PARENT BODY PROCESSING IN CR CHONDRITES RECORDED BY NOBLE GASES. H. Busemann[1], D. L. Schrader[2], C. M. O'D. Alexander[3], N. H. Spring[4], M. Kuga[1] and C. Maden[1], Institute of Geochemistry and Petrology, ETH Zürich, 8092 Zurich, Switzerland (henner.busemann@erdw.ethz.ch), [2]Center for Meteorite Studies, Arizona State Univ., Tempe, AZ, USA, [3]Earth and Planets Laboratory, Carnegie Institution of Washington, DC, USA, [4]School of Earth and Environmental Sciences, Univ. of Manchester, UK.

Introduction: The CR Renazzo-like carbonaceous chondrites (~190 meteorites, [1]) are among the most pristine carbonaceous chondrite classes and preserved almost unaltered solar nebula material [2]. Most CR chondrites experienced only mild, if any, thermal alteration on their parent bodies [e.g., 2, 3]. However, evidence for different degrees of aqueous alteration is abundantly present and classified in different studies using mineralogy-petrology, O isotopes, H, C and N elemental compositions and isotopes [e.g. 4-7]. The analysis of noble gases is an additional important method to better characterize pristine solar system material and to understand the processes that altered the material that accreted to form the CR parent body(ies).

Here we present in more detail than previously possible [8] results of a comprehensive study on a large number of CR chondrites and discuss trends that appear to be caused by aqueous alteration and heating.

Table 1. CR chondrites analyzed here for noble gases

Meteorite	Type[1]	Weathering	
Grosvenor Mountains (GRO) 95577	1	B	SW
Miller Range (MIL) 090292	ungr (1)	B	
Graves Nunataks (GRA) 95229	2	A	SW
Elephant Moraine (EET) 87770	2	B	
Elephant Moraine (EET) 92042	2	B	
LaPaz Icefield (LAP) 02342	2	A/B	
Pecora Escarpment (PCA) 91082	2	Be	
Miller Range (MIL) 07525	2	B/C	
Queen Alexandra Range (QUE) 94603	2	C	
Northwest Africa (NWA) 6957	2	W2	
LaPaz Icefield (LAP) 04720	2	B/C	
Dhofar 1432	2	mod.	
Graves Nunataks (GRA) 06100[2]	2	B	heated
Elephant Moraine (EET) 96259	2	B/C	
Gao-Guenie (b)	(2)	mod.-ext.	
Miller Range (MIL) 090657	2 (2.7)	Be	
Meteorite Hills (MET) 00426	2 (3)	B	SW
Queen Alexandra Range (QUE) 99177	2 (3)	Be	
Northwest Africa (NWA) 12474	3	high	

[1]classification from [1], (reclassified in [4-7, 10]).[2]heated, most likely by impact [3,4].

Samples and Methods: We selected 19 CR chondrites (Table 1, some measured as two aliquots) that cover the whole range of aqueous alteration observed in CR chondrites. Bulk samples (~5 to 30 mg) were extracted in one step at ~1700 °C, see [9] for details of our standard method to release noble gases from bulk meteorites. "Re-extractions" at ~1750 °C demonstrated full degassing under these conditions. Blank corrections were mostly negligible, or at maximum within a few % of the released gas amounts.

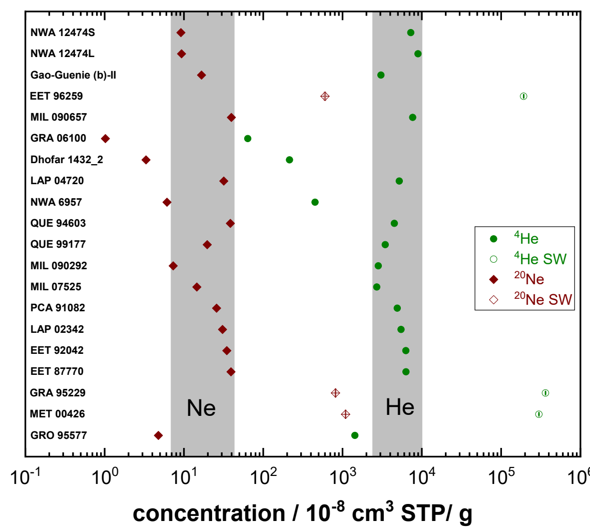

Fig. 1. Trapped ^{4}He and ^{20}Ne concentrations in CR chondrites (after [11]).

