NORTHWEST AFRICA 6693 : A UNIQUE ACHONDRITIC CUMULATE. A. Jambon[1], M. Humayun[2], J-A. Barrat[3], R. C. Greenwood[4] and I. Franchi[4]. [1]UPMC Paris 6, ISTeP, UMR 7193, 4 place Jussieu 75005 Paris, France albert.jambon@upmc.fr. [2]Dept. of Earth, Ocean & Atmospheric Science, and National High Magnetic Field Laboratory, Florida State University, Tallahassee, FL 32310, USA (humayun@magnet.fsu.edu), [3]UBO-IUEM, UMR 6538, place Nicolas Copernic, 29280 Plouzané, France.[4] PSSRI, Open University, Walton Hall, Milton Keynes, UK.

Introduction: NWA 6693 is an ungrouped meteorite with a typical igneous texture[1,2]. Oxygen isotope analyses were performed at the OU by infrared laser-assisted fluorination following the procedures outlined by [3]. The mode (vol. %) is: Orthopyroxene 76.7 (±2.2), plagioclase 11.7 (±1.1) olivine 10.9 (±1.7), awaruite 0.3, chromite 0.24, high-Ca

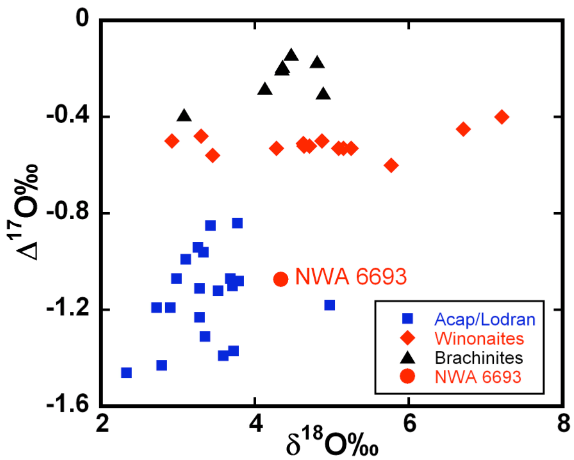

Fig 1. Oxygen isotopic composition of NWA 6693 compared to other achondrites.

pyroxene 0.05, merrilite 0.16, glass 0.03 and Fe-Ni sulfide <0.02 (Fig. 2). The minerals are homogenous with the following compositions: Opx: En57Wo3, Ol: Fo47(±1), Pl:Ab92Or3. The chromite composition is Ct85Uv7Sp4; the glass is feldspar rich with 5% K_2O; clinopyroxene En37Fs18Wo39Jd6; the metal contains 81% Ni and the sulfide about 71%Ni. All mafic phases contain significant amounts of Ni: 0.9% in olivine, 0.3% in orthopyroxene, 0.24% in chromite. The mineralogy appears far from chondritic and differs

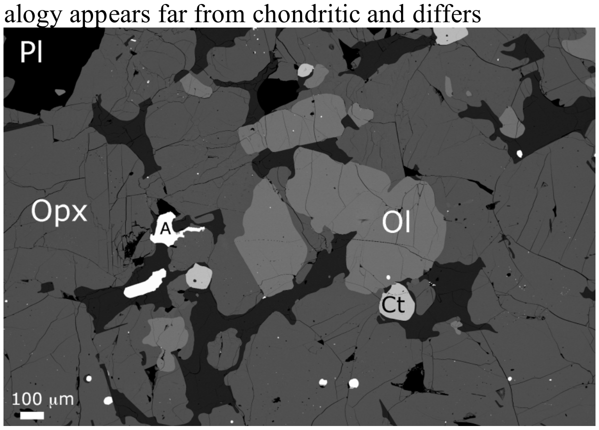

Figure 2 : BSE image of NWA 6693.

significantly from any achondritic composition described so far.

Geochemistry: Bulk rock major and trace elements were analysed by ICP-AES and ICP-MS respectively on a 2 g chunk. Metal grains were analysed by LA-ICP-MS on a polished section according to [4].

