Radiometric dating

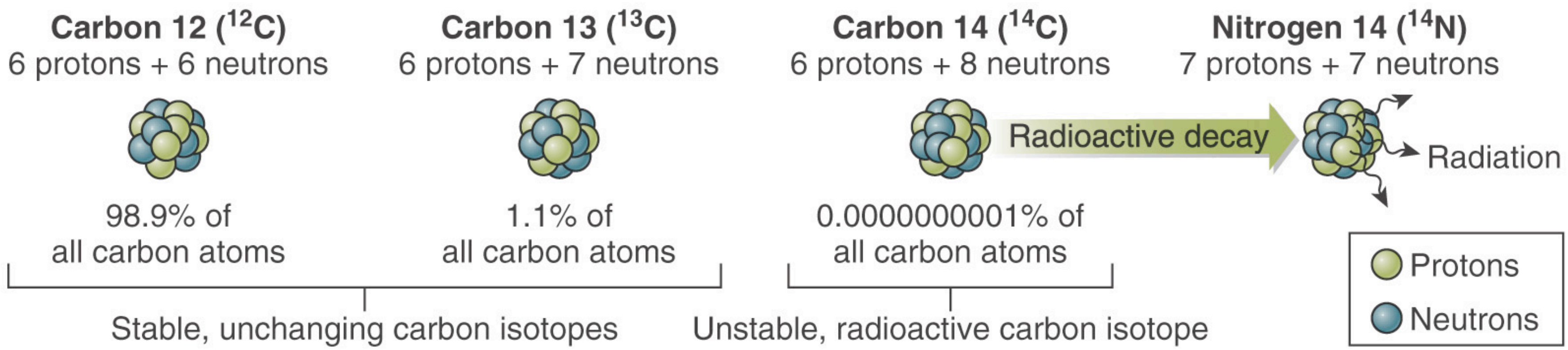
Used to determine absolute age of the Earth

"absolute age" means that you know a date, in years

Determining absolute ages is based on radiometric dating

- “radioactivity” describes the energy and subatomic particles that are released when atoms of an unstable isotope transform into another isotope.
- Isotopes: atoms of the same element with different numbers of neutrons (=different atomic weight) and the same atomic number…..

The element Carbon has 3 isotopes:



C_{12} and C_{13} are stable isotopes, that is they do not change over time

C_{14} is an unstable isotope: over time it decays, or transforms to N_{14} with the release of energy.

"Radioactive decay" is the name we give to this process.

How do geologists use radioactive decay to determine the age of rocks?

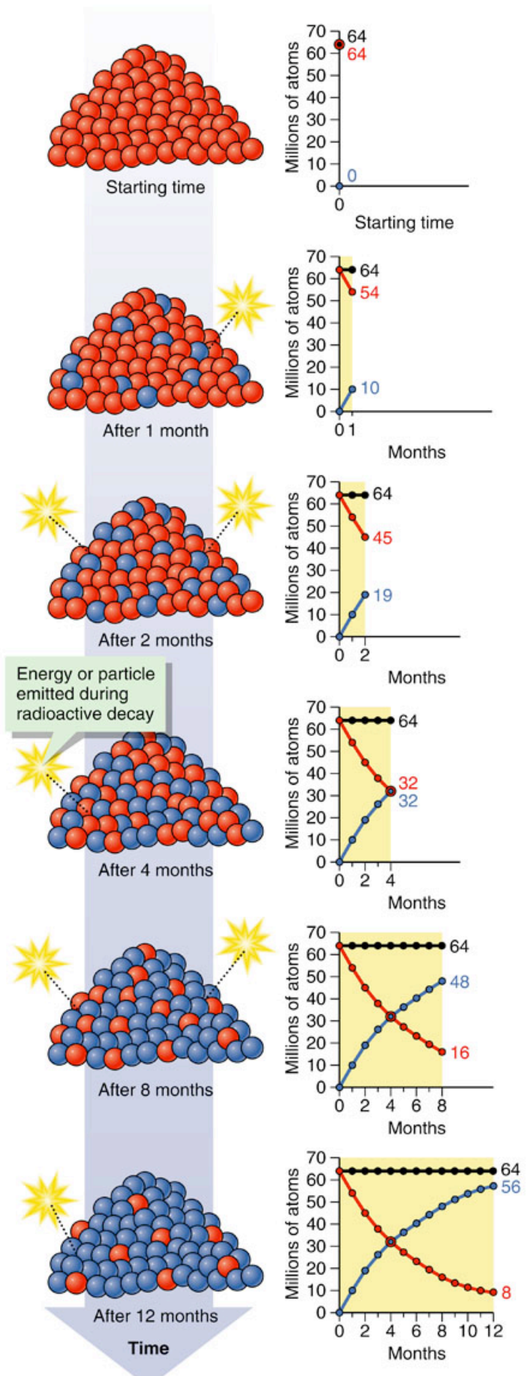
- Minerals contain trace amounts of unstable isotopes. For example, muscovite and biotite mica contain K_{40}, which decays to Ar_{40}
- Quartz contains minute amounts of zircon, which has even more minute amounts of uranium in it.. Ur_{238} decays to Pb_{206}

