Unraveling Earth's Early History — High School Sample Classroom Task
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 addressed by the task; where all parts of the standard are not addressed by the task, bolding represents the parts addressed..)

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.**

<u>CCSS-ELA/Literacy</u>

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 within an instructional unit on early Earth history and events to check for student understanding regarding the targeted science and math concepts included within the task. Because the interpretation of the plots is essential for successful completion of the other task components, it is recommended that students are given ample opportunity to develop their understanding of the plotting before creating the arguments and explanations included in the task. To support this, Task Components

B, E, I and J can serve as a check for understanding, or formative assessment, of math standards within an instructional unit on creating and interpreting plots in a math or math/science blended course. This will allow students to revisit plotting, and ultimately have accurate plots as well as an understanding of the benefits and limitations of the technique 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 check for understanding for the full unit. Alternatively, the entire task (Task components A–L) could be combined into one project, 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. Some of these options are currently reflected in the task components detailed below, as examples of flexibility for different student populations.

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, Task component K can serve as a check for understanding for writing arguments as well.

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

Note that this timeline only refers to the approximate time a student may spend engaging in the task components, and does not reflect any instructional time that may be interwoven with this task.

Assumptions

- To do this task, teachers and students should have a basic knowledge of the important events in the early history of the solar system, 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.

Materials Needed

All materials are provided. If the teacher decides to allow students to use a spreadsheet/plotting program or graphing calculators, then the students need to have access to such tools and know how to use them.

Supplementary Resources

- *Radiometric Dating of Early Solar System Materials:*
  www.psrd.hawaii.edu/Sept02/isotopicAges.html
  www.geology.wisc.edu/zircon/Earliest%20Piece/Earliest.html
  http://serc.carleton.edu/NAGTWorkshops/earlyearth/questions/zircons.html
  www.indiana.edu/~geol105b/images/gaia_chapter_10/Early_Life.htm
- *Tungsten and Differentiation of the Moon:*

www.psrd.hawaii.edu/Nov03/Hf-W.html
www.universetoday.com/19599/age-of-the-moon/

- *Cratering Information:*

www.universetoday.com/99365/what-craters-on-the-Moon-can-teach-us-about-Earth/

Accommodations for Classroom Tasks

To accurately measure three dimensional learning of the NGSS along with CCSS for mathematics, modifications and/or accommodations should be provided during instruction and assessment for students with disabilities, English language learners, and students who are speakers of social or regional varieties of English that are generally referred to as “non-Standard” English.

Classroom 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.

C. Using what you know about radiometric age dating methods and the information in the half-life chart provided (Attachment 3), construct an argument for why scientists chose to use the isotopic systems listed in the data chart in Attachment 1 for dating these samples rather than other elemental isotopic systems, such as the carbon-nitrogen system.

D. The minerals contained in rocks from the Jack Hills site in Australia have the oldest radiometric ages found on Earth. As scientists become better able to determine how much of each radioactive isotope is present in a rock or mineral, they are finding evidence for older and older rocks. There was a time when scientists thought that the oldest rocks on Earth were less than 4 billion years old. Reconsider the dot plot that you made of the radiometric ages. This time cross out/disregard all ages from the Jack Hills samples. Create an evidence-based argument for how and why your interpretation of how long it took Earth to accrete and cool might be different if the Jack Hills samples were not present in your dot plot.

E. When the oxygen-18 data for all samples from one planetary body is plotted against the oxygen-17 data, the sample points should all roughly fall along a line that is unique to that planetary body. As a result, scientists can use oxygen isotopes to tell which planetary body a particular rock might have come from. Oxygen isotopes can also tell scientists how 'related' two planetary bodies are. For example, if oxygen isotopes from two separate planetary bodies fall on the same line with nearly the same slope and the same intercept, then they may have started out as one single object. If two planetary bodies have similar histories, such as both having been formed from the same originating planetary body, then the oxygen isotope best fit lines will also be similar in slope but not in the y-intercept. If two planetary bodies have very different oxygen isotope trendlines (different slopes and intercepts), then they likely have had very different histories since formation of the Solar System. Plot the oxygen isotope data (Oxygen-18 vs. Oxygen-17) from Earth and extraterrestrial materials on the scatter plot provided (Attachments 4 & 5). Use separate colors for (or specifically label) the different classes of samples: chondrite, Mars, Earth, and Moon. Draw a trendline (line of best fit) for each class of data and derive a linear equation that describes that trendline.

I. The impact hypothesis is the preferred explanation for how the Moon formed. Consider what the oxygen isotope trendlines (lines of best fit) tell you about the relationship between the

Earth and Moon, and use your observations to identify evidence to support an explanation that the Moon formed from Earth material following a collision with another small planetary body. Describe your reasoning, specifically addressing the slope and y-intercept of the line(s) of best fit, the units they represent and how the slope and y-intercept support the claim.

II. Use the data on the oxygen isotope scatter plot and the dot plot of the radiometric age dates to make an evidence-based claim for where on your timeline the formation of the Moon should be placed. Based on your interpretation of the data, update and label your timeline.

F. Compare the oxygen isotope scatter plot with the dot plot of the radiometric age dates. Consider how the data for the planetary bodies (Earth, Moon, and Mars) are similar to one another, and consider how they are different from the data for the chondrites. Use your observations and interpretations of the plots and reasoning to construct an argument for how the data support the claim that "the chondrites followed a different formation history from the planetary bodies". Use the range and cluster of ages of rock material from the dot plot, and the slope values of the trendlines (lines of best fit) from the oxygen isotope scatter plot as evidence to support your explanation.

G. Consider the provided plot of the tungsten isotope data from Earth and extraterrestrial materials (Attachments 6 & 7). Separate colors indicate the different classes of samples: chondrite, Mars, Earth, and Moon. Tungsten is a metal element that sinks into the center of the planetary body with iron when the core forms. The ratio of tungsten isotopes of newly formed rocks at the surface will be more positive (relative to the standard of the Earth) overtime as the core forms. A group of samples that record a range of tungsten ratio values were formed as the core was forming.

Scientists know that the Earth, the Moon, and Mars all have an iron-rich core at their center. Consider what the tungsten isotope data tell you about core formation on the different planetary bodies, and use your observations and interpretation of the data as evidence to support the claim that the impact that formed the Moon occurred after the Earth's core had already formed.

Based on the data and your reasoning, update and label your timeline.

H. Compare the image of the Earth showing the location of known impact sites (red dots on map in Attachment 9) and compare it with the image of the Moon (Attachment 8). Although the impact craters are not labeled on the image of the Moon, you can still easily see where the impact craters are located. Construct a causal explanation for why impact sites on the Earth are not as obvious as those on the Moon and why scientists must rely on other planetary bodies like the Moon for information about cratering early in the history of the Solar System. In your explanation, consider and describe at least two processes may have altered Earth samples and features to be different from extraterrestrial samples and features.

I. When scientists don't have actual samples from a planetary body, they cannot directly date the age of rocks from that body using radiometric age dating. Instead, they use crater density to estimate the age of any exposed surface. This method works by assuming that the oldest planetary surfaces will be exposed the longest and have the most craters per square kilometer whereas the younger surfaces will not be exposed as long and have fewer craters per square kilometer. As a result, surfaces with a greater crater density will be older than surfaces that have a lower crater density. To calibrate this method, scientists compared their "crater counting ages" from the different areas of the surface of the Moon to the radiometric ages of samples collected in those areas on Apollo Moon missions. Some of this data for the Moon is listed in the chart provided in Attachment 10. Using this data and the plot of the number of craters per square kilometer relative to the radiometric ages of rocks from those areas (Attachments 10 & 11), describe the mathematical relationship of the data. Identify which parts of the data set have the greatest deviation from the trendline that is provided.

J. If the rate of crater bombardment on a planetary body was constant over time (a constant cratering rate), then the relationship between the age of the surface and the crater density would be linear, with one single trendline (line of best fit) for the entire history of the Solar System. If the rate of cratering was changing over time, then the data would not be linear. Scientists have determined from lunar data and similar cratering data from other planets that the rate of cratering was much higher in the past and changed significantly after a period of heavy bombardment approximately 3.8–3.9 billion years ago, with some amount of error. The data used to create the “crater density vs. age scatter plot” has been divided into subgroups using the 3.8–3.9 billion year window as a guide (Attachment 10). The trendlines (line of best fit) for each subset of the data is also shown (Attachment 12). (Note: teachers can also either simply provide the scatterplot without the trendlines, or have students continue working with and update the scatterplot and trendline from Attachment 11. For this option, direct students to identify and indicate the appropriate trendlines on the scatterplot).

Analyze the provided crater density data, and argue for how the subdivided data serves as better supporting evidence for the scientists' interpretation of the cratering rate than does the undivided dataset and trendline. In your analysis, consider what mathematical relationship(s) best characterizes each data subset, and how different representations allow for that to be visualized. Based on the data analysis and your argument, update and label your timeline.

K. Use the data plots and your understanding of the early history of the Solar System to construct an evidence-based narrative of your timeline that chronicles the formation and early history of Earth and that justifies the ages and order of events in early Earth history with evidence from the data. In your narrative, make note of which parts of the history of Earth are unique (things that are unlikely to happen again or are not going to happen again in the history of Earth) and which parts reflect processes that are still occurring today.

L. <u>*Additional Optional Task Component*</u>*: There are two types of areas on the surface of the Moon, the lunar mare and the lunar highlands. The lunar mare are the dark, less rugged,* *lower elevation areas of the lunar surface (see Attachment 8, whereas the highlands are the lighter, more rugged, higher elevation regions. Go back to the plots you created in the preceding task components and label the mare and highland Moon data samples wherever possible. Use the data, plots, and images as evidence to construct an argument for whether and how the data and observations support the claim "the mare regions are younger areas of igneous rock that formed later in the history of the Moon during core formation".*

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 address 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 addresses 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 can demonstrate their understanding on parts of 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 addressing 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 demonstrating their understanding of 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 addresses ELA/Literacy standards **W.9-10.1, W.9-10.1.a, WHST.9-10.1**, and **WHST.9-10.1.a**, writing argument.

