INSTRUMENTAL OBSERVATIONS OF THE FIREBALL AND CRATER FORMATION ASSOCIATED WITH THE CARANCAS METEORITE FALL

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Introduction: On September 15, 2007 at 16:41 UT a bright fireball was witnessed close to the southern tip of Lake Titicaca near the Peru – Bolivia border. The fireball left a vapor train visible in broad daylight and produced detonations heard over a large area. Shortly thereafter, a 14 m diameter crater was discovered near the town of Carancas, Peru and fragments of an H4-5 chondrite recovered [1]. Here we describe the acoustic and seismic records associated with the crater formation and fireball, together with trajectory reconstruction, potential pre-atmospheric meteoroid mass and orbit and cratering energy estimates based on these records.

Instrumental records: Airwaves from the Carancas event were detected at infrasound stations in Bolivia (I08BO) and Paraguay (I41PY) and at least at five seismic stations in Bolivia. The seismic records included direct airwave arrivals from several portions of the fireball trajectory as well as seismic waves produced by the impact. Airwaves associated with the crater production may also be present. The closest seismic station was less than 50 km distant from the crater and its records shows clear P and S wave arrivals from the crater impact. This is the first unambiguous seismic recording of a meteorite impact on Earth.

Trajectory Reconstruction: From the backazimuths and arrival times available at I08BO, together with the time of arrivals at seismic stations, a trajectory solution is possible using a number of assumptions. Identification of the airwave arrivals with either point source fragmentations at discrete locations along the trajectory or as ballistic waves emanating from different portions of the trajectory produces somewhat differing solutions. In both approaches, however, there is substantial uncertainty in the values but the general trend for all solutions suggests that the fireball emanated from a radiant with an azimuth within ~20° of due East as seen from the crater. The slope of the trajectory was moderately steep at 50° – 60° from the horizontal. It is difficult to directly estimate the initial velocity. Appealing to the fact that few meteorite producing fireballs have trans-jovian orbits [2], the upper limit to the velocity can be constrained to be ~17 km/s. The resulting orbits are of low inclination and otherwise typical of Apollo-type NEAs.

Crater Energy and Initial Meteoroid Mass: Applying previously derived energy relations between acoustic amplitude and energy for fireballs [3] to data from I41PY yields an energy estimate of 3 tons TNT equivalent, presumed to relate to the crater production or near end point of the fireball. Using I08BO acoustic amplitudes and applying similar scaling relations for period and amplitude derived from man-made explosions [4-5] produce energy estimates of 2 - 5 tons TNT equivalent for the crater production. By using a line source weak-shock modeling approach [6] together with the previous trajectory solution, we are able to match the overpressure and amplitude for the arrival at I08BO which is unambiguously from the fireball with a source energy of ~200 tons TNT equivalent. This is comparable to the initial energy estimated from modeling estimates [7]. From this initial energy and our velocity constraints the initial mass is found to be in the range of ~5000 - 10^4 kg corresponding to an object ~1m in radius. It is instructive to note that only about ~1% of the initial energy remains to form the impact crater.

Discussion: From the crater source energy estimates above and the apparent seismic magnitude found from the direct seismic body waves, we find a seismic energy conversion efficiency of order a few percent. This is near the predicted range of theoretical estimates for small craters [8]. The Carancas crater is exceptional in that it appears to have been produced by a small ordinary chondrite of order 1 m in radius travelling at hypervelocity when impacting the ground. This is at variance with much of existing entry modeling theory [9].

References: [1] Tancredi, G. et al. (2008) *LPS XXXIX* Abstract #1216 [2] Wetherill, G.W. and ReVelle, D.O. (1981) *Icarus.*, **48**, 308–328. [3] Edwards, W.N.. et al. (2006) *J. Atmos. Terr. Phys.*, **68**, 1136-1160. [4] Davidson M. and Whitaker R.W. (1992). *LAUR-12074-MS*, 1-28. [5] ReVelle, D.O. (1997) *Ann. NY Ac. Sci.*, **822**, 284-302. [6] ReVelle, D.O. (1976) *JGR*, **81**, 1217-1237. [7] Brown et al. (2008) *JGR* , in press [8] Shishkin, N.I. (2007) *J. App. Mech and Tech Phys*, **48**, 145-152. [9] Bland, P.A. and Artemieva, N.A. (2003) *Nature*, **424**, 288-291.