..the list of minerals containing trace amounts of unstable isotopes isn’t huge, but it includes some of the most abundant:

- Micas (biotite and muscovite)
- Feldspar
- Quartz
- calcite

Some terms:

- We use the terms “parent” and “daughter” isotopes to describe respectively the starting isotope and the new element produced as a result of radioactive decay.
- ***The “half-life” of an unstable isotope is the amount of time for the number of atoms of the parent isotope to decrease by 1/2***.
- Half lives can range from less than a second for some isotopes to billions of years for others

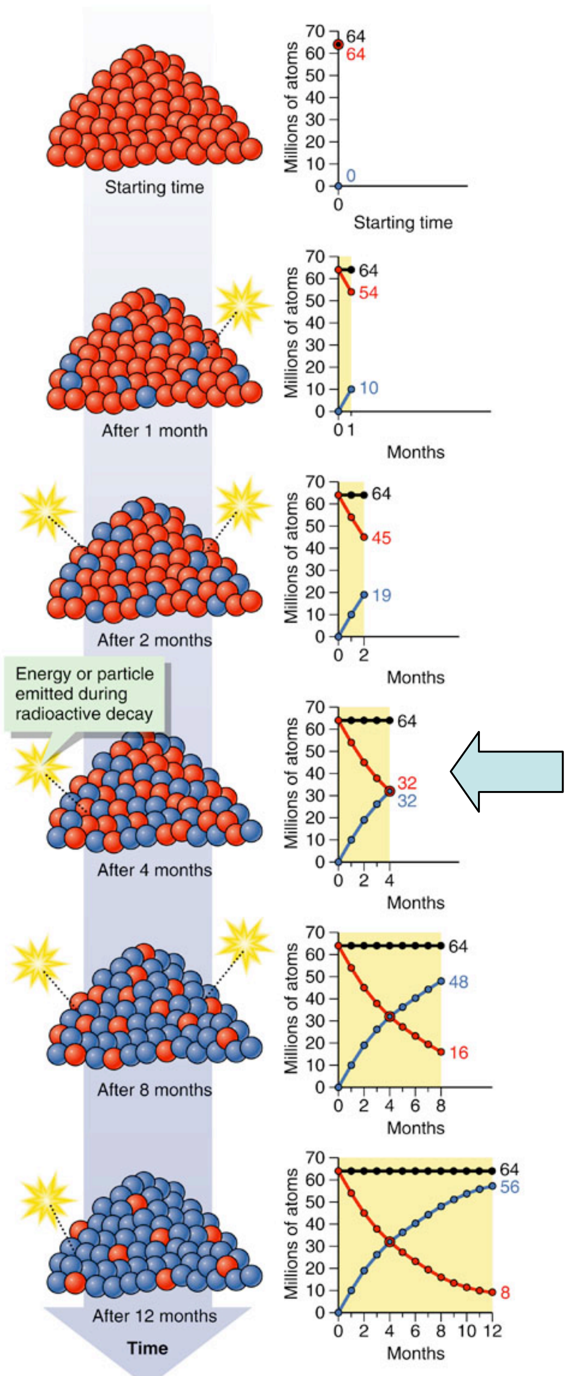


The pile of red atoms represents the # of atoms of the parent isotope.

