CALCULATING IRIDIUM FALLOUT FROM AN ASTEROID IMPACT

INTRODUCTION

The Howard Hughes Medical Institute short film *The Day the Mesozoic Died* tells the story of how geologist Walter Alvarez and colleagues discovered that a thin band of clay that marks the boundary between the **Cretaceous** and **Tertiary** periods (the **K-T boundary**) contains an extremely high concentration of the element iridium. The element is rare in the Earth's crust and relatively abundant in **asteroids** and comets. Based on that discovery, Dr. Alvarez and colleagues proposed that an Earth-crossing asteroid collided with the planet, and the fallout from this collision spread a layer of iridium across the globe. Consequences of that impact resulted in profound climate change that led to the mass extinction at the end of the Cretaceous period—the extinction that most famously ended the reign of dinosaurs.

The Alvarez team initially set out to measure iridium in order to understand how long it had taken for the K-T boundary clay layer to be deposited. Earth is continuously bombarded by fine extraterrestrial material (10^4 tons/year). Iridium falls from space as **meteors** burn up in the atmosphere at a regular rate, and slowly accumulates at the bottom of oceans. When sediments are deposited slowly, iridium has more time to accumulate and becomes relatively more abundant in those sediments. Dr. Alvarez and colleagues knew there was an abrupt change in the fossil record that occurred at the K-T boundary, and they hoped to use the abundance of iridium in the clay layer at the boundary as a type of clock to determine how quickly this change had occurred. What they found, however, was that the amount of iridium in the clay band was much higher than would have been predicted by the slowest possible deposition rate. They proposed that the iridium came from a 10 km-asteroid striking Earth. The asteroid was thought to have the chemical composition of a **carbonaceous chondrite** of the C1 group, or a **C1 chondrite**, one the oldest materials in the solar system.

In this activity, you will calculate the amount of iridium that a 10 km-asteroid falling to Earth would release and how much of it would end up in the K-T boundary clay layer, to see if this amount is consistent with what Dr. Alvarez and colleagues actually found.

(Note: calculation hints and a glossary can be found at the end of the acitivity.)

Description	Value
Estimated Diameter of Impactor	10 km
Average Density of a C1 Chondrite	2200 kg/m^3
Average Iridium (Ir) Abundance in C1 Chondrites	500 ppb
Diameter of Earth	12,756 km
Average density of Earth's crust	2.7 g/cm^3
Average Ir abundance in Earth's crust	0.02 ppb

PROCEDURE

Complete each of the questions on the following pages, being careful to show your work and label all units correctly. You will need the information in this data table to complete your calculations.

CALCULATIONS

A. Determine the volume of a spherical 10-km-diameter asteroid. Convert units so that your final answer is in m^3.

B. Using the answer from step 1 above, calculate the total mass of the asteroid.

C. Based on the expected composition of a C1 chondrite, calculate the total mass of iridium in the asteroid.

D. Assume that when the asteroid collided with the Earth, it vaporized and all of the asteroid's contents, including iridium, settled evenly on the Earth's surface within a few years following the impact. Calculate the expected distribution of iridium over the Earth's surface produced by the asteroid impact in terms of grams per square centimeter (g/cm^2).

E. Calculate the abundance of iridium resulting from the asteroid impact in ppb in a 1-cm layer of sediment. We will assume that this is the average thickness of the K-T boundary layer, although it varies from location to location.

F. Compare the abundance of iridium from the asteroid strike to the natural abundance in the Earth's crust. How many times more iridium would an asteroid impact add to the iridium found on the Earth?

DISCUSSION QUESTIONS

1. Iridium in the K-T boundary layer has been studied at more than 100 sites around the world. Scientists have documented iridium abundance ranging from about 1 ppb to 25 ppb at these sites. Does your calculation of how much iridium should have been spread on Earth by this asteroid fit within this range?

2**.** The calculations in this exercise were based on a number of assumptions. The first assumption is that all the iridium in the asteroid was spread over the Earth. In addition, we assumed that the iridium was evenly distributed in the Earth's crust. Are these reasonable assumptions?

3**.** Why might iridium deposited after the K-T impact be more abundant at some locations than others? How might this affect our effort to understand this event?

HINTS FOR SOLVING CALCULATIONS

- Look up the mathematical formula for the volume of a sphere and use it to calculate the asteroid's volume. Remember to use the radius of the asteroid and not its diameter. The problem asks for an answer in m^3, so figure out the diameter and radius of the asteroid in meters before proceeding.
- If you don't remember it, look up the formula for calculating density. The data table gives you the density of an average asteroid and you determined the volume in Part A, so you should be able to solve for the mass.
- To figure out the mass of iridium in the asteroid, use the "Average Iridium Abundance in C1 Chondrites" listed in the data table. Parts per billion notation (ppb) is dimensionless, and you can treat it like a fraction of the asteroid that's made out of iridium.
- To calculate the distribution of iridium, start by determining the surface area of Earth. Because your answer should be expressed in units of g/cm^2, you might convert the diameter of Earth listed in the table into centimeters before starting. You probably figured the answer to Part C in kilograms, so be sure to convert to grams so your final answer is in g/cm^2.
- Remember that parts per billion notation is dimensionless. You're going to need to divide the mass of iridium in a cubic centimeter of sediment by the mass of a cubic centimeter of sediment. Because "mass"/"mass" is g/g, the units cancel. Adjust the exponent in the answer to 10^{-9}, and you will have parts per billion.

