

**PHASE Q - A CARRIER FOR SUBSOLAR NOBLE GASES** H. Busemann<sup>1</sup>, H. Baur<sup>2</sup>, and R. Wieler<sup>2</sup>, <sup>1</sup> University of Bern, Physics Institute, Space Research & Planetary Science, Sidlerstr. 5, 3012 Bern, Switzerland, (busemann@phim.unibe.ch), <sup>2</sup> ETH Zürich, Isotope Geochemistry, Sonneggstr. 5, 8092 Zürich, Switzerland.

**Introduction:** In our series of experiments to determine the noble gases of phase Q in various classes of meteorites [1,2] we analysed the HF/HCl-resistant residue of an enstatite chondrite [3]. We have chosen the EH5 chondrite St. Mark's because of its short cosmic-ray exposure age (~1Ma [4]) which is essential to reliably determine the He-Q and Ne-Q isotopic composition. E-chondrites might have accreted in regions closer to the Sun (e.g. [5]) than the ordinary and carbonaceous chondrites previously analysed [1,2]. E-chondrites contain, in addition to common Q-gases [6], abundant "subsolar" noble gases [4,7]. This component has elemental and Ar-Xe isotopic compositions intermediate between solar and meteoritic and is supposed to reside in enstatite [8].

Here, we present new data, obtained by pyrolysis, for an aliquot of the residue and its oxidised remnants that remained after on-line stepped etching [3] to analyse the presolar noble gas contents of St. Mark's and to assess the gas release efficiency. The on-line etch data yield  $^3\text{He}/^4\text{He} = (1.80 \pm 0.06) \times 10^{-4}$ ,  $^{20}\text{Ne}/^{22}\text{Ne} = 11.72 \pm 0.25$  (by extrapolation to  $^{21}\text{Ne}/^{22}\text{Ne} = 0.0294$ ), and  $^{36}\text{Ar}/^{38}\text{Ar} = 5.44 \pm 0.13$  for the subsolar component. The latter is in agreement with  $5.46 \pm 0.04$  obtained from South Oman [7]. In addition, we re-determine the elemental composition of the subsolar component including its previously unknown He abundance.

**Tab. 1.** Element concentrations of separates of St. Mark's, re-calculated per gram of bulk meteorite (dissolution of 5.56 g bulk yielded 31.7 mg of residue).

	bulk [4]	residue	residue/bulk [%]	Q [3]	oxidized res. (avrg.)	(Q+ox. res.) /res. [%]
$^3\text{He}^*$	109	0.60	<b>0.6</b>	0.33	0.26	98
$^4\text{He}$	304	25.4	8.4	14.6	6.9	85
$^{20}\text{Ne}$	1.33	0.098	7.4	0.064	0.035	101
$^{21}\text{Ne}^*$	27	0.066	<b>0.2</b>	0.027	0.016	65
$^{36}\text{Ar}$	38.0	3.3	8.6	2.3	0.6	88
$^{84}\text{Kr}^\#$	1645	118	7.2	91	27	100
$^{132}\text{Xe}^\#$	697	83	12.0	55	22	93

In  $10^{-8} \text{ cm}^3/\text{g}$ ,  $^*10^{-10} \text{ cm}^3/\text{g}$ ,  $^\#10^{-12} \text{ cm}^3/\text{g}$ .

**Results:** Table 1 gives gas concentrations released by etching of the residue [3] as well as by various pyrolysis analyses of a bulk sample [4], an aliquot of the residue, and the average for two aliquots of the etched

residue. For comparison, all concentrations are given normalised to those of the bulk sample. The data show that most of the gas ( $\geq 88\%$ ) in St. Mark's indeed resides in an acid-soluble carrier such as enstatite. This is in contrast to most unequilibrated meteorites where most of the trapped Kr and Xe reside in the insoluble phase Q. The last column of Table 1 compares the Q-gas released by oxidation plus remaining gas in the oxidised residue with the concentrations in the unoxidised residue. Most numbers close to 100% indicate an almost complete extraction. The smaller portion of 65% for  $^{21}\text{Ne}$  indicates an enrichment of cosmogenic Ne in the bulk residue as also seen in the higher  $^{21}\text{Ne}/^{22}\text{Ne}$  ratio of 0.042 compared to ~0.033 in the oxidised residues.

