NOBLE GASES IN MARTIAN METEORITE QUE94201; T.D. Swindle, B. Li and D.A. Kring, Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721-0092.

Abstract: Noble gases in QUE94201 seem to be typical of shergottites in terms of cosmic ray exposure history, amount of radiogenic ^{40}Ar, and ^{129}Xe/^{132}Xe ratio (indicative of trapped martian gas). Like other shergottites, QUE94201 seems to have been exposed to a higher ratio of solar cosmic rays to galactic cosmic rays than most other meteorites, which defies simple explanations.

Introduction: Noble gases in martian meteorites (shergottites, nakhlites, Chassigny and ALH84001) can provide constraints on the exposure history and thermal history of the rocks themselves, as well as information on the martian atmosphere, in cases where atmospheric gases have been trapped. We have analyzed all five noble gases in a 23.7 mg chip of the recently recovered shergottite QUE94201.

Gases were extracted in four temperature steps, at 400°C, 800°C, 1400°C and 1650°C, purified by exposure to SAES getters, partially separated cryogenically, and analyzed on a high-sensitivity, pulse-counting VG5400 noble gas mass spectrometer. Combined data for the 800°C and 1400°C steps are given in Table 1. As expected, the 400°C step was dominated by terrestrial atmospheric contamination. The 1650°C step for Ne, Kr and Xe was lost when the filament in the mass spectrometer burned out, but, based on the He and Ar of this sample, and our previous analyses of other martian meteorites, we suspect there was little gas anyway.

Discussion of noble gas results: With the exception of EET79001 (which has a shorter exposure age and abundant trapped martian gas), the shergottites all have 2-3 Ma exposure ages, and low amounts of radiogenic ^{40}Ar and ^{4}He (indicative of relatively recent resetting) [1-6]. The abundances of cosmogenic ^{21}Ne and radiogenic ^{40}Ar that we measure are well within the range measured in other shergottites, while the amounts of cosmogenic ^{3}He and radiogenic ^{4}He are about 30% lower, and the amount of cosmogenic ^{38}Ar is about 15% higher than any other shergottite. Given that we only believe our calibrations of absolute amounts to be accurate to about 20%, there is no reason to think that the exposure or thermal history of QUE94201 is any different from the other shergottites, and hence it seems plausible that this meteorite is a shergottite and comes from the same impact as the others.

The isotopic composition of the cosmogenic Ne (^{21}Ne/^{22}Ne = 0.76 ± 0.02) is also well within the range of the shergottites. As Garrison et al. [1] have pointed out, shergottites frequently have ^{21}Ne/^{22}Ne ratios of <0.80, indicative of a high enough ratio of solar cosmic ray-produced (SCR) Ne to galactic cosmic ray-produced (GCR) Ne that the presence of SCR Ne is measurable. Since SCR's have lower energy than GCR's, and hence do not penetrate as far, this presumably represents either low shielding or a change in the flux of SCR or GCR. Such a high ratio of SCR to GCR effects is rarely seen among other meteorites, suggesting something unique about the orbital or atmospheric entry history of shergottites. We return to this point below.

We were particularly interested in the Xe isotopic composition, since the meteorite has patches of impact melt glass [7], and impact melt glass in the shergottite EET79001 contains the highest ^{129}Xe/^{132}Xe ratio (and presumably the purest trapped martian Xe) of any martian meteorite. However, the highest ^{129}Xe/^{132}Xe ratio we measured was only 1.26 ± 0.06 in the 1400°C step,

Table 1: Noble gases in QUE94201

^{3}He	^{4}He	^{22}Ne	^{20}Ne/^{22}Ne	^{21}Ne/^{22}Ne	^{38}Ar$_c$	^{40}Ar	^{84}Kr	^{132}Xe	^{129}Xe/^{132}Xe
3.0	21	1.21	0.68 ± 0.03	0.76 ± 0.02	0.44	393	6.0	5.0	1.11 ± 0.05

Amounts of He, Ne and Ar in 10^{-8}cm^{3}STP/gm, Kr and Xe in 10^{-12}cm^{3}STP/gm compared to ratios of >2 measured in EET79001 [2-4]. Either the single chip that we analyzed was deficient in impact melt glass, or the glass in QUE94201 does not contain as much trapped martian atmosphere as the glass in EET79001.

