Unraveling Earth's Early History — High School Sample Classroom Assessment

Introduction

Direct terrestrial evidence about the formation of Earth and its early history is rare on Earth itself, driving scientists look to evidence from other planetary bodies and extraterrestrial materials to help them build a more complete picture of Earth's early history. In this task, students plot and interpret the same observations and data used by scientists to create their own evidence-based narrative that chronicles the early history of Earth. Specifically, students plot and interpret radiometric age dates, tungsten isotope data and oxygen isotope data from surface samples and meteorites as well as surface lunar crater count data to build evidence for the occurrence and/or timing of planetary accretion, planetary cooling, Earth core formation, formation of the Moon and the end of the "heavy bombardment" period.

This task was developed using the data from several peer-reviewed scientific journal articles, the citations for which are listed at the end of this document.

Standards Bundle

(Standards completely highlighted in bold are fully assessed by the task; where all parts of the standard are not assessed by the task, bolding represents the parts assessed.)

CCSS-M

MP.2 **Reason abstractly and qualitatively.**

MP.4 **Model with mathematics.**

HSF.IF.9 **Compare properties of two functions each represented in a different way** (algebraically, **graphically,** numerically in tables, **or by verbal descriptions**).

HSF.LE.1 **Distinguish between situations that can be modeled with linear functions and with exponential functions.**

HSF.LE.5 **Interpret the parameters in a linear** or exponential **functions in terms of a context.**

HSS.ID.1 **Represent data with plots on the real number line (dot plots,** histograms, and boxplots).

HSS.ID.6 **Represent data on two quantitative variables on a scatter plot and describe how the variables are related.**

HSS.ID.6a **Fit a function to the data; use functions fitted to data to solve problems in the context of data.**

HSS.ID.6c **Fit a linear function for a scatter plot that suggests a linear association.**

HSS.ID.7 **Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of data.**

HSS.IC.6 **Evaluate reports based on data.**

NGSS

HS-ESS1-6 **Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.**

CCSS-ELA/Literacy

W.9-10.1 **Write arguments to support claims in an analysis of substantive topics** or texts, **using valid reasoning and relevant and sufficient evidence.**

WHST.9-10.1 **Write arguments focused on discipline-specific content.**

W.9-10.1.a & WHST.9-10.1.a

Introduce precise claim(s), distinguish the claim(s) from alternate or opposing claims, **and create an organization that establishes clear relationships among claim(s),** counterclaims, **reasons, and evidence.**

W.9-10.1.b **Develop claim(s)** and counterclaims **fairly, supplying evidence for** each while pointing out **the strengths and limitations** of both in a manner that anticipates the audience's knowledge level and concerns.

WHST.9-10.1.b **Develop claim(s)** and counterclaims **fairly, supplying data and evidence** for each **while pointing out the strengths and limitations of** both **claim(s)** and counterclaims **in a discipline-appropriate form** and in a manner that anticipates the audience's knowledge level and concerns.

W.9-10.1.c & WHST.9-10.1.c

Use words, phrases, and clauses to link the major sections of the text, create cohesion, and **clarify the relationships between claim(s) and reasons, between reasons and evidence,** and between claim(s) and counterclaims**.**

Information for Classroom Use

Connections to Instruction

This task can be used as a series of assessments within an instructional unit on early Earth history. Because the interpretation of the plots is essential for successful completion of the other task components, it is recommended that Task Components B, E, I and J serve as a formative assessment of math standards in a math/science blended course or as a summative assessment in a math course in an instructional unit on creating and interpreting plots where students ultimately have correct plots for the science-related arguments and explanations. Task Components B through J (and optional Task Component L) could each be used as formative assessments after the teacher covers different parts of early history within an instructional unit, with Task Component A and K serving as a summative assessment on the whole unit. Alternatively, the entire assessment task (Task components A–L) could be combined into one large summative assessment, provided that the students have completed instruction on all science and math content and principles addressed in the task components and detailed by the standards bundles.

This task could be tailored to lower levels of the grade band by providing the scatterplots to the students rather than expecting them to construct the scatterplots on their own, by altering the plotting parts in Task Component I and J, and/or by making all components formative tasks rather than summative. Some of these options are currently reflected in the task components detailed below, as examples of flexibility for different student populations.