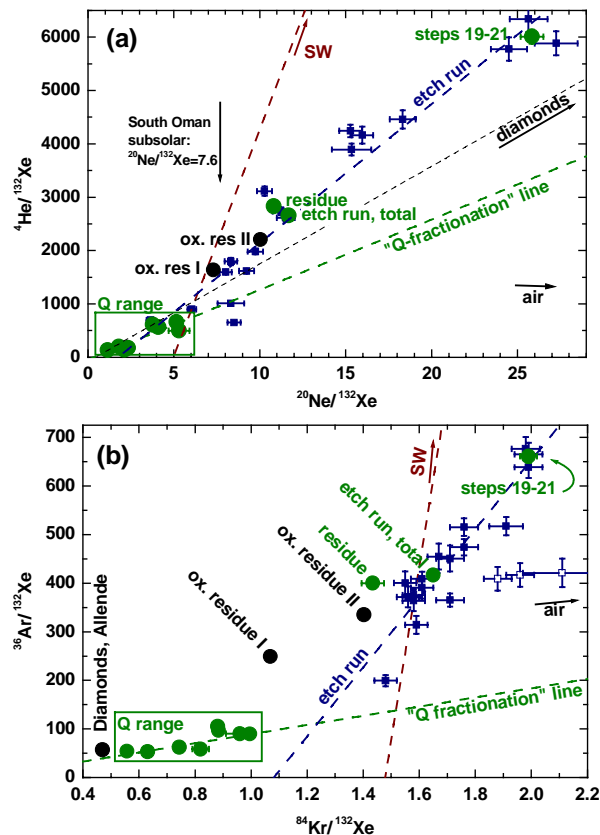
**Tab. 2.** Elemental composition of the subsolar component in phase Q of EH5 St. Mark's obtained by subtraction of Q-gas ( $^{132}\text{Xe} \equiv 1$ ). See text for assumptions. In italics: Subsolar contributions to the total in %.

	(a) Lower Limit		(b) Upper Limit			
	Xe-Q: 77%		solar from [9]		solar from [10]	
	Xe-Q: 77%	<i>95</i>	Xe-Q: 94%	<i>94</i>	Xe-Q: 96%	<i>94</i>
$^4\text{He}$	$25 \times 10^3$	<i>95</i>	$94 \times 10^3$	<i>94</i>	$141 \times 10^3$	<i>94</i>
$^{20}\text{Ne}$	102	<i>90</i>	380	88	569	88
$^{36}\text{Ar}$	$2.6 \times 10^3$	<i>91</i>	$9.8 \times 10^3$	89	$15 \times 10^3$	89
$^{84}\text{Kr}$	5.9	<i>69</i>	20	62	30	<i>61</i>
$^{132}\text{Xe}$	1	<i>23</i>	1	6	1	<i>4</i>

Surprisingly, phase Q released significant amounts of the subsolar component. Fig. 1 shows the element ratios (a) He/Xe vs. Ne/Xe and (b) Ar/Xe vs. Kr/Xe for all samples and the 23 etch steps. Most data points (except for those indicating air contamination) lie on mixing lines between the Q-like and subsolar composition. The low portions of  $^3\text{He}$  and  $^{21}\text{Ne}$  in the residue relative to the concentrations in the bulk silicates (Table 1) imply that phase Q is the carrier of the subsolar gases and not enstatite that has survived the treatment with HF/HCl. If enstatite would be the main carrier of the gas released upon etching, the numbers for  $^3\text{He}$  and  $^{21}\text{Ne}$  should be similar to those of the other isotopes.

For Ne-Xe the subsolar element composition so far has best been represented by EH3 chondrite South Oman, which is particularly rich in the subsolar component [7]. From our steps most rich in the subsolar component (steps 19-21, Fig. 1), we now can straightforwardly estimate a lower limit for  $(^4\text{He}/^{132}\text{Xe})_{\text{sub}} =$