Task Component C asks students to construct an argument for why scientists chose to use certain isotopic systems over others for finding radiometric age dates of materials formed early in the history of the solar system. This partially addresses part of the NGSS disciplinary core idea of **Nuclear**

Processes (PS1.C, as it relates to HS-ESS1-6) and part of the NGSS practice of **Engaging in Argument from Evidence.** Because the students must compare the radiometric data with the half-lives of a set of isotopic systems commonly used in age dating, the students also partially address part of the NGSS practice of **Analyzing and Interpreting Data** and part of the NGSS crosscutting concept of **Scale, Proportion, and Quantity.** By asking students to reason from evidence to construct an explanation, this task component partially addresses ELA/Literacy standards **W.9-10.1, W.9-10.1.a,**

WHST.9-10.1, and **WHST.9-10.1.a**, writing argument.

Task Component D asks students to re-evaluate the claim they made in Task Component B after removing the Jack Hills age dates. By constructing an evidence-based argument for how their original claim would change in the light of new data, students demonstrate the understanding on parts of the NGSS practices of **Analyzing and Interpreting Data** and **Engaging in Argument from Evidence.**

Because the students are interpreting radiometric ages of meteorites, students partially address 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 asking students to create an evidence-based argument, this task component partially addresses 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 E asks students to plot oxygen isotope data from Earth and extraterrestrial materials and to use these data as evidence for an explanation about the origin of the Moon and when determining the timing of Moon formation. By creating the scatterplots, determining trendlines (lines of best fit), and using the data distribution and trendlines (slope and intercept) as evidence to assess the claim, students partially demonstrate their understanding of the CCSS-M content standards of

HSS.ID.B.6, HSS.ID.6a, HSS.ID.6c, HSS.ID.7 and **HSS.IC.6;** the CCSS-M practices of **MP.2** and **MP.4;** parts of the NGSS practices of **Analyzing and Interpreting Data, Constructing Explanations and Designing Solutions,** and **Using Mathematics and Computational Thinking;** and parts of the NGSS crosscutting concept of **Patterns.** By specifically evaluating the claim about the formation of the Moon using evidence from meteorites and lunar samples, students partially demonstrate their understanding of part of the NGSS disciplinary core idea of **The History of Planet Earth (ESS1.C as**

it relates to HS-ESS1-6) and part of the crosscutting concept of **Stability and Change (as it relates to HSS-ESS1-6).** In this task component (and Task Component F), the plotting and mathematical modeling of the data via the trendlines provide evidence essential for the evaluation of the claim and for a deeper understanding of the formation of the Moon, while the data provide a context for how slope and intercept values of trendlines can be important tools for data interpretation. By asking students to use evidence to construct an explanation for how data support a claim as well as to make a claim, this task component partially addresses 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 F asks students to describe how the scatterplots and trendlines (lines of best fit) of oxygen isotope data can be used to support the claim that the planetary bodies and chondrites followed different formation histories. This partially addresses the CCSS-M content standards of **HSS.ID.7** and **HSS.IC.6,** parts of the NGSS practices of **Analyzing and Interpreting Data, Engaging in Argument from Evidence,** and **Using Mathematics and Computational Thinking,** the CCSS-M practice of **MP.2,** and parts of the NGSS crosscutting concept of **Patterns.** By specifically constructing an explanation for how the data support an interpretation of the history of formation of extraterrestrial materials using two types of data, from meteorites and from Earth and lunar samples, including radiometric age data, students can demonstrate their understanding of parts of the NGSS practice of **Engaging in Argument from Evidence,** 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),** and the NGSS crosscutting concept of **Stability and Change (as it relates to HSS-ESS1-6).** By asking students to use evidence to construct an explanation for how data support a claim, this task component partially addresses 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 G asks students to use provided tungsten isotope data to evaluate a claim about the timing of Moon formation in Earth's history. By using the tungsten data as evidence, students addresses parts of the CCSS-M content standard of **HS.S.IC.6**, parts of the NGSS practice of **Analyzing and Interpreting Data,** and parts of the NGSS crosscutting concept of **Patterns**. By evaluating a claim for the timing of early earth events using data from meteorites and lunar samples, students are partially assessed on parts of the NGSS practice of **Engaging in Argument from Evidence,** parts of the NGSS disciplinary core idea of **The History of Planet Earth (ESS1.C as it relates to HS-ESS1-6),** and parts of the NGSS crosscutting concept of **Stability and Change (as it relates to HSS-ESS1-6).** By asking students to use evidence to construct an explanation for how data support a claim, this task component partially addresses 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 H asks students to compare impact sites on Earth and the Moon and to construct an explanation for why they are different. This partially addresses part of the NGSS practice of **Constructing Explanations and Designing Solutions,** part of the NGSS crosscutting concept **Cause and Effect,** and part of the NGSS disciplinary core idea of **The History of Planet Earth (ESS1.C via**

as it relates to HS-ESS1-6). By asking students use reasoning to construct an explanation for why images are different, this task component partially addresses ELA/Literacy standards **W.9-10.1, W.9-10.1.a, W.9-10.1.b, WHST.9-10.1**, **WHST.9-10.1.a**, and **WHST.9-10.1.b**, writing argument.

Task Components I and J ask students to plot crater density data against radiometric age data of lunar samples and then to mathematically describe the data on the scatterplot. By plotting the data, choosing a single trendline (line of best fit), evaluating the fit of the single trendline, dividing the data into subsets and determining which mathematical relationship best models the trendline (linear or exponential) given the scientific context, students can demonstrate their understanding of the CCSS-M content standards of **HSF.IF.9, HSF.LE.1, HSF.LF.5** and **HSS.ID.6a;** the CCSS-M practice of **MP.4;** part of the NGSS practices of **Analyzing and Interpreting Data** and **Using Mathematics and Computational Thinking;** and parts of the NGSS crosscutting concepts of **Patterns** and **Scale,**

Proportion, and Quantity. By constructing an explanation for how the divided data (including radiometric age dates of meteorites and lunar samples) are useful for the interpretation of cratering rate, students partially address part of the NGSS practice of **Engaging in Argument from Evidence,** 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),** part of the NGSS crosscutting concept of **Stability and Change (as it relates to HSS-ESS1-6),** and the CCSS-M practice of **MP.2.** In this task component, the change in the cratering rate, particularly around the end of heavy bombardment, is most apparent when plotted, so the interpretation of the data is essential for the evaluation of the scientific claim, while the scientific context of cratering provides a dataset with which students can demonstrate a deeper understanding of how to use plots to interpret data and how to model the mathematical relationships of the data. By asking students to use reasoning to determine the better supporting evidence in **Task Component J**, students can address ELA/Literacy standards **W.9-10.1,**

W.9-10.1.a, W.9-10.1.b, WHST.9-10.1, **WHST.9-10.1.a**, and **WHST.9-10.1.b**, writing argument.

Optional Task Component L *asks students to use the difference between mare and highland lunar samples in previous data plots as evidence to evaluate a given claim about the timing of the formation of these regions on the Moon. By interpreting the data plots, students can demonstrate their understanding of parts of the NGSS practices of* ***Analyzing and Interpreting Data*** *and part of the*

NGSS crosscutting concept of ***Patterns.*** *By using the data (including radiometric age data) as evidence to evaluate the claim, students are partially assessed on part of the NGSS practice of* ***Engaging in Argument from Evidence,*** *the CCSS-M content standard of* ***HSS.IC.6,*** *the CCSS-M practice of* ***MP.2,*** *part of the NGSS disciplinary core idea of* ***Nuclear Processes (PS1.C, as it relates to HS-ESS1-6),*** *and part of the NGSS crosscutting concept of* ***Stability and Change (as it relates to HS-ESS1-6).*** *By asking students to use evidence to construct an explanation for how data and observations support a claim,* *this task component 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.*

Together, **Task Components A, B, C, D, E, F, G, H, I, J and K** address the NGSS performance expectation of **HS-ESS1-6.** The task components address several parts of the core idea of **ESS1.C: The History of Planet Earth,** the secondary core idea of **PS1.C: Nuclear Processes** and the crosscutting concept of **Stability and Change** through the practice **Constructing Explanations and Designing Solutions, as they relate to HS-ESS1-6,** by having students develop a timeline for and construct a narrative of the early history of Earth using as evidence data collected from Earth and extraterrestrial materials, including radiometric age dates of samples, and by using scientific reasoning to interpret the meaning of the data and to determine relative timing relationships implied by the data. By using radiometric age dates for Earth and extraterrestrial material, by considering extraterrestrial materials for evidence of early events in Earth's history not preserved on Earth, and by using scientific reasoning to synthesize the evidence within a narrative of this early history, including an indication of whether the changes in Earth's early history represent unique events, students completing the task components are integrating the disciplinary core idea with the crosscutting concept and the practice.

Evidence Statements
Task Component A ● Students construct a timeline that is based on an appropriate linear scale from 4.6 to 3.6 billion years ago. ● The timeline contains the following events:

- Planetary Accretion
- Planetary Cooling
- Core Formation
- Formation of the Moon
- End of Heavy Bombardment

Task Component B

- Students represent the radiometric ages of chondrites, Mars, Earth and the on the dot plot.
- Students make a claim that includes the idea that it took around 100 million years (actual cited timespans will vary) for planetary accretion and cooling to occur following the formation of the solar system.
- In support of the claim, students cite data from the dot plot indicating that chondrites were

material left over from the process of planetary accretion (building blocks or debris from accretion) and reason that the age of the chondrites represents the timing of accretion.

- Students support the claim by citing the gap in age between youngest chondrite meteorites and the oldest rocks from the planetary bodies (Mars, Earth and the Moon), as viewed on the plot, as evidence for the age estimate.
- Students describe that the oldest rocks on the planetary bodies were the first rocks to form on a

cooling planet and reason that the age of these rocks represents the timing of the end of significant planetary cooling.

