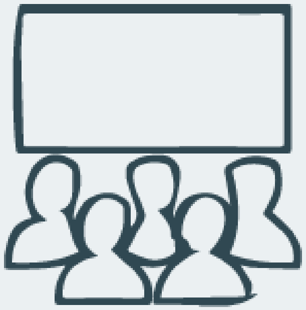
Slide A

# Navigate



## With your class

Radioactivity drives mantle convection deep inside Earth. But there is also naturally occurring radioactive material on Earth's surface, and humans use radioactive materials in technology.

Where else have you heard about radioactivity occurring naturally or being used?

Slide B

# Navigate

## Turn and Talk

In some regions, such as Afar, magma reaches the surface and cools, forming solid rocks.

Based on our ideas, would we expect to find evidence of radioactive materials in the rocks in Afar?

Slide C

# Navigate

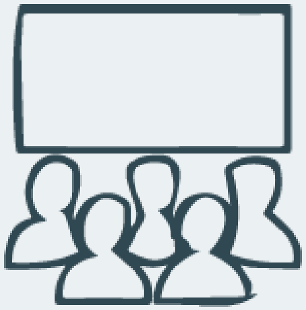
All rocks that contain radioactive elements undergo radioactive decay at a known rate, acting like a clock. By measuring the amount of radioactive elements in a rock sample, scientists can determine its age when it first solidified.

## On your own

How can comparing the amounts of radioactive materials in rocks help us reconstruct past processes that have shaped a place, and predict its future?

Slide D

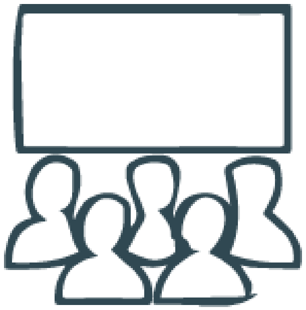
# Navigate



## With your class

What questions from our DQB involve reconstructing the past or predicting the future in Afar?

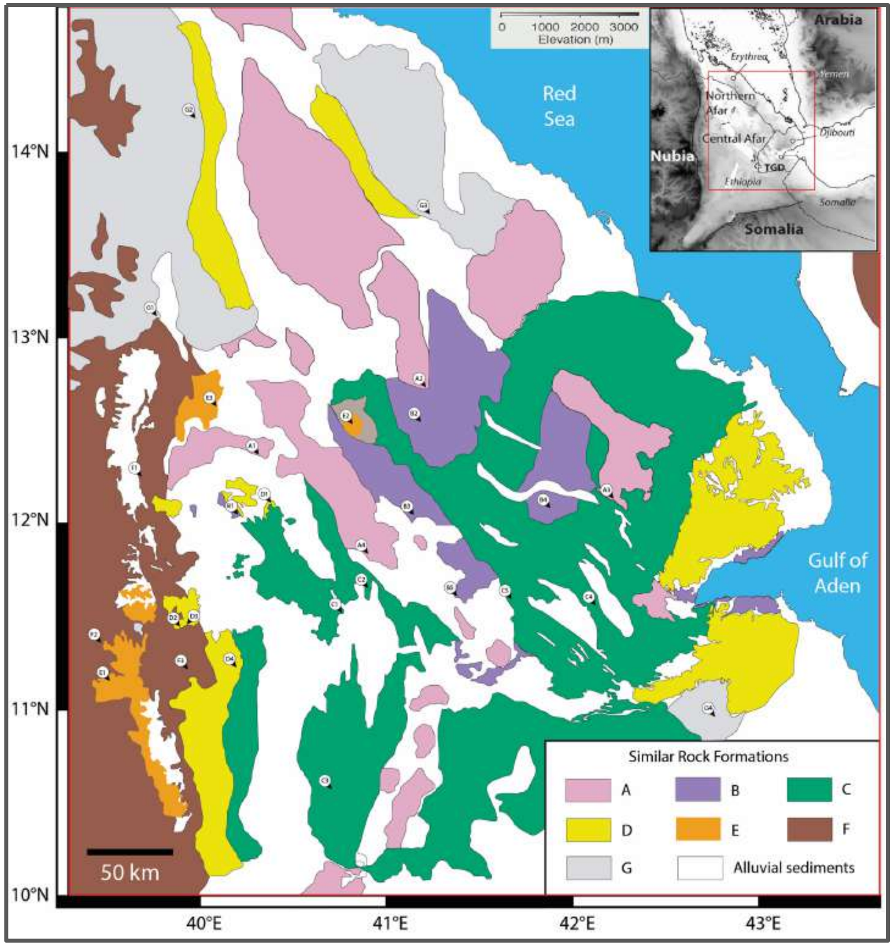
# Analyze and Interpret Data



## With your class

Orient to the Rock Sample Site Map.

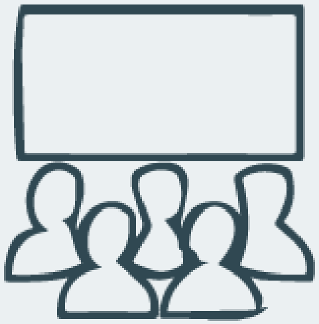
What do the colors indicate?




Based on Stab, M., et.al. (2015) *Modes of rifting in magma-rich settings: Tectono-magmatic evolution of Central Afar*. Tectonics.

Slide F

# Analyze and Interpret Data



**With your class**

What patterns do you notice in the data across these volcanic rock samples?

| | | Radioactive elements | |
|---|---|---|---|
| Sample | Site | K-40 (ppm) | U-238 (ppm) |
| AF12-02 | C1 | 11,670 | N/A |
| AF12-11 | D1 | 1260 | N/A |
| AF13-98 | D2 | 890 | N/A |
| AF13-102 | E1 | 5650 | N/A |
| AF12-15 | B1 | N/A | 163.5 |
| AF12-21 | D3 | N/A | 216 |

*ppm = parts per million*

Based on Stab, M., et.al. (2015) *Modes of rifting in magma-rich settings: Tectono-magmatic evolution of Central Afar*. Tectonics.

