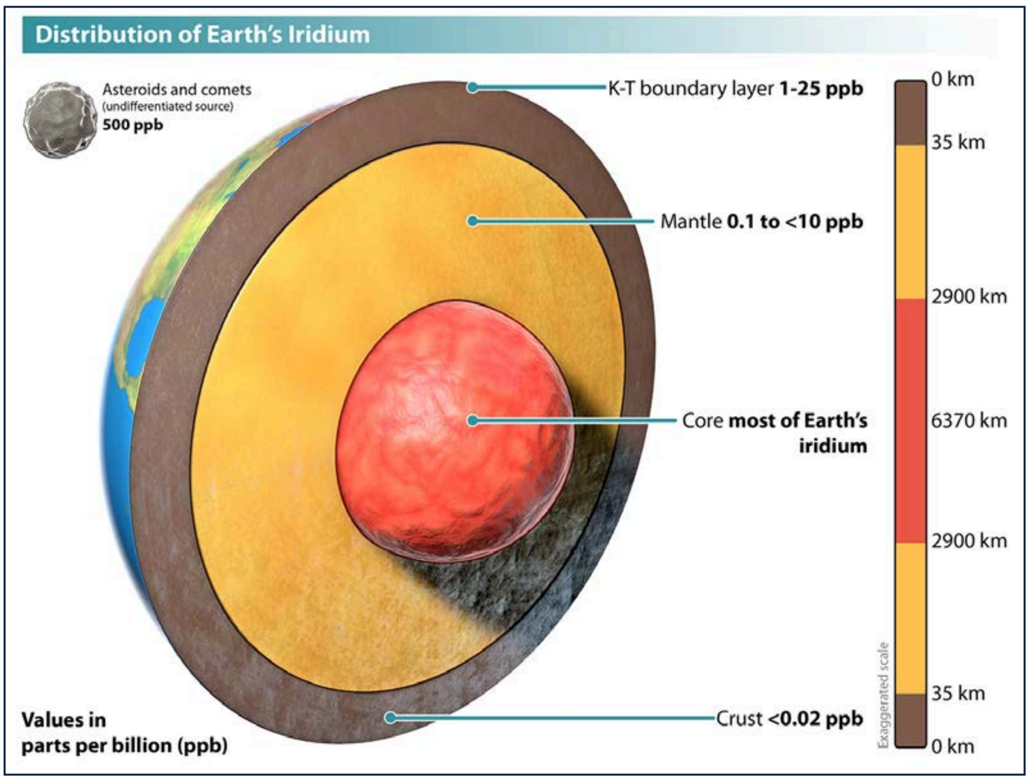
CHEMICAL SIGNATURES OF ASTEROID IMPACTS

INTRODUCTION

The film *The Day the Mesozoic Died* identifies the presence of high quantities of iridium (Ir) in the clay layer at the boundary between the **Cretaceous (K)** and **Tertiary** (**T**) periods as a key piece of evidence for the asteroid impact hypothesis. Because iridium is rare on Earth's crust and abundant in asteroids and comets (see figure), Dr. Walter Alvarez and colleagues thought the iridium in the **K-T boundary** came from space. There are, however, other possible sources of this element. For example, some scientists proposed that the iridium might have come from volcanic eruptions. This activity will guide you through an example of how scientists determine the source material for sedimentary deposits.

Sedimentary rocks are formed by the deposition of material on Earth's surface over time. Depending on the original source of the sediment, a sample of rock will have a particular mixture of elements that matches that of the source it came from. For example, **platinum-group elements**, such as iridium, osmium, and palladium, are quite rare in the mantle, crust, and on Earth's surface so they can be used as indicators for the origin of sediments. During formation of the Earth, dense elements (including platinum-group elements) migrated to the core during a process called **differentiation**.



In this activity, you will analyze the composition of platinum-group elements in different rock samples. The Columbia River **basalt** is a sample of volcanic rock located in Washington State.

This type of rock contains about 27 atoms of palladium (Pd) and nine atoms of osmium (Os) for every one atom of iridium (Ir). The pattern of elements in a sample is known as its chemical signature, and this particular signature (27 Pd: 9 Os: 1 Ir) is typical of volcanic rocks that come from Earth's mantle.

Asteroids have different chemical signatures compared to rocks that come from Earth's mantle or crust because these small planetary bodies did not differentiate. Scientists have analyzed **meteorites** that have struck Earth; based on the chemical composition of these meteorites, scientists can infer the composition of asteroids. A **C1 chondrite** is the type of **meteorite** originating from the type of asteroid described in the short film *The Day the Mesozoic Died*, which caused the mass extinction at the end of the **Cretaceous** period. C1 chondrites contain just a little bit less than one atom of osmium and one atom of palladium for every atom of iridium in them. In this type of rock, the three elements occur in almost equal proportions (1 Pd: 1 Os: 1 Ir)—a striking difference from Earth's rocks.

