
# Underground diamonds reveal unknown Earth history

## Educator guide

## PAPER DETAILS

**Original title:** Primordial and recycled helium isotope signatures in the mantle transition zone

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## TABLE OF CONTENTS

# DISCUSSION QUESTIONS

| | LEARNING STANDARDS |
|---|---|
| 1. Why is the atomic weight of strontium (Sr) reported in the periodic table as 87.62 rather than the average of the atomic masses of two stable isotopes (Sr-87 and Sr-86) as given in this paper? | **RST.11-12.4**<br>**SP2**<br>**EK1.E.2**<br>**VC2** |
| 2. How are seismic waves used to determine the structure of Earth's interior? | **ESS2.A**<br>**Scale, proportion, and quantity**<br>**RST.11-12.9**<br>**SP6**<br>**VC1**<br>**NS4** |
| 3. Suppose a sample of a diamond fluid inclusion contains a fixed amount of rubidium-87, strontium-86, and strontium-87. Among these three, which isotopes will change? Explain why. | **ESS2.B**<br>**Stability and change**<br>**SP2**<br>**EK1.E.2**<br>**VC1** |
| 4. Why is it important to do a baseline correction on a spectrum? | **SEP4**<br>**Stability and change**<br>**RST.11-12.6**<br>**SP5**<br>**VC2** |

# ACTIVITIES FOR INTERACTIVE ENGAGEMENT

| | LEARNING STANDARDS |
|---|---|
| **Writing an abstract**<br><br>Students write a new abstract for the article at a grade-appropriate reading level. | **ESS2.A**<br>**RST.11-12.2**<br>**SP6** |
| **Locating this study in the larger field**<br><br>Students use the annotated list of references to explain how this research builds on the published work of at least one other independent group of scientists. Students will evaluate whether data from this research supports or contradicts previous conclusions, and reflect on the statement that scientific knowledge is a "community effort." | **RST.11-12.8**<br>**VC1**<br>**NS4** |
| **Science in the news**<br><br>Students explore news stories in the Related Resources tab and evaluate the stories for tone, accuracy, missing information, etc. They may then write their own news stories on the article. | **RST.11-12.5**<br>**RST.11-12.6**<br>**RST.11-12.8**<br>**NS4** |
| **Radioisotopes**<br><br>Make a list of radioactive and non-radioactive isotopes by referring to the trace metals featured in Fig. 4 of this research article. Are any of the elements connected via radioactive decay (e.g. Rb-87, Sr-87)? If so, how? | **SEP4**<br>**ESS2.B**<br>**Stability and change**<br>**SP5**<br>**EK1.E.2** |
| **Results and conclusions**<br><br>Students diagram each of the experiments presented in the study (divided up by figure, if appropriate). They then consider the results depicted in each figure, and how these results support the conclusions of the study. | **SEP4**<br>**Scale, proportion, and quantity**<br>**SP5**<br>**EK1.E.2**<br>**VC2**<br>**NS2** |
| **The next steps**<br><br>Students design a follow-on experiment to this study that either addresses flaws or unanswered questions in the research at hand, or builds on it to explore a new question. | **SP4**<br>**NS4** |

# ARTICLE OVERVIEW

**Article summary (recommended for educator use only)**

The isotope compositions of basalts buried deep underneath Earth's surface reveal crucial information about the chemical structure of our planet. However, much of this information is lost due to damages inflected on the basalts as they push upward towards the surface of Earth. Therefore, it has been challenging for scientists to measure the isotope composition of the mantle below depths of a few hundred kilometers. The research by Timmerman *et al*. shows how fluid trapped in diamonds can provide insights into the existence of intact chemical reservoirs inside Earth, whose existence was not known earlier. The research team probed 24 superdeep diamonds from 410 to 660 kilometers under Earth's surface in Brazil. On analysis of helium gases emitted from the fluid inclusions in the diamonds, Timmerman *et al.* have detected elevated concentrations of helium-3, which confirms the existence of rocks that remained undisturbed for billions of years.

**Importance of this research**

The researchers performed this study to confirm the existence and chemical composition of undisturbed reservoirs present in Earth's interior. Past studies by Class and Goldstein (*Nature*, 2005) and Jackson *et al.* (*Nature*, 2017) have demonstrated helium isotope rations measured from the hottest regions on Earth's surface can provide evidence for primordial chemical reservoirs buried deep inside the planet. This study is a promising attempt toward pinpointing the exact location and chemical composition of these chemical reservoirs.