Slide G

# Periodic Table of Elements

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | H | | | | | | | | | | | | | | | | | He |
| 2 | Li | Be | | | | | | | | | | | B | C | N | O | F | Ne |
| 3 | Na | Mg | | | | | | | | | | | Al | Si | P | S | Cl | Ar |
| 4 | K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |
| 5 | Rb | Sr | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe |
| 6 | Cs | Ba | * | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn |
| 7 | Fr | Ra | ** | Rf | Db | Sg | Bh | Hs | Mt | Ds | Rg | Cn | Nh | Fl | Mc | Lv | Ts | Og |
| | | | * | La | Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Le |
| | | | ** | Ac | Th | Pa | U | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lr |

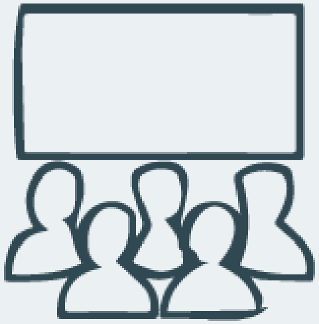
Metals
- Alkali metal
- Alkaline earth metal
- Lanthanide
- Actinide
- Transition
- Post-transition metal

Nonmetals
- Other nonmetals
- Halogens
- Noble gases

Other
- Metalloids

Rottoni

# Analyze and Interpret Data



**With your class**

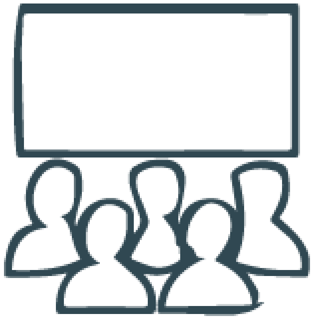
Why would there be different amounts of radioactive parent elements in different rock samples?

| | | Radioactive elements | |
|---|---|---|---|
| Sample | Site | K-40 (ppm) | U-238 (ppm) |
| AF12-02 | C1 | 11,670 | N/A |
| AF12-11 | D1 | 1260 | N/A |
| AF13-98 | D2 | 890 | N/A |
| AF13-102 | E1 | 5650 | N/A |
| AF12-15 | B1 | N/A | 163.5 |
| AF12-21 | D3 | N/A | 216 |

*ppm = parts per million*

Based on Stab, M., et.al. (2015) *Modes of rifting in magma-rich settings: Tectono-magmatic evolution of Central Afar*. Tectonics.

# Connect to Related Phenomena



## With your class

How many of you have found solid rocks with what look like tiny crystals of different colors and sizes in them?

Khruner

# Orient to Related Tools and Processes

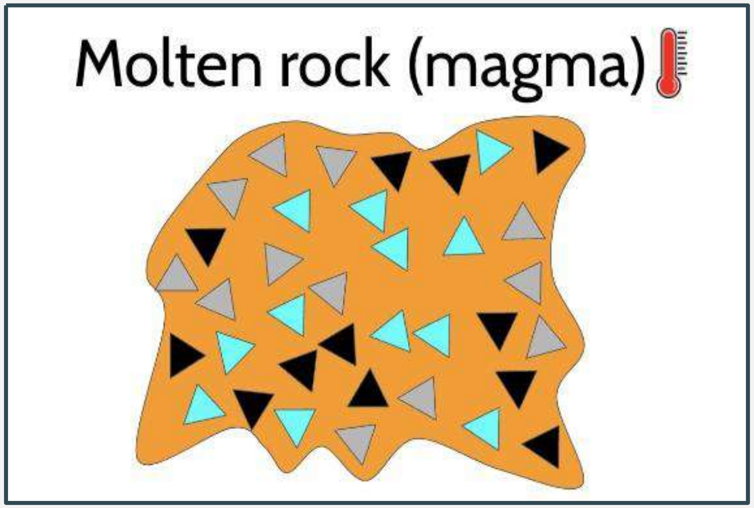
## On your own

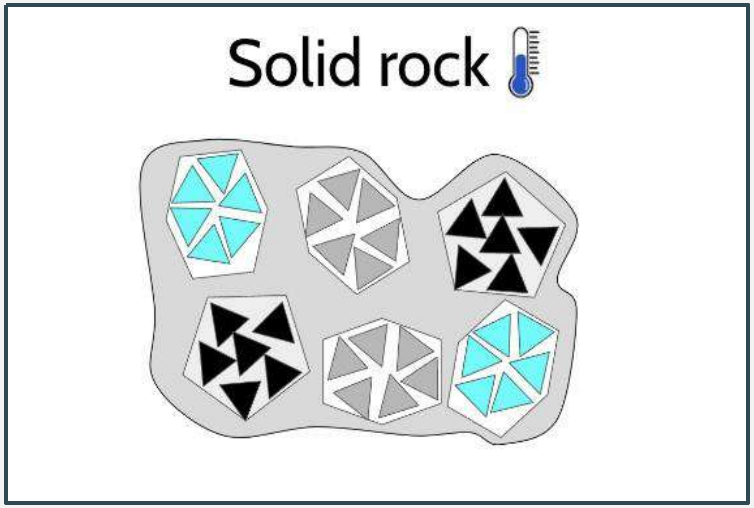
In your notebook, summarize the main ideas from the following 3 slides that can help to explain the patterns we identified in the presence of radioactive materials across the volcanic rock samples collected from Afar.

