

THE ORIGIN AND EVOLUTION OF VOLATILES IN THE EARTH-MOON SYSTEM: A HALOGEN PERSPECTIVE. F. E. McDonald¹, K. H. Joy¹, P. L. Clay¹, R. Burgess¹ ¹School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Oxford Road, Manchester, M13 9PL, UK (francesca.mcdonald@manchester.ac.uk).

Introduction: The volatile elements are an important constituent of planetary bodies, having a major influence on thermal and chemical processes such as melting, rheology and volcanism [1, 2]. Determining and comparing the volatile budgets of the lunar and terrestrial mantles will provide an understanding of volatile behaviour and distribution during the formation and evolution of the Earth-Moon system.

Volatiles Of The Earth-Moon System: The purported giant impact is widely believed to be the Moon forming event [3]. Such an impact can also explain the close similarity of the terrestrial and lunar oxygen isotope composition [4] and the current angular momentum of the Earth-Moon system [5, 6]. This event is also considered to have created a lunar magma ocean (LMO) [7, 8], which crystallised to form the current differentiated Moon. How the giant impact event and planetary differentiation affects the origin and evolution of the volatile elements on the Earth and the Moon is not currently well understood.

Accretionary versus later veneer. There are two main arguments concerning the origin of the volatile elements: either they were accumulated during the main planetary early accretion phase from solar and chondritic material [9, 10], or the giant Earth-Moon forming impact caused major degassing by hydrodynamic escape, with volatiles being subsequently acquired by both bodies as a “late veneer” of chondritic material, post-dating planetary formation and pre-dating mantle closure [11, 12, 13].

Processes affecting volatile evolution. Other factors to consider that affect the isotopic signatures and concentrations of the volatile elements are the role of impact erosion of an early crust [14], and with regard to the Earth, the role of recycling of volatiles at subduction boundaries [15, 16].

The Halogens As Tracers Of Volatiles: The halogens are very reactive due to their high electronegativity and show a range from moderate (F, Cl) to highly volatile (I) behaviour. However, because the halogens have such large ionic radii (particularly the heavy halogens, Cl, Br and I), they are highly incompatible. This means that their distribution is strongly influenced by fluid mobility and processes such as fractionation and degassing, making the halogens very good tracers for other volatile elements (e.g., H, C) [17].

Samples: To constrain the halogen composition of the primitive terrestrial and lunar mantles, we will target olivine hosted melt inclusions in ancient terrestrial komatiites and lunar mare basalts of comparable age. The volatile and halogen

composition of the melt inclusions should have remained relatively unaltered since their time of entrapment [18].

Terrestrial komatiites. A range of Achaean komatiites have been sourced from different greenstone belts around the world (i.e., Canada, S. E. Baltic Shield and South Africa). These locations provide a variety of geographic locations and flow depth and range in age from 3.3 – 2.4 Ga. This sample set will provide a global representation of the primitive terrestrial mantle and insight into its heterogeneity and evolution through time.

Lunar samples. Predominantly olivine rich mare basalts from a range of Apollo missions (age range from 4.2 – 3.2 Ga) have been selected to represent different lunar mantle source locations, depths and variation in chemistry (e.g., high and low-Ti and high-Al compositions). Analysis of picritic glass beads and some plutonic samples provide samples of mantle partial melts up to 4.2 Ga in age. They also potentially provide insight into degassing behaviour of volatiles on ascending to, erupting on, and ponding near to the lunar surface.

Research Plan: All samples will be petrographically and compositionally characterised using electron microscopy and microprobe techniques.

Halogen determination. The analytical technique used to determine halogens is Neutron Irradiation Noble Gas Mass Spectrometry (NI-NGMS). The initial neutron irradiation of samples converts the halogens Cl, Br and I into their respective noble gas isotopes, Ar, Kr and Xe, which are then readily measured by NGMS at the University of Manchester. CO₂ laser or furnace step heating releases the noble gas component for measurement, which is then used to determine the original halogen abundances. This analysis method is particularly sensitive and able to detect the least abundant and most difficult to measure halogen, iodine, which can be present at just 1 ppb per 1 mg of sample material.

Targeting melt inclusions. Laser ablation of melt inclusions hosted in individual olivine grains will provides access to halogen compositions representing the least unaltered and least degassed, primitive mantle compositions.

References: [1] Hirth, G. A. and Kohlstedt, D. (1996) *Earth Planet. Sci. Lett.*, 144, 93–108. [2] Saal, A. E. et al. (2008) *Nature. Lett.*, 454, 192–195. [3] Hartman, W. K. and Davis, D. R. (1975) *Icarus*, 24, 504–515. [4] Weichert, U. et al. (2008) *Science*, 294, 345–348. [5] Canup, R. M. and Esposito, L. W. (1996) *Icarus*, 119, 427–446. [6]

Canup, R. M. (2012) *Science*, 338, 1052-1055. [7]
Taylor, S. R. (1975) *Pergamon Press, New York*, pp.390. [8] Warren, P. H. (1985) *Annu. Rev. Earth Planet. Sci.*, 13, 201-240. [9] Mukhopadhyay, S. (2012) *Nature. Lett.*, 486, 101-104. [10] Pepin, P. O. (1991) *Icarus*, 92, 2-79. [11] Tartèse, R. and Anand, M. (2013) *Earth Planet. Sci. Lett.*, 361, 480-486. [12] Marty, B. (2012) *Earth Planet. Sci. Lett.*, 313-314, 56-66. [13] Albarède, F. (2009) *Nature*, 461, 1227-1233. [14] Sharp, Z. D. and Draper, D. S. (2013) *Earth Planet. Sci. Lett.*, 369-370, 71-77. [15] Holland, G. and Ballentine, C. J. (2006) *Nature*, 441, 186-191. [16] Sumino, H. et al. (2010) *Earth Planet. Sci. Lett.*, 294, 163-172. [17] Kendrick, M. A. (2012) *Chemical Geology*, 292-293, 116-126. [18] Bucholz, C. E. et al. (2013) *Earth Planet. Sci. Lett.*, 374, 145-155.

Acknowledgements: For their generous donation of komatiite samples, I am most thankful to Gary Byerly, Igor Puchtel, Bernard Marty, Euan Nisbet and Mary McGee. We thank CAPTEM and NASA for allocation of Apollo basalts.