THE COMPLEX EXPOSURE HISTORY OF A VERY LARGE L/LL5 CHONDRITE SHOWER: QUEEN ALEXANDRA RANGE 90201.

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Introduction: Compared to iron meteorites, large stony meteorites (>100 kg) are relatively rare. Most large stony meteoroids fragment during atmospheric entry, producing large meteorite showers. Interestingly, many of these large chondrites, such as Bur Gheluai, Gold Basin, Jilin and Tsarev appear to have a complex exposure history with a first-stage exposure on the parent body. The question is whether complex exposure histories are simply more readily detected in large objects or large objects are more likely to experience a complex exposure. Investigation of these two hypotheses is the motivation for this work in which we report on the exposure history of QUE 90201, a large L/LL5 chondrite shower found near Queen Alexandra Range, Antarctica. Previous cosmogenic nuclide studies have led to the consensus that most of the ~2000 L5 and LL5 chondrites from the QUE area are derived from a single object with a pre-atmospheric radius of 1-2 m [1,2]. The terrestrial age of the QUE 90201 shower was determined at 125±20 kyr. Here, we present a more complete set of cosmogenic radionuclide results in the metal and stone fractions of eleven L/LL5 chondrites from the QUE stranding area, as well as noble gases in seven of these samples. The main goal of this work is to unravel the cosmic-ray exposure history of the QUE 90201 meteoroid. In addition, we will discuss the pre-atmospheric size and exposure history of QUE 93013 (H5) and 93081 (H4) with similar shielding conditions as the QUE 90201 shower and a terrestrial age of 145±25 kyr [2].

Radionuclide analysis: Samples weighing 2-3 g were gently crushed, saving 0.2-0.3 g in small chips for noble gas analysis. After further crushing, the metal was separated with a magnet and purified as described previously [2]. Metal samples were dissolved in the presence of 1-5 mg of Be, Al, Cl and Ca carrier, stone samples with 3-5 mg of Be and Cl. Additional sample preparation steps were performed following the procedures described elsewhere [3]. Concentrations of ^{10}Be (half-life=1.5×10^6 yr), ^{26}Al (7.05×10^5 yr), ^{36}Cl (3.01×10^5 yr) and ^{41}Ca (1.04×10^5 yr) were measured by accelerator mass spectrometry (AMS) at the Lawrence Livermore National Laboratory. We corrected the measured radionuclide concentrations for radioactive decay during the terrestrial residence of 125 kyr for QUE 90201 and 145 kyr for QUE 93013/93081.

Noble gas analysis. Samples consisting of one or several chips of meteorite (100-200 mg), free of fusion crust, were wrapped in aluminum foil. Prior to analysis at ETH, samples were preheated for about a day at 90 °C to desorb loosely bound atmospheric noble gases. Helium, neon and argon were measured following the procedures described previously [4].

Model calculations. We calculated production rates of cosmogenic nuclides in the stone and metal fraction assuming a bulk chemistry of L-chondrites and pre-atmospheric radii of 0.3–3 m. Particle fluxes are based on the Los Alamos High Energy Transport (LAHET) Code System (LCS), assuming an effective flux of primary GCR particles of 4.8 nucleons cm^{-2}s^{-1} for energies >10 MeV [5].

QUE 90201 - pre-atmospheric size. The concentrations of ^{10}Be and ^{26}Al in the stone fraction of the L/LL5 chondrites vary by a factor of 2-3, and are well correlated with those in the metal fraction. Fig. 1 shows a comparison of the ^{10}Be concentrations in the QUE 90201 shower with those measured in other large chondrite showers, such as FRO 90174 [3] and Gold Basin [6]. Fig. 1 suggests that QUE 90201 was intermediate in size between these two objects, which have estimated pre-atmospheric radii (R) of 80-100 cm and 3-5 m, respectively. Comparison of the ^{10}Be results with calculated ^{10}Be production rates in the stone and metal fraction of large chondrites indicates R = 1-2 m for QUE 90201.