Slide K

# Rock Transformation Process

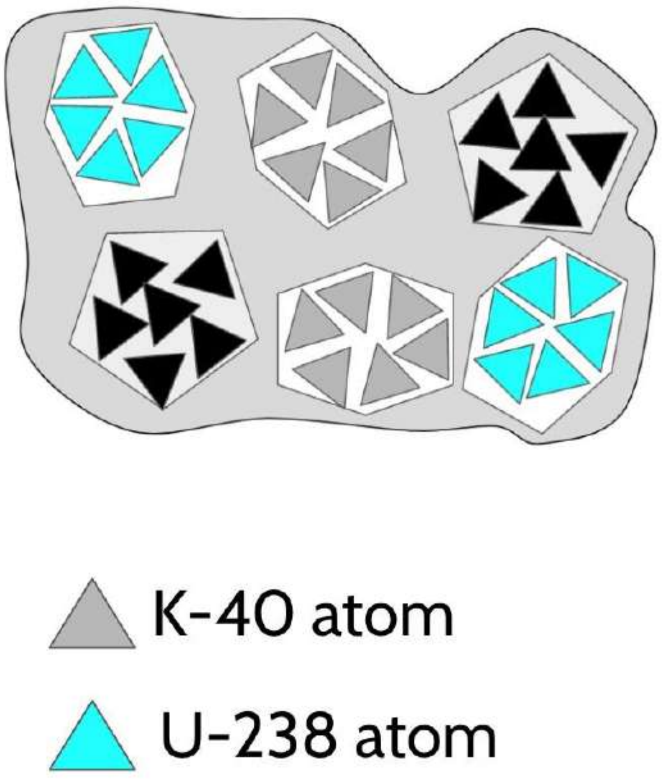
When molten rock, known as *magma*, rises from Earth's mantle and cools, it solidifies into rocks. During this process, different substances in the molten rock turn into crystals at different temperatures. These crystals have unique structures and give the rocks their shape and color.



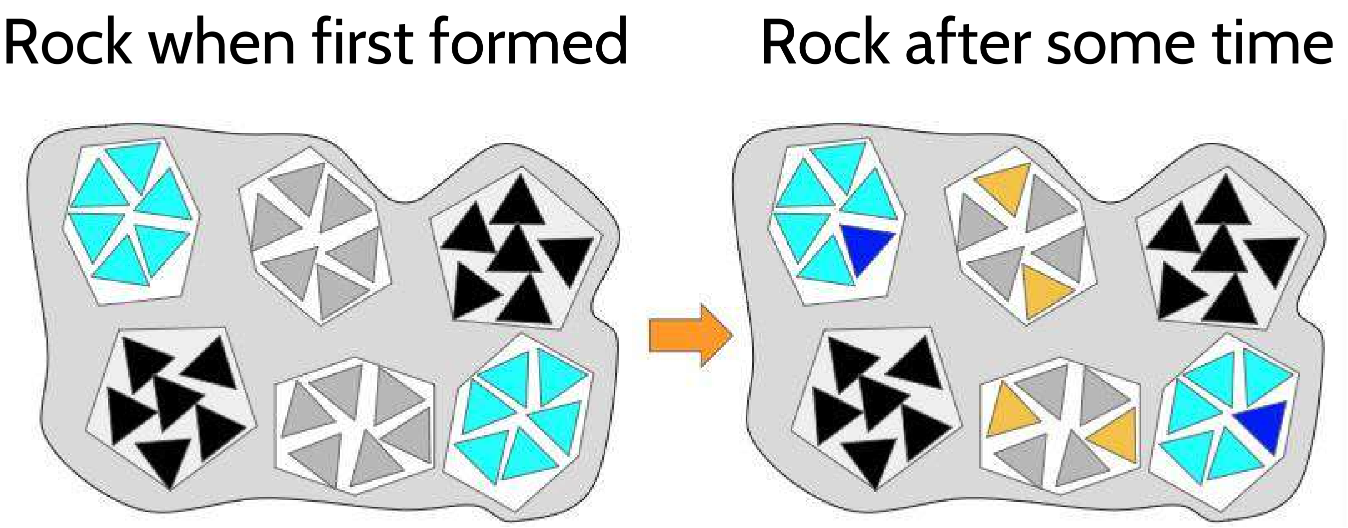
# Rock Transformation Process

Sometimes, rocks contain radioactive materials. When crystals form in these rocks, some of them have unique radioactive elements like K-40, U-238, or U-235. When these crystals have formed, they have only 1 type of radioactive atom in them. For example, a crystal might have K-40, or U-238, but never both.

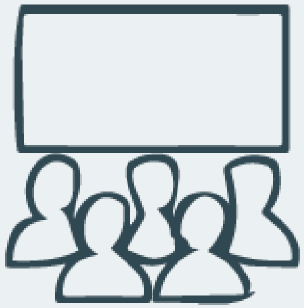


# Rock Transformation Process

These radioactive elements don't stay the same forever. Over time, they slowly change into different atoms through a process called *decay*. So, although the crystals start with only 1 type of radioactive atom, they change as time goes on, becoming other elements over time.



# Navigate

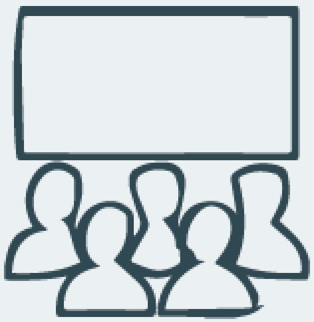


## With your class

How does the information in this reading help to explain some of the patterns we identified across the volcanic rock samples collected from Afar?

| | | Radioactive elements | |
|---|---|---|---|
| Sample | Site | K-40 (ppm) | U-238 (ppm) |
| AF12-02 | C1 | 11,670 | N/A |
| AF12-11 | D1 | 1260 | N/A |
| AF13-98 | D2 | 890 | N/A |
| AF13-102 | E1 | 5650 | N/A |
| AF12-15 | B1 | N/A | 163.5 |
| AF12-21 | D3 | N/A | 216 |