Bulk Rock Composition. The major element composition indicates that, unlike lodranites, NWA 6693 is far from a chondritic composition (Si/Mg and Si/Fe are 2.9 and 2.5 x chondritic respectively) as expected from the olivine-poor feldspar-rich mineralogy; simple core separation is no viable explanation either. When considering the trace element abundances (Fig. 3) and in contrast with the metal composition (see below), we see no evidence for a significant effect of volatilization except probably for Pb: for instance Na/Mg is 1.5 x chondritic. The alkalis show a gradual depletion in the order K<Rb<Cs, with the Cs depletion of ~0.1xCI. For Cs, this is about half the depletion observed for the Earth [5]. The composition of NWA 6693 is not that of a partial melt either: it would exhibit a depletion in compatible elements which is not observed here and a significantly higher concentration of both Ca and Al. The incompatible elements (e.g. REE) are lower than chondritic which is impossible for a partial melt.

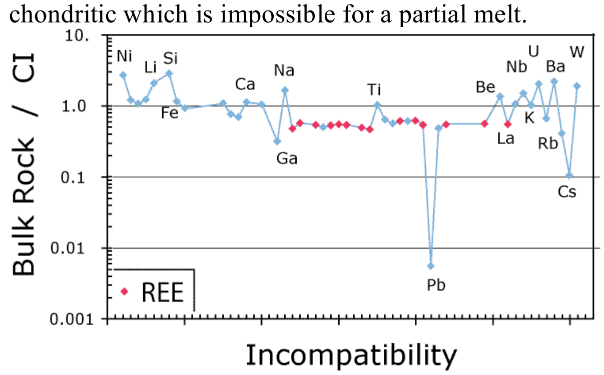

Fig. 3 CI normalized composition of NWA 6693.

A more likely interpretation which is consistent with textural evidence, is that NWA 6693 is a magmatic cumulate. The major element composition reflects the accumulation of orthopyroxene, plagioclase and olivine. Incompatible elements including the REE are significantly depleted confirming that it is not a partial melt. The REE pattern is flat unlike what is expected for a cumulate. The only viable explanation is that the incompatible elements are inherited from the intercumulus liquid with a chondritic signature.

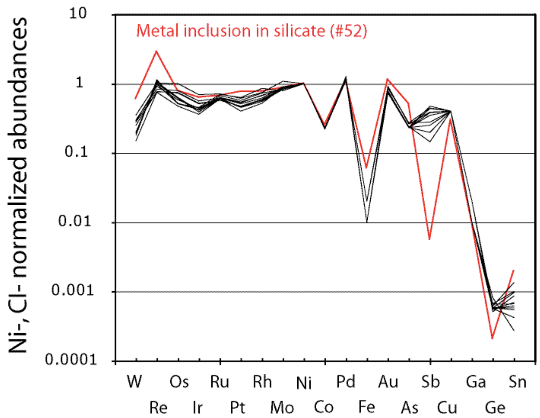

Fig. 4. Siderophile element pattern of metal from NWA 6693. Note homogeneity in Pd, Au, Sb, Cu and Ga, relative to range in Pt, Ir and Os.

Metal composition. We analyzed 9 metal grains for 25 elements, including one large grain (clump) for which four spots were analysed, and one metal inclusion within silicate. The metal is rather homogeneous and, therefore, its average composition will be considered here (fig 4); it differs from a chondritic composition, due to severe oxidation as will be discussed next. For one set of elements the total variability relative to Ni is small: Fe, Co, Pd, Cu, Au, As, Mo and Ru show less than 10% variability, less than 4% for Fe, Co, Pd, Cu. These elements are all fast diffusers in metal [6]. The slower diffusers, W, Re, Os, Ir, Pt and Rh [6] exhibit variability of about 15-30%.