6008±265. We also revise the previous lower limit for  $(^{20}\text{Ne}/^{132}\text{Xe})_{\text{sub}}$  of 7.6 [7]. Our new value is 25.8±1.3. Furthermore, steps 19-21 allow us to determine the subsolar element composition more stringently by subtracting their Q-gas content: Upper and lower limits for the Q-Xe contribution are estimated by (a) the assumption that  $(\text{Kr}/\text{Xe})_{\text{subsolar}}$  resulting from this subtraction should not exceed the respective solar ratio [9,10] and (b) conservatively assuming the composition of South Oman to be purely subsolar. We used the Q average with uncertainties encompassing the entire range of reported Q values [2]. Assumption (b) yields a lower limit of 77% of Xe-Q in steps 19-21. Assumption (a) yields upper limits of the Xe-Q contribution of between 94 and 96%, respectively, depending on the assumed  $(^{84}\text{Kr}/^{132}\text{Xe})_{\text{solar}}$  values of 20.6 [9] and 29.4 [10].



**Fig. 1.** (a)  $^4\text{He}/^{132}\text{Xe}$  vs.  $^{20}\text{Ne}/^{132}\text{Xe}$  ratios and (b)  $^{36}\text{Ar}/^{132}\text{Xe}$  vs.  $^{84}\text{Kr}/^{132}\text{Xe}$  ratios. Bulk values: [4].

The composition of the subsolar component and its contribution to the gas released from phase Q in steps 19-21 are given in Table 2. Most of the He, Ne, and Ar is subsolar. A determination of the isotopic composition of He-Q and Ne-Q in St. Mark's is thus not possible. The Ne and Ar isotopic ratios determined by pyrolysis for the oxidised and non-oxidised residues agree with

the subsolar ratios obtained from the etch experiment and given above. The subsolar Kr and Xe isotopic composition could not be determined due to the large contribution of Q (Table 2).

**Discussion:** The comparison of the gas composition of the oxidised residues and phase Q reveals only slight differences for the light elements (Fig. 1a), indicating that essentially no He and Ne from presolar diamonds is present. Furthermore, Fig. 1 shows that both, phase Q and the non-oxidisable (presolar?) fraction of the residue, contain subsolar gas. Surprisingly, the heavy elements (Fig. 1b) allow the presence of presolar diamonds - or fractionated Q-gas - in the oxidised residues. Their data points lie on a mixing line between the presolar diamonds' composition [11] and the data point representing the total of the etch run. However, it is unclear, how presolar diamonds could lose their He and Ne contents and retain the heavy noble gases. Furthermore, the isotopic composition of the residues can be explained by mixtures of subsolar and Q-gas alone and does not indicate the presence of presolar Xe-HL, Ne-HL, He-HL, or Ne-E. Possibly, this indicates some re-trapping of Q-gases into more refractory carriers.

Subsolar gases have now been found in the carbonaceous phase Q, bulk silicates [8], the more refractory non-oxidisable etch remnants, and in chondrules of an EH chondrite [12]. It is difficult to find a mechanism that fractionates trapped solar wind in the distinct carriers resulting in such a similar subsolar composition. This implies that the subsolar composition most likely has been established from solar composition prior to the trapping by the carriers. The mixing lines formed by Q and most data points (Fig. 1) clearly do not lead to solar (wind) composition. Subsolar gases cannot be explained as a mixture of solar and Q composition.

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**References:** [1] Wieler R. (1994) in *Noble Gas Geochemistry and Cosmochemistry*, Matsuda J. (ed.), 31-41. [2] Busemann H. et al. (2000) *Meteoritics & Planet. Sci.*, 35, 949-973. [3] Busemann H. et al. (2000) *Meteoritics & Planet. Sci.*, 36, A34. [4] Patzer A. & Schultz L. (2001) *Meteoritics & Planet. Sci.*, 36, 947-961. [5] Scott E. R. D. & Taylor G. H. (2000) *LPS*, 31, #1546 (CD-ROM). [6] Huss G. R. et al. (1996) *GCA*, 60, 3331-3340. [7] Crabb J. & Anders E. (1981) *GCA*, 45, 2443-2464. [8] Crabb J. & Anders E. (1982) *GCA*, 46, 2351-2361. [9] Palme H. & Beer H. (1993) in *Landolt Börnstein New Series VI/3a*, Voigt H. H. (ed.), 196-221. [10] Anders E. & Grevesse N. (1989) *GCA*, 53, 197-214. [11] Wieler R., *pers. comm.* [12] Okazaki R. et al. (2001) *Nature*, 412, 795-798.