Your task will be to analyze the chemical signature of several samples of sediment and determine from that analysis the source that likely deposited them. For example, if an asteroid strikes Earth and vaporizes, its iridium will be scattered over a vast area and diluted in other sediments. While the original asteroid contained approximately 500 **parts per billion (ppb)** of iridium—in other words, 500 atoms of iridium per 1 billion atoms of all elements in the sample—sediment deposited at some distant location after the impact might end up with a much lower concentration, say 30 ppb of iridium. In contrast, the concentration of iridium in Earth's crust is as low as 0.02 ppb, which is more than 25,000 times lower than what is found in a typical chondrite and still 1,500 times lower than sediment deposited after an asteroid impact might contain!

(Note: words in bold are defined in a glossary at the end of this document.)

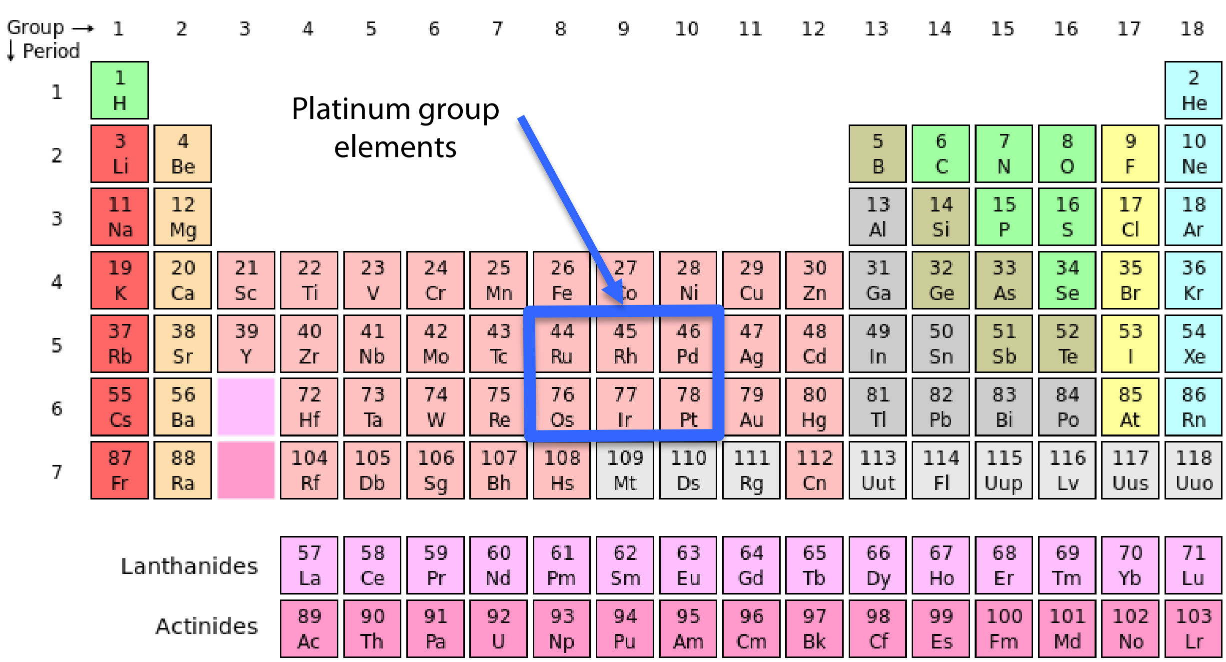
PROCEDURE

1. Watch the HHMI short film *The Day the Mesozoic Died*. As you watch, pay special attention to the case presented for using the abundance of the element iridium as evidence of an asteroid impact.
2. Perform the calculations outlined below to determine the chemical signatures of rock samples.
3. Answer the questions following the calculations.

CALCULATE CHEMICAL SIGNATURES OF DIFFERENT SAMPLES

Examine the data in Table 1on the next page. It presents results from chemical analyses of a C1 chondrite, the Columbia River basalt, and two samples of clay. These clay samples were taken from a K-T boundary layer in Denmark.

How can you tell from the data whether the Danish samples are connected to either the chondrite or the **basalt** as their original source of sediment? One way to do it is to measure the concentrations of different elements in the Denmark Clay samples and compare them to those in the C1 Chondrite or Columbia River Basalt to determine which samples are the more similar. The most diagnostic elements for identifying samples of chondrite origin are the platinum group elements (Ru, Rh, Pd, Os, Ir, and Pt).



To compare samples, the data in Table 1 have to be normalized.