In order to create an evidence-based narrative, the primary writing focus in this task is on the writing of argument to make, support, and evaluate claims in order to determine the best information to include in an evidence-based narrative. When making and supporting claims and/or reasoning from evidence in Task Components B, C, D, E, F, G, students can be formatively assessed on writing argument. In addition, students can be partially assessed on writing argument when they construct an explanation for why images are different in Task Component H and when they explain how subdivided data serve as better supporting evidence in Task Component J. Finally, by incorporating the claims, evidence and reasoning from the earlier task components to create an evidence-based narrative, students can be summatively assessed on writing argument in Task Component K.

This task has been aligned to the 9–10 grade band ELA/Literacy standards for writing argument. Teachers using this task in 11^{th} or 12^{th} grade should refer to the comparable CCSS for the 11–12 grade band.

Approximate Duration for the Task

The entire task could take 5–12 class periods (45–50 minutes each) spread out over the course of an instructional unit, with the divisions listed below:
Task Components A and K: 1–2 class periods each, depending on whether students will have the option of completing the narrative at home
Task Component B: 1–2 class periods, depending on whether developing the evidence-based claim is used or finished as homework
Task Components C and D: up to 1 class period each, depending on whether the explanation is used as homework
Task Components E, F, G, and H: up to 1 class period each, depending on whether the evidence-based evaluation of the claim is used or finished as homework
Task Components I and J: 1–2 class periods total
Optional Task Component L: 1–2 class periods, depending on whether the evidence-based evaluation of the claim is used or finished as homework.

Assumptions

- To do this task, teachers and students should have a basic knowledge of the principle events in the early history of the solar system and the planets and have a functional understanding of isotopes, meteorites and impact craters.
- This task assumes that the teacher(s) is completely familiar with the task components, understands the relationships in the data that should be used as evidence and has worked through the task components him/herself.
- This task builds on students' understanding of relative ages from middle school (e.g., NGSS MS-ESS1-4) and assumes that at the high school level students understand the difference between relative ages and absolute ages.
- For this task, students have a general knowledge of radiometric dating: that it is the technique used to calculate the absolute age of a rock using the half-life of radioactive isotopes and the measured ratio of daughter to parent isotopes in the rock. Specific knowledge of exactly how to calculate radiometric age dates for rocks is not a prerequisite for this task.
- The term "planetary surfaces" that is used in the performance expectation is a general reference to the surfaces of both planets and moons. It is not restricted to planets only.
- The term "planetary bodies" as used in this task is a general term that refers to the Moon, Mars, and Earth.

Assessment Task

Context

Direct terrestrial evidence about the formation of Earth and its early history is rare, leading scientists to look to evidence from other planetary bodies and extraterrestrial materials to help them build a more complete picture of the early solar system.

An important tool for understanding the early history of the solar system is the use of isotopic ratios, where the amount of different isotopes of an element in rocks or meteorites is compared. The ratio of isotopes of some elements is set once a planetary body is formed and does not change over time, creating an isotopic ratio that is unique to that planetary body. Conversely, the ratio of isotopes of other elements is set at the time the planet forms but then changes as the planet changes, such as when a planetary core forms or when the rocks melt and reform during igneous processes. The isotopes of some elements are radioactive and unstable; these isotopes break down to other isotopes of the same element or different elements at specific rates that can be used to measure the passage of time since a rock or mineral formed. Because we understand isotopic behaviors so well, we can use patterns we observe in isotopic ratios to determine the age of a rock from a planetary body, how a planetary body may have changed since its formation, and whether planetary bodies that are now separate were once part of a single, larger planetary body.

Scientists also compare other planetary bodies with Earth to find evidence for Earth's early history. If a feature is present on other planetary bodies in the solar system, then scientists can use that as evidence supporting the possibility of the same feature once being present on Earth's surface. For example, if craters are found on the surface of other planetary bodies in the inner solar system, then it is very likely that Earth also experienced cratering in its early history. Even differences between planetary bodies can be useful if those differences can be accounted for by such things as differences in the size of the planetary bodies or their location in the solar system.