**Experimental methods**

- Sampling of material from diamonds using technique called laser ablation
  - Laser ablation is a process in which a laser beam is focused on a sample surface (in this case, a piece of rock) to remove material (in this case, small pieces of diamonds) from the irradiated zone.
- Measuring relative abundance of isotopes using mass spectrometry:
  - Mass spectrometry is an analytical tool which is used to measure mass-to-charge ratios of one or more chemical species present in the sample.

**Conclusions**

- Fluids trapped in the diamonds sampled by Timmerman *et al.* provide crucial information on Earth's geologic history that can be deciphered using isotopic signatures. The probed samples also helped to confirm the location of the chemical reservoirs, a technique that had not been done before.
- Timmerman *et al.* successfully analyzed the relative abundances of helium-3 and helium-4 using samples from the diamond fluid inclusions using the techniques of laser ablation and mass spectrometry.
- In order to ascertain the chemical content of the reservoir, the research team studied the isotopic concentrations of other chemicals, namely, lead, and strontium.

# LEARNING STANDARDS ALIGNMENT

The following tables provide an overview of the learning standards covered by this article, including the A Framework for K-12 Science Education (Framework), Common Core State Standards English Language Arts-Literacy (CCSS ELA), Common Core State Standards Statistics and Probability (CCSS HSS), AP Science Practices, and Vision and Change for Undergraduate Education. Where applicable, activities and information will be marked with specific standards to which they are linked.

| A Framework for K-12 Science Education | | |
|---|---|---|
| Science and Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts |
| **Analyzing and Interpreting Data (SEP4)**<br>Recognize patters in data that suggest relationships worth investigating further. Distinguish between causal and correlational relationships. | **ESS2.A: Earth Materials and Systems**<br>Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials towards the interior.<br><br>**ESS2.B: Plate Tectonics and Large-Scale System Interactions**<br>The radioactive decay of unstable isotopes continually generates new energy with Earth's crust and mantle providing the primary source of heat that drives mantle convection. | **Scale, proportion, and quantity**<br>In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.<br><br>**Stability and change**<br>For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study. |

<table>
<tr><th colspan="3">Common Core State Standards English Language Arts-Literacy</th></tr>
<tr><th>Key Ideas and Details</th><th>Craft and Structure</th><th>Integration of Knowledge and Ideas</th></tr>
<tr>
<td>RST.9-10.1<br>Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.<br><br>RST.9-10.2<br>Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.<br><br>RST.11-12.1<br>Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.<br><br>RST.11-12.2<br>Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.</td>
<td>RST.9-10.4<br>Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.<br><br>RST.9-10.5<br>Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).<br><br>RST.9-10.6<br>Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, defining the question the author seeks to address.<br><br>RST.11-12.4<br>Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.<br><br>RST.11-12.5<br>Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas.<br><br>RST.11-12.6<br>Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved.</td>
<td>RST.9-10.8<br>Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.<br><br>RST.9-10.9<br>Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.<br><br>RST.11-12.8<br>Evaluate the hypotheses, data, analyses, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.<br><br>RST.11-12.9<br>Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.</td>
</tr>
</table>

| AP Science Standards | |
|---|---|
| AP Science Practices | AP Chemistry Content Standards |
| **Science Practice 2 (SP2)**<br>The student can use mathematics appropriately.<br><br>**Science Practice 4 (SP4)**<br>The student can plan and implement data collection strategies in relation to a particular scientific question. (Note: Data can be collected from many different sources, e.g., investigations, scientific observations, the findings of others, historic reconstruction and/or archived data.)<br><br>**Science Practice 5 (SP5)**<br>The student can perform data analysis and evaluation of evidence.<br><br>**Science Practice 6 (SP6)**<br>The student can work with scientific explanations and theories. | **Essential knowledge 1.E.2 (EK1.E.2)**<br>Conservation of atoms makes it possible to compute the masses of substances involved in chemical and physical processes Chemical processes result in the formation of new substances, and the amount of these depends on the number and the types and masses of elements in the reactants, as well as the efficiency of the transformation. |

| Connections to the Nature of Science | |
|---|---|
| Vision and Change for Undergraduate Biology Education<br>Core Competencies and Disciplinary Practices | A Framework for K-12 Science Education<br>Understandings About the Nature of Science |
| **Ability to Apply the Process of Science (VC1)**<br>Science Is evidence based and grounded in the formal practices of observation, experimentation, and hypothesis testing.<br><br>**Ability to Use Quantitative Reasoning (VC2)**<br>Science relies on applications of quantitative analysis and mathematical reasoning. | **Scientific Knowledge is Based on Empirical Evidence (NS2)**<br>Science includes the process of coordinating patterns of evidence with current theory.<br><br>**Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena (NS4)**<br>A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed through observation and experiment, The science community validates each theory before it is accepted. If new evidence is discovered that a theory does not accommodate, the theory is generally modified in light of new evidence. |