EXPERIMENTAL CONSTRAINTS ON THE MAJOR-ELEMENT COMPOSITION OF THE UREILITE PARENT BODY. M. Collinet and T. L. Grove, Massachusetts Institute of Technology, Department of Earth, Atmospheric and Planetary Science, 77 Mass Ave, 02139, MA, e-mail: collinet@mit.edu

Introduction: The majority of the 500+ ureilites contain olivine and a single low-Ca pyroxene (usually pigeonite) with lesser amounts of graphite, metal and sulfide. They are widely recognized as residues of partial melting representing the mantle of a planetesimal/planetary embryo, which lost sulfide melts and Al-rich silicate melts. However, many facets of the formation of ureilites remain a matter of debate (e.g. size of the parent body, initial bulk composition, affinities with chondrite groups, location in the early solar system and style of melting).

The isotopic composition of ureilites points both to affinities with carbonaceous chondrites (negative and variable $\Delta^{17}O$) and other "non-carbonaceous" chondrite groups based on their $\varepsilon^{54}Cr$, $\varepsilon^{50}Ti$ and $\varepsilon^{62}Ni$ [1]. Therefore, it provides no (or conflicting) constraints on the major element composition of the UPB.

Here, we describe two series of experiments that were performed from various (synthetic) chondritic materials to identify the key chemical parameters required to form olivine-pigeonite residues identical to ureilites. All experiments were conducted at an fO_2 of IW-1 to IW-2, assuming that olivine Fe-Mg concentration in ureilites is fixed by the fO_2 (also consistent with Cr and Ni concentrations). We used a MHC-alloy pressure vessel filled with CO and samples were contained in graphite capsules (see [2]).

Batch melting experiments: We first performed experiments on various chondritic compositions (Table 1) between 1065 and 1180 ºC. Due to their higher $(Na_2O+K_2O)/(Na_2O+K_2O+CaO)$ ratios (NaK#), H and LL chondrites contain An_{10-20} plagioclase and melt at a lower temperature (~1050 ºC) than CM and CV chondrites (An_{40-60}; 1100-1120 ºC). H and LL chondrites produce liquids richer in SiO_2 and poorer in Ca (low CaO/Al_2O_3 ratios; Fig. 1).

It has been suggested that a high Ca/Al ratio of the parent body is necessary to stabilize pigeonite [3] but Ca and Al have identical condensation temperatures and their ratio is virtually constant in all chondrites. This first series of experiments show that all chondrites with a high NaK# (e.g. H, LL, EH, and CI) fractionate Al from Ca during partial melting. The UPB was richer in alkali elements than all carbonaceous chondrites (e.g. CM and CV) with the exception of CI and the super-chondritic Ca/Al is not a primary feature of the UPB. The formation of Si- and alkali-rich melts in the UPB was also confirmed by the discovery of the trachyandesite ALM-A [4].

Incremental melting experiments: A high Ca/Al ratio is not sufficient to stabilize pigeonite in a mantle residue. To identify additional requirements for pigeonite stability, we removed a large percentage of a low-degree melt rich in Al, calculated the compositions of melting residues and re-equilibrated/re-melted them at higher temperature.

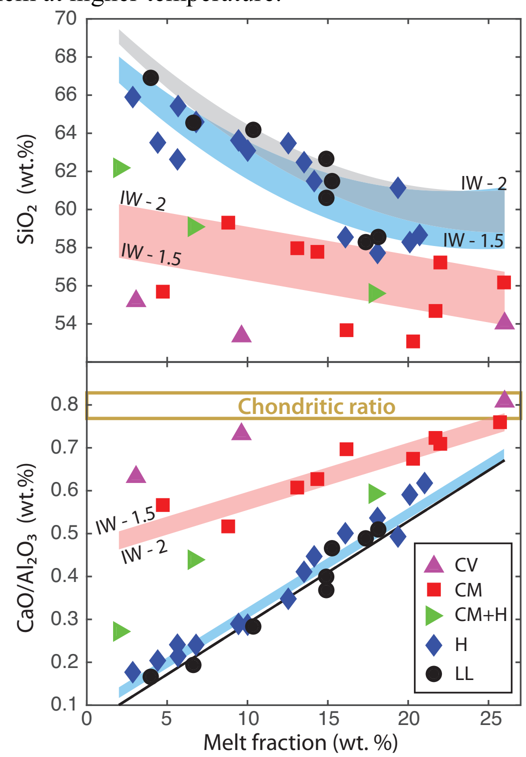

Figure 1: Composition of liquids in batch melting experiments between IW-1 and IW-2. See Table 1 for the chemical composition of starting materials.