# Orient to Related Tools and Processes



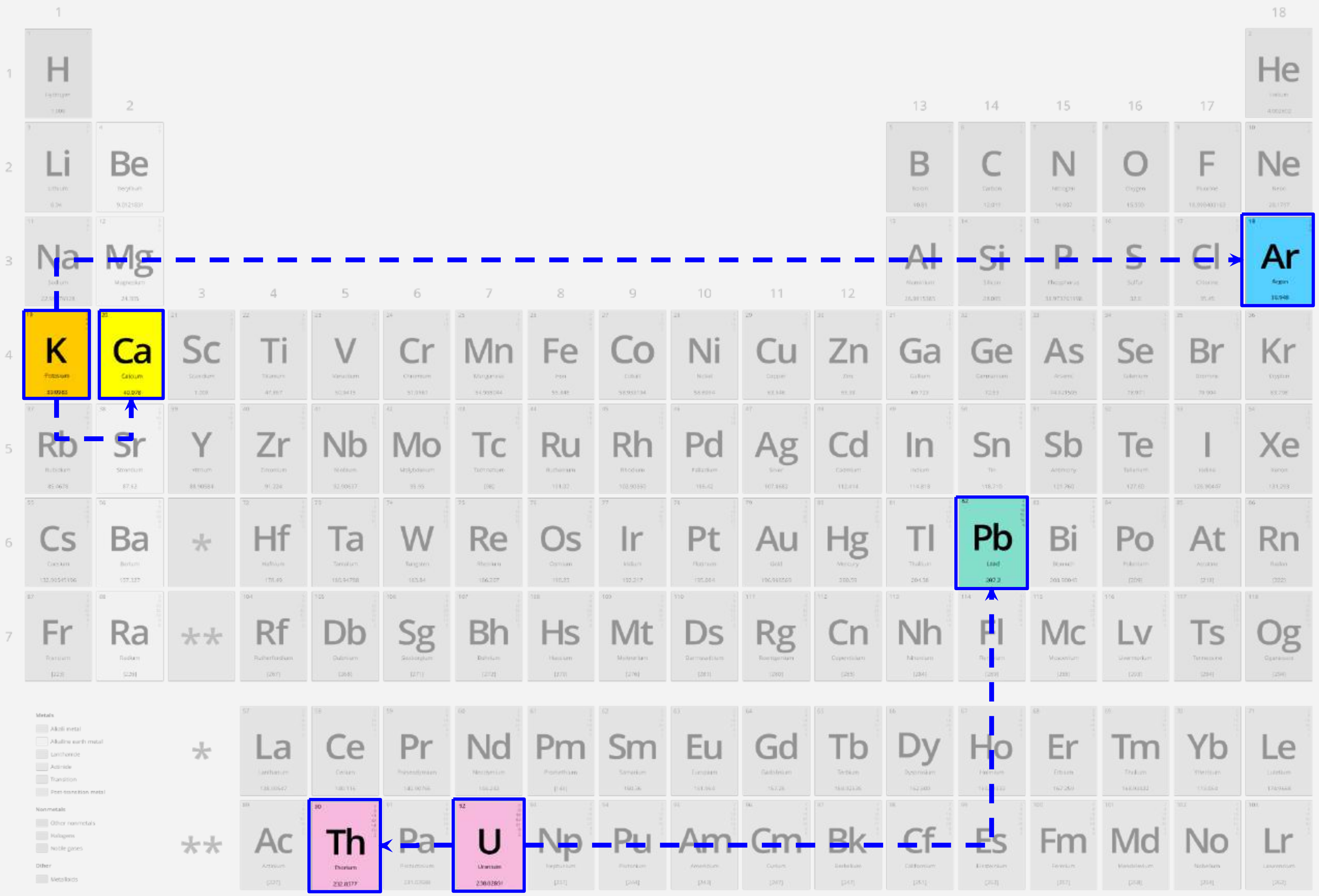
Scientists can use a *spectrometer* to analyze how much of each of these radioactive elements is in a rock crystal.




| Parent element | *decays and transforms into* → | Daughter element(s) |
| --- | --- | --- |
| K-40 | → | Ar-40 |
| U-235 | → | Th-231 |
| U-238 | → | Pb-206 |

Slide P

# Periodic Table of Elements

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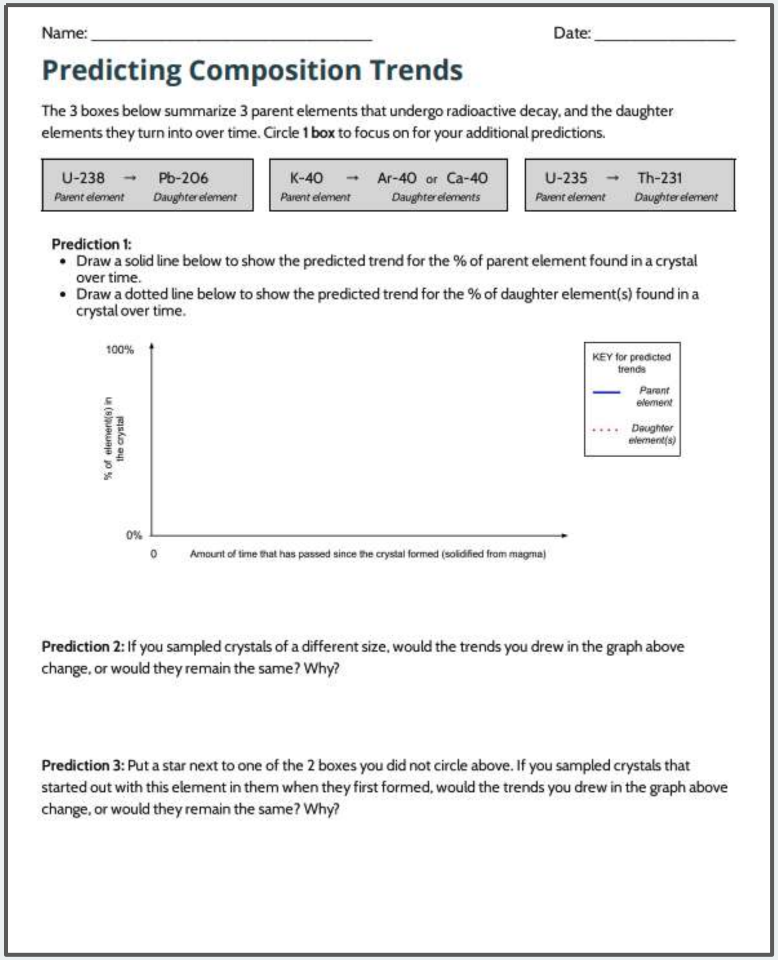
Slide Q