In this task you will be interpreting the same observations and data used by scientists to create your own timeline and narrative that chronicles the early history of Earth.

Task Components

A. Using what you already know about Earth's early history, construct a basic timeline of Earth's history for the first billion years following the formation of the Solar System. Include on your timeline the following events:
   - Planetary Accretion
   - Planetary Cooling
   - Core Formation
   - Formation of the Moon
   - End of Heavy Bombardment

   Your timeline should have a consistent timescale throughout and include relevant information about the timing of events wherever possible. As you consider the different pieces of evidence in the next task components, adjust and/or label your timeline to account for this evidence.

B. Plot the radiometric ages of Earth and extraterrestrial materials on the dot plot provided (see Attachments 1 & 2). These ages were calculated using the half-life of radioactive isotopes and the measured amount of those isotopes present in actual rock samples. Earth and Moon samples were collected directly from the surface of the Earth and the Moon. Mars and chondrite samples were collected as meteorite rocks that fell to Earth. Earth, Moon, and Mars sample ages represent the time when those rocks formed on the planetary bodies. The oldest Moon and planet samples formed when the newly formed planetary bodies cooled off enough for rocks to crystallize. Chondrite samples represent small clusters of rock material that formed and accumulated in space during the formation and accretion of the planets in the Solar System. Use the data on your dot plot to make an evidence-based claim for how much time it took for planetary cooling to occur following the formation of the Solar System and planetary accretion. Based on your interpretation of the data, update and label your timeline from task component A. If task component A was not completed, make a prediction of the ages of each planetary body using your data to justify your predication.

Alignment and Connections of Task Components to the Standards Bundle

Task Components A and K ask students to create a timeline and to use that timeline to create an evidence-based narrative for Earth's early history. These tasks together partially assess parts (individual bullets from Appendix F) of the NGSS practice of **Constructing Explanations and Designing Solutions** when students develop the narrative, parts of the NGSS disciplinary core ideas of **The History of Planet Earth (ESS1.C as it relates to HS-ESS1-6)** and **Nuclear Processes (PS1.C, as it relates to HS-ESS1-6)** when citing and using the evidence developed in the task, and part of the crosscutting concept of **Stability and Change (as it relates to HS-ESS1-6)** when noting unique and continuing early Earth events/processes in their narrative. **Task Component K**, by asking students to use evidence from other task components to construct an evidence-based narrative, partially assesses ELA/Literacy standards **W.9-10.1, W.9-10.1.a, W.9-10.1.b, W.9-10.1.c, WHST.9-10.1**, **WHST.9-10.1.a**, **WHST.9-10.1.b**, and **WHST.9-10.1.c**, writing argument.

Task Component B asks students to plot radiometric age dates for Earth, Mars, Moon and chondrite samples. By creating and interpreting these dot plots, the students are partially assessed on the CCSS-M content standard **HS.S.ID.1** and part of the NGSS practice **Analyzing and Interpreting Data.** Because the students are interpreting radiometric ages of meteorites, students are partially assessed on parts of the secondary NGSS disciplinary core ideas of **Nuclear Processes (PS1.C, as it relates to HS-ESS1-6)** and **The History of Planet Earth (ESS1.C as it relates to HS-ESS1-6).** By using the dot plot as the basis for evidence to make and support their claim for how much time it took for planetary accretion and planetary cooling to occur, students are partially assessed on part of the NGSS practice of **Engaging in Argument from Evidence** and part of the NGSS crosscutting concept of **Stability and Change.** In this task component (and in Task Component D), the presentation of the radiometric ages in the dot plot aids in the interpretation of the data, while the plotting of the age dates provides a context for the use and usefulness of a dot plot. By asking students to make an evidence-based claim, this task component partially assesses ELA/Literacy standards **W.9-10.1, W.9-10.1.a, WHST.9-10.1**, and **WHST.9-10.1.a**, writing argument.