- Students update their timeline to reflect the formation of the solar system at approximately 4.6 billion years ago.
- Students update their timeline to reflect the range of time between accretion and cooling of the Earth to be between approximately 4.4 billion and 4.5 billion years ago.

- Students update their timeline to indicate that accretion occurred before cooling.

Task Component C

- Students make a claim that includes the idea that scientists chose to use one set of isotopic systems over another based on the ability of that system to date older rocks, such as those that were formed during the formation of solar system objects

- Students cite the following as evidence for their claim:
    - Based on a comparison of the charts, isotopic systems with longer half-lives are used to date rocks from the early history of the solar system, such as chrondites, older Mars, Earth, and Moon samples
    - Based on a comparison of the charts, isotopic systems with shorter half-lives are used to date younger rocks

- Students evaluate and describe how the evidence is relevant to supporting the claim. In their evaluation, students include the idea that the half-life length is directly related to how fast (the temporal scale on which) the original material transitions to the new material.
- In their argument, students relate the evidence and evaluation to support the claim by reasoning that:
    - A radiometric age date is a proportional age, calculated by comparing the measured

quantity (number) of the parent isotopes with the measured quantity (number) of the daughter isotopes.

- For an isotopic system with a very short half-life, there will not be enough (or any) parent material left over to measure and use to calculate the age of a very old rock.
- For an isotopic system with a very long half-life, there will not be enough daughter material produced to measure and use to calculate the age of a very young rock.

Task Component D

- Students make a claim that the interpretation of how long it took for Earth's accretion and cooling to occur would change from an estimate of approximately 100 million years to an estimate of nearly 600 million years (actual timespan estimates will vary).
- To support the claim, students describe the age gap between chondrite meteorites and the oldest

age of Earth samples (with and without the Jack Hills samples), as viewed on the plot, as evidence for the age estimate.

- Students evaluate the evidence by identifying and describing the relevance of the evidence to the claim, and sufficiency of the evidence for supporting the claim
- To support the claim, students relate the evidence and evaluation to the claim by reasoning that:
  - Without the Jack Hills samples, the dot plot demonstrates a larger age gap between

chondrite meteorites and the oldest age of Earth samples

- The larger gap indicates a greater amount of time between accretion and cooling.

Task Component E

- Students represent, identify and label the oxygen isotope data for chondrites, Mars, Earth and the Moon on the scatterplot.

- Students draw trendlines on the scatterplot that show an increasing liner relationship (with a positive slope) for the chondrite, Mars, Earth and Moon data.
- Students derive an equation that models each trendline (chondrite, Mars, Earth and the Moon) on the scatterplot.
- I. Based on observation and interpretation of the scatterplot, students identify and use the following patterns as evidence to support the explanation:

- The oxygen isotope data for Earth and the Moon would lie approximately along the same trendline
- The Earth and Moon trendlines are comparable and have approximately the same slope and y-intercept

- I. Students support the explanation by showing their reasoning, including that because the oxygen isotope data for Earth and the Moon would lie on approximately the same trendline (comparable slope and y-intercept), the Moon material and Earth material were likely once part of the same planetary body.

- II. Students make a claim that the formation of the Moon occurred at a time between approximately 4.4 billion and 4.6 billion years ago.
- II. Students support the claim by identifying and describing the following patterns in their plots as supporting evidence:

- Based on observations and interpretation of the scatterplot, the oxygen isotope data for Earth and the Moon would lie approximately along the same trendline
- Based on the dot plot, the oldest Earth and Moon samples have approximately the same age
- II. Students describe how the evidence supports the claim by reasoning that:
  - Because the oxygen isotope data for Earth and the Moon would lie on approximately

the same trendline (comparable slope and y-intercept), the Moon material and Earth material were likely once part of the same planetary body.

- Because the oldest Earth and Moon samples are approximately the same age, the impact event that formed the Moon likely occurred before the formation of the oldest Earth and Moon samples.
- The collision that formed the Moon likely occurred after the two colliding planetary

bodies accreted but before Earth cooled.

- Students update and label the timeline they began in task component A, now including and labeling the formation of the Moon at a point between approximately 4.4 billion and 4.6 billion years ago, after planetary accretion and before planetary cooling.

Task Component F

- Students construct an argument that supports the given claim that the chondrites followed a different formation history from the planetary bodies.
- Students identify and describe the following evidence for the given claim:
    - Based on the scatterplot of the oxygen isotope data, the Earth, Moon and Mars trendlines have approximately the same slope
    - Based on the scatterplot of the oxygen isotope data, the chondrites trendline has a

different slope from that of the Earth, Moon and Mars trendlines

- ○ Based on the dot plot, the oldest rocks in the data range for the Earth, Moon, and Mars have approximately the same age
- ○ Based on the dot plot, the chondrite ages have a range that does not overlap with and is much older than the age range of samples from the Earth, Moon, and Mars

- Students evaluate the evidence for its relevance to the claim and its sufficiency for supporting the claim.

- Students synthesize the relevant and sufficient evidence to construct an argument that:
    - The data support a common formation history for Earth, the Moon and Mars, because the slope of the trendlines for the oxygen isotope data of Earth, Moon and Mars rocks are approximately the same and because the age of the oldest rocks from these planetary bodies are approximately the same.

- The data indicate that chondrites followed a different history from the planetary bodies, because the slope of the trendline for the oxygen isotope data for chondrites is different from that of Earth, the Moon and Mars and because the age dates for the chondrites are much older than any rocks from the planetary bodies.

Task Component G

- Students identify the following patterns as evidence from the tungsten isotope plot to support the given claim:
    - The data from the Moon and Mars show a large range in tungsten isotope values that are more positive than the standard.
    - The data from the Earth cluster around zero and do not show a large range in tungsten

isotope values that are more positive than the standard.

- Students evaluate the evidence for its relevance to the claim and its sufficiency for supporting the claim
- In support of the claim, students synthesize the relevant and sufficient evidence with reasoning that:
  - The range in positive tungsten isotope values for Mars and the Moon represent

evidence of core formation in these planetary bodies.

- Although Earth did form a core at some point in the past, the cluster of tungsten isotope values indicate that the oldest surface rocks on Earth do not preserve evidence for the formation of the core.
- Because the Moon shows evidence of core formation but Earth does not, the evidence suggests that Earth's core formed before the impact event that formed the Moon.

- Students update their timeline to show that the formation of the core on Earth occurred after planetary accretion but before the formation of the Moon.

Task Component H

- Students construct an explanation that surface and tectonic processes operating on Earth are the cause for the lack or obfuscation of impact craters and samples that preserve evidence of

Earth's early history.

- Students identify and describe any two of the following as an example of the surface and tectonic processes:
    - destruction of rock during weathering and erosion
    - burial of rock by sediment during deposition
    - destruction of crust during subduction

    - changes in the rock during mountain building events
    - destruction of rock during crustal melting or volcanism
- In their explanation, students describe reasoning that other planetary bodies experienced the same or similar events in their early history as Earth, and because of that the early history of those other planetary bodies can be used as a proxy for Earth's early history.
- In their explanation, students identify samples and surface features from extraterrestrial bodies

as preserving evidence of events in the early history of the solar system, and describe reasoning that the surface and tectonic processes affecting Earth samples and features have not affected extraterrestrial samples and features.

Task Component I

- Students correctly represent lunar crater density and radiometric age data on the scatterplot.

- Students identify and indicate the mathematical relationship that best characterizes the entire dataset (linear, exponential, etc.), and students draw a single trendline that represents this relationship.
- Students identify the parts of the dataset that show the greatest deviation from the trendline.

Task Component J

- Students identify subgroups of the lunar craters density versus radiometric age data based on the table and scatterplot.
- Students identify and indicate the mathematical relationship that best characterizes each of the data subsets (linear, exponential, etc.), and draw a trendline for each dataset that represents this relationship, if trendlines were not already given.
- Students identify and describe the connection between the changing rate of cratering and the

number of trendlines needed to fully characterize the dataset, and include the following ideas:
  - The data are best represented by more than one trendline.
  - The trendlines that best fit the data are consistent with a change in cratering rate around 3.8 billion to 3.9 billion years ago, with room for error (3.5–3.9 billion years).
- Students make the claim that the subdivided data serves as better supporting evidence of the scientists' interpretation of the cratering rate than does the undivided dataset and trendline

- Students identify and describe the following evidence in support of their claim:
  - A subgroup of data has ages older than around 3.5 billion to 3.9 billion years and is best characterized by an exponential trendline.
  - A subgroup of data has ages younger than around 3.5 billion to 3.9 billion years and is characterized by a linear trendline.
  - The data do not show a good fit to the single trendline in the undivided dataset

- The parts of the plot where the data deviate the greatest from the single trendline represent data points with ages older than around 3.5 billion to 3.9 billion years.
- Students evaluate the evidence for relevance to and support of the claim
- Students describe the following reasoning for their argument:
    - The entire dataset does not fit either a single linear or a single exponential trendline, which is consistent with the scientists' interpretation of a changing rate of cratering.

- The deviation of the data from the single trendline at around 3.5 billion to 3.9 billion years ago and the division in the dataset at around 3.5 billion to 3.9 billion years ago to create subsets are consistent with the scientists' interpretation that there was major change in cratering rate around that time period.
- Students update their timeline to show the End of Heavy Bombardment to have occurred around 3.8 billion years ago and after planetary cooling.

Task Component K

- In their narrative, students identify and describe the following as important events in the early history of Earth and indicate the order of their occurrence (oldest to youngest) as follows:
    1. Formation of the Solar System
    2. Planetary Accretion

3. Core Formation
4. Formation of the Moon
5. Planetary Cooling
6. End of Heavy Bombardment

- In their narrative, students identify:
    - The formation of the solar system at around 4.6 billion years ago.

