MINERALOGY, PETROGRAPHY AND PB-PB ISOTOPE SYSTEMATICS OF A TYPE II ALLENDE CHONDRULE . M. B. Olsen[1], A. N. Krot[1,2], J. N. Connelly[1] K. Larsen[1] C. B. Paton[1] D. Wielandt[1] M. Schiller[1] and M. Bizzarro[1]. [1]Centre for Star and Planet Formation, Natural History Museum of Denmark, University of Copenhagen, Copenhagen 1350 Denmark. E-mail: mia.b.olsen@snm.ku.dk. [2]HIGP, University of Hawai'i at Manoa, HI, USA.

Introduction: Chronology of early Solar System solids such as calcium-aluminum-rich inclusions (CAIs) and chondrules can provide important constraints on processes and the life-time of the protoplanetary disk [1]. Previous studies of the ages on chondrules have concluded that they formed after CAIs and over a period of several million years [2, 3] but these data were obtained on sets of 10-20 chondrules combined together such that no absolute age on a single chondrule exists. In addition, recently reported variations in $^{238}U/^{235}U$ ratios amongst CV CAIs and chondrules [4, 5] cast doubts on previously published Pb-Pb ages.

Analytical procedures: We report on the mineralogy, petrography and Al-Mg and Pb-Pb systematics of a single, large (~ 2.5cm in diameter) ferroan porphyritic olivine-pyroxene (type II) chondrule (A20b-1) from the Allende CV3 chondrite. The mineralogy and petrography was done on a polished slab using a scanning an electron microscope and an electron microprobe both equipped with energy dispersive spectrometers at the University of Hawai´i at Manoa.

A fragment of A20b-1 was lightly crushed and extensively pre-cleaned with 5 cycles of ethanol, acetone and water. Stepwise dissolution (9 steps) was accomplished by progressively stronger acids and a final complete dissolution of the residual material with HF-HNO3. Pb was separated according the method of [6] and its isotopic composition determined by using a Thermo-Fisher Triton thermal ionization mass spectrometer.

For Al-Mg analyses of the chondrule, four spots of the chondrule were sampled, dissovled and put trough a Mg-purification chemistry described in [7]. Both Mg isotopic and Al/Mg elemental ratios were analyzed using high-resolution inductively-coupled plasma mass-spectrometry that yielded measurements of $\mu^{26}Mg$ (per 10^6 deviation from terrestrial $^{26}Mg/^{24}Mg$) and Al/Mg ratios in silicate materials with an external reproducibility of 2.5 ppm and 2%, respectively.

Results: A20b-1 consists of ferroan olivine phenocrysts, secondary lath-shaped ferroan olivine, opaque nodules, chromite, abundant relict grains of forsteritic olivine, with a microcrystalline mesostasis, composed of nepheline and sodalite, replacing high-Ca pyroxene and plagioclase. The olivine phenocrysts and relict forsterite grains are overgrown by rims and crosscut by

