THE H$_2$O CONTENT OF THE ALM-A UREILITIC TRACHYANDESITE. L. D. Peterson[1*], M. E. Newcombe[1], S. G. Nielsen[2], C. M. O'D. Alexander[3], J. Wang[3], A. R. Sarafian[4], A. Bischoff[5]

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Introduction: Water is a primary factor in establishing habitability and is a critical component of terrestrial life. Within our solar system, the source(s) of water for the terrestrial planets is a subject of debate [1]. Potential sources of Earth's water include: 1) bulk carbonaceous chondrite-like material [2,3]; 2) ingassing of nebular hydrogen [4,5]; 3) comets [6,7]; 4) solar wind implantation [8]; and 5) bulk non-carbonaceous chondrite-like material, similar to Earth's primary feedstock [9]. Additionally, it has been proposed that thermally processed planetesimals may be a source of terrestrial volatiles [10,11]. To provide additional constraints to this debate, recent work has characterized the water content of the main group ureilites [12]. The ureilites are a group of C-rich, primitive achondrites derived from the non-carbonaceous (NC) reservoir [13] that have been posited as a potential source of volatiles to the Earth [10,11]. Main group ureilites are a subgroup of ureilites interpreted as the restitic mantle of the ureilite parent body (UPB) [16,11]. Analyses of H$_2$O in main group ureilite clinopyroxenes yielded values of ~2 to 6 µg/g H$_2$O, corresponding to a bulk UPB value of 29 to 240 µg/g H$_2$O assuming batch melting with a melt fraction of 0.1 to 0.3 [12]. Therefore, Peterson et al. [12] concluded that the UPB is H$_2$O depleted relative to the Earth (700 to 3000 µg/g H$_2$O) [1], and ureilite-like material is not a primary source of terrestrial H$_2$O.

We have conducted analyses of clinopyroxene, feldspar, melt inclusions, and interstitial glass in a trachyandesitic clast from the Almahata Sitta ureilite (ALM-A). ALM-A is thought to represent a rare sample of UPB crustal material [14] derived from the first stage of melting on the UPB [15]. Due to the highly incompatible nature of H$_2$O during mantle melting, crustal materials derived from mantle melts are expected to be H-rich relative to their source. Therefore, assuming ALM-A represents a ureilitic crustal lithology, analyses of ALM-A may provide a complimentary upper bound on ureilite volatile contents when compared with analyses of the main group ureilites.

Sample & Methods: ALM-A has a trachyandesitic bulk composition, adding to the population of feldspathic ureilitic materials [16-18] and is considered to be crustal material from the UPB. ALM-A is composed predominantly of feldspars (anorthoclase and plagioclase) and clinopyroxene, the latter of which contains glassy melt inclusions [14].

We performed analyses of feldspars, clinopyroxene, melt inclusions, and interstitial glass using a Cameca nanoSIMS 50L at Carnegie EPL. Analyses were conducted using a Cs$^+$ ion beam following established protocols [19-22]. Well characterized glass [19] and clinopyroxene [20] reference materials were used for calibrating volatile abundances. Matrix-matched calibrations were used when available; however, no plagioclase standards were available during the analyses, so the glass calibration curve was used to estimate volatile concentrations in plagioclase.

Results: Our data from ALM-A clinopyroxene (cpx), feldspar (fd), melt inclusions (MIs), and interstitial glass (Int. Gl.) is summarized in Table 1. Clinopyroxene in ALM-A is enriched in H$_2$O relative to main group ureilites by a factor of 2 to 11.