- Planetary accretion, core formation and Moon formation occurring between approximately 4.4 billion and 4.6 billion years ago.
    - Significant cooling of Earth by around 4.4 billion years ago.
    - The end of heavy bombardment by approximately 3.8 billion to 3.9 billion years ago.
- In their narrative, students describe that all of the listed events are unique changes that gave rise to relatively stable conditions afterward in the history of Earth.

- In their narrative, students identify and describe the following as evidence from ancient Earth and extraterrestrial materials:
    - radiometric ages of the oldest rock samples
    - the y-intercept and/or slope values of trendlines of oxygen isotope data
    - the range in tungsten isotope ratio data
    - the patterns of data of plotted lunar surface crater density versus sample age

- In their narrative, students describe their synthesis of the evidence, including:
    - The approximately 4.6 billion-year age of the oldest chondrite meteorites indicates the age of the solar system because these samples were formed during the first stages of accretion.
    - The approximately 4.0 billion-year age of the oldest Earth materials (as corroborated by the oldest age of samples from other planetary bodies) indicates the timing of

planetary cooling because the Earth must cool enough for rocks to form on the surface.
  - The similarities in oxygen isotope data (slope and y-intercept of the trendline) indicate that the Moon formed from Earth material, and the similarities in ages of the oldest Earth and Moon rocks indicate that the Moon formed before both of those planetary bodies cooled.
  - The small range in tungsten isotope data for Earth as compared with the wider, positive range in tungsten isotope data for Mars suggests that Moon formation occurred after Earth core formation because evidence for the formation of the core was not preserved on Earth and may have been destroyed during Moon formation.
  - The difference between the pattern of data before and after approximately 3.8 billion to 3.9 billion years ago on plots of lunar crater density versus rock age indicate a significant change in the rate of cratering around the end of heavy bombardment.

Optional Task Component L

- *Students identify and label the mare and highland Moon data samples*
- *Students include a statement that the evidence supports the part of the given claim that states "the mare regions are younger areas" and "formed…during core formation."*
- *In their argument, students identify and describe the following evidence:*
  - *Based on the image of the Moon, there is a greater crater density in the highland regions than in the mare regions*
  - *Based on the dot plot of radiometric age dates, samples from the mare regions have younger ages than the samples from the highland regions*
  - *Based on the tungsten isotope ratio plot, the mare rock data have a wide, positive range of tungsten isotope values*
- *Students evaluate the data available for relevance and sufficiency to support the claim, identifying that the evidence supports part of, but not the entire, given claim (e.g., there is no evidence of igneous rock)*
- *In their argument, students relate the evidence to the claim using the following reasoning:*
  - *A lower crater density in the mare regions than in the highlands regions indicates that the mare surface has not been exposed to cratering events for as long as the highlands regions have been, therefore indicating that the mare regions are younger than the highlands regions. This is consistent with the radiometric ages of the lunar samples.*
  - *The range in tungsten isotope values indicates that the core was forming while the mare rocks were forming*

Attachment 1. Absolute Radiometric Ages Data Chart

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

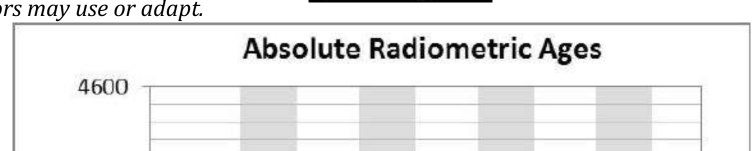
Highlands Sample	4245	75	U-Pb
Highlands Sample	4216	7	U-Pb
Highlands Sample	4141	5	U-Pb
Highlands Sample	3965	25	U-Pb
Mare Sample	3800	20	Ar-Ar
Mare Sample	3770	70	Ar-Ar
Mare Sample	3750	10	Rb-Sr
Mare Sample	3660	40	Ar-Ar
Mare Sample	3580	10	Ar-Ar
Mare Sample	3570	50	Ar-Ar
Mare Sample	3310	40	Ar-Ar
Mare 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

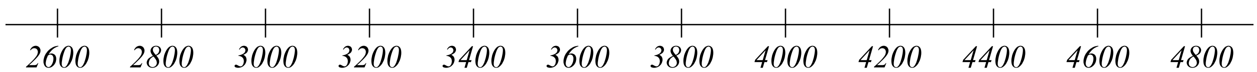
Note: Teachers may choose to have their students design their own plots rather than be given the plot on this page.



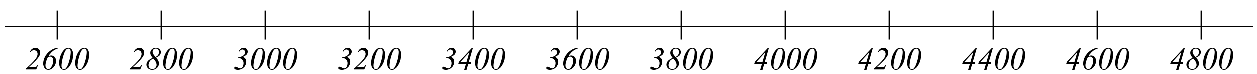
Alternative Dot Plot

Absolute Radiometric Ages (in millions of years)

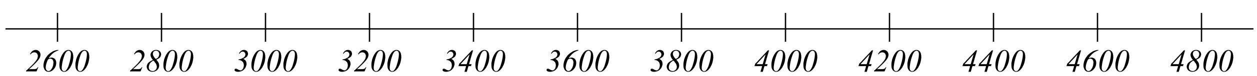
Chrondrites



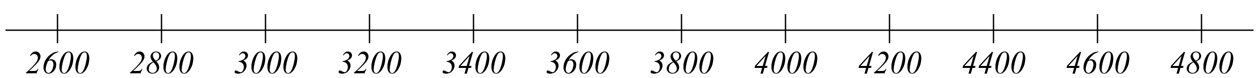
Mars



E***arth***



Moon



Attachment 3. Radiometric Dating Isotopic System Half-Life Chart

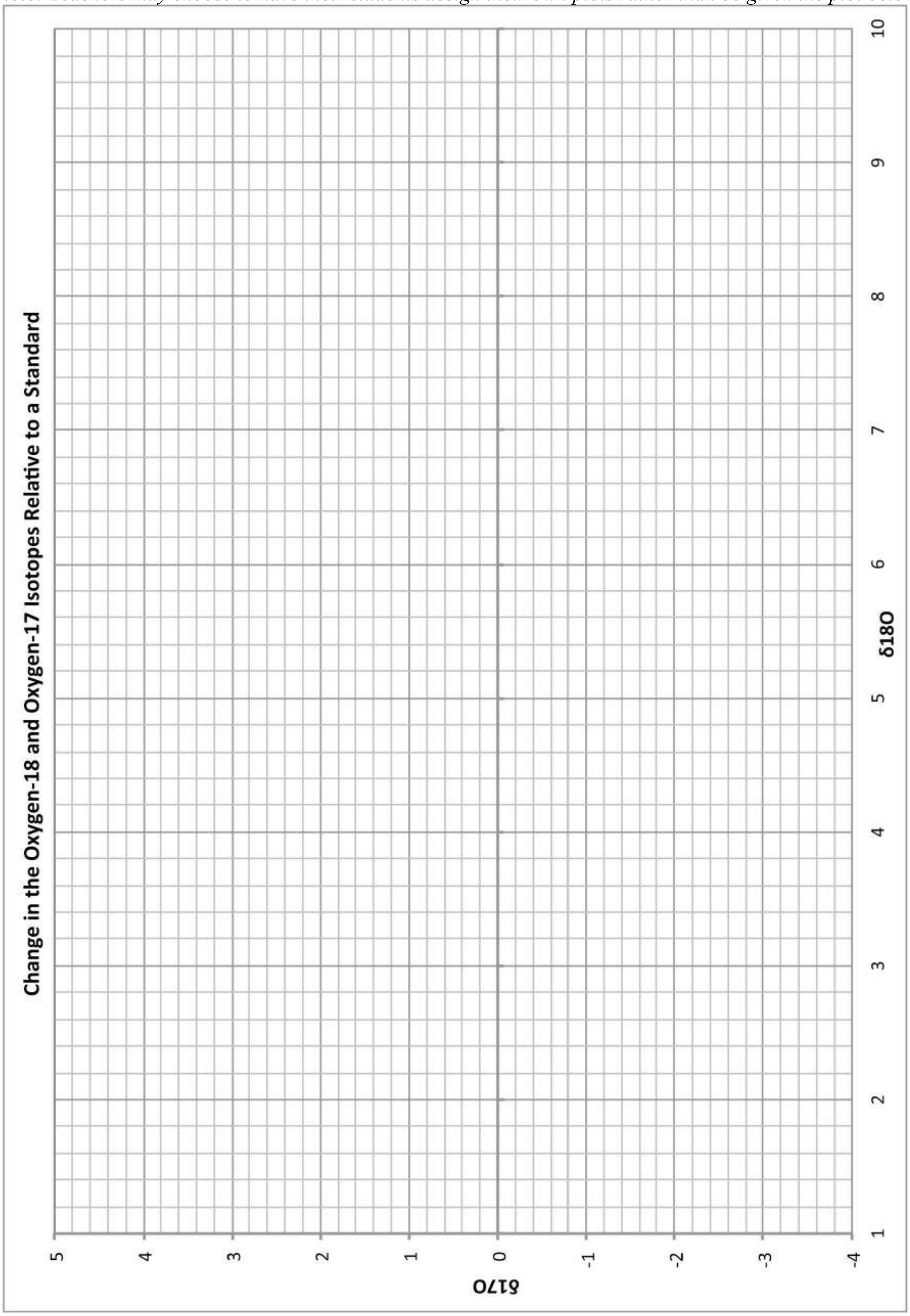
Radioactive Isotopic System	Half-life (billion years)
Sm-Nd	106
Rb-Sr	48.8
U-Pb	4.47
Ar-Ar	1.248
Be-B	0.00152
Cl-Ar	0.0003
C-N	0.00000573

Attachment 4. Oxygen Isotope Data Chart

Sample Material	δ18O	δ17O
Chondrite Meteorite	1.19	-3.61
Chondrite Meteorite	1.51	-2.73
Chondrite Meteorite	1.52	-2.56