More About "Parts Per" Notation

The abundance of any particular element in a sample is often expressed in "parts per" notation. Typical scales are parts per thousand (‰), parts per million (ppm), parts per billion (ppb), and parts per trillion (ppt). These are not units. They are dimensionless terms that represent a fraction, with the denominator being the specified base quantity. Seawater has a salt concentration of about 35‰. Thus, given 1000 kg of seawater, about 35 kg would be salt and the remaining 965 kg would be water.

Parts per notation can be used to determine the quantity of a component substance in any particular amount of the mixed substance it is part of. If you want to know how much salt is in 2,500 kg of seawater, simply multiply by 35‰ to get your answer in kilograms.

2,500 kg seawater x 35‰ salt = 87.5 kg salt

Iridium is much less abundant in the universe than salt is in the ocean, and in a C1 chondrite its abundance is measured in parts per billion (ppb). A typical chondrite of this type has about 500 ppb iridium in its mass (the other 999,999,500 parts being other elements and compounds). To find the amount of iridium in a chondrite of a particular mass, multiply the mass of the chondrite by 500 ppb (500 x 10^{-9}). The units of your answer would be the same as the mass unit of the chondrite.

GLOSSARY

Asteroid: a large, rocky body in orbit around the sun.

C1 chondrite or chondrite: a type of stony meteorite that formed without melting of the source material. **Carbonaceous chondrites** are thought to be some of the oldest materials in the solar system.

Cretaceous: a geologic time period lasting from 145.5 million years ago to 65.5 million years ago. The Cretaceous was the last period in the age of the dinosaurs.

K-T boundary: the boundary between the Cretaceous (K) and Tertiary (T) periods. It is characterized by a thin layer of clay found all over the world. The Tertiary has been recently reclassified as the Paleogene and Neogene. The K-T boundary is now known as the K-Pg boundary.

Meteor: particles of dust or larger fragments of materials that enter Earth's atmosphere and burn up from friction. This is the scientific name for a shooting star.

Meteorite: an asteroid or other body that did not burn up after entering the Earth's atmosphere and hits Earth's surface.

"Parts per" notation: a dimensionless notation in which the abundance of something is expressed as so many parts per the whole. Mathematically, this is the equivalent of a fraction in which the term that follows the word "per" in the notation acts as the denominator.

Tertiary: a geologic time period lasting from 65.5 million years ago to 2.6 million years ago. The Tertiary was the beginning of the era in which mammals greatly diversified and filled ecological niches vacated by the extinction of the dinosaurs.

GUIDED CALCULATIONS

A. Determine the **volume** of a spherical 10-km-diameter asteroid. Convert units so that your final answer is in m^3.

- Convert the diameter to meters. 10 km = ____________________meters
- Calculate the volume of a sphere. The formula is $V = 4/3 \prod r^3$. Remember that r is radius, which is ½ the diameter.

B. Using the answer from step 1 above, calculate the **total mass of the asteroid**.

- What is the density of a C1 Chondrite? __________________________
- Use the formula for density (density = mass / volume) to calculate the mass of the asteroid.

C. Based on the expected composition of a C1 chondrite, calculate the **total mass of iridium in the asteroid**.

- What is the average abundance of Ir in chondrites? _________________
- Convert that number to scientific notation (ppb is parts per billion, which is 1×10^{-9}): ________________________
- Calculate mass of iridium (Ir) = mass of asteroid × average abundance of Ir in chondrites

D. Assume that when the asteroid collided with the Earth, it vaporized and all of the asteroid's contents, including iridium, settled evenly on the Earth's surface within a few years following the impact. Calculate the **expected distribution of iridium over the Earth's surface** produced by the asteroid impact in terms of grams per square centimeter (**g/cm^2**).

- Look at the units you need for your answer. Convert the Mass Ir (from part C) to grams: ________________
- Surface area of a sphere = $4 \prod r^2$. You need the radius of the earth! What is it? _________________
- Look at the units you need for your answer – cm! Convert the radius to centimeters: ____________________
- Calculate the surface area of Earth in cm^2: __________________________________
- Calculate average Ir distribution over Earth's surface = mass of iridum in grams / surface area of Earth.
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E. Calculate the **abundance of iridium resulting from the asteroid impact** in ppb in a 1-cm layer of sediment. We will assume that this is the average thickness of the K-T boundary layer, although it varies from location to location.

- Calculate the mass of 1 cm^3 of sediment (use the density of Earth's crust): ___________________
- Calculate average abundance of Ir = Average mass of Ir spread over 1 cm^2 / mass of 1 cm^3 of sediment
- Adjust exponent to 10^{-9} to get parts per billion: _______________________

F. Compare the abundance of iridium from the asteroid strike to the natural abundance in the Earth's crust. How many times more iridium would an asteroid impact add to the iridium found on the Earth?

- Divide the answer from Part E by the average Ir abundance in Earth's crust.

DISCUSSION QUESTIONS

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