivine.

Discussion: The microporphyritic texture of the NWA 092 clast is unlike that of most chondrules, and

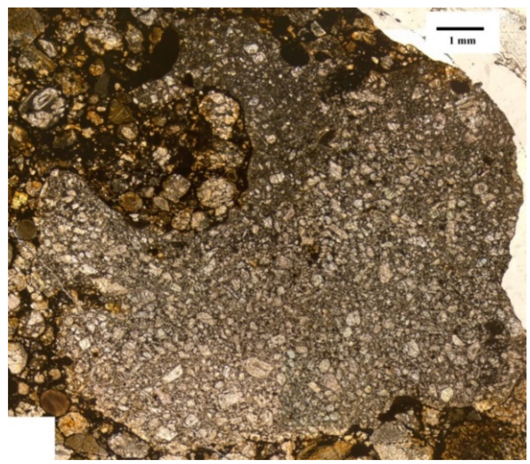

Fig. 1. Plane light image of large melt clast in NWA 092. One area within the clast (central, upper) is finer-grained and appears darker in plane light.

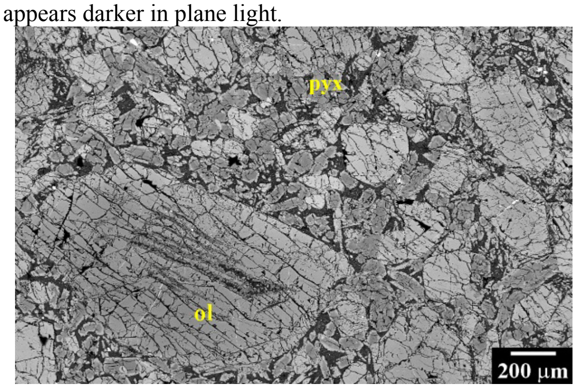

Fig. 2. Back-scattered electron image (BEI) showing microporphyric texture of the melt clast. Olivine (ol) phenocrysts are commonly skeletal. pyx = pyroxene.

resembles textures of many achondrites or planetary igneous rocks. This texture, along with the mineralogy and zoned mineral compositions of the clast, indicates that it crystallized from a melt that was experiencing fractional crystallization. The irregular shape of the clast suggests that it did not form as a free-floating melt droplet (i.e., macrochondrule).

Based on the large size of the clast, the absence of overall shock-darkening, and a relatively low shock state for the host, it is unlikely that it formed as a local (in situ) impact melt pocket (e.g., [11]). Further, it contains no obvious relict grains or chondrules, such as might be present if it was an impact melt of either local or non-local material [13]. In addition, it may have cooled too slowly to be an impact melt. Although the skeletal morphologies of some olivine crystals and absence of crystalline feldspar indicate relatively rapid cooling, the largely crystalline nature of the groundmass and the oscillatory zoning in pyroxene cores suggest that the cooling rate was only moderate.

Nevertheless, the bulk composition of this clast (so far as we can estimate from mineralogy and mineral compositions) may be broadly similar to that of L/LL chondrites, except for being depleted in metal-troilite component like most large melt clasts in OC [8-10,13]. Its olivine compositions (Fo) mostly fall in the L/LL range. The Co content of its kamacite is in the L/LL range. And it does not appear to be grossly enriched in feldspar or SiO_2 (as are some lithic clasts in OC [7,18,19]). Thus, we cannot rule out formation as a total melt of L or LL material. Discrepancies between the modal mineralogy of the clast and OC could reflect true crystal fractionation or apparent fractionation due to incomplete crystallization [21].

The Fe-Mn composition of pyroxenes in this clast distinguish it from igneous rocks on Earth, Moon, Mars, and Vesta, as well as various ungrouped igneous meteorites (Fig. 4). Their Fe/Mn values are in the range of pyroxene in some previously studied large melt clasts in OC, as well as H chondrite impact melts [20]. They are higher than in Semarkona (LL3.0) chondrules, but this could be due to loss of volatile Mn during melting. These observations also suggest formation by total melting of L or LL material.

The fine-grained/melt rim along some boundaries with the host suggest that the clast was hot and was quenched when it contacted the surrounding material. However, other interpretations are possible, depending on the composition(s) of the rim, which have not yet been determined. These rims will be studied in detail.