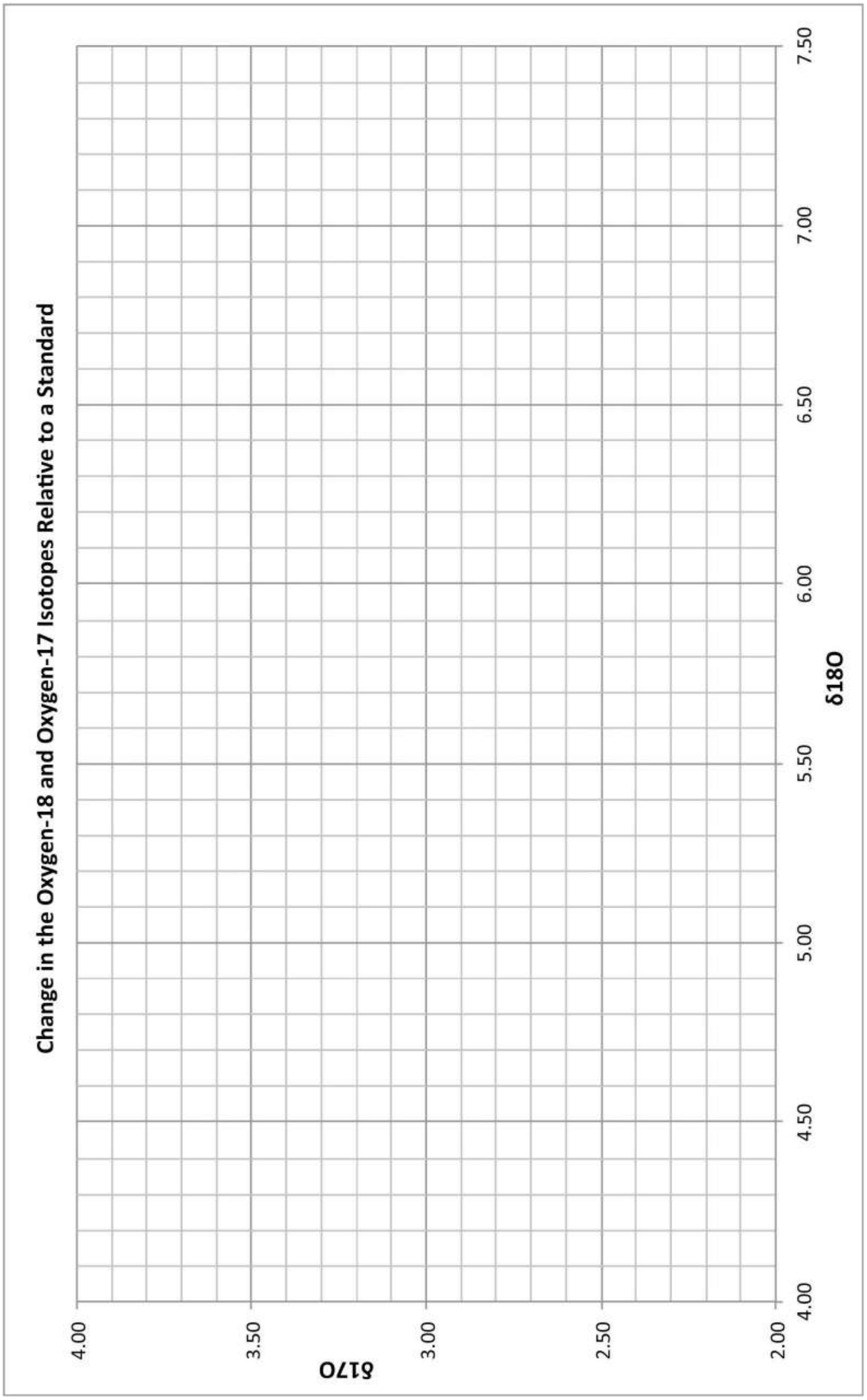
Attachment 5. Oxygen Isotope Scatterplots

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



Attachment 5 (continued). Oxygen Isotope Scatterplots (Earth-Mars-Moon closeup)

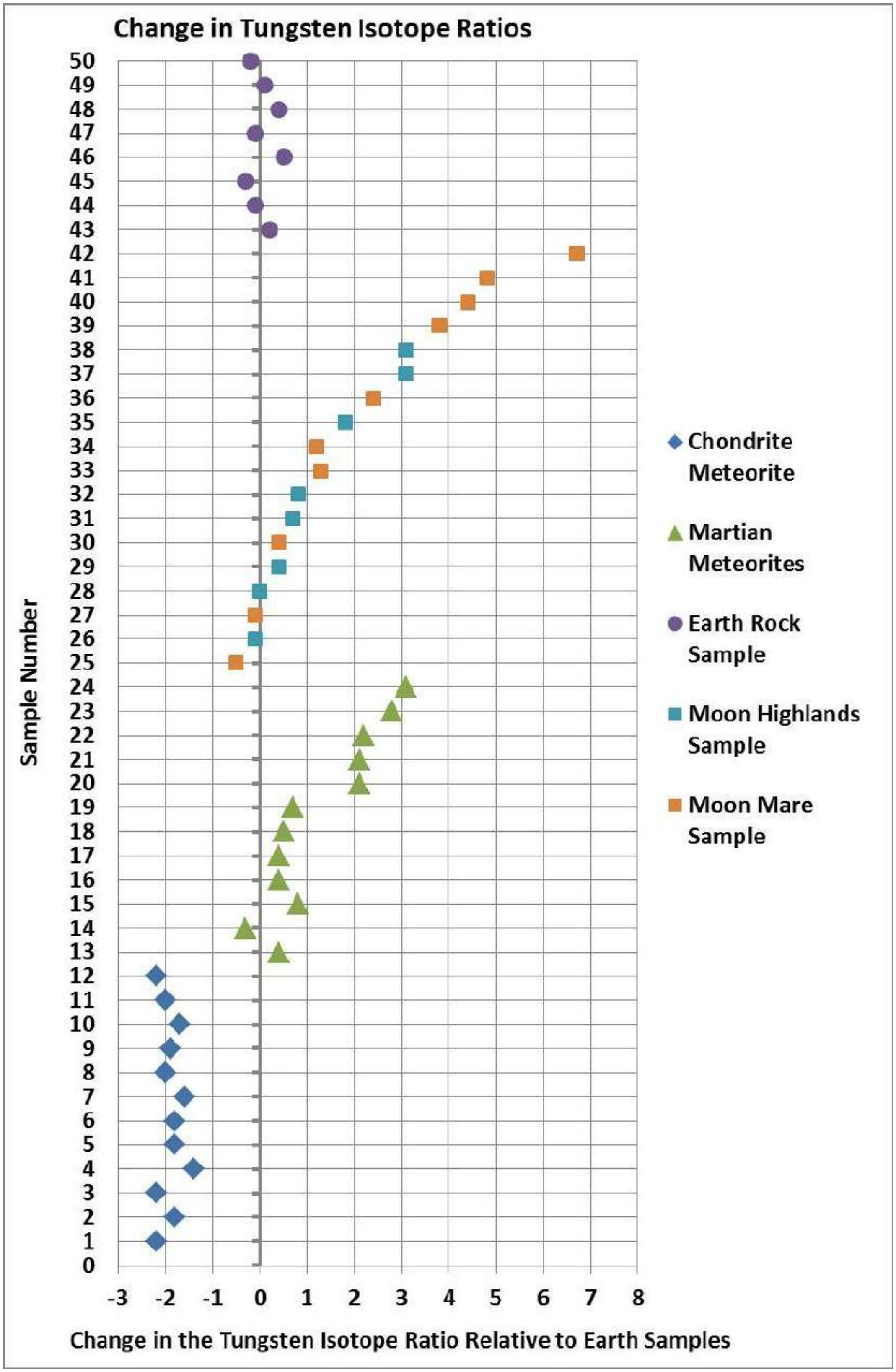
Note: Teachers may choose to have their students design their own plots rather than be given the plot below.