# Make Predictions

## On your own

Record your predictions on your handout.

➔ Be ready to share your ideas with the class!



Name: ______________________________ Date: ______________

**Predicting Composition Trends**

The 3 boxes below summarize 3 parent elements that undergo radioactive decay, and the daughter elements they turn into over time. Circle **1 box** to focus on for your additional predictions.

| | | |
|---|---|---|
| U-238 → Pb-206<br>*Parent element* *Daughter element* | K-40 → Ar-40 or Ca-40<br>*Parent element* *Daughter elements* | U-235 → Th-231<br>*Parent element* *Daughter element* |

**Prediction 1:**

- Draw a solid line below to show the predicted trend for the % of parent element found in a crystal over time.
- Draw a dotted line below to show the predicted trend for the % of daughter element(s) found in a crystal over time.



**Prediction 2:** If you sampled crystals of a different size, would the trends you drew in the graph above change, or would they remain the same? Why?

**Prediction 3:** Put a star next to one of the 2 boxes you did not circle above. If you sampled crystals that started out with this element in them when they first formed, would the trends you drew in the graph above change, or would they remain the same? Why?

# Connect to Our Anchoring Phenomenon

## Turn and Talk

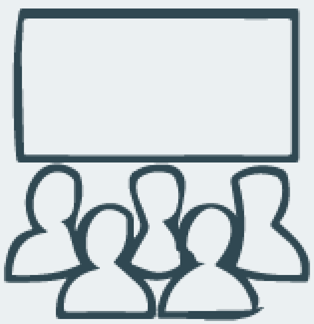
How could understanding these relationships help us explain...

- ...the rate at which different processes happened at Afar in the past?
- ...the rate at which things might happen in the future?

➔ Be ready to share your ideas with the class!

# Plan an Investigation

Scientists have come up with a general mathematical model that predicts how long ago a crystal formed based on how much of each radioactive parent and daughter element is in it.

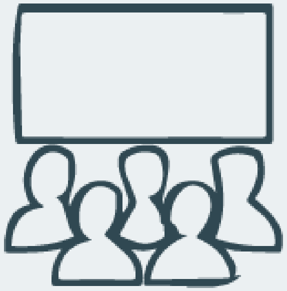


## With your class

We are about to try a simulation that we can use to explore these relationships further.

What data would we need to collect from this simulation to help us develop such a mathematical model?

# Plan an Investigation



## With your class

- Review the structure of the spreadsheet.
- Several group members can contribute data to a group copy at the same time.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *parent element in crystal tested* | | *crystal width tested* | | | | | | | |
| | | | | | **TRIALS:** Carry out as many trials as you think are neccesary based on your data | | | | |
| *parent element in crystal* | *crystal width* | *% of parent element (at A)* | *% of daughter element (at A)* | *Average time (mya)* | *time (mya)* | *time (mya)* | *time (mya)* | *time (mya)* | *time (mya)* |

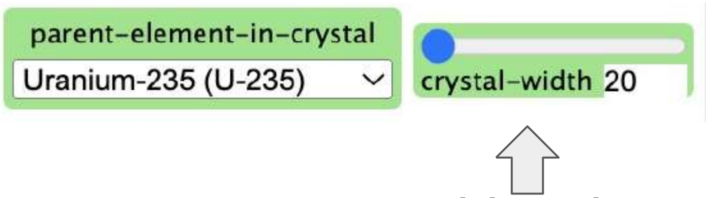
Condition 1 | Condition 2 | Condition 3 | Condition 4 | Condition 5

# Plan an Investigation

## With your group

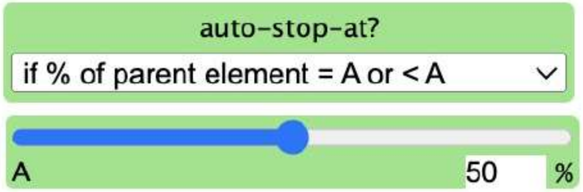
1) Share a group copy of https://www.openscied.org/general/radioactivedecay/

2) Choose a constant value for parent-element and crystal-width for your first experiment. Enter these into the green cells.




Possible values: 20-40

3) Enter the points where you want the simulation to auto-stop (for you to record data) into the blue cells.




Possible values: 5%-95%

# Carry Out an Investigation

## With your group

Use the simulation link to carry out your investigation:

https://www.openscied.org/general/radioactive-element-decay/

Several members can start collecting and recording data for different rows in your spreadsheet.

# Navigate

## On your own

Take a moment to look at your group's data.

How did you know whether you had completed enough trials for a condition?

→ Be ready to share your ideas with the class!

# Collect Data for One Condition

## With your group

Decide with your group whether you have collected enough trials for each of the points you collected data on last time.