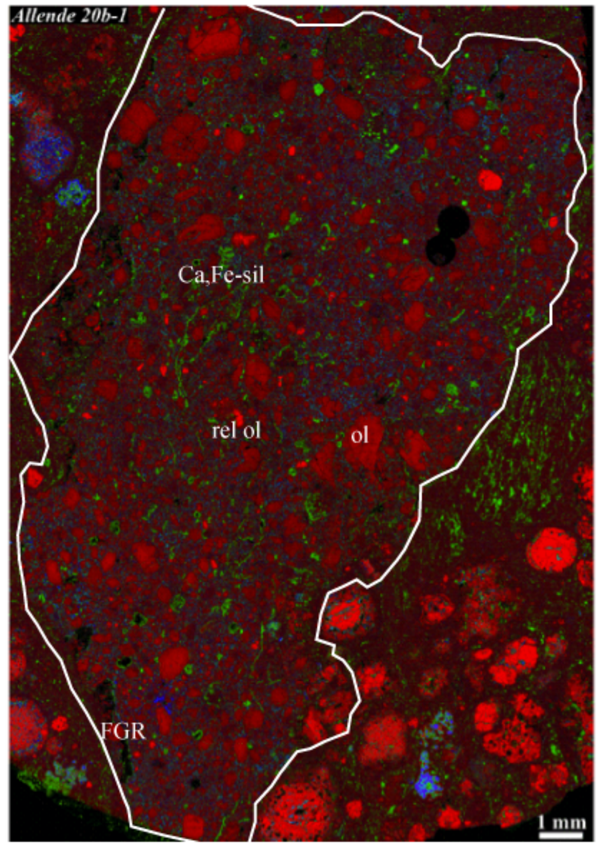

Fig. 1: *Combined x-ray elemental map with Mg:Ca:Al of type IIa chondrule A20b-1. The chondrule consists of ferroan olivine (ol), relict forsterite grains (rel ol). The mesostasis is composed of high-Ca pyroxene, plagioclase, nepheline, sodalite, Ca,Fe-silicates (Ca,Fe-sil) and Ca,Fe-sulfides and is surrounded by a fine-grained rim. (FGR)*

veins of secondary ferroan olivine. Primary minerals of the opaque nodules have been extensively replaced by Fe, Ni-sulfides, ferroan olivine, phosphates and Ca,Fe-rich silicates. Using the Na content as a proxy for alteration the level of secondary alteration is estimated to be approximately 25% by volume.

Four of nine dissolution steps define a line that passes through primordial Pb and defines a Pb-Pb age of 4565.52± 0.37 Ma (MSWD = 1.6) using a $^{238}U/^{235}U$ ratio of 137.79, the weighted average of inner Solar System components including chondrules [8]. The five remaining points lie both above and below the line.

The regression line through the Al-Mg data defines an isochron with an initial $^{26}Al/^{27}Al$ = v 4.36± 4.9 $\times 10^{-6}$ (MSWD = 0.02, the large error reflecting the small spread in Al/Mg ratios.

Discussion: A20b-1 show signs of *in situ* iron-alkali-halogen alteration to varying degrees throughout the inclusion, but most of the chondrule has experienced alteration and the secondary minerals (nepheline, sodalite, ferroan olivine, andradite and salite-hedenbergite pyroxenes) are common**.**

The Pb-Pb age of A20b-1 of around 1.6 Myr after CAI formation, may indicate that: 1) the primary crystallization of the chondrule occurred at this time, 2) the alteration on the Allende parent body has affected the Pb-Pb system in A20b-1, so that the younger age reflects the timing of redistribution of Pb isotopes within the chondrule associated with the formation of secondary minerals, or 3) the alignment of the 4 of 9 points in fortuitous such that no meaningful age information is possible from this data.

For the age to reflects primary crystallization, the 4 stepwise dissolution must have attacked primary minerals that acted as closed system despite secondary alteration while not affecting the secondary minerals. While possible, it seems more likely that the calculated age reflects either the time of secondary alteration or a meaningless age intermediate to the primary crystallization and alteration ages.

The large error on the ^{26}Al-^{26}Mg age precludes a rigorous independent test of the significance of the Pb-Pb age.

Conclusion: Due to the extent of secondary alteration documented by detailed petrography of chondrule A20b-1, we are uncertain whether the 4-point isochron reflects a real age (either a primary formation age or metamorphic age) or a meaningless age between the formation and metamorphic age. Chondrules we have examined in Allende show different states of secondary reworking ranging from insignificant to nearly complete replacement of all primary minerals. This study shows the importance for future studies to thoroughly examine each chondrule prior to embarking on Pb-Pb isotope work for the sake of defining the range of chondrule ages.

References: [1] Krot, A. N. et al. 2009 *Geochimica et Cosmochimica Acta* 73:4963-4997. [2] Amelin, Y. et al 2002 *Science* 297:1678-1683. [3] Connelly , J. N. et al. 2008 *Astrophysical Journal.* 675:L121-L124 [4] Brennecka, G. A. et al 2010 *Science* 327:1103-1105 [5] Amelin, Y. et al. 2010 *41st Lunar Planetary Science Conference* 1648 [6] Connelly, J. N. and Bizzarro, M. 2009 *Chemical Geology* 259: 143-151 [7] Bizzarro, M. et al. 2011 Journal of Analytical Atomic Spectrometry 26: 565-577 [8] Connelly et al. 2011 This meeting