Attachment 6. Change in Tungsten Isotope Ratio Data Chart

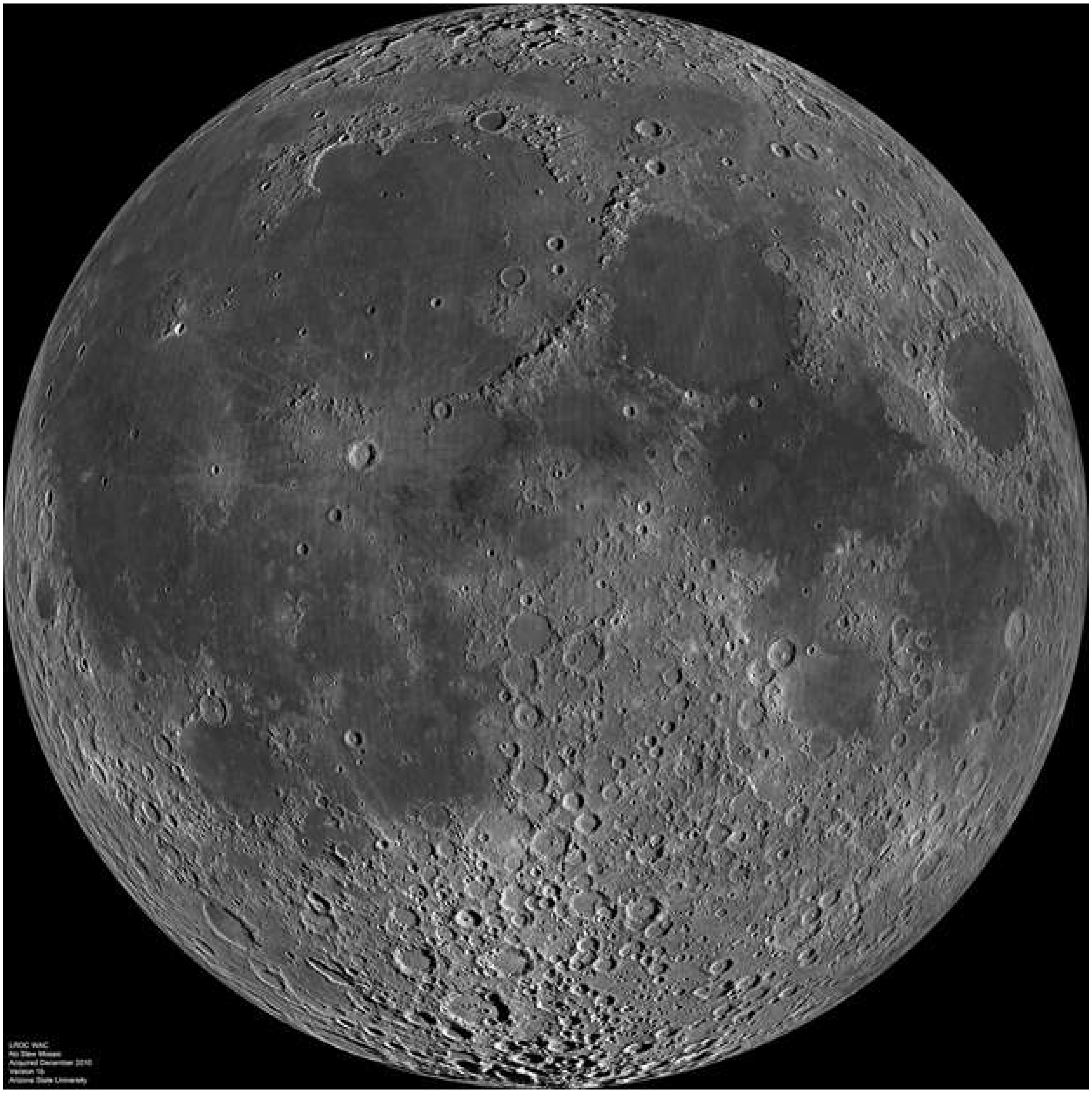
Sample #	Sample Source	Change in Tungsten Isotope Ratio Relative to Earth Samples	Error (+/-)

Attachment 7. Change in Tungsten Isotope Ratio Plot



Attachment 8. Image Showing the Lunar Nearside

The smooth dark areas are the lunar mare and the more rugged areas are the lunar highlands.



Source: http://lroc.sese.asu.edu/news/uploads/lroc_wac_nearside_noslew.png
Lunar Reconnaissance Orbiter image: http://lroc.sese.asu.edu/index.html
Last accessed: January 22, 2014

Attachment 9. Locations of Known Earth Impact Sites

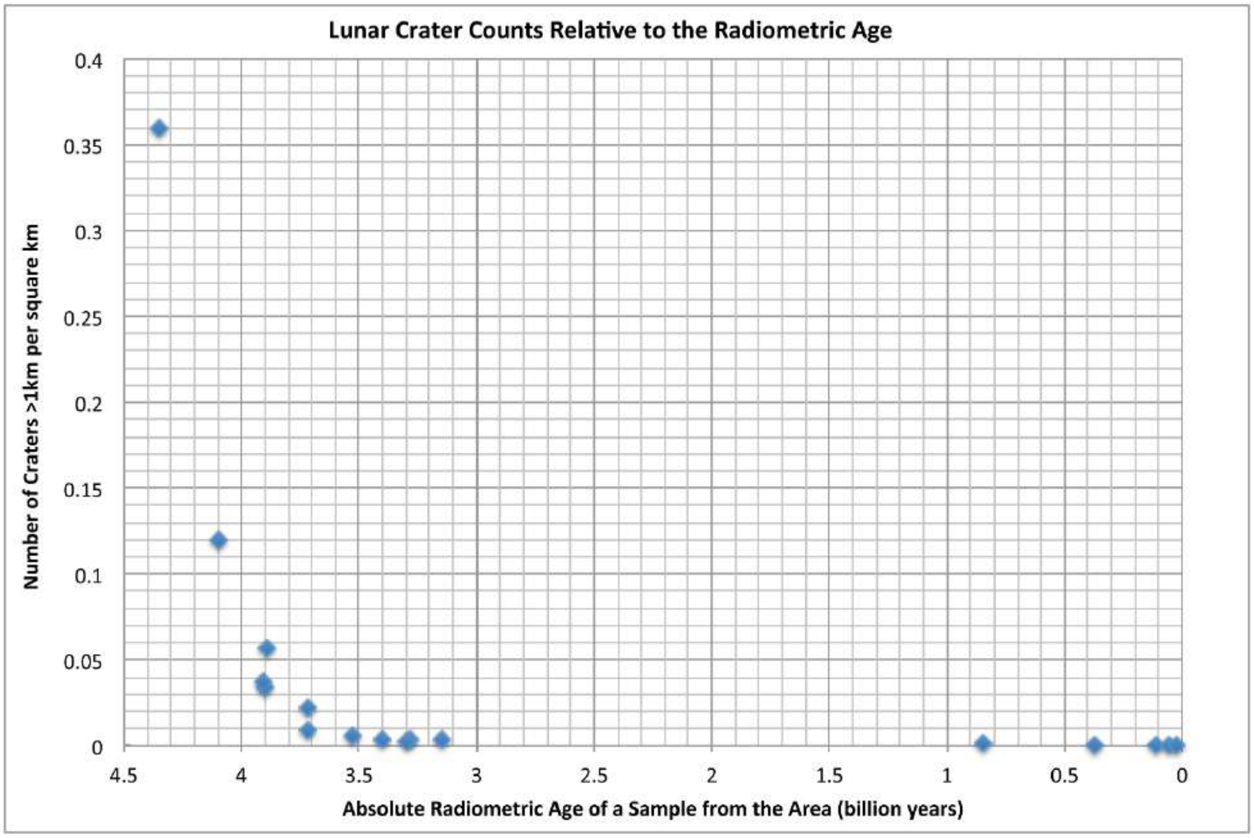
From Earth Impact Database, Planetary and Space Science Centre, University of New Brunswick
www.passc.net/EarthImpactDatabase/Worldmap.html
A higher-resolution version of this image (showing clearer topographic relationships) can be obtained by request through the following form:
www.passc.net/EarthImpactDatabase/maprequest.html
Last accessed: February 14, 2014

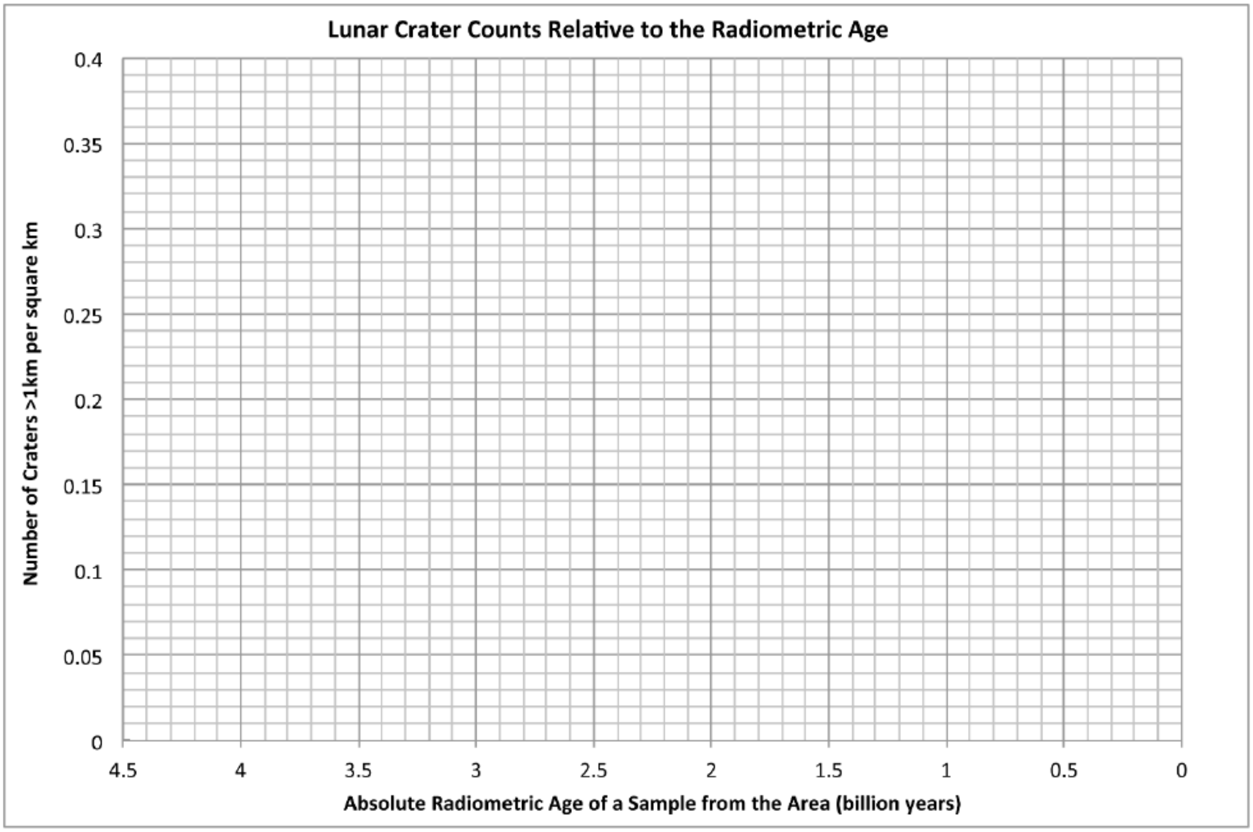
Attachment 10. Crater Number Versus Age of Lunar Sample Data Chart

Number of Craters with Diameter > 1km within a square kilometer	Absolute Radiometric Age of a Sample from the Area (billion years)
0.36	4.35
0.12	4.1
0.034	3.9
0.057	3.89
0.037	3.91
0.022	3.72
0.009	3.72
0.0064	3.53
0.0033	3.4
0.0032	3.28
0.003	3.3
0.0036	3.15
0.0013	0.85
0.00036	0.375
0.00009	0.109
0.000044	0.053
0.000021	0.026