Starting compositions. We extracted completely a ~10% batch melt from a LL chondrite (R1, Table 1). R1M is identical in composition but has more MgO to match the Mg/Si ratio of the sun photosphere and CI before melt extraction. The R2 and R2M residues are derived from R1 and R1M by extracting an additional 10 % batch melt at higher temperature (1180ºC). Finally, RB and R2MC represent residues for which Al was removed by low-temperature melts extremely efficiently. A large fraction of Al is extracted while the Ca/Si ratio remains close to the one of the sun photosphere and CI (Table 1).

Mineralogy of experimental residues. Batch melting experiments do not produce olivine-pigeonite residues with a CM chondrite and only between 1140 and 1160ºC with a H chondrite (plagioclase is present at lower temperature; Fig. 2a). However, at those temperatures, the Cr_2O_3 content of olivine is <0.4 wt.% (as opposed to ~0.6 wt.% in both ureilites and experiments between 1200 and 1250 ºC).

The re-equilibration of most residues produce 20-45 wt.% of pigeonite (Fig 2b) with Wo_{6-7} at IW-1.5 (in equilibrium with olivine Fo_{76-81}; Fig. 2a). To produce residues containing a pigeonite with a higher wollastonite content (9-12), higher Ca/Si and Mg/Si ratios are necessary (R2MC, Table 1).

This second series of experiments confirms that only planetesimals with a high NaK# can produce ureilite-like residues. In addition, the UPB had a Mg/Si ratio at least as high as ordinary chondrites. Lower Mg/Si ratios (e.g. EH- or EL-like) would produce higher proportions of pyroxene in the residue (even at IW-1) and dilute its CaO concentration to Wo <5. Ureilites with Wo>9 pigeonite were likely produced by incremental melting of a chondritic material with a high Mg/Si (~1.05) and $(Ca/Si)_{CI}$ (>0.9), which was rich in alkali elements. Al-rich melts were efficiently extracted at low temperature while leaving most of the Ca in the pyroxene. Slight variations in the Mg/Si (0.95-1.05) of the UPB would also explain some of the scatter displayed by the ureilite population in figure 2b. Overall, the bulk composition of the UPB was very similar to the sun's photosphere in terms of major elements (and, by extension, elements less volatile than Na).

References: [1] Warren P. H. (2011) *GCA, 75,* 6912-6926. [2] Collinet M. and Grove T. L. (2018) *49th LPSC*, 1841. [3] Goodrich C. A. et al. (2007) *GCA, 71,* 2876-2895. [4] Bischoff A. et al. (2014) *PNAS, 111,* 12689–12692.

