THE THREAT FROM BEYOND: IMPACTS AND CRATERS

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The formation of the Solar System left behind large numbers of comets and asteroids. The first billion years or so after the formation was known as the **period of heavy bombardment**, where most of the leftover fragments of formation impacted upon the surfaces of the major bodies of the Solar System. Still today, there are many bodies of notable size left over, any number of which could do significant damage to the Earth and to our civilization. This lab explores the sizes of craters left behind by such impacts, the immediate consequences of the impact and briefly touches on whether or not we would even see such an impactor approaching.

Part I. Crater Diameter vs. Impactor Size

Several factors are involved in obtaining a reasonable estimate of crater diameter. They can be put into an equation (de Pater and Lissaur 2001, p. 165):

$$R = \frac{(0.401)(D)^{1.28}\,(\rho_p)^{0.42}\,(g_p)^{0.28}}{(\rho_m)^{0.42}\,(v)^{0.56}}$$

Where we have already made a few simplifying assumptions, such as the impactor is a spherical, uniformly dense object impacting at an angle of 45°. Making a few further simplifications:

ρ_p is the density of material on the impacted surface, in kg/m^3. Recall that water has a density of 1000 kg/m^3.

ρ_m is the density of material in the impactor, also in kg/m^3. For our purposes here, let's assume that we are talking about asteroids, made up of dense rock, 3,000 kg/m^3. Comets will have a range of densities from 300 to 700 kg/m^3, but we'll stick with asteroids.

G_p is the gravitational acceleration of the planet being impacted, Earth in this case, so 9.8 m/s^2.

v is the speed of the asteroid (or other object) upon impact. This value can range between 10 and 40 km/s or 1×10^4 m/s to 4×10^4 ms. That's an astonishing top speed of 89,000 miles per hour! Let's assume a slightly faster than mid-range object, 3.0×10^4 m/s.

Inserting these numbers into the equation above leaves a simplified formula for impactor size of:

$$R = (2.26 \times 10^{-3})(D)^{1.28}$$

In this formula, "D" stands for the diameter of the crater in particular units. To ensure accuracy of your calculations, **insert only measurements in units of meters**. The result will be in meters, then, as well.

Part II. Craters of Various Sizes on Earth and Elsewhere

1. Barringer, or Meteor, Crater in Arizona is a well preserved impact from 55,000 years ago (http://www.barringercrater.com) which is about 1.2 km across. Convert this to meters by multiplying by the number of meters in a kilometer (1,000) and insert it into our formula. Your result will be the radius of the impactor in meters.

R = ________m

2. Let's assume an impactor will completely destroy a major metropolitan area on Earth, such as Atlanta. Assume that the entire region inside the perimeter will be the size of the crater, about 40 km. This would naturally ruin everyone's day, but we'll get to specific effects in the next part of the lab. For now, find the size of the object responsible for such a disaster. Once you've found the radius of the impactor in km, convert to miles by dividing by 1.6.

R = _______ m, or _______ km, or _______ miles

3. Current theories say that the last mass extinction on Earth was caused by an asteroid or comet impacting the surface. Evidence suggests that the impact occurred on what is now the Yucutan Peninsula. Chicxulub Crater is 180 km across; meaning an impactor of what size caused this mass extinction?

R = _______ m, or _______ km, or _______ miles

Let's leave Earth for a second to explore just how large some of these impactors were during the time of heavy bombardment, based on the sizes of craters better preserved on other surfaces. We'll talk about two different surfaces, the Moon and Mercury. Since some of our assumptions made above are only valid for Earth, we need to reevaluate the value of the constant before the variable for crater diameter. The Moon's gravity is about 1/6 that of Earth's, and we will assume our hypothetical impactors will hit in the darker regions, or Mare, which have a density of about 3,300 kg/m^3 (http://www.astronomynotes.com/solarsys/s13.htm). Inserting these values into the equation, our new constant becomes (1.49×10^{-3}) for the Moon.

4. In one of our previous labs, we measured the diameter of craters on the Moon. One of the Moon's most prominent craters is Copernicus, at a diameter of about 95 km. How large an impactor created Copernicus? Remember to use the updated constant for the Moon in the equation.

R = _______ m, or _______ km, or _______ miles

5. Let's check and see how an impactor would differ in size between the Earth and Moon while creating the same size crater. Assume the same size crater as for the Chicxulub Crater on Earth, but use the Moon's value for the constant and find the size of the impactor.

R = _______ m, or _______ km, or _______ miles

6. Where would you need a larger impactor to make the same size crater, Earth or Moon?

Now let's look at the largest impact basin seen in the Solar System, the Caloris Basin on Mercury. The Caloris Basin is 1,400 km wide. Once again, we must alter a few values in our constant to reflect the differences between the Earth and Mercury. Let's keep the Moon's surface density of 3,300 kg/m^3, and only alter the value for the gravity on Mercury, which is about 38% of Earth's gravity. Inserting these new numbers, the new value for the constant becomes (1.73×10^{-3}).