Summary: Preliminary observations suggest that this melt formed from OC-like materials, which seems to be the case for most large melts clasts in OC (e.g., 13]). Thus, OC may not have acquired many foreign clasts from outside of the OC-forming region of the early solar system. Further petrologic, bulk compositional and oxygen isotopic studies will be conducted to constrain the origin of this clast.

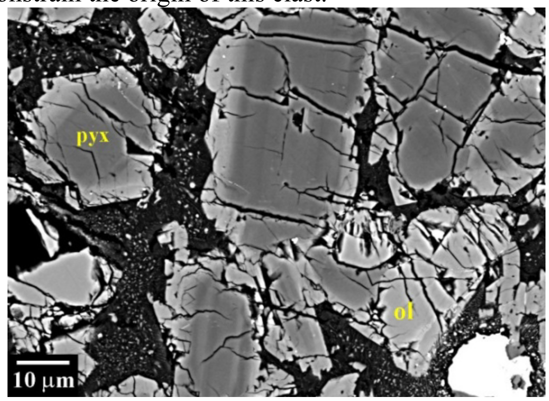

Fig. 3. BEI showing zoned pyroxenes (pyx) and small olivine (ol) in feldspathic mesostasis. Orthopyroxene cores of pyroxenes show oscillatory zonation in mg#. Rims (brighter) are enriched in CaO, Al_2O_3 and TiO_2.

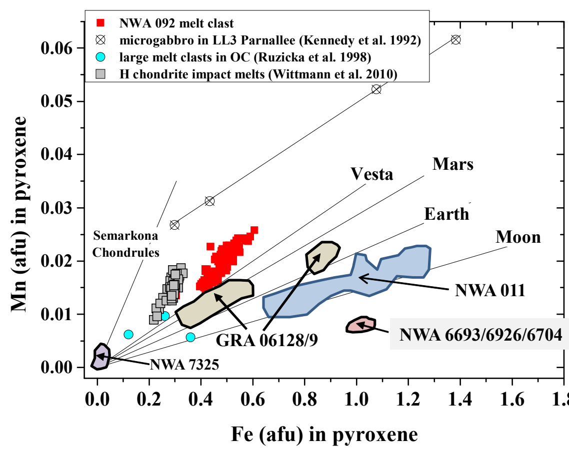

Fig. 4. Fe vs. Mn in pyroxenes in the NWA 092 melt clast compared with other solar system materials.

References: [1] Bischoff A. et al. (2006) in MESS II, 679-712. [2] Ikeda Y. et al. (2000) Ant. Met. Res. 13, 177-221. [3] Goodrich C.A. et al. (2004) Chemie der Erde 4, 283-327. [4] Horstmann M. et al. (2014) Chemie der Erde 74, 149-183. [5] Goodrich C.A. et al. (2015) MAPS 50, 782-809. [6] Bridges J.C. & Hutchinson T. (1997) MAPS 32, 389-394. [7] Kennedy A.K. et al. (1992) EPSL 113, 191-205. [8] Ruzicka A. et al. (1998) GCA 62, 1419-1442. [9] Armstrong K. & Ruzicka A. (2013) 76th MSM, #5278. [10] Armstrong K. & Ruzicka A. (2015) LPSC 46, #1572. [11] Dodd R.T. & Jarosewich E. (1976) Meteoritics 11, 1-20. [12] Dodd R.T. & Jarosewich E. (1979) EPSL 44, 335-340. [13] Fodor F.V. and Keil K. (1976) GCA 40, 177-189. [14] Jamsja N. & Ruzicka A. (2010) MAPS 45, 828-849. [15] Binns R. (1967) Mineral. Mag. 36, 319-324. [16] Weisberg M.K. (1988) Meteoritics 23, 309-310. [17] Hutchison R. et al. (1988) EPSL 90, 105-118. [18] Ruzicka A. et al. (1995) Meteoritics 30, 57-70. [19] Ruzicka A. et al. (2012) MAPS 47, 1809-1829. [20] Wittmann A. et al. (2010) JGR 115, 22p. [21] Folco L. et al. (2005) Mem. S.A. It. Suppl. 6, 116.