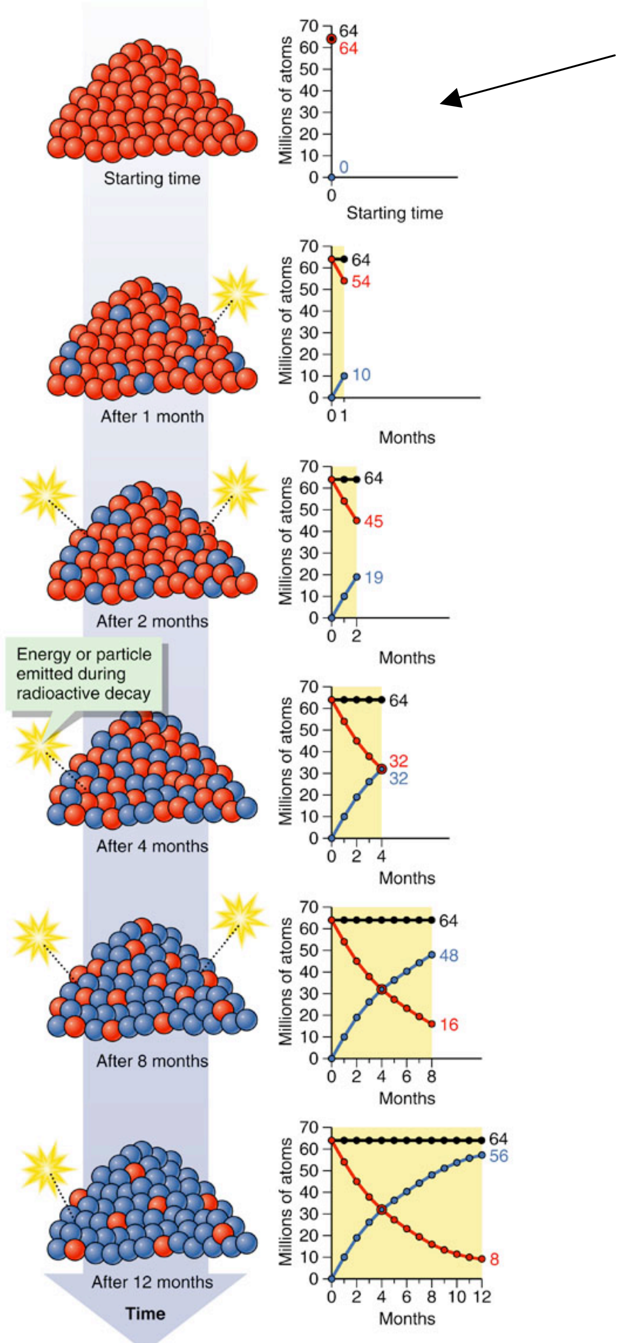
The blue atoms represent the # of daughter atoms produced after some time t.

After a time interval based on the decay rate, 1/2 of the # of atoms of the parent = 1/2 the # of atoms of the daughter. This = the half life.

