

## ASTR 220 Homework #3 Solutions

### Spring 2005

1. This problem used the images on the class website. You can find information about what planets the images are from on the webpage: <http://www.astro.umd.edu/~avondale/ASTR220/hw3-ans.html> .
  - (a) Ordering the images in terms of oldest to youngest makes an assumption: we assume that the oldest surfaces have the most craters per area, and the younger surfaces have fewer craters per area. It was stated on the webpage that each of the images has approximately the same surface area, so the images with the most craters are older, and the images with the fewest craters are younger. You can simply estimate the number of craters by eye.  
The order from oldest to youngest is: A, I, E, F, H, C, B, D, J, G.
  - (b) I answered this question in the previous part.
  - (c) The oldest two surfaces (A and I) have about 200 craters, on average. Averaging the number of craters on the two youngest surfaces (J and G) gives about 2 craters. That means that the oldest surfaces are approximately  $200/2 = 100$  times older than the two youngest surfaces.
2. This discovery is surprising. The discovery states that we have found an area on Earth covered with thousands of craters. The Earth's surface has been extensively altered by erosion, volcanism, and tectonics since the heavy bombardment when the solar system was young. No terrain that old exists on the Earth's surface. Since the heavy bombardment ended, the rate of new crater formation has been pretty low, so that many craters couldn't have been created.
3. This discovery is not surprising. Although the Earth doesn't have many craters, we have discovered over 100 worldwide. An object 5 km in diameter would leave a crater approximately 50 km across (using our rule of thumb), which is also not an unusual size for a crater on Earth. We have found individual craters similar to this size.
4. Several geologic and biologic processes can affect the accuracy of measurements from geologic layers. You needed to explain three.
  - Erosion can affect geologic layers by wearing away parts of them so that sections are missing.
  - Tectonics can break the Earth's lithosphere so that geologic layers don't match up correctly or move parts of the crust so that geologic layers that were created together are now widely separated.
  - Reworking is geologic process where the dirt and fossils in geologic layers are stirred up and redeposited (in the wrong places) by water.
  - Bioturbation is similar to reworking, except that animals in water do the mixing up of geologic layers.
5. Page 77 in *Night Comes to the Cretaceous* discusses the idea of a blind test. A blind test is used when scientific results are in dispute, possibly because of a bias in the scientist performing the measurement or experiment.  
  
In such a case, a blind test might be used: several independent laboratories perform the analysis, with none of the scientists aware of the origin, history, or circumstances of the samples being analyzed. That way the scientists will not be biased toward a certain outcome.

6. As described in *Night Comes to the Cretaceous*, there are two main types of volcanoes: silicic and basaltic. These names come from the primary type of rock found in their lava: silicon-based rocks, and basaltic-based rocks.

Silicic volcanoes tend to erupt in an explosive manner and spew iridium, ash, and aerosols high up into the atmosphere, where they are circulated for thousands of miles. However, their eruptions are very short-lived and so they only release a relatively small amount of material.

Basaltic volcanoes tend to erupt in a more gentle manner, with lava flowing out of them rather than exploding. Because the lava flows, it can't spread over a very wide area of the Earth, but basaltic volcanoes do produce more poisonous aerosols than silicic volcanoes.

In order to produce a "cosmic winter" with volcanoes, we would have to either suppose a large number of silicic volcanoes erupted at once, or a large number of basaltic volcanoes erupted at once spread all over the world. Neither of these possibilities is very likely, which is why this idea was eventually discarded.

7. Zircon is a mineral that is found as crystals naturally in many granite-type rocks all over the world. It contains uranium, but not lead. Thus, it is a prime candidate for radioactive dating using the parent/daughter relationship of a radioactive isotope of uranium decaying into lead. Zircon is also very hard, so it doesn't erode very well.

If zircons were found in the K-T crater, they would have been heated by the impact. The heating would have partially melted them so that when they re-solidified, parts of each crystal would have an "age" from when it was originally formed and parts would have an "age" from the time of the impact. Radioactive dating using uranium and lead could measure both of these ages.

Additionally, if zircons really were present at the site of the K-T impact, then many of them would have been ejected from the crater and thrown thousands of miles away.

These ideas have been confirmed. Samples of zircon crystals from the Chicxulub crater have been located all over the world. These crystals all have the same composition and have two ages: their original formation age of about 550 million yrs and their re-heating age of 65 million yrs from the K-T impact.

8. The Signor-Lipps effect is when the time of extinction of a species is estimated to be longer ago than it really was, just because the fossils for that species are rare. Page 136 of *Night Comes to the Cretaceous* gives a good example of this effect.

We know that dinosaurs were the largest and dominant animals of their time. However, because they were so large, they were not necessarily very numerous. (Think about how a lion must hunt over many square miles to find enough prey, but thousands of mice could live successfully in that same area.) A further problem is that only a very small fraction of dinosaurs that died ended up being fossilized.

Scientists originally tried to determine when the dinosaurs became extinct by finding the "youngest" dinosaur fossils. The fossils they found all seemed to be significantly prior to the K-T boundary. However, because of the reasons in the previous paragraph, for every one dinosaur fossil that is found, there were probably dozens, if not hundreds, of other dinosaurs living in that area at around the same time period. Consequently, estimating the time of extinction of the dinosaurs strictly on the age of the youngest fossil is not accurate, and would find that the dinosaurs died out earlier than the K-T boundary. This is the Signor-Lipps effect.