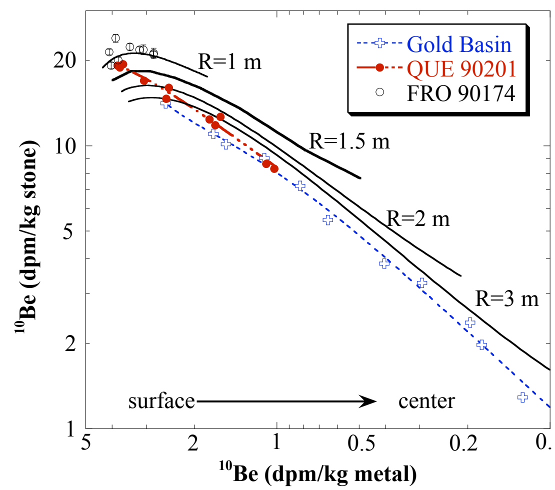

Fig. 1. Concentrations of ^{10}Be in the stone and metal fractions of the QUE 90201 shower (red symbols) compared to those in the Gold Basin (R=3-5 m) and FRO 90174 (R=80-100 cm) showers. The solid lines represent calculated production rates for chondritic objects with radii of 1-3 m, based on the LCS model.

In large objects, ^{36}Cl and ^{41}Ca are not only produced by spallation from K, Ca, Fe and Ni, but also by neutron-capture on ^{35}Cl and ^{40}Ca, respectively. The concentrations of ^{36}Cl and ^{41}Ca in the stone fraction provide additional constraints on the pre-atmospheric size of chondrites. The QUE 90201 meteorites show large contributions of neutron-capture ^{41}Ca (up to 15 dpm/kg), which correspond to production rates of 0.5-2.0 atom/min/gCa. In contrast, the concentrations of ^{36}Cl in QUE 90201 are dominated by the spallation component. The small contributions of neutron-capture ^{36}Cl (<2 dpm/kg) in the stone fractions are most likely due to native Cl concentrations ≤10 ppm, i.e. an order of magnitude lower than typical chondritic values of ~100 ppm.

Figure 2 shows the concentrations of neutron-capture ^{41}Ca in the stone fraction (a low-energy product) vs. those of ^{10}Be in the metal fraction (a high-energy product) of QUE 90201 and two other large chondrite showers. Comparison with calculated production rates constrains the pre-atmospheric radius of QUE 90201 to ~1.5 m.

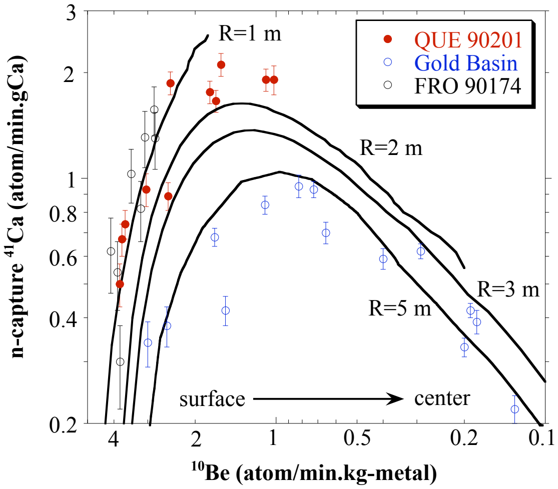

Fig. 2. Concentrations of neutron-capture ^{41}Ca in the stone fraction vs. ^{10}Be in the metal fraction of QUE 90201, FRO 90174 (H5-6) and Gold Basin (L4). The solid lines represent calculated production rates in chondrites with radii of 1-5 m.

QUE 90201 - exposure history. The cosmogenic ^{21}Ne concentrations range from 4.0–11.5 x 10^{-8} cm^3 STP/g (Fig. 3). Due to the large pre-atmospheric size we cannot obtain reliable ^{21}Ne production rates based on the ^{22}Ne/^{21}Ne ratio, but have to rely on the ^{10}Be/^{21}Ne and ^{26}Al/^{21}Ne ratios, which are relatively independent of shielding [6-8].

