CHEMICAL SIGNATURES OF ASTEROID IMPACTS

OVERVIEW

This lesson serves as an extension to the Howard Hughes Medical Institute short film *The Day the Mesozoic Died*. In this lesson, students will calculate the chemical signatures of two K-T boundary samples and compare them to those of a chondrite—a rock that originated from space—and a basalt—a rock with the chemical composition found in the Earth's mantle. Students then evaluate the data to determine how well the evidence supports the conclusion that the iridium signal in K-T sediments was produced by an extraterrestrial impact.

KEY CONCEPTS AND LEARNING OBJECTIVES

- The presence of high quantities of iridium (Ir) in the clay layer at the K-T boundary is a key piece of evidence for the asteroid impact hypothesis.

Students will be able to:

- calculate and use ratios to identify the source of a sample based on its chemical composition.
- explain how studying the composition of extraterrestrial bodies (i.e., asteroids and comets) can help inform us about Earth's history.
- understand how even on a global scale, conservation of atoms allows us to link an extraterrestrial impact to the chemical composition of sediments that result from it.
- evaluate the hypotheses, data, analyses, and conclusions in a scientific or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

CURRICULUM CONNECTIONS

Curriculum	Standards
NGSS (April 2013)	HS-PS1.A, HS-ESS1.B, HS-ESS1.C, HS-ESS2-2, HS-ESS2.A
Common Core (2010)	CCSS.Mathematics.MP.4, CCSS.Mathematics.MP.2, CCSS.ELA-Literacy. RST.9-10.7, CCSS.ELA-Literacy. RST.11-12.7 CCSS.ELA-Literacy.WHST.9-12.1, CCSS.ELA-Literacy.WHST.9-12.2

KEY TERMS

platinum-group elements, differentiated, basalt, C1 chondrite, Cretaceous, iridium, "parts per" notation, Tertiary

TIME REQUIREMENT

This activity requires a minimum of 50-minutes to view the film and begin the calculations. Students may finish the calculations in class but will likely need some time to complete the entire worksheet as homework in preparation for a 10-minute follow-up discussion in the following class meeting.

SUGGESTED AUDIENCE

This activity was designed for high school level classes in the disciplines of physics, chemistry, and earth science. It also provides a curriculum resource that addresses Common Core language arts requirements for the science content area at this level.

PRIOR KNOWLEDGE

Students should be proficient in algebra and familiar with the computation and application of ratios.

MATERIALS

Students will need:

- The student version of these materials
- Calculator

TEACHING TIPS

- Read over the introductory material as a class to help students understand the big picture and goals being pursued.
- Consider doing the first few ratios in Table 2 as a class to ensure that all students understand the procedure.
- Students might work in pairs to check each other's data and calculations for Tables 3–5.
- Students should answer the follow-up questions independently.
- Posting the results while discussing student answers to these questions will support critical analysis of student responses.
- The Supporting Information at the end of this document may be used as a resource to help students understand the use of the "parts per" notation.

ANSWER KEY

CALCULATE CHEMICAL SIGNATURES OF DIFFERENT SAMPLES

1. Given the elemental abundance of a typical C1 chondrite (Table 2), calculate the ratio of abundance of each element to that of iridium and fill in the remaining blanks in the table.

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	**0.30 : 1**
Pt	900	**1.8 : 1**
Ni	10,300,000	**20,600 : 1**
Co	483,000	**966 : 1**
Pd	460	**0.92 : 1**
Re	35	**0.07 : 1**
Ru	690	**1.38 : 1**

2. Prepare chemical signatures for Denmark clay 1, Denmark clay 2, and the Columbia River basalt samples. Enter the abundance data based on the values provided in Table 1, then 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 1 Sample

Element	Abundance (ppb)	Ratio (Element:Ir)
Ir	47	**1.00 : 1**
Os	40	**0.85 : 1**
Au	8.8	**0.19 : 1**
Pt	24	**0.51 : 1**
Ni	310,000	**6,596 : 1**
Co	38,000	**809 : 1**
Pd	45	**0.96 : 1**
Re	35	**0.74 : 1**
Ru	37	**0.79 : 1**

Table 4:
Chemical Signature of Denmark 2 Sample

Element	Abundance (ppb)	Ratio (Element:Ir)
Ir	55	**1.00 : 1**
Os	49	**0.89 : 1**
Au	12.3	**0.22 : 1**
Pt	17	**0.31 : 1**
Ni	322,000	**5,855 : 1**
Co	46,000	**836 : 1**
Pd	53	**0.96 : 1**
Re	59	**1.07 : 1**
Ru	-	-

Table 5:
Chemical Signature of Columbia River Basalt

Element	Abundance (ppb)	Ratio (Element:Ir)
Ir	0.0011	**1.00 : 1**
Os	0.01	**9.09 : 1**
Au	0.35	**318 : 1**
Pt	-	**-**
Ni	7,300	**6,636,364 :1**
Co	28,000	**25,454,545 : 1**
Pd	0.03	**27.27 : 1**
Re	0.64	**582 : 1**
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) for the Danish samples?*

The signature of the chondrite is clearly the best match for the two Danish clay samples. The abundance ratios of osmium, gold, cobalt, and palladium match very closely. The remaining elements diverge to some degree, but nowhere near as much as the ratios exhibited by the Columbia River basalt.

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?*

The chemical signatures are a good match, but there are important differences. Platinum, nickel, rhenium, and to a lesser degree ruthenium, all diverge somewhat from the chondritic signature.

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

The differences between the chemical signatures exhibited by the Danish samples and those of a C1 chondrite might be explained in a number of different ways. It is possible that the material that produced the Danish samples did not come from a chondrite of the type that was sampled. Perhaps there are other chondrites with similar, but different compositions. Perhaps some elements that were deposited were later mobilized or removed by processes that are not immediately apparent. Some chemical process in the ocean could dissolve or remove nickel, for example. This would lead to the Danish samples having less nickel than a C1 chondrite source. It's possible that material in the Danish samples came from a C1 chondrite, but that it was mixed with other materials that diluted or enriched these particular elements.

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.*

Given the information available, the original source of the platinum-group and other metals in the Danish samples is consistent with a C1 chondrite, with some modification that occurred after the impact of the meteorite. Abundances of five of the elements (iridium, osmium, gold, palladium, and cobalt) match pretty well. None of the remaining elements are so far off as to be completely unreasonable. It would be interesting to compare data from K-T boundary samples taken from many different places around the world. If these samples were modified by local chemical or physical processes, we would expect to find most samples around the world matching a chondrite with only small differences.

SUPPORTING INFORMATION

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‰ (parts per 1,000). Thus, given 1,000 kg of seawater, about 35 kg would be salt and the remaining 965 kg would be water. 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 <u>billion</u> (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.

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