In a plot of CI-normalized concentration vs condensation temperature (Fig. 5), obvious features emerge: i) Volatile elements like S, Zn, Sn, Ge, Sb and Ge display a strong correlation with their condensation temperature indicating that volatility exerted a significant control at some stage. ii) Refractory siderophiles from Ni to Re exhibit a nearly constant normalized concentration at 60 x the chondritic value. The dispersion of the data points, e.g., for Pt, however indicates

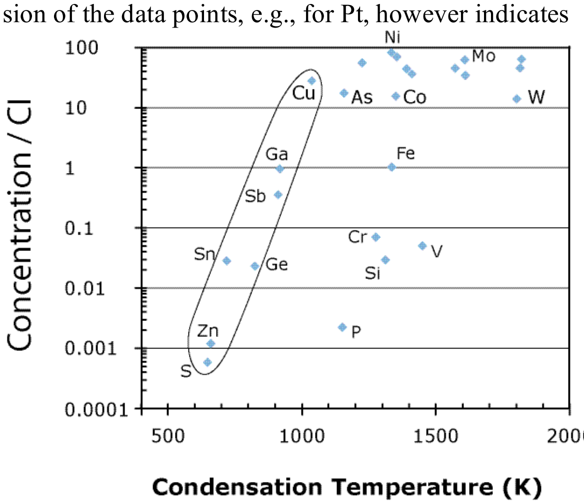

Fig. 5: Major and trace elements in awaruite plotted according to condensation temperatures.

that secondary processes were significant. iii) Mildly siderophile elements (P, Si, V, Cr, Fe W, Co and As) are severely to slightly depleted independently of their condensation temperature.This is the most Ni-rich metal ever studied by LA-ICP-MS and this Ni-enrichment is likely due to oxidative removal of Fe from the metal, along with the other mildly siderophiles. W has a slight negative anomaly relative to Re-Os-Ir, but it is not out-of-line with what one might see for other reasons, like solid metal-liquid metal fractionation. The abundance of Ni in the silicate fraction, however, indicates that all element less siderophile than Ni have been affected by oxidation to some extent. Ga is low in the metal, but less depleted than Ge. The severe depletion of Ge appears to be related to volatility alone since Ge was not detected in the silicates. Ga however is present in the silicates, and particularly high in the dark gray "melt" regions which are in contact with metal. If Ga has been transferred from the metal to the adjacent silicates then that is a signature of late oxidation.

Discussion and interpretation: The textural evidences and the bulk rock composition indicate that NWA 6693 is an igneous cumulate. The unusual metal composition implies an unusually high oxygen fugacity still lower than that observed in terrestrial or martian samples. In particular the fraction of Fe^{3+} in chromite and the high Ni content of silicates, which appear in equilibrium with the metal, confirm this inference. The overall siderophile element pattern of the awaruite is chondritic. This metal may have settled out of the magma chamber, although metal-silicate separation should have preceded crystal accumulation. Alternatively, the metal may have entered the magma chamber by assimilation of a chondritic wallrock during emplacement of the magma. Models for the emplacement of magma into the chondritic layers of partially differentiated planetesimals have been proposed [7]. Once inside the magma chamber the metal would have equilibrated with the magma rapidly and undergone oxidation. Another possibility is that the magma assimilated brecciated wallrock and the metal originated from an impactor. This may explain the severe depletion in volatile siderophile elements in contrast to the mild depletion of volatile lithophile elements.

References: [1] Warren P.H. et al. (2011) *Meteoritics & Planet. Sci., 46,* A246.. [2] Irving A. J. et al. (2011) *Meteoritics & Planet. Sci., 46,* A108. [3] Miller M. F. et al. (1999). Rapid Commun. Mass Spectrom. 13, 1211-1217. [4] Humayun M. et al. (2007) *GCA, 71*, 4609-4627. [5] McDonough W. F. et al. (1991) *GCA*, *56*, 1001-1012. [6] Righter K. et al. (2005) *GCA*, *69*, 3145-3158. [7] Elkins-Tanton L. T. et al. (2011) *EPSL*, *305*, 1-10.