# Collect Data for a Second Condition

## With your group

What other conditions do you want to test? *Use a different tab for each condition, indicating the parent element and crystal width tested.*

| | | | |
|---|---|---|---|
| *parent element in crystal tested* | | *crystal width tested* | |

# Carry Out an Investigation

## With your group

- Carry out your data collection for all your conditions and trials.
- You can have several members start collecting and recording data for different rows and tabs in your spreadsheet.

# Analyze and Interpret Data

## On your own

Look at the graphs generated from your results to answer these questions on your handout.

- How do the patterns across your graphs compare?
- How do these patterns compare to your predictions?

# Analyze and Interpret Data

## With your group

Analyze your graphs to approximate the times (on average) when this much parent element was left:

½ (50%) and ¼ (25%)

| Parent element | Crystal size | % parent element | Time in mya |
|---|---|---|---|
| K-40 | | 50% | |
| | | 25% | |
| U-235 | | 50% | |
| | | 25% | |
| U-238 | | 50% | |
| | | 25% | |

Add this approximate value to the related row of this table.

# Analyze and Interpret Data

## With your NEW Jigsaw group

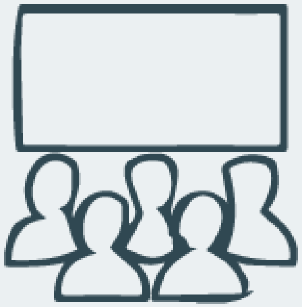
Compare data to determine an answer to this question:

***Does crystal size affect the time at which there is a certain fraction (e.g., ½ or ¼) of the parent material left?***

Which of these claims does the data support?

- No, regardless of the crystal size, the time is similar.
- Yes, the larger the crystal size, the longer the time.

# Argue from Evidence



## With your class

***Does crystal size affect the time at which there is a certain fraction (e.g., ½ or ¼) of the parent material left?***

Which of these claims does the data support?

- No, regardless of the crystal size, the time is similar.
- Yes, the larger the crystal size, the longer the time.

# Analyze and Interpret Data

## Turn and Talk

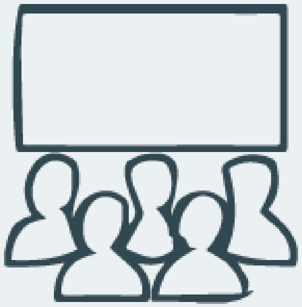
Our analysis has helped us determine how long it takes radioactive elements to decay.

How can our findings help us reconstruct the past or predict the future of Afar?

| | | Radioactive elements | |
|---|---|---|---|
| Sample | Site | K-40 (ppm) | U-238 (ppm) |
| AF12-02 | C1 | 11,670 | N/A |
| AF12-11 | D1 | 1260 | N/A |
| AF13-98 | D2 | 890 | N/A |
| AF13-102 | E1 | 5650 | N/A |
| AF12-15 | B1 | N/A | 163.5 |
| AF12-21 | D3 | N/A | 216 |

→ Be ready to share your ideas with the class!

# Use Mathematical Thinking



## With your class

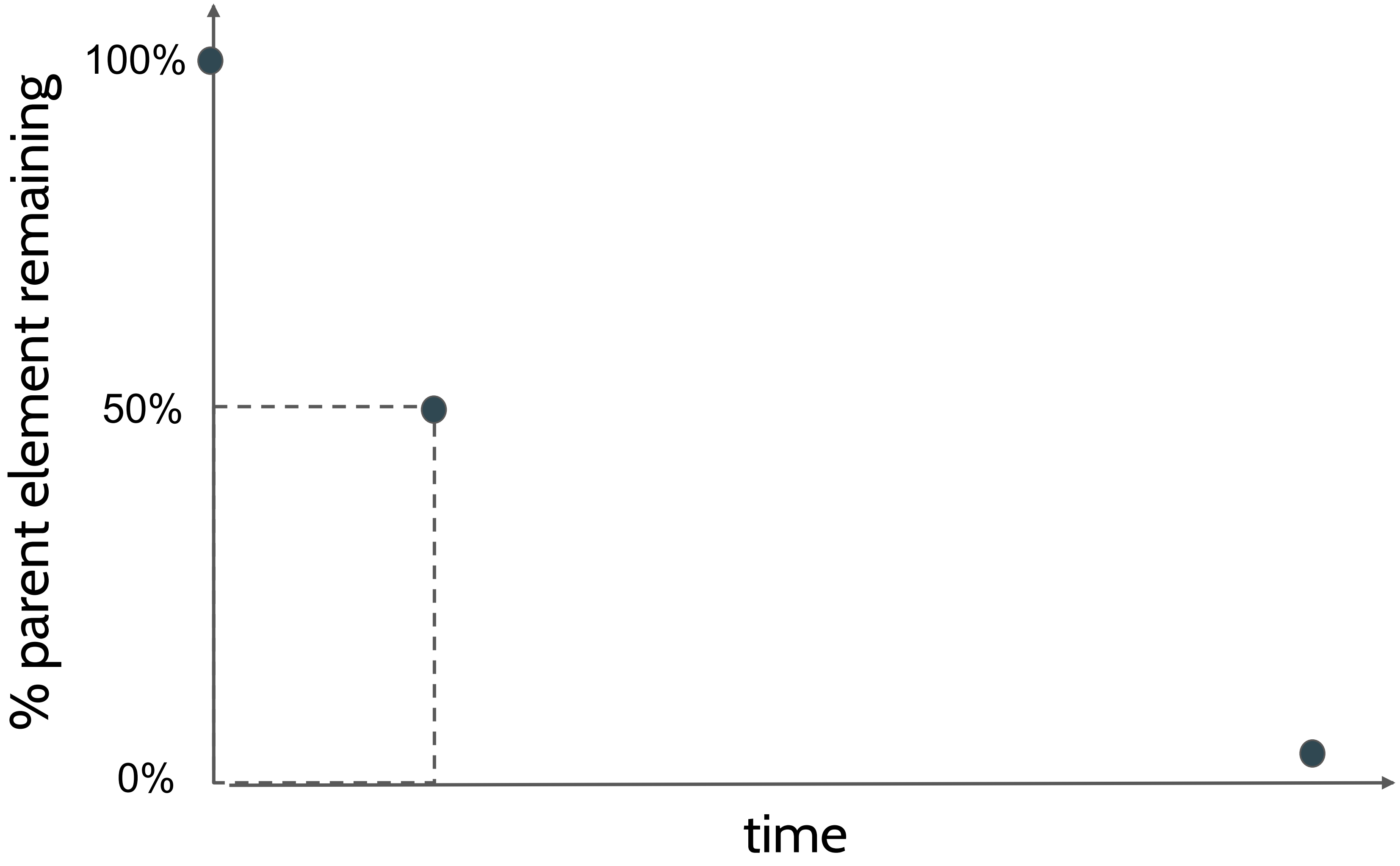
What are these times (on average) when there was this much parent element left?