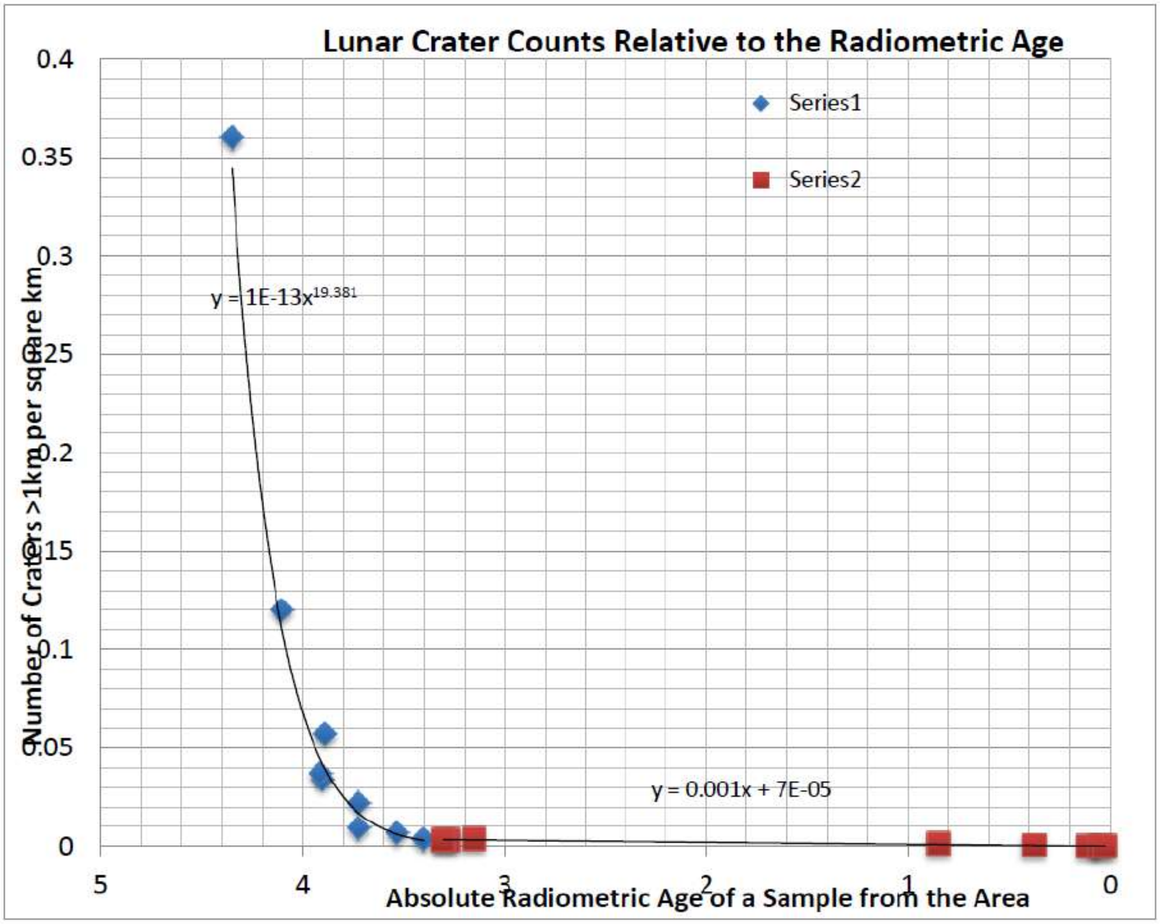
Attachment 11. Crater Number Versus Age of Lunar Sample Scatterplot

Note: Teachers may choose to have their students design their own plots rather than be given the sample plots found below.




Lunar Crater Counts Relative to the Radiometric Age
Number of Craters >1km per square km
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Absolute Radiometric Age of a Sample from the Area (billion years)

Attachment 12



Reference List for Data Included in This Task

Radiometric Age Dates

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Oxygen Isotopes

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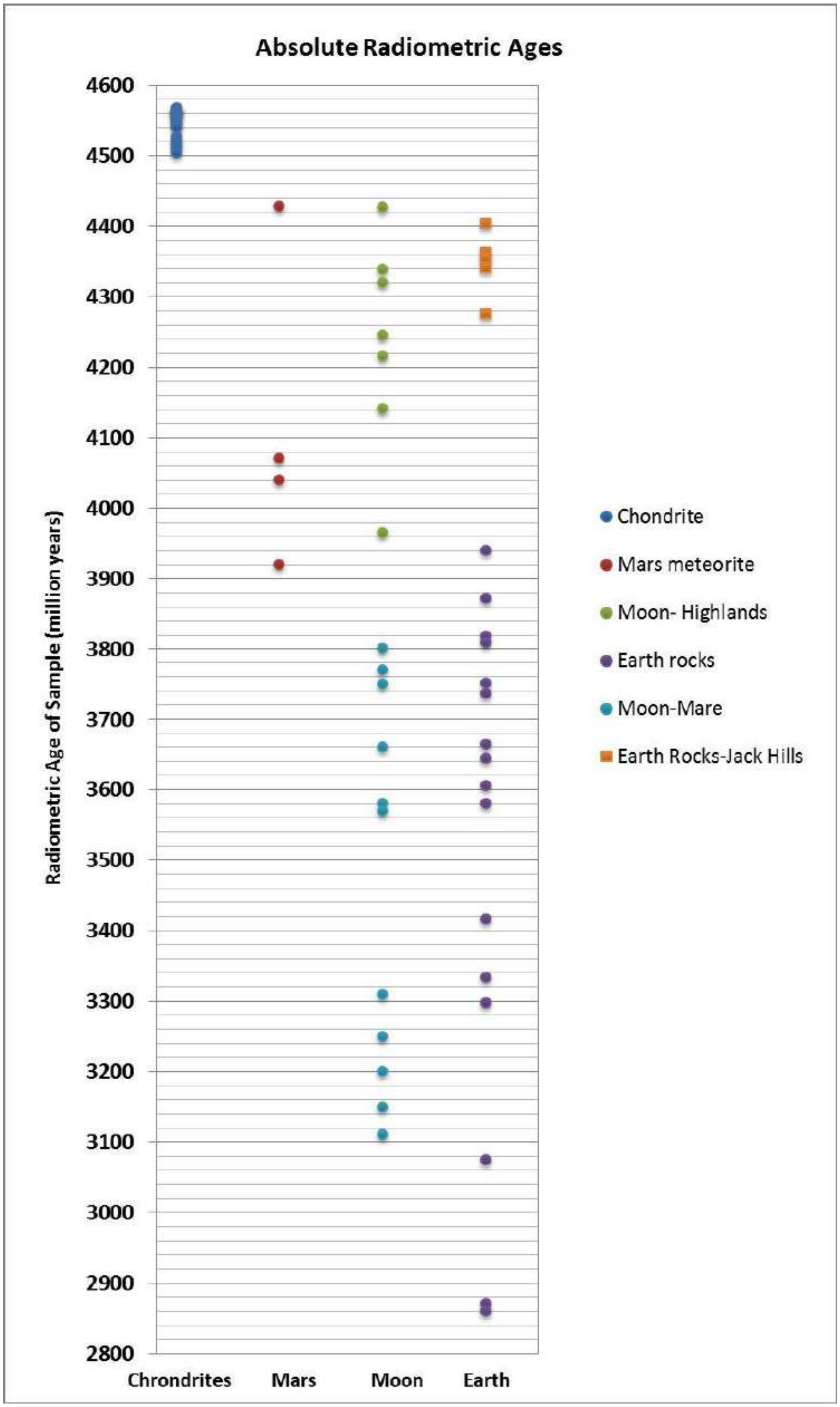
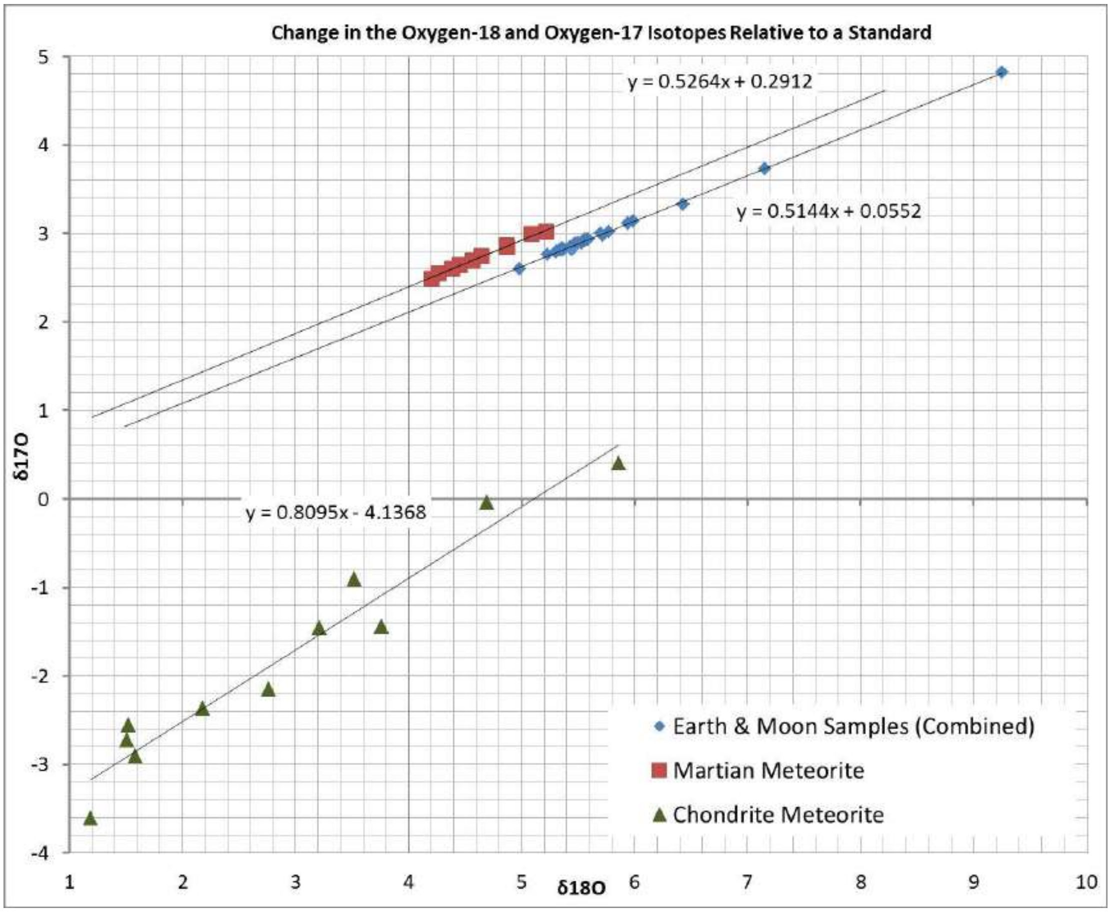
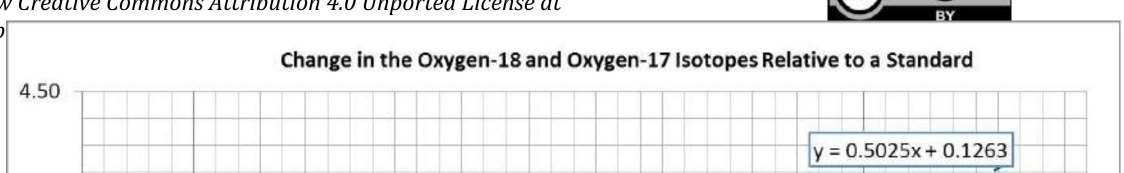
Crater Density Versus Ages