Table 1) Concentration of H$_2$O in studied phases

	H$_2$O µg/g			
	Min	Max	*Avg.	n
cpx	12	23	17±6	33
fd	10	19	12±4	15
MIs	48	220	113±120	8
Int. Gl.	47	71	60±24	4

* Uncertainty reported as two standard deviations from the mean

Discussion: From our analyses of clinopyroxene and melt inclusions in ALM-A, we can calculate an apparent clinopyroxene-melt partition coefficient for H$_2$O ($D_{H_2O}^{cpx-melt}$) in ALM-A, yielding $D_{H_2O}^{cpx-melt}$ = ~0.15 from average values. This value is higher than expected based upon experimental data at 200 MPa ($D_{H_2O}^{cpx-melt}$ = ~0.008) [23,24], but is similar to a single experimentally determined partition coefficient at 0.1 MPa ($D_{H_2O}^{cpx-melt}$ = ~0.1) [23]. We argue that secondary effects such as degassing and alteration are unlikely to account for the high apparent $D_{H_2O}^{cpx-melt}$ in ALM-A, as melt inclusions and late-stage glass yield similar H$_2$O concentrations and no H$_2$O gradients in clinopyroxene are discernable within the uncertainty of our dataset. Therefore, we suggest that the apparent partition coefficient may reflect the effect of pressure and/or

water concentration on equilibrium partitioning of water in cpx; however, further experimental work will be required to assess this hypothesis.

We can use our analyses of ALM-A to estimate the H_2O content of the bulk UPB. The ALM-A trachyandesite is thought to be the product of a low degree of partial melting (<15%) on the UPB with efficient melt extraction [14,15,25]. We are not aware of any direct estimates of the degree of crystallization from the ALM-A parent melt. However, pyroxene is expected to be one of the first phases to crystallize from the melt. Therefore, pyroxene hosted melt inclusions can be considered as approximations of the parental melt composition prior to crystallization. We consider our highest H_2O melt inclusion analysis as an upper limit of the parental melt H_2O content. Assuming equilibrium melting of initial UPB compositions [10,15], melt inclusions represent the composition of the melt following <15% partial melting [15,25]. For batch melting with a melt fraction, F, <15%, $D_{H_2O}^{solid-melt} = 0.1$ which assumes H_2O is more compatible in olivine and pyroxene at low pressure (~0.1 MPa), and the maximum melt H_2O content as defined by ALM-A melt inclusions (Table 1), we estimate the UPB H_2O content to be < 52 µg/g. If we assume a partition coefficient of $D_{H_2O}^{solid-melt} = 0.007$, similar to bulk peridotite at pressures <1.5 GPa [26], we estimate the UPB H_2O content to be < 34 µg/g. Additionally, we can estimate the bulk UPB volatile content via mass balance by combining 70% mantle restite containing ~2 to 6 µg/g H_2O [12] with 30% melt containing ~48 to 220 µg/g H_2O (Table 1), yielding a bulk UPB H_2O content of ~7 to 70 µg/g H_2O. Our new estimates for the bulk UPB H_2O content overlap with estimates from the main group ureilites [12], albeit with a lower maximum H_2O content by a factor of ~3 (70 µg/g vs. 240 µg/g). Therefore, analyses of ALM-A and main group ureilites suggest that 1) the UPB is volatile element depleted relative to the Earth (Fig. 1), 2) ureilite-like material was not a primary source of terrestrial H_2O, and 3) the earliest stages of planetesimal melting (as represented by primitive achondrites) result in efficient loss of H_2O.
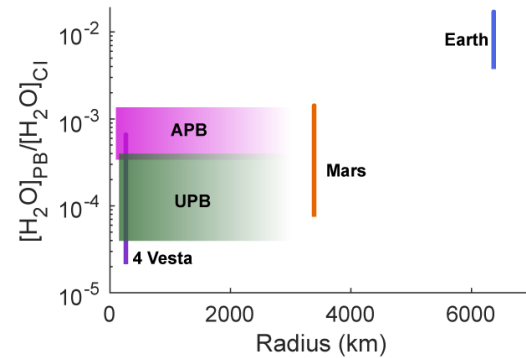

Fig. 1) Parent body volatile contents normalized to CI Chondrite [27] for the angrite parent body (APB) [28,29], 4 Vesta [23,1], UPB, Mars [30,1], and Earth [1].

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