Attachment 1. Absolute Radiometric Ages Data Chart

EARLY SOLAR SYSTEM MATERIAL			
Rock type	Age (my)	Error (+/-)	Isotopic Dating Method
Chondrite Meteorite	4568.2	0.3	Pb-Pb
Chondrite Meteorite	4566	0.7	Pb-Pb
Chondrite Meteorite	4565.1	0.9	Pb-Pb
Chondrite Meteorite	4564	0.7	Pb-Pb
Chondrite Meteorite	4562.5	0.8	Pb-Pb
Chondrite Meteorite	4560.9	0.7	Pb-Pb
Chondrite Meteorite	4557.8	0.4	Pb-Pb
Chondrite Meteorite	4556	6	Pb-Pb
Chondrite Meteorite	4551.4	0.6	Pb-Pb
Chondrite Meteorite	4547.6	3.2	Pb-Pb
Chondrite Meteorite	4543.6	2.1	Pb-Pb
Chondrite Meteorite	4539.5	1	Pb-Pb
Chondrite Meteorite	4526.8	0.9	Pb-Pb
Chondrite Meteorite	4521.1	0.5	Pb-Pb
Chondrite Meteorite	4515.5	2.5	Pb-Pb
Chondrite Meteorite	4510.7	0.5	Pb-Pb
Chondrite Meteorite	4504.4	0.5	Pb-Pb

MOON			
Rock type	Age (my)	Error (+/-)	Isotopic Dating Method
Highlands Sample	4426	65	U-Pb
Highlands Sample	4339	5	U-Pb
Highlands Sample	4320	2	U-Pb
Highlands Sample	4245	75	U-Pb
Highlands Sample	4216	7	U-Pb
Highlands Sample	4141	5	U-Pb
Highlands Sample	3965	25	U-Pb
Mare Sample	3800	20	Ar-Ar
Mare Sample	3770	70	Ar-Ar
Mare Sample	3750	10	Rb-Sr
Mare Sample	3660	40	Ar-Ar
Mare Sample	3580	10	Ar-Ar
Mare Sample	3570	50	Ar-Ar
Mare Sample	3310	40	Ar-Ar
Mare Sample	3250	60	Ar-Ar
Mare Sample	3200	50	Sm-Nd
Mare Sample	3150	10	Ar-Ar
Mare Sample	3110	90	Ar-Ar

MARS			
Rock type	Age (my)	Error (+/-)	Dating Method
Mars Meteorite	4428	25	U-Pb
Mars Meteorite	4070	40	Ar -Ar
Mars Meteorite	4040	100	U-Pb
Mars Meteorite	3920	100	Ar -Ar
Mars Meteorite	1330	30	Ar -Ar
Mars Meteorite	1320	40	Ar -Ar
Mars Meteorite	1320	70	Ar -Ar
Mars Meteorite	327	12	Sm-Nd
Mars Meteorite	212	62	U-Pb
Mars Meteorite	178	3	Sm-Nd
Mars Meteorite	173	70	Sm-Nd

EARTH			
Rock type	Age (my)	Error (+/-)	Dating Method
Jack Hills-Australia	4404	68	Pb-Pb
Jack Hills-Australia	4363	8	Pb-Pb
Jack Hills-Australia	4355	4	Pb-Pb
Jack Hills-Australia	4341	6	Pb-Pb
Jack Hills-Australia	4276	6	Pb-Pb
Acasta-Canada	3939	31	Pb-Pb
Itasq-Greenland	3871	11	U-Pb
Nuvvuagittuq-Canada	3818	190	U-Pb
Itasq-Greenland	3809	7	U-Pb
Nuvvuagittuq-Canada	3751	10	U-Pb
Acasta-Canada	3737	23	Pb-Pb
Acasta-Canada	3665	34	Pb-Pb
Itasq-Greenland	3644	6	U-Pb
Itasq-Greenland	3606	8	U-Pb
Acasta-Canada	3581	56	Pb-Pb
Vaalbara-Africa	3416	5	U-Pb
Vaalbara-Africa	3334	3	U-Pb
Vaalbara-Africa	3298	3	U-Pb
Vaalbara-Africa	3074	6	U-Pb
Vaalbara-Africa	2871	30	Sm-Nd
Vaalbara-Africa	2860	20	Sm-Nd
Vaalbara-Africa	2765	8	U-Pb
Vaalbara-Africa	2714	8	U-Pb

Attachment 2. Absolute Radiometric Ages Dot Plot

Note: Teachers may choose to have their students design their own plots rather than be given the plot on this page.