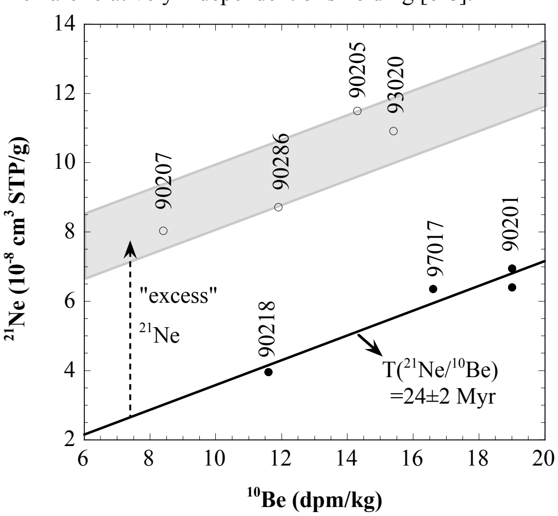

Fig. 3. Variation of ^{21}Ne concentration vs. ^{10}Be in seven members of the QUE 90201 shower. The solid line represents a fit through QUE 90201, 90218 and 97017, which show an average ^{21}Ne/^{10}Be ratio of 85±5 atom/atom. This ratio corresponds to an exposure age of ~24 Myr. The other four samples (represented by open symbols) show excess ^{21}Ne of 4.5-6.5 x 10^{-8} cm^3 STP/g due to previous exposure on the parent body.

Three fragments of the QUE 90201 shower show relatively constant ^{21}Ne/^{10}Be and ^{21}Ne/^{26}Al ratios of 85±5 and 60±6 atom/atom, respectively, whereas the ratios in the other four samples are a factor of 1.8-2.7 times higher. This wide range in ^{21}Ne/^{10}Be and ^{21}Ne/^{26}Al ratios in the QUE 90201 shower is very similar to that observed in the Gold Basin shower [6], and suggests that QUE 90201 experienced a complex exposure history similar to that of the Gold Basin meteoroid. Based on a constant ^{26}Al/^{21}Ne production rate ratio of 0.40±0.02 atom/atom [6-8], the ^{21}Ne/^{26}Al ratios in QUE 90201/90218/97017 correspond to an exposure age of 24±2 Myr. Assuming that these samples were buried deep enough in the parent body to prevent the production of detectable amounts of ^{21}Ne, this age represents the transfer time from parent body to Earth. The other four samples of the QUE 90201 shower were exposed much closer to the surface of the parent body, building up significant amounts of ^{21}Ne. Based on the excess of ^{21}Ne produced during the first stage and calculated depth profiles for the production of ^{21}Ne under 2π irradiation [9], we estimate a minimum first-stage exposure of 40-100 Myr.

QUE 93013/93081. The radionuclide concentrations in the stone and metal fractions of QUE 93013 and 93081 are very similar to those of the more shielded samples of the QUE 90201 shower. This implies that these two samples came from an object similar in size as the QUE 90201 shower. The two H-chondrites (QUE) show ^{21}Ne concentrations of ~1.3 x 10^{-8} cm^3 STP/g, which correspond to an average ^{21}Ne/^{26}Al exposure age of 8.0±0.5 Myr. This age overlaps with the main impact event on the H-chondrite parent body, suggesting a simple exposure history.

Conclusions. The complex exposure history of the QUE 90201 shower confirms the trend that many large chondrites were exposed on the surface of the parent body before being ejected into space. This trend is especially interesting in the light of recent observations of the asteroid 433 Eros, which has a surface mineralogy and chemistry consistent with that of an ordinary chondrite [10]. Imaging of the surface revealed an abundance of boulders in the 2-10 m size range [11]. The multi-stage exposure histories of large chondrites like Jilin, Tsarev, Gold Basin and QUE 90201 may indicate that the presence of large boulders is common on chondrite parent bodies. The lifetime of such boulders on the surface of an asteroid is largely unconstrained. Our work on Gold Basin and QUE 90201 suggests that some of these boulders may have survived on or near the surface of these chondrite parent bodies over time scales on the order of ~100 Myr.

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References: [1] Welten K. et al. (2002) Lunar Planet. Sci. 33, #1763. [2] Welten K. et al. (2004) sumbitted to MAPS. [3] Welten K. et al. (2001) MAPS 36, 301-318. [4] Wieler R. et al. (1989) GCA 53, 1449-1459. [5] Masarik J. and Reedy R. C. (1994) GCA 58, 5307-5317. [6] Welten K. et al. (2003) MAPS 38, 157-173. [7] Graf T. et al. (1990) GCA 54, 2521-2534. [8] Leya I. et al. (2000) MAPS 35, 259-286. [9] Leya I. et al. (2001) MAPS 36, 1547-1561. [10] McCoy T. J. et al. (2001) MAPS 36, 1661-1672. [11] Chapman C. et al. (2002) Icarus 155, 104-118.