ESTIMATED IMPACT PROBABILITY ON EARTH OF A SUPER TUNGUSKA, ~ 200 MEGATON , METEORITE. A. Ruiz[1], and W. Bruckman[1] ; [1]University of Puerto Rico At Humacao, Department of Physics, Call Box 860, Humacao, PuertoRico, 00792 (abraham.ruiz@upr.edu), (miguelwillia.bruckman@upr.edu).

1. Introduction: We will present, in the following sections, evidence that a near 4 km diameter lunar crater (named Hell Q, Figure 1) has a formation age of less than about τ_L =20,000 years, thereby strongly suggesting that impacts of this nature happen within a period comparable to τ_L. On the other hand, since on our planet, due to the larger surface area and gravitational effects, the frequency of these events is larger by a factor of nearly 20, then the corresponding upper period implied here is close to 1,000 years. The above conclusion is in contrast to some previous predictions for this type of blast on Earth. However, it is consistent with fluxes estimated by other researchers, for these super Tunguska energies of ~200 megatons, (Figure 2) , such as Poveda et al , 1999, [1], Ortiz et al, 2006, [2], and Bruckman et al, 2013, [3]. Furthermore, NASA/JPL, compilation of data, from government sensors and infrasound ground monitors, has provided evidence of a larger than previously thought probability of hazardous meteorites, similar to the Chelyabinsk meteorite (see for example Brown et al [4],and the B612 Foundation reports). These new findings can be extrapolated to collisional rates predictions for higher, Tunguska (10 to 20 megatons), or super Tunguska energies that are closer to those shown in Figure (2).

Consequenly, objects capable of producing impacts similar to Hell Q are probably part of our not so distant past, and should be now a concerning threat requiring special attention.

2. Hell Q Crater Upper Limit Age Determination. The Hell Q crater is a near circular structure , at the coordinates latitude 33.0 south, and longitude 4.45 west, with a maximum and minimum rim to rim distances of 4.2 and 3.7 km, (Figure 1) . The age of this seemingly young looking crater can be calculated by the traditional method of counting the number of craters, N(D), around and near, external to the rim, larger than certain diameter D. Then, N(D) is equate to the product of the average crater cumulative production rate, $\bar{\Phi}$(D), and the age of the impacted surface, τ :

$$N(D) = \bar{\Phi}(D)\ \tau \ , \qquad 1$$

and, therefore, the knowledge of N(D) and $\bar{\Phi}$(D) gives the value of τ. Figure 3 shows N(D) counted, for several diameters D, around Hell Q, using the Lunar Reconnaissance Orbiter Camara (LROC). The diameter 34 meters is of particular interest, because a value for $\bar{\Phi}$(D) was estimated, from the direct observation of a very large lunar flash, with luminous energy ε = 1.3x10^{8}J ,(Madiedo et al , 2014, [5]) together with the subsequent identification, by the LROC Team, of the 34 meter crater that was formed. According to Madiedo et al, a total of 300 hours of observing time was used, over a total area of about $8.8x10^6\ km^2$. This translated to approximately 126 such impacts for the whole moon per year, which statistically allows an estimated rate of $\bar{\Phi}$(34m) = $3.3x10^{-6}km^{-2}$/year. Thus, using this result and data in Figure 3, for D=34m, we obtain, from Eq.(1), that τ = 20,000 years. We should mention that the actual number counted may include craters formed by so-called secondary impacts, which are not considered in $\bar{\Phi}$(34m). Therefore the value for τ above is an upper limit.

Another crater of 18m (Robinson et al, 2014, [6]), associated with a large lunar flash with ε = 7.1x10^{6}J (Moser et al, 2013,[7]), can be put together with the 34m crater data to provide the following very interesting relationship, that will be useful for an additional estimate age for Hell Q :

$$D \approx (0.56)\varepsilon^{0.22} \ . \qquad 2$$

The above equation remarkably gives the same ε exponent as the well known diameter-energy scaling law (Gault, 1974, [8]; Melosh, 1989, [9]):

$$D=1.8x\rho_p{}^{0.11}\rho_t{}^{-0.33}g^{-0.22}d^{0.13}(\cos\gamma)^{0.33}\ E_k{}^{0.22}\ , \qquad 3$$