The decay of parent atoms to daughter atoms continues

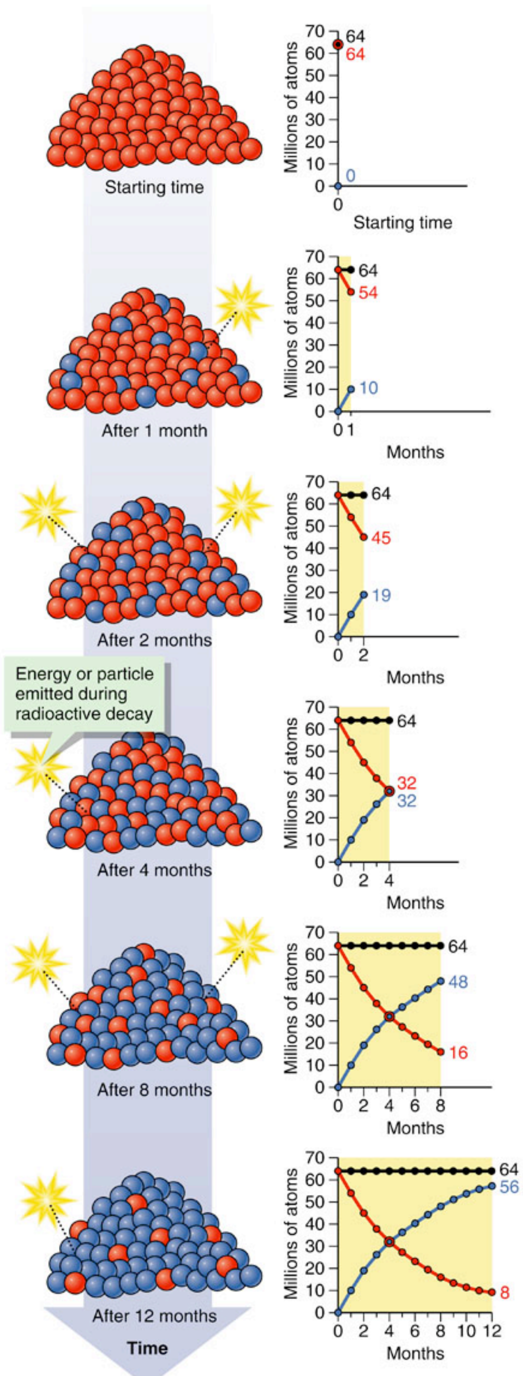


If the half-life of this example is 4 months. This means that after 4 months 1/2 of the parent isotope will decay to form the daughter isotope.



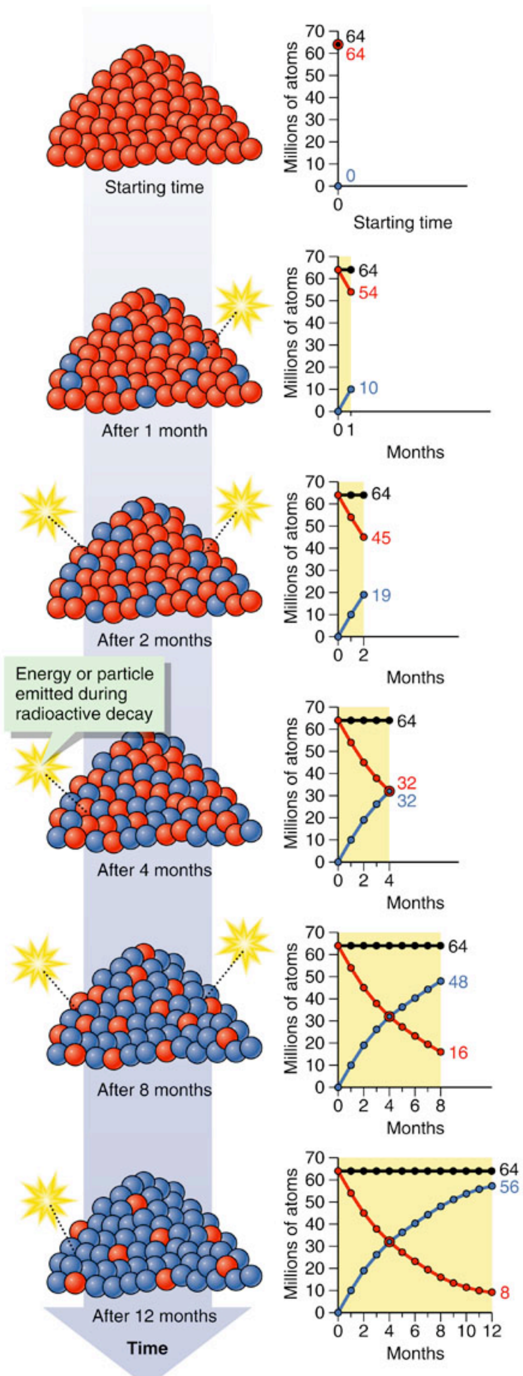
Examine the graph that plots the abundance of atoms of the parent and daughter isotopes. Initially 100% of the atoms are parent and 0% are daughter.

At the end of one half-life, 50% of the atoms are parent and 50% are daughter.



Suppose that there are 64 million parent isotope atoms at the beginning of decay.