7. How large an impactor created the Caloris Basin? Remember to use the updated constant in your calculation.

R = _______ m, or _______ km, or _______ miles

Part III. Effects of an Impact

So far, we've only talked about the sizes of craters. The initial effects after impact can be devastating, as well as the subsequent cloud cover similar to "nuclear winter." Here we will only focus on the initial after effects, and not consider "nuclear winter" type effects. To begin, go to a computer and go to the following URL in the web browser:

http://www.lpl.arizona.edu/impacteffects/

This website runs a computer simulation detailing results from an impact at a particular distance away from the impact site on Earth's surface. Let's explore some of these to get an idea of how widespread the damage will be. First, we'll focus on our hypothetical impact which takes out Atlanta to the perimeter. Using the drop down menus, enter the values we used in Part I for both "Projectile Parameters" and "Impact Parameters." **Be careful to input your projectile diameter rather than the radius which you calculated in Part II.** For "Target Parameters" select sedimentary rock. Once these parameters are entered, we are ready to continue. Please be careful to enter everything in the correct units, or convert accordingly.

1. Let's start pretty close, say at Peachtree City, with a distance of 27 miles from impact. Once you enter this value scroll down to the bottom of the page and click the button labeled "Calculate Effects." The resulting page will list many descriptions of various kinds. First, note that the final crater dimensions are slightly larger than our calculation, owing to the more accurate nature of this simulation. We want the transient crater dimensions to be close to our impact crater size estimated above. Now, let's look at some of the effects of being fairly close to impact.

   List the worst effect from Thermal Radiation. What do you think will happen to most humans? How quickly does this happen after impact?

   What is the Richter Scale magnitude of the earthquake from this impact? What's the worst effect listed by the Mercalli Scale Intensity? How long after impact does this occur?

   What is your position relative to the ejecta and how deep is it at your location?

   What is the sound intensity of the air blast and list one consequence of this air blast.

2. Let's move further away from the impact, now at Athens, 61 miles distant.

   Many of the effects are the same. However, a few things are different. For example, how thick is the ejecta? Describe one aspect of seismic damage to structures.

3. Moving still further away, let's try and see how you'd fare in Savannah, at 226 miles distant.

   Note in general that some effects are getting less severe. Each effect comes at different times, with the air blast arriving last. When does the air blast arrive in Savannah? What percentage of trees are knocked down or stripped of branches? What is the average thickness of the ejecta?

4. Lastly, lets go out of the state and try Miami, Florida, at 605 miles distant.

   What are the most drastic seismic events felt? What is the thickness of the ejecta? What effect does the air blast have in Miami?

5. Now let's try to understand the devastating effects caused by the impactor which destroyed the dinosaurs. Insert its **diameter** into the simulator. Atlanta is roughly 1,000 miles from the impact site, in the midst of the Yucatan Peninsula. With these entered into the simulator, give the ejecta thickness as well as the Richter Scale magnitude of the subsequent earthquake below:

6. Since that was not far enough away, let's try 1,500 miles away. What is the average ejecta thickness now and when does it arrive? Do you see the fireball? What happens to highway truss bridges?

7. Now at a distance of 3,000 miles, what's the average ejecta thickness and when does it arrive? List two effects of the air blast.

Part IV. Will We See It?

Let's do some simple calculations to determine if we'd actually see an object coming. The absolute brightness of an asteroid is determined by two factors, its diameter and its albedo (how much light it reflects). The darkest asteroids only reflect 5% of the light they receive from the sun, while the lightest can reflect almost all of it. The absolute magnitude of a dark asteroid (albedo ~ 0.05) can be estimated by the equation:

$$H = -5 * \mathrm{Log}(2R) + 34$$

where R is the radius of the asteroid in meters.

Using the radius of the asteroid that would destroy Atlanta, calculate the Absolute magnitude of the asteroid.

H = _____ Magnitudes

The typical ground based telescope searching for near Earth objects, as these are called, is about 1 meter in aperture. At best, taking the atmosphere into account, these telescopes can detect objects less than about 20th magnitude. (Magnitudes are a kind of funny in that brighter objects have a lower magnitude. For a sense of scale, the full moon has an apparent magnitude of about -13.) Using the following equation, calculate the distance in astronomical units at which this asteroid can be detected by a 1 meter telescope. Use 20 for m, and plug in the H calculated previously.

d = 10(m – H10) =________ AU

Finally, how long would it take for this object to hit Earth if it were heading straight at us from this distance? Assume, as we did above, that the impactor is travelling at 30 km/s and remember that 1 AU is 150,000,000 km. Convert your answer from seconds to days. Do you think we would be able to see such an asteroid before it reached the Earth?