One way to normalize the data is to determine the ratios of all the elements in the meteorite to iridium and then compare those ratios to the ones calculated for the other samples.

Table 1:
Abundance of Selected Elements (ppb)

Element	Denmark Clay 1	Denmark Clay 2	C1 Chondrite	Columbia River Basalt
Ir	47	55	500	0.0011
Os	40	49	480	0.01
Au	8.8	12.3	152	0.35
Pt	24	17	900	-
Ni	310,000	322,000	10,300,000	7300
Co	38,000	46,000	483,000	28,000
Pd	45	53	460	0.03
Re	35	59	35	0.64
Ru	37	-	690	-

Data adapted from Ganathapy, 1980.

Table 2:
Chemical Signature of C1 Chondrites

Element	Abundance (ppb)	Ratio (Element:Ir)
Ir	500	1.00:1
Os	480	0.96:1
Au	152	
Pt	900	
Ni	10,300,000	
Co	483,000	
Pd	460	
Re	35	
Ru	690	

Here is how it works:

- Calculate the ratio of abundance of each element to that of iridium for the C1 chondrite by completing Table 2.
- The first two ratios were calculated as follows:
- Abundance Ir / Abundance Ir = 500 ppb/500 ppb = 1.00
- Abundance Os / Abundance Ir = 480 ppb/500 ppb = 0.96
- Use the following template to calculate the abundance ratio of gold (Au) to iridium:
- Abundance Au /Abundance Ir = ____ ppb / ____ ppb = ____
- Now, calculate the abundance ratios of each of the remaining elements to iridium and fill in Table 2. Show your work on a separate sheet of paper and transcribe your answers into the table.
- Note: In chondrites of this type, we expect to find iridium and osmium in roughly equal proportions, but only about 1/3 as much gold and 1¾ times more platinum. If a sample of rock or clay has iridium and osmium in similar proportions, that's evidence that its original source might have been a C1 chondrite.

Prepare chemical signatures for the Denmark clay 1, Denmark clay 2, and Columbia River basalt samples. Calculate the ratios using the same method as for the C1 chondrite (Table 2). Be sure to base the ratio of each element on the abundance of iridium in the sample.

Table 3: Chemical Signature of Denmark Clay 1 Sample		
Element	Abundance (ppb)	Ratio (Element:Ir)
Ir	47	
Os	40	
Au	8.8	
Pt	24	
Ni	310,000	
Co	38,000	
Pd	45	
Re	35	
Ru	37	

Table 4: Chemical Signature of Denmark Clay 2 Sample		
Element	Abundance (ppb)	Ratio (Element:Ir)
Ir	55	
Os	49	
Au	12.3	
Pt	17	
Ni	322,000	
Co	46,000	
Pd	53	
Re	59	
Ru	-	

Table 5: Chemical Signature of Columbia River Basalt		
Element	Abundance (ppb)	Ratio (Element:Ir)
Ir	0.0011	
Os	0.01	
Au	0.35	
Pt	-	
Ni	7300	
Co	28,000	
Pd	0.03	
Re	0.64	
Ru	-	

QUESTIONS

1. Examine the chemical signatures of the clay samples and compare them to those of the C1 chondrite and Columbia River basalt. Which of these two sources seem to provide the best match (meaning that they are more similar) to the Danish samples? Justify your answer in one or two sentences.

2. Considering the source rock you identified in Question 1, what are some of the ways that the Danish clay samples differ from the likely source material?

3. What could be some possible explanations for the differences you noted in your answer to Question 2? List one or two possible reasons.

4. Based on these data, discuss the source of material that produced the Danish clay deposits. Assume that the Columbia River basalt is typical of mantle and crustal sources of platinum-group elements on Earth. Discuss and support your conclusion, including any uncertainty you feel is warranted as a result of these data.

GLOSSARY

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

Basalt: a type of igneous rock rich in iron. Typically formed from magma that originates in the mantle.

C1 chondrite or chondrite: a type of stony meteorite that formed without melting of the source material. C1 chondrites are a group of **carbonaceous chondrites**, which 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. It was the last period of the age of the dinosaurs.

Differentiation: the process by which a newly forming planet develops compositional layers according to the density of elements and minerals.

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.

Meteorite: an asteroid or other particle from space that does not burn up in Earth's atmosphere and lands on Earth's surface.

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

Platinum-group elements: a group of six transition metals (ruthenium, rhenium, palladium, osmium, iridium, and platinum) that are among the rarest elements on Earth.

Sedimentary rock: a kind of rock formed from the deposition of sediment at Earth's surface, which subsequently became consolidated and cemented together. It can form in both terrestrial and aquatic environments.

Tertiary: a geologic period lasting from 65.5 million years ago to 2.6 million years ago. The Tertiary period was the beginning of the age of the mammals.

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