Discussion of the high SCR/GCR ratio in shergottites: Garrison et al. [1] suggested several possible reasons why shergottites might have been exposed to higher ratios of SCR to GCR than virtually any other meteorites (including the other martian meteorites). They rejected size, micrometeorite erosion and temporal changes in cosmic ray fluxes as possible explanations, and concluded that the most likely possibilities are either orbits that stay closer to the Sun (hence see higher SCR fluxes), or lower entry velocities (hence lower ablation rates) because of orbital peculiarities. We have performed some calculations relevant to the latter possibility, and wish to suggest yet another possible cause.

ReVelle [8] has calculated ablation losses as a function of entry velocity and meteoroid size. He found that a maximum of 60% of the mass could remain after ablation losses. The amount retained is a weak function of size (being a minimum for $r = 2\text{-}10$ cm) and a strong function of entry velocity. The maximum amount is retained at the minimum velocity (Earth's escape velocity, 11.2 km/sec). For entry velocities of 15 km/sec, no more than 30% of the mass can be retained. Taking this velocity as a cutoff, we find that the encounter velocity V_{enc} (the velocity before considering the effects of Earth's gravity) must be less than 10 km/sec.

We then took a list of the known asteroids whose orbits currently cross 1 A.U. (Jeddicke, pers. comm.), and calculated how v_{enc} varies as a function of orbital parameters. Overall, 17% (31 of 184) have $v_{enc} < 10$ km/sec. Martian meteoroids might be expected to have semi-major axes (a) of 1-1.5 A.U., between those of Earth and Mars, and lower inclination (i), since they originate near the ecliptic. Of the known asteroids, the fraction with $v_{enc} < 10$ km/sec is virtually the same for those with $a > 1.5$ A.U. (15%) and those with a between 1 and 1.5 A.U. (16%). If only those asteroids with $i < 10°$ are considered, then 35% (9 of 26) of those with a between 1 and 1.5 A.U. have $v_{enc} < 10$ km/sec, compared with 26% (14 of 54) of those with $a > 1.5$ A.U. The orbital parameter that exerts the strongest influence on v_{enc} is the perihelion, q. Fully 50% (23 of 46) of the known asteroids with $q > 0.9$ (q must be <1 to cross Earth's orbit) have $v_{enc} < 10$ km/sec. Thus, while we might expect martian meteorites to have slightly lower v_{enc} than Main Belt-derived meteorites, the effect does not seem to be large enough to explain the preponderance of shergottites (and lack of other martian meteorites) among meteorites with evidence for SCR. There are two caveats. First, the orbits of shergottites could be more similar to one another than we have assumed; i.e., they could be of a stream with the "right" orbital elements. The existence of a stream has been suggested [9], but for all martian meteorites, not just shergottites. Second, if shergottites (but not other martian meteorites) are preferentially represented among asteroids with very Earth-like orbits (but see [10]), they could have very low encounter velocities.

One other possibility that we believe should be considered is that because they are unbrecciated igneous rocks, the shergottites may be physically stronger than most meteorites. During atmospheric entry, they may be less likely to fragment and reveal deeper material. The other group of meteorites in which low $^{21}Ne/^{22}Ne$ ratios (evidence for SCR effects) are common is the lodranites/acapulcoites [1]; we have also measured a very low ratio in the olivine-rich achondrite LEW88763. All might be uniquely strong among meteorites. The lack of SCR effects in the other martian meteorites remains a puzzle.

References: [1] Garrison D.H. et al. (1995) *Meteoritics* **30**, 738; [2] Bogard D. D. et al. (1984) *GCA* **48**, 1723; [3] Swindle T.D. et al. (1986) *GCA* **50**, 1001; [4] Wiens R. et al. (1986) *EPSL* **77**, 149; [5] Ott U. (1988) *GCA* **52**, 1937; [6] Becker R.H. and Pepin R.O. (1993) *Meteoritics* **28**, 637; [7] Kring D.A. et al. (1996) This volume; [8]ReVelle D.O. (1979) *J. Atm. Terr. Phys.* **41**, 453; [9] Trieman A. H. (1992) *Meteoritics* **27**, 93; [10] Bottke W. et al. (1994) *Meteoritics* **29**, 447.