## Turn and Talk

What patterns do you notice between the time for 50% and the time for 25%?

| Parent element | % parent element | Time in mya |
|---|---|---|
| K-40 | 50% | 1,250 |
| | 25% | 2,500 |
| U-235 | 50% | |
| | 25% | |
| U-238 | 50% | |
| | 25% | |

# Use Mathematical Thinking



# Navigate

## Turn and Talk

What data do we need in order to determine how much percentage of the parent element is left in each sample?

| | | Radioactive elements | |
|---|---|---|---|
| Sample | Site | K-40 (ppm) | U-238 (ppm) |
| AF12-02 | C1 | 11,670 | N/A |
| AF12-11 | D1 | 1260 | N/A |
| AF13-98 | D2 | 890 | N/A |
| AF13-102 | E1 | 5650 | N/A |
| AF12-15 | B1 | N/A | 163.5 |
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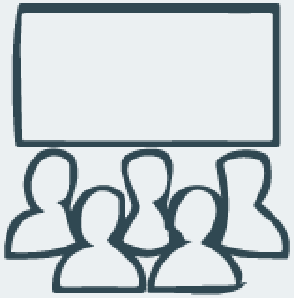
➔ Be ready to share your ideas with the class!

# Use Mathematical Thinking



## With your class

Here is a mathematical model that scientists developed for the relationships we identified. Let's compare the variables.

**Amount** of parent element now

Age of rock

$$\frac{A_{p-n}}{A_{p-f}} = \left(\frac{1}{2}\right)^{(t/h)}$$

half-life

**Amount** of parent element when formed

Age of rock

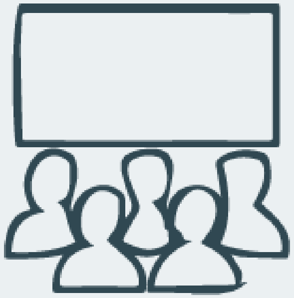
$$P_r = \left(\frac{1}{2}\right)^{(t/h)}$$

half-life

**Ratio** of amount of parent element now to amount when formed

Slide JJ

# Use Mathematical Thinking



## With your class

Here is a mathematical model that scientists developed for the relationships we identified. Let's compare the variables.

*If half-life (h) is 500 mya...*

*....then at t = 0 mya:*

$$P_r = \left(\frac{1}{2}\right)^{(0\,/\,500)}$$

Age of rock

$$P_r = \left(\frac{1}{2}\right)^{(t\,/\,h)}$$

half-life

**Ratio** of amount of parent element now to amount when formed

# Use Mathematical Thinking

## With your group

Assign a different person in your group a different value for t, to calculate (P) for.

*If half-life (h) is 500 mya…*

| t (in mya) | $P_r$ |
|---|---|
| 0 | $(1/2)^0 = 1.0$ |
| 500 | ? |
| 1000 | ? |
| 1500 | ? |
| 2000 | ? |

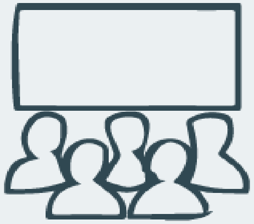
$$P_r = \left(\frac{1}{2}\right)^{(t/h)}$$

Age of rock ($t$)

half-life ($h$)

**Ratio** of amount of parent element now to amount when formed ($P_r$)

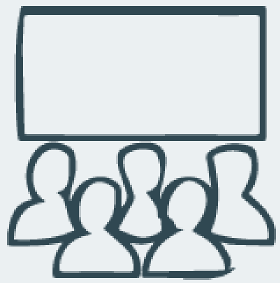
# Use Mathematical Thinking



Let's check our reasoning.

| *If half-life (h) is 500 mya...* | |
|---|---|
| t (in mya) | $P_r$ |
| 0 | $(1 / 2)^0 = 1.0$ |
| 500 | $(1 / 2)^1 = (½) = 0.5$ |
| 1000 | $(1 / 2)^2 = (½) * (½) = 0.25$ |
| 1500 | $(1 / 2)^3 = (½) * (½) * (½) = 0.125$ |
| 2000 | $(1 / 2)^4 = (½) * (½) * (½) * (½) = 0.06125$ |

# Use Mathematical Thinking



- Which variables from this model do we want to calculate?
- For which variables do we have data to substitute into the equation?
- Which variables do we lack evidence for?

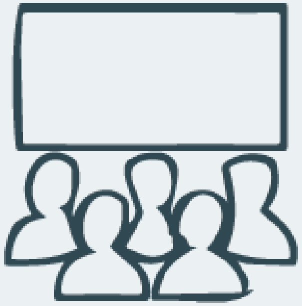
Age of rock

$$P_r = \left(\frac{1}{2}\right)^{(t / h)}$$

half-life

**Ratio** of amount of parent element now to amount when formed

# Use Mathematical Thinking



Though we cannot directly measure the amount of parent element $A_{p\text{-}f}$ when it was formed, we can calculate it based on the amount of daughter element found now $A_{d\text{-}n}$.

