THE CHELYABINSK FIREBALL AND METEORITE: IMPLICATIONS FOR ASTEROID HAZARD ASSESSMENT.

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Introduction: At 9:22 a.m. on February 15th 2013, an extremely large fireball detonated in the atmosphere close to Chelyabinsk, Russia, with a total energy equivalent to 440 kilotons of TNT [1]. It was the most energetic fireball event since the Tunguska incident in 1908 [2] and caused many injuries and extensive property damage. Shortly afterwards a shower of fragments fell in the area of Lake Chebarkul. Within minutes this highly unusual event was being reported by the global news media and has raised awareness of the potential threat from NEOs [3].

Meteorite classification: Analysis of the Chelyabinsk meteorite indicates that it is an LL5 type ordinary chondrite, shock stage S4. The many thousands of small fragments collected comprise either of two distinct lithologies: a chondrule-rich light-coloured material (~66%), or a less-abundant (~34%) dark shock-melt. Fragments composed of both lithologies are rare. Shock veins up to 1mm wide cut both the light and dark lithologies.

Sm-Nd isotopes: The results of the Sm/Nd analyses define a linear trend with a slope corresponding to an age of ~290 Ma and $\varepsilon_{Nd}(T) = -1.1\pm0.2$. This age may date an impact event during which significant disturbance of the Sm-Nd system took place.

Stable isotopes: The oxygen isotope compositions of the dark and light lithologies are almost indistinguishable, with both plotting on the edge of the LL chondrite field. The total carbon and nitrogen abundances of both the light and dark lithologies are low; carbon yields were: 341ppm, $\delta^{13}C$ = -28.5‰ and 137ppm, $\delta^{13}C$ = -27.7‰ respectively. Stepped combustion reveals that only a small amount of carbon is released below 400°C suggesting that Chelyabinsk is amongst the 'cleanest' equilibrated ordinary chondrites available. Simultaneous nitrogen, neon and argon analysis suggests that the samples contain only a component of absorbed terrestrial atmospheric gases. The low carbon and nitrogen as well as primordial Ne and Ar contents may be due to impact-induced volatile loss. Cosmogenic ^{21}Ne content is also very low corresponding to the exposure age of <1 Ma.

Hazard assessment implications: The break-up of the fireball was probably facilitated by its pre-entry shock-induced structure. Typically bolides are much weaker than laboratory experiment suggest, due largely to pre-entry shock features [4]. The Chelyabinsk event demonstrates that effective asteroid-hazard mitigation requires structural knowledge of the threatening body similar to that obtained by the Hayabusa spacecraft at Itokawa [5]. Analysis of the Chelyabinsk event suggests that the Tunguska bolide may also have been a structurally weakened object.

References: [1] Yeomans D. and Chodas P. **http://neo.jpl.nasa.gov/news/fireball_130301.html** [2] Chyba C. F. et al. 1993. *Nature* 361, 40-44. [3] Chapman C. R. 2004. *Earth Planet. Sci. Lett*., 222, 1-15. [4] Popova O. et al. 2011. MAPS 46, 1525-1550 [5] Noguchi T. et al. 2010. *Icarus* 206, 319-326 (2010).