After one half life, there will be 32 million parent isotopes and 32 million daughter isotopes

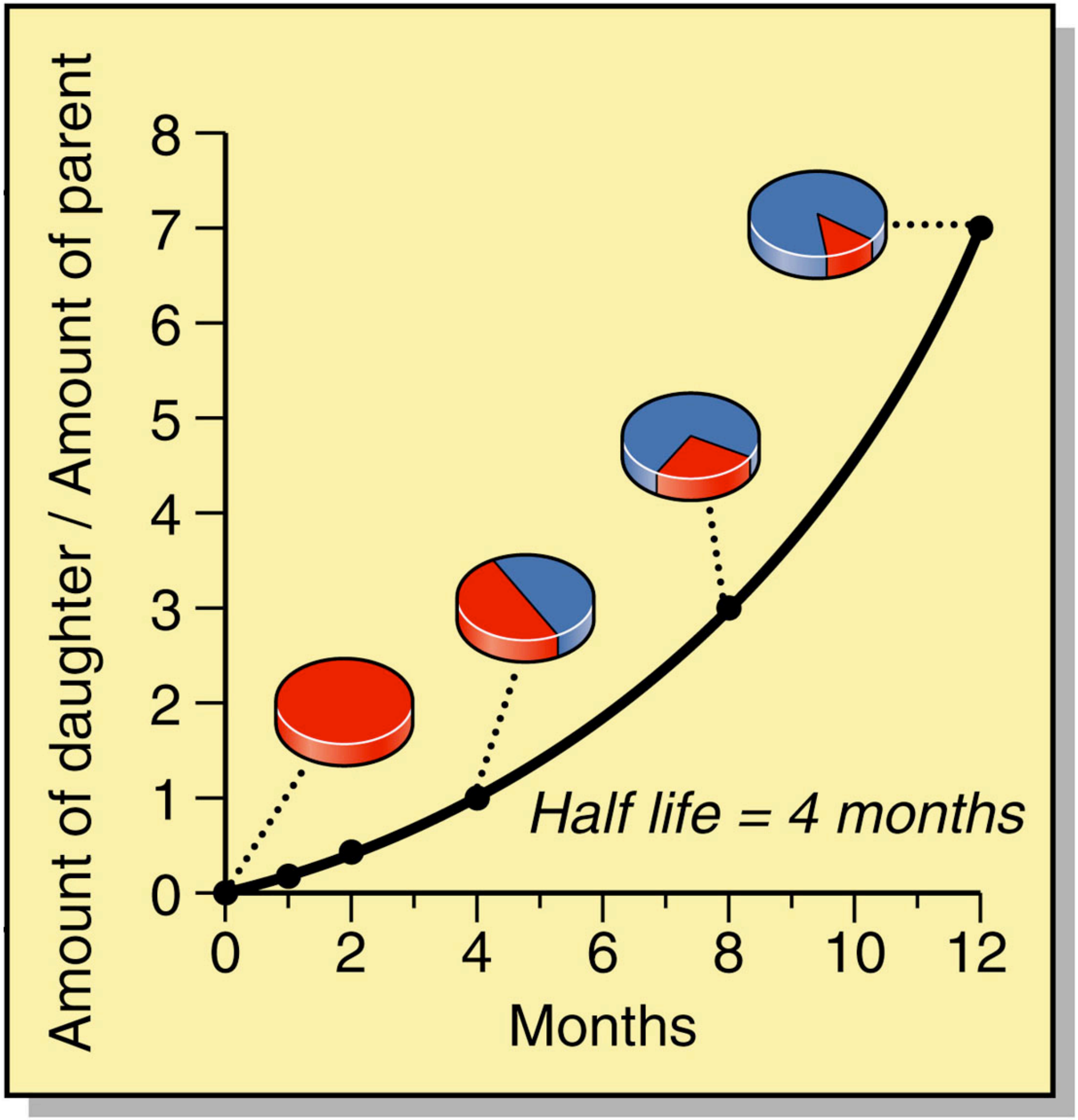


Note that after 4 months (1 half life) there are 32 million parent atoms and 32 million daughter atoms.

You might predict that after *half* of one half life (2 months) you would have 64 million atoms - 16 million atoms (1/2 of 1/2 atoms) or 48 million parent atoms and 16 million daughter atoms. However, you have 45 million vs.19 million…why?