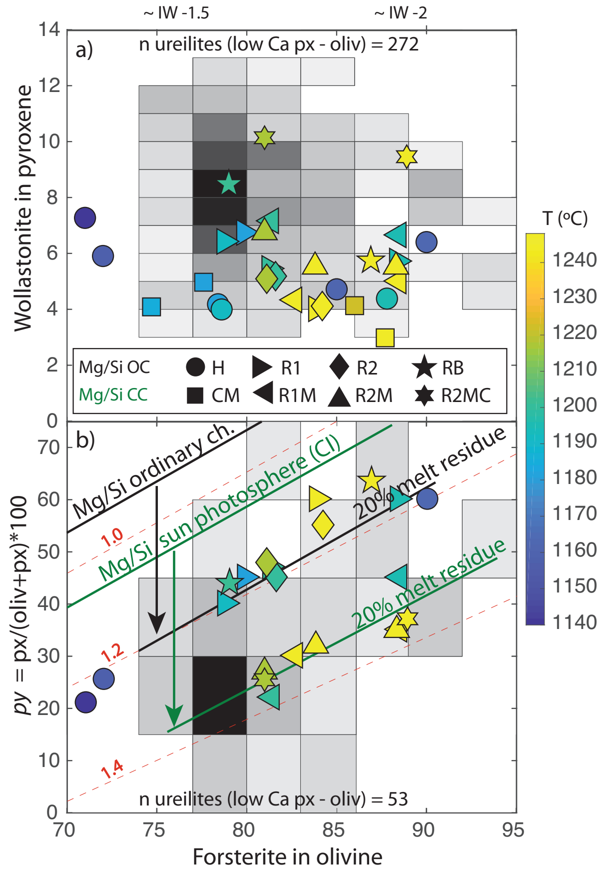

Figure 2: Composition of olivine vs. pyroxene (a) and vs. px/(oliv+px) ratio (b) in ureilites (gray bivariate histograms projected as a grid with peaks in black) and experiments (symbols, color refers to T in ºC). The red numbers and dashed lines indicate the Mg/Si ratio of a pigeonite ($Wo_{7.5}$) + olivine assemblage using the experimental K_D Fe-Mg olivine-pigeonite of 1.05. Solid lines represent the Mg/Si ratio of residues after 20 wt.% of cumulative melting.

Table 1: Starting materials of experiments compared to CI chondrites

		batch melting starting compositions					low Mg/Si residues			high Mg/Si residues		
	CI	H	LL	CM+H	CM	CV	R1	R2	Rb	R1M	R2M	R2MC
SiO_2	33.27	37.64	43.44	36.85	37.52	36.83	41.56	40.26	34.65	39.65	38.27	38.10
TiO_2	0.11	0.12	0.12	0.13	0.18	0.16	0.09	0.05	0.08	0.09	0.05	0.05
Al_2O_3	2.39	2.21	2.44	2.50	2.91	3.48	1.20	0.39	0.58	1.15	0.38	0.37
Cr_2O_3	0.57	0.55	0.59	0.61	0.55	0.56	0.63	0.65	0.57	0.60	0.62	0.60
FeO	34.22	30.88	21.87	29.12	28.23	27.75	23.46	24.49	34.08	22.39	23.28	22.73
MnO	0.37	0.32	0.36	0.29	0.32	0.22	0.38	0.39	0.34	0.36	0.37	0.36
MgO	23.51	23.74	26.75	25.99	25.70	26.00	28.83	30.70	26.41	32.09	34.13	34.25
CaO	1.89	1.78	2.11	2.02	2.43	2.82	1.96	1.41	1.78	1.87	1.34	2.00
Na_2O	0.99	0.93	0.99	0.75	0.62	0.50	0.56	0.26	0.27	0.54	0.25	0.24
K_2O	0.10	0.11	0.10	0.08	0.07	0.05	0.03	0.01	0.02	0.03	0.01	0.01
P_2O_5	0.32	0.24	0.22	0.28	0.27	0.28	0.21	0.20	0.23	0.20	0.19	0.19
NiO	2.10	1.49	1.01	1.30	1.20	1.25	1.09	1.18	1.00	1.04	1.12	1.10
Total	99.82	100.00	100.00	99.92	100.01	99.90	100.00	100.00	100.00	100.00	100.00	100.00
Mg#	55.05	57.82	68.55	61.40	61.88	62.55	68.65	69.08	58.01	71.87	72.32	72.87
NaK#	0.36	0.37	0.34	0.29	0.22	0.16	0.23	0.16	0.14	0.23	0.16	0.11
Mg/Si	1.05	0.94	0.92	1.05	1.02	1.05	1.03	1.14	1.14	1.21	1.33	1.34
$(Ca/Si)_{CI}$	1.000	0.829	0.854	0.963	1.140	1.345	0.827	0.616	**0.905**	0.827	0.616	**0.924**