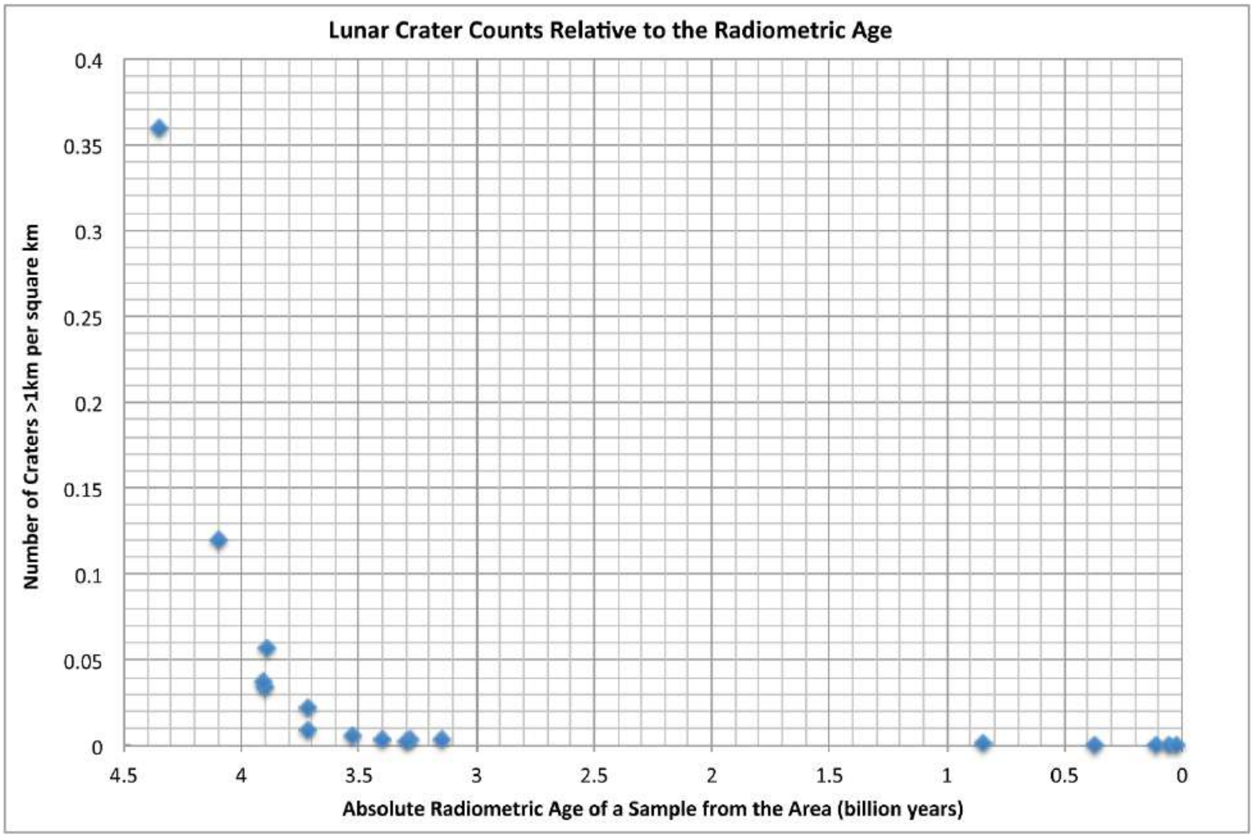
Stöffler, D., Ryder, G., Ivanov, B. A., Artemieva, N. A., Cintala, M. J., & Grieve, R. A. (2006). Cratering history and lunar chronology. *Reviews in Mineralogy and Geochemistry,* 60(1), 519–596.

Sample Answer Plots

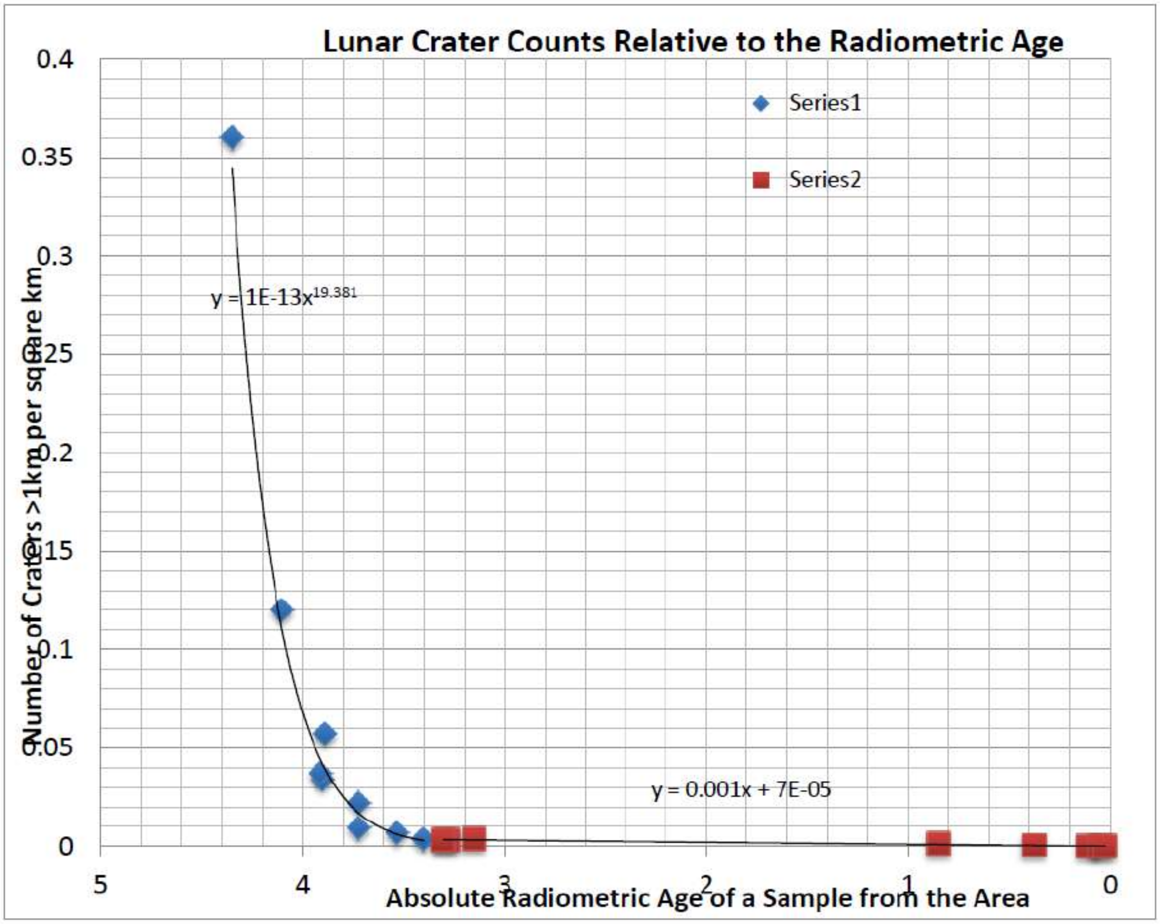



Change in the Oxygen-18 and Oxygen-17 Isotopes Relative to a Standard
y = 0.5264x + 0.2912
y = 0.5144x + 0.0552
y = 0.8095x - 4.1368
Earth & Moon Samples (Combined)
Martian Meteorite
Chondrite Meteorite
δ17O
δ18O
5
4
3
2
1
0
-1
-2
-3
-4
1
2
3
4
5
6
7
8
9
10


Change in the Oxygen-18 and Oxygen-17 Isotopes Relative to a Standard
4.50
y = 0.5025x + 0.1263



Lunar Crater Counts Relative to the Radiometric Age
Number of Craters >1km per square km
Absolute Radiometric Age of a Sample from the Area (billion years)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0


Lunar Crater Counts Relative to the Radiometric Age
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Series1
Series2
y = 1E-13x^19.381
y = 0.001x + 7E-05
Number of Craters >1km per square km
5
4
3
2
1
0
Absolute Radiometric Age of a Sample from the Area