The number of transformations of parent to daughter isotopes is not the same for each month because the rate of transformations of parent to daughter isotopes is a function of the number of parent atoms. Thus, as the number of parent atoms decreases, the rate of decay also decreases. In other words, the rate of decay is exponential

What exponential decay looks like:



If we plot the number of half-lives (x axis) vs. the parent to daughter isotopes, (y axis) we see that the relationship is exponential. This reflects the fact that the ratio of parent to daughter isotopes changes as a function of the amount of the parent that you have.

To determine the age of a rock:

- You need to be able to measure two things:

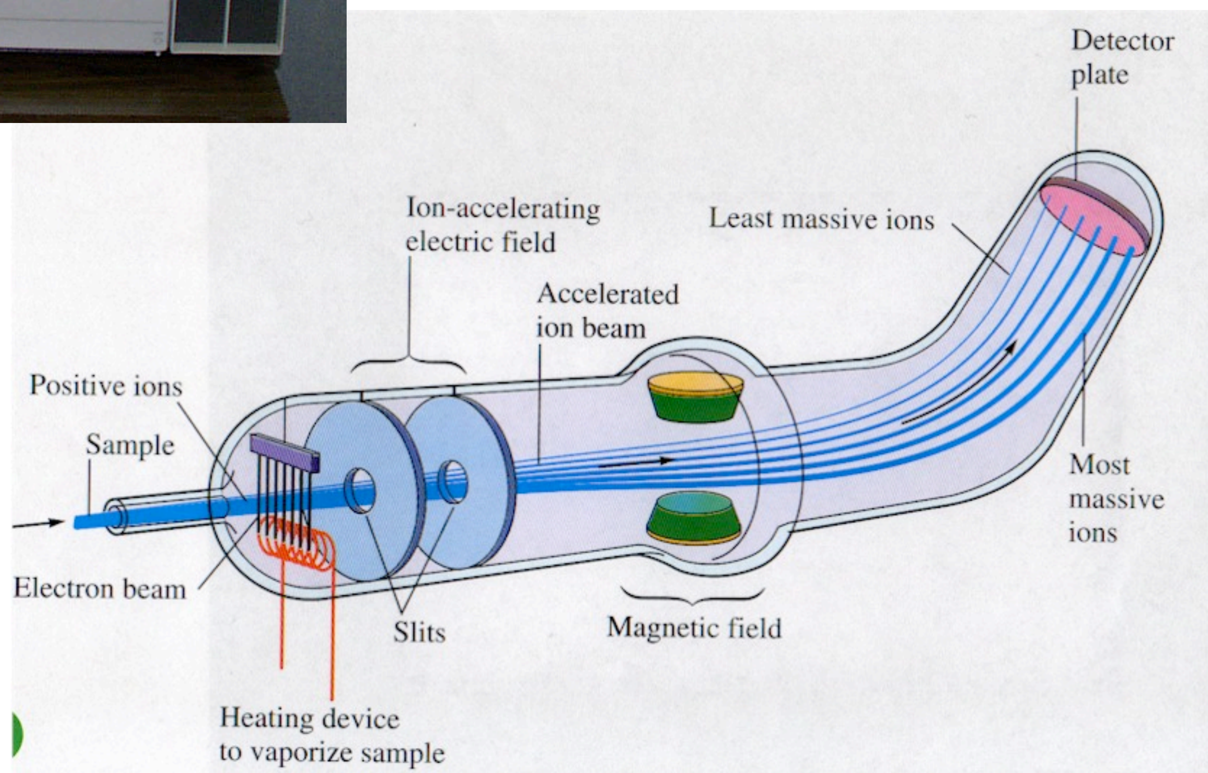
  1. the abundance of the parent and daughter isotopes (=the # of atoms of each)

  2. the rate of decay

How do we do this?