Results and Discussion: Most CR chondrites contain very similar He respectively Ne concentrations (see grey bands in Fig. 1). These are roughly comparable to those found in CM chondrites [11]. EET 96259, GRA 95229 and MET 00426 show abundant solar wind (SW), which is also evident in their Ne isotopic compositions. Only these three can safely be considered to originate from a regolith environment. Interestingly, samples of all petrologic type 1-3 are found to contain SW.

In contrast, GRA 06100, Dhofar 1432, NWA 6957 and GRO 95777 show up to two orders of magnitude lower concentrations, particularly in ^{4}He. GRA 06100 is among the most strongly heated CR observed so far [3,4]. The least aqueously altered CRs (apart from MET 00426, which contains abundant SW-He and -Ne) QUE 99177, MIL 090657 and NWA 12474 contain trapped ^{4}He (incl. radiogenic ^{4}He) and ^{20}Ne within the typical range, illustrating that their main carriers are not strongly affected by aqueous alteration.

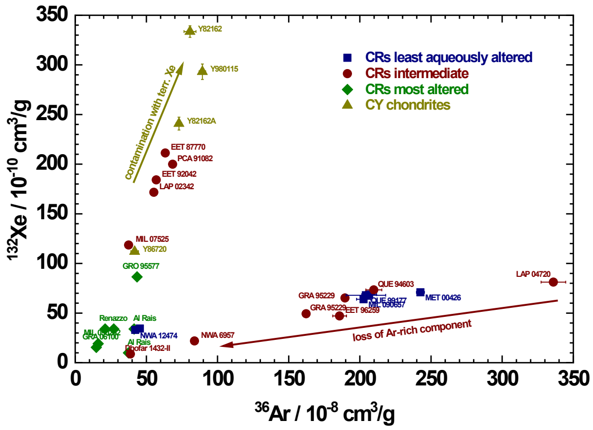

Fig. 2. Trapped ^{36}Ar vs. ^{132}Xe concentrations in CR and a few CY [14] chondrites.

The Ar and Xe concentrations in Fig. 2. show two trends. Generally, trapped ^{36}Ar decreases with the degree of aqueous alteration experienced on the parent body. NWA 12474 is the exemption, suggesting that it might be significantly more aqueously altered than implied by its type 3 classification [1]. All most severely altered CR chondrites (data for Al Rais and Renazzo: [12]; both CRs have experienced significant aqueous alteration [13]) plot to the lower left of the figure, indicating that significant amounts of an Ar-rich carrier are susceptible to aqueous alteration. The Xe concentrations shows much less dependency on aqueous alteration. However, a few samples show elevated ^{132}Xe. This could be due to contamination with terrestrial Xe. Some CY-type chondrites, also plotted, could have acquired >50 % of the measured ^{132}Xe from air [14]. The Xe isotopic compositions of the respective CR chondrites, however, plot much closer to Q composition [15], which renders significant Ar loss, rather than Xe addition, more likely. Extremely Ar-rich, yet unidentified carriers have been observed elsewhere, e.g. in CI-like lithologies of Almahata Sitta and the least aqueously altered CM chondrites [11, 16].

Most of the moderately and least aqueously altered CRs show $^{36}Ar/^{132}Xe$ ratios between 260 to 450 (Fig. 3), while all strongly aqueously altered samples and NWA 12474 show very low ratios <150. They plot essentially on the mixing line between air and Q . This suggests that the Ar-rich carrier is effectively destroyed by water. Type 1 CR chondrites completely lack this component.