where ρ_p, d and $E_k = \varepsilon/\eta = (\pi/_{12})\rho_p d^3 v^2$ are the density, diameter and kinetic energy of the projectile , respectively, ρ_t the density of the target, g the acceleration of gravity, and γ the impact angle relative to the vertical. The luminous efficiency , η, is a function of v, but for the impact velocities considered here, $v \geq\ \sim 17{,}000 m/s$, is not expected to change much (Moser et al, 2011, [10]) , and, furthermore, it enters Eq. (3) with a small exponent of -0.22 . Also, the other physical factors, ρ_p, d, and γ , exponents are small, so that the coefficient of $E_k{}^{0.22}$ is a slowly changing function. For instance, a duplication of d in Eq (3) only represents a 1.09 factor change. Hence, Eq (2) can be view as a reasonable empirical approximation to Eq (3), for other similar impacts ,like those to be considered below.

The observations by Ortiz et al of three large flashes, and their estimated $\bar{\Phi}(\varepsilon)$, can be combined with Madiedo et al observations into the simple equation,

$$\bar{\Phi}(\varepsilon) \approx 21.6\ \varepsilon^{-0.84} \ . \qquad 4$$

For example, for the Madiedo flash energy we get , as expected, $\bar{\Phi}(\varepsilon = 1.3\text{x}10^8\text{J}) \approx\ 3.3x10^{-6}km^{-2}$/year, while Ortiz et al results for $\bar{\Phi}(\varepsilon)$ are also well approximately reproduced. Putting together Eq. (2) and (4) give the interesting and useful relation:

$$\bar{\Phi}(D) \approx 2.36\, D^{-3.82} \quad , \qquad 5$$

and therefore the number of craters formed by the flux $\bar{\Phi}(D)$ during the time τ is

$$N(D) = \bar{\Phi}(D)\ \tau \approx 2.36\, \tau\, D^{-3.82} \quad . \qquad 6$$

In Figure 3 we have a plot of the N(D) counted(column 2), vs D, and it is compared with Eq.(6) for different values of τ. We see the excellent description of the Hell Q data by Eq. 6 for $\tau = \tau_L = 20{,}000\ y$.

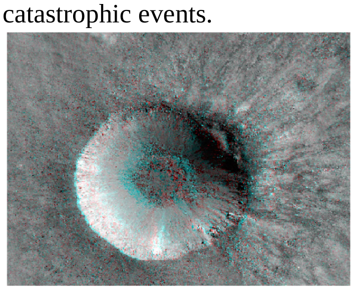
3. The Kinetic Energy of Hell Q Meteorite.

Equation (3) can be rewritten in the convenient form

$$D = a\rho_{sp}{}^{0.067}\rho_{st}{}^{-0.33} g^{-0.22} v_s{}^{-0.086} \cos\gamma^{0.33}\, E_k{}^{0.26}, \qquad 7$$

where a≈ $1/9.7$, and ρ_{sp}, ρ_{st}, v_s are defined by $\rho_p \equiv (2{,}700 kg/m^3)\ \rho_{sp}$, $\rho_t \equiv (2{,}700 kg/m^3)\ \rho_{st}$, $v \equiv (20{,}000 m/s)\ v_s$. According to Eq.(7) we have that an impactor energy $E_k = 7x10^{17} J \approx 170$ megatons produces in the Moon , $g \approx 1.6\ m/s,^2$ a crater $D \approx \rho_{sp}{}^{0.067}\rho_{st}{}^{-0.33} v_s{}^{-0.086} (\cos\gamma)^{0.33} 4{,}000m$, and with densities of $2{,}700 kg/m^3$ and $v = 20{,}000 m/s$, we then obtain a diameter $D \approx \cos\gamma^{0.33}\, 4{,}000m \le 4{,}000m$. Note that a considerable variation ,like a factor 3, in impactor density or velocity has a small effect on D. Thus, ~170 megaton energy can be considered a lower limit for craters like Hell Q. Furthermore, a similar meteorite will hit our planet with even more energy than the Moon, due to the extra gained gravitational energy, so that on Earth the above statistical estimated energy grows to nearly 200 megatons. Figure 2 shows that the point with 200 megatons and a period of 1000 years lies near the predicted values of the three models curves depicted.

