Journal of Physics Special Topics

P3_10 Extinction Event

Ashley Clark, Kate Houghton, Jacek Kuzemczak, Henry Simms

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH.

November 21, 2012

Abstract

This article calculates the dimensions of the crater that triggered the series of events leading to the extinction of the dinosaurs. The diameter of a crater due to an asteroid traveling at escape velocity was calculated to be 71.2 km. An incoming velocity estimate of 54.2 kms^{-1} was made and the crater depth is estimated to be 4.00 km using Newton's projectile penetration depth approximation.

Introduction

The events that caused the extinction of the dinosaurs are believed to have been triggered by the impact of an incoming body [1]. This paper investigates the dimensions of the resulting impact crater from an assumed initial size and velocity. Firstly, the minimum velocity, or escape velocity, is considered to calculate the crater width. This width is then compared with the known crater diameter to estimate the incoming velocity.

The crater depth is calculated using Newton's approximation for the impact depth and to assess its validity the estimated crater dimensions are compared to other known craters.

Theory

An estimation for the crater diameter, D, resulting from an asteroid impact [2], is given by

$$D = 0.07C_f\left(\frac{g_E}{g_t}\right)^{\frac{1}{6}}\left(W\frac{\rho_i}{\rho_t}\right)^{\frac{1}{3.4}}\ , \qquad (1)$$

where C_f is a dimensionless quantity called the crater collapse factor, which has a value of 1.3 for craters larger than 4 km in diameter [2]. W is the kinetic energy of the impacting body in kilotons of TNT equivalent, g_E is the gravitational acceleration of the Earth and g_t is the gravitational acceleration of the target body (this ratio is equal to 1 for all craters on Earth). The density of the impacting body and density of the target body are ρ_i and ρ_t respectively.

An asteroid traveling with velocity, v, has a kinetic energy of

$$W = \frac{1}{2}m_i v^2\alpha = \frac{1}{2}\rho_i V v^2\alpha\ , \qquad (2)$$

where m_i is the mass, V is the volume and α is a conversion factor equal to 2.39x10^{-13} J (1 Joule is equivalent to 2.39x10^{-13} kilotons of TNT, where kilotons refers to metric tons). The asteroid was assumed to be approximately spherical, with a mean radius R. This model assumes that all of the kinetic energy is converted into displacing material to form a crater.

If an asteroid that is at an infinite distance and is initially at rest, then it will have an impact velocity equal to the escape velocity, 11200 ms^{-1}. If the initial velocity is non-zero then this value should be added to the escape velocity.

Substituting equation (2) into (1) gives the crater diameter in kilometres to be

$$D = 0.07C_f\left(\frac{2}{3}\pi R^3 v^2\alpha\frac{{\rho_i}^2}{\rho_t}\right)^{\frac{1}{3.4}}\ . \qquad (3)$$

The impact depth is considered using Newton's approximation for the impact depth, which relates the impact depth, I, to the length of a projectile, $2R$, traveling at high velocities to be

$$I \approx 2R\frac{\rho_i}{\rho_t}\ . \qquad (4)$$

Discussion

The impact crater believed to remain from the extinction event is the Chicxulub crater in Mexico. The asteroid is estimated to have been 10 km in diameter [3]. Firstly the escape velocity, 11200 ms^{-1}, was assumed. The density of the asteroid is assumed to be 2200 kgm^{-3} [4], and the density of the Earth is assumed to be 5520 kgm^{-3} [5]

Equation (3) was used to find the diameter of the resulting crater, giving a value of 71.2 km. This value is smaller than the known diameter of the crater in question. The diameter of the Chicxulub crater has been measured to be 180 km [6]. This implies that the asteroid had a velocity relative to the Earth before it became influenced by its gravity.

Equation (3) was re-arranged for v, taking D to be 180 km, in order to calculate the impact velocity. From this, the velocity relative to Earth was found. The impact velocity was calculated to be 54.2 kms^{-1}. Therefore the impacting body was travelling at 43 kms^{-1} before being influenced by the Earth. Asteroids have been observed to travel around the solar system with velocities between 11 and 72 kms^{-1} [7], leaving the value calculated above within these limits.

Equation (4) was used to calculate the depth of the crater using the two densities involved and the size of the asteroid, as 4.00 km deep. The value found here can be compared to data plotted in figure 1 [8]. For a crater with a diameter of 180 km the diameter to depth ratio is 0.006. This implies a depth of 1.08 km.

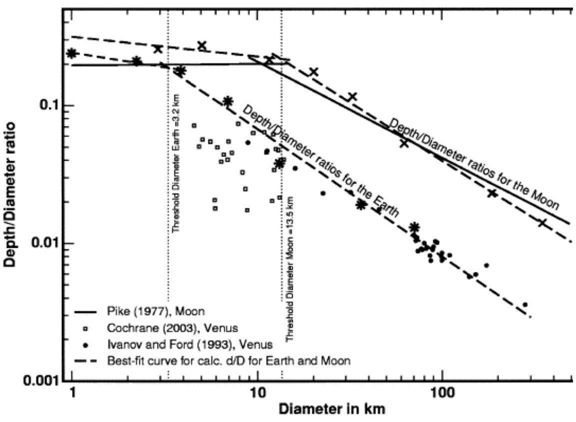

Figure 1: To show depth/diameter ratio versus crater diameter for Earth and lunar craters. These trends were found using observed crater geometries.

Conclusion

The asteroid is believed to have had an initial velocity of 54.2 kms^{-1}, which lies within expected velocities. The kinetic energy was also assumed to be entirely converted into material displacement. One way that this assumption is broken is through air resistance, which has been neglected in calculating the velocity. It is proposed that this could have significant alterations on the incoming velocity.

An in-depth model would need to be utilised to calculate the velocity with which the impacting body struck the Earth.

Clearly using the model of Newton's approximation is insufficient as the depth was found to be almost 4 times the actual measurements. A probable reason for this is that Newton's model neglects the energy converted into horizontal displacement of material making it more appropriate for smaller objects.

References

[1]www.sciencedaily.com/releases/2010/03/100304142242.htm accessed on 20/11/2012.

[2]palaeo.gly.bris.ac.uk/Communication/Brana/equation.html accessed 19/11/2012.

[3]T. Kusky, *Encyclopaedia of Earth and Space Science* (Infobase Publishing, New York, 2010), p. 439.

[4]www.lpi.usra.edu/publications/slidesets/craters/slide_37.html accessed on 20/11/2012.

[5]ircamera.as.arizona.edu/NatSci102/NatSci102/lectures/earth.htm accessed 19/11/2012. accessed on 19/11/2012.

[6] D. A. Kring, *The dimensions of the Chicxulub impact crater and impact melt sheet*, J. Geophys. Res., Vol. 100, No. E8, (1995).

[7]britannica.com/EBchecked/topic/378109/meteor-and-meteoroid/258997/Basic-features-of-meteors accessed 19/11/2012.

[8]K. Wünnemann and B. A. Ivanov, Planetary and Space Science, Vol. 51, Iss. 13, p.831-845, (2003).