The Signor-Lipps effect has a big impact on the interpretation of dinosaur extinction data. Scientists have generally accepted that the Signor-Lipps effect exists. However, the extent of the effect is hotly debated. Should we assume that dinosaurs lived 1 year longer than the "youngest" fossil found? 1 million yrs? 5 million yrs? The more dinosaur fossils that are

discovered in the Cretaceous period, the better idea we get of their population and the better we can compensate for the Signor-Lipps effect.

## 9. Large impacts.

- (a) We know the formula for kinetic energy:  $K = \frac{1}{2}mv^2$ . That means that the impact with the largest kinetic energy probably had large mass and high velocity. From looking at the table on the homework, the impact with the highest mass is the one that tilted Uranus. The impact with the highest velocity was the Shoemaker-Levy 9 collision with Jupiter. Finally, the impact that formed the Moon has nearly as much mass as the Uranus collision and higher velocity. You can work out the math to figure out which impact had more kinetic energy: it is the impact that tilted Uranus.

$$\begin{aligned} K &= \frac{1}{2}mv^2 = \frac{1}{2}(8.7 \times 10^{25} \text{ kg})(6.8 \times 10^3 \text{ m/s})^2 \\ &= 2.0 \times 10^{33} \text{ kg} \cdot \text{m}^2/\text{s}^2 \end{aligned}$$

- (b) Again, from looking at the table, we can see that the mass of the Deep Impact impactor is much smaller than the other masses (370 kg), so it's likely to have the least energetic impact. Also, its velocity of  $1 \times 10^4 \text{ m/s}$  is not extraordinarily fast.

$$K = \frac{1}{2}(370 \text{ kg})(1 \times 10^4 \text{ m/s})^2 = 1.85 \times 10^{10} \text{ kg} \cdot \text{m}^2/\text{s}^2$$

- (c) Now compare these energies to Table 4.1 in the book. The energy from part a,  $2 \times 10^{33} \text{ kg} \cdot \text{m}^2/\text{s}^2$ , is about 5 times less than the amount of energy given off by the Sun in a year. That's a lot of energy!

The energy from part b,  $1.85 \times 10^{10} \text{ kg} \cdot \text{m}^2/\text{s}^2$ , is about halfway between the amount of energy released by burning 1 liter of oil and the energy released by the fission of 1 kg of uranium. The energy released by oil doesn't seem like that much to me, but the energy released by the fission of uranium seems like a lot (a bomb). It's impressive to me that the Deep Impact mission will be able to create a crater in a comet with about 1000 times less energy than that.

Note: remember that a Joule is a unit of energy.  $1 \text{ J} = 1 \text{ kg} \cdot \text{m}^2/\text{s}^2$ , so the numbers above can be compared directly to the table in the book.

- (d) As given in lecture, the total gravitational potential energy of a spherical object is:

$$U_g = \frac{-3GM^2}{5R}$$

$G = 6.67 \times 10^{-11} \text{ m}^3/\text{s}^2/\text{kg}$ ,  $M$  is the mass of the object, and  $R$  is the radius of the object. Since we're talking about the Earth, the mass is  $6 \times 10^{24} \text{ kg}$  and the radius is  $6.4 \times 10^6 \text{ m}$ . Plug in these values.

$$\begin{aligned} U_g &= \frac{-3(6.67 \times 10^{-11} \text{ m}^3/\text{s}^2/\text{kg})(6 \times 10^{24} \text{ kg})^2}{5(6.4 \times 10^6 \text{ m})} \\ &= \frac{-7.2 \times 10^{39} \text{ kg} \cdot \text{m}^3/\text{s}^2}{3.2 \times 10^7 \text{ m}} = -2.25 \times 10^{32} \text{ kg} \cdot \text{m}^2/\text{s}^2 \end{aligned}$$

The minimum amount of energy needed to blow up the Earth is  $2.25 \times 10^{32} \text{ kg} \cdot \text{m}^2/\text{s}^2$ . (The negative sign in the equation for total gravitational potential energy means that the Earth is currently bound together by its gravity, and in order to destroy it, we must apply energy to it.)

- (e) If an object hit the Earth at a velocity of  $3 \times 10^4 m/s$ , what mass would it have to have for the impact to have  $2.25 \times 10^{32} kg \cdot m^2/s^2$  of kinetic energy?

We need to turn around the kinetic energy equation and solve for mass.

$$K = \frac{1}{2}mv^2$$

$$2K = mv^2$$

$$m = \frac{2K}{v^2}$$

Now we can plug in our values.

$$m = \frac{2(2.25 \times 10^{32} kg \cdot m^2/s^2)}{(3 \times 10^4 m/s)^2} = 5.0 \times 10^{23} kg$$

The mass of the object would have to be  $5 \times 10^{23} kg$ .

- (f) Looking at the table in the homework, the mass that is closest is the mass of the object that made the Moon. In fact, it's a little smaller than the mass of the object that hit the Earth, resulting in the Moon's formation. What's up?

Remember that using the total gravitational potential energy of an object as a minimum energy to destroy the Earth is an approximation. The density of the Earth increases toward its core, so possibly more energy is required to completely destroy it.

Also, we do not know the velocity of the object that hit the Earth and caused the Moon to be created. It may have been traveling slower than the stated velocity, which is just a guess. In that case, the impact would have had less energy.