Further development, in the near future, in lunar flashes research, will provide more refined impact rates, at meteoroid scale, from which we can then extrapolate to the probabilities for larger and potentially catastrophic events.



The table below gives the counted area in the ejecta blanket around Hell-Q, for crater of 12 , 15, 18, 24, 34, and 48m

D(m)	Counted Area (km ^{2})
12	39
15	39
18	64
24	64
34	137
48	137

Figure 1: Crater Hell Q [NASA/GSFC/Arizona State University]

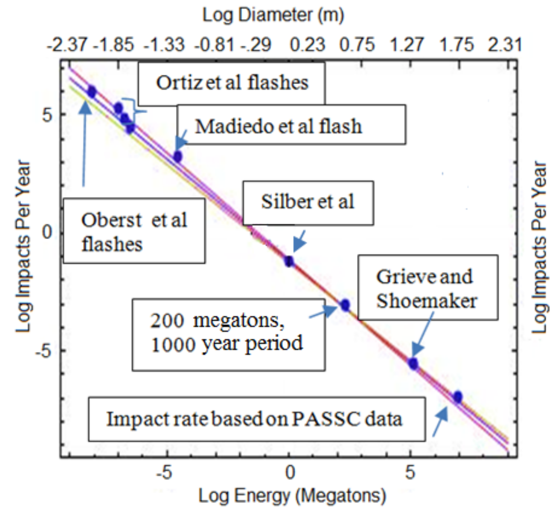
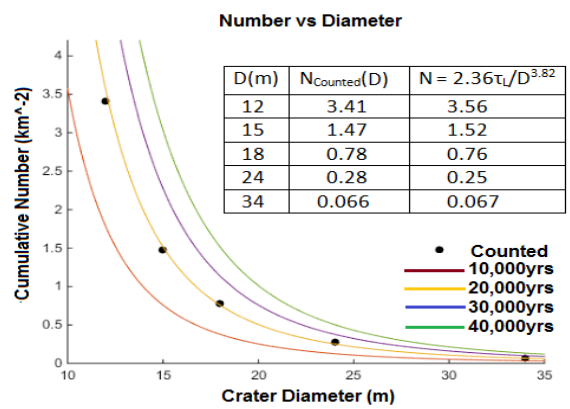


Figure 2 : Log $\bar{\Phi}$ vs Log E_k for Earth. The three green, blue, and red straight lines,with slopes -0.83, -0.86, and -0.90, represent the models of Poveda et al, Bruckman et al, and Ortiz et al, respectively. Other results,from several relevant investigations [11],[12], are plotted.



D(m)	$N_{Counted}$(D)	$N = 2.36\tau_L/D^{3.82}$
12	3.41	3.56
15	1.47	1.52
18	0.78	0.76
24	0.28	0.25
34	0.066	0.067

Figure 3 : Constant τ curves, based on Eq.(6), and plot of the included Table representing Hell Q data.

References:[1] Poveda A., et al (1999), Planetary and Space Science, 47, 679. [2] Ortiz J. L. et al (2006), Icarus, 184, 319, [3] Bruckman W.,et al (2013), http://arxiv .org/ftp/arxiv/ papers/1212/1212.3273.pdf. [4] Brown P. et al (2013),Letter to Nature, [5] Madiedo J. M. et al, (2014), MNRAS, 439, 2364. [6] Robinson M. S. et al (2014), Lunar Planetary Sci XLV., Abstract 2164. [7] Moser D., et al (2014). ACM 2014 Helsinki. Astract.[8]Gault, D.E. (1974) In “Impact Cratering”, Greeley R. and Schultz P. (Eds.),A Primer In Lunar Geology, Ames Research. [9] Melosh,H. J.(1989). Impact Cratering, A geological Process. Oxford Univ. Press.NY. [10] Moser, D. E., et al (2011), Proceedings of the Meteoroids 2010 Conference. NASA CP-2011-216469, 142. [11]Oberst et al (2012),Planetary and Space Science,74,179.[12]Silber et al,(2009),JGR,114