**Amount** of parent element now

Age of rock

$$\frac{A_{p\text{-}n}}{A_{p\text{-}f}} = \left(\frac{1}{2}\right)^{(t/h)}$$

half-life

Age of rock

$$\frac{A_{p\text{-}n}}{A_{p\text{-}n} + A_{d\text{-}n}} = \left(\frac{1}{2}\right)^{(t/h)}$$

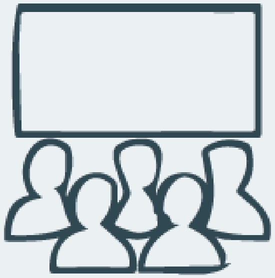
half-life

**Amount** of parent element when formed

$$A_{p\text{-}f} = A_{p\text{-}n} + A_{d\text{-}n^*}$$

**Amount** of parent element that decayed into daughter element*

# Use Mathematical Thinking



- What information do you notice has been provided for this rock sample data?
- What values have we already calculated?
- What values do we need to calculate?

Age of rock

$$P_r = \left(\frac{1}{2}\right)^{(t\,/\,h)}$$

half-life

**Ratio** of amount of parent element now to amount when formed

# Use Mathematical Thinking

## With your group

Assign each group member a different set of rock samples (A, B, C, D, E, F, G).

Use the value for portion of parent element remaining ($P_r$) and your spreadsheet to estimate the age of each rock sample. Add this to your handout.

# Use Mathematical Thinking

## With your group

Record and share the age of the rocks you calculated, and add everyone's results to this data table.

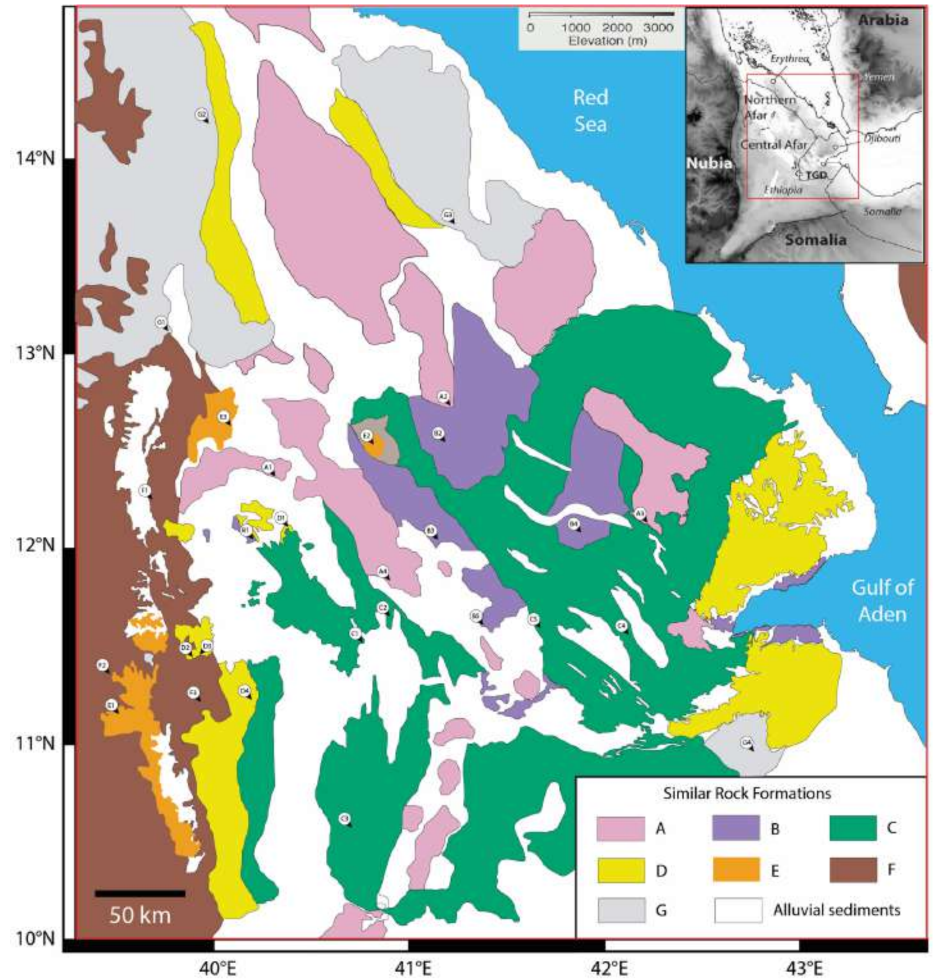
| Estimated age range of rocks | |
|---|---|
| All samples from | Approximate age of these rocks |
| A | |
| B | |
| C | |
| D | |
| E | |
| F | |
| G | |

# Analyze and Interpret Data

## With a partner

- What patterns do you notice in the locations of older versus younger volcanic rocks?
- Use evidence to support your ideas.

➔ Be prepared to share your ideas with the class!




Based on Stab, M., et.al. (2015) *Modes of rifting in magma-rich settings: Tectono-magmatic evolution of Central Afar*. Tectonics.

# Add New Ideas to the Scale Chart Poster

## Scientists Circle

Update the Scale Chart poster.

- What phenomena or patterns should we include?
- What new connections can we draw?

# Navigate

## On your own

Take a moment to consider these questions:

- How do you think the age of rocks found in other parts of the world would compare to those found at Afar?
- How could such comparisons help us better understand what is happening at Afar and what might happen there in the future?

→ Be prepared to share your ideas with the class!

# Licensing Information