Again, NWA 12474 appears to have completely lost this Ar-rich soluble component, although being classified as type 3 CR chondrite [1]. Perhaps terrestrial processing contributed to this loss: Samples from hot deserts (NWA 12474, but also to a lesser extent NWA 6957, Al Rais, Dhofar 1432) show depletions in Ar, while at least Dhofar 1432 and NWA 6957 carry comparably high $^{36}Ar/^{132}Xe$ ratios, within the typical range observed in CR2 to 3 chondrites.

It will be interesting to compare these measurements with the noble gases in samples returned with JAXA's Hayabusa2 and NASA's OSIRIS-REx missions, which will have escaped any terrestrial weathering and contamination, but may have experienced different degrees of thermal and aqueous alteration on their C-rich asteroidal parent bodies Ryugu and Bennu.

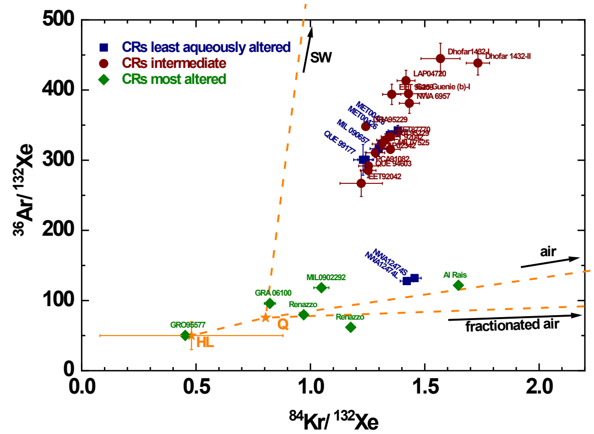

Fig. 3. Trapped $^{36}Ar/^{132}Xe$ vs. $^{84}Kr/^{132}Xe$ ratios in CR chondrites.

Acknowledgments: Samples have been kindly allocated by NASA's Meteorite Working group and J. Gattacceca.

References: [1] Meteoritical Bulletin Database. [cited 12 Jan. 2021], https://www.lpi.usra.edu/meteor/metbull.php. [2] Abreu N. M. et al. (2020) *Geochemistry, 80*, 125631. [3] Schrader D. L. et al. (2015) *Meteorit. & Planet. Sci., 50,* 15-50. [4] Alexander C.M.O'D. et al. (2013), *Geochim. Cosmochim. Acta, 123,* 244-260. [5] Schrader D. L. et al. (2011) *Geochim. Cosmochim. Acta, 75,* 308-325. [6] Howard K.T. et al. (2015) *Geochim. Cosmochim. Acta, 149,* 206–222. [7] Harju E.R. et al. (2014) *Geochim. Cosmochim. Acta, 139,* 267–292. [8] Busemann H. et al. (2019) *82nd Ann. Meeting Meteoritical Society*, abstract #6383. [9] Riebe M.E.I. et al. (2017), *Meteorit. & Planet. Sc., 52,* 2353-2374. [10] Davidson J. et al. (2015) *Lunar Planet. Sci. Conf., 46,* abstr. #1603. [11] Krietsch D. (2020) *Ph.D. thesis #26964*, ETH Zurich, 213 pages. [12] Mazor E. et al. (1970) *Geochim. Cosmochim. Acta, 34,* 781-824. [13] Schrader D. L. et al. (2014) *Earth & Planet. Sci. Lett., 407,* 48-60. [14] King A.J. et al. (2019) *Geochemistry, 79,* 125531. [15] Busemann H. et al. (2000) *Meteorit. & Planet. Sci., 35,* 949-973. [16] Goodrich C.A. et al. (2019) *Meteorit. & Planet. Sci., 54,* 2769–2813.