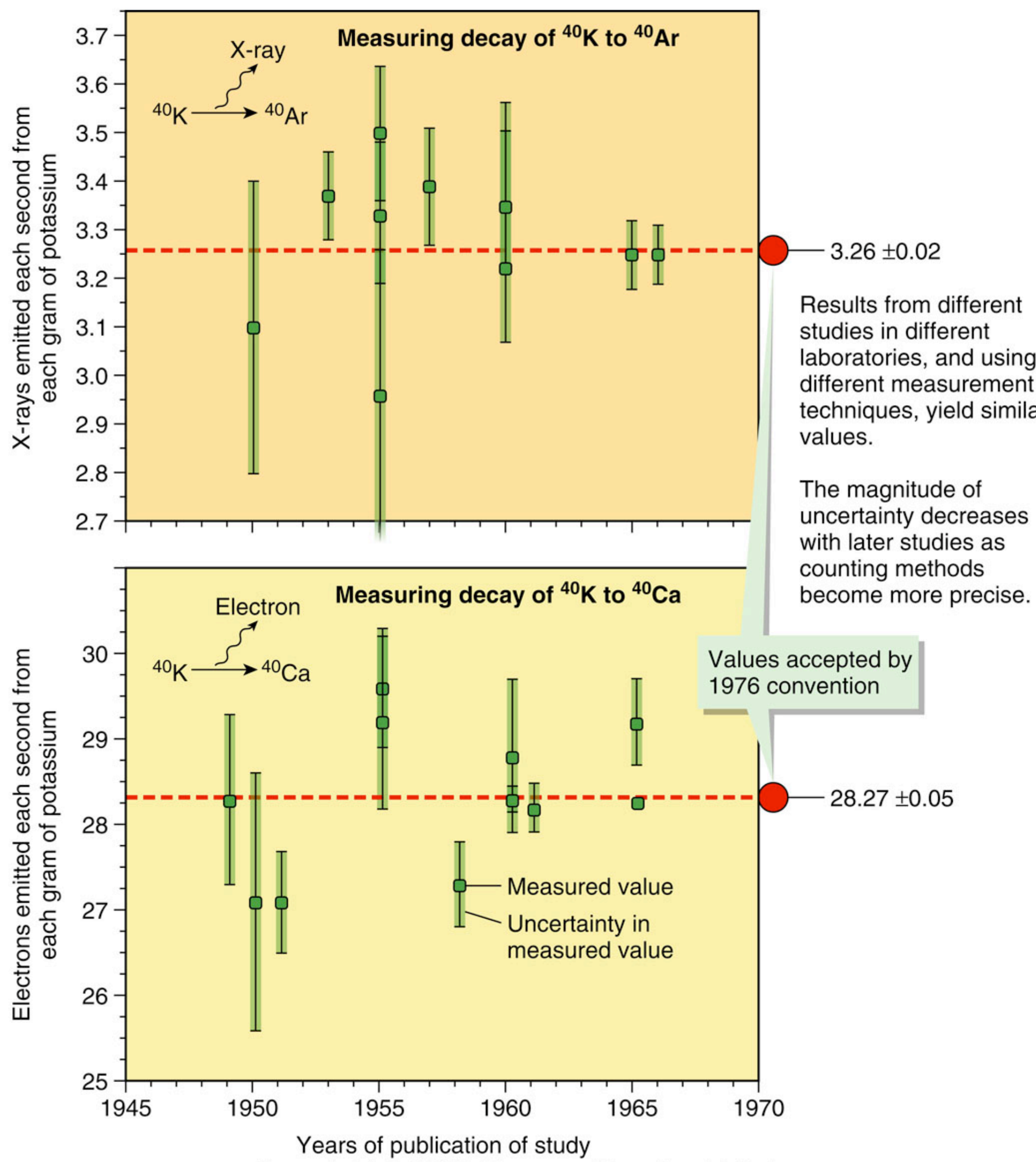
1. An instrument called a mass spectrophotometer can measure the # of atoms of an element

Because atoms of different elements have different atomic weights, they can be identified by how they respond when passed thru a magnetic field



How do we measure the decay rate?

- most of the unstable isotopes present in minerals have such long half-lives that their decay rates are VERY slow.. no one can conduct a measurement for a process that may take billions of years to occur! Instead, geologists measure the amount of energy released when each parent atom decays. Remember that the number of transformations is a function of the number of parent isotopes that are decaying, so, the amount of energy released is a function of the number of parent isotopes. Since we know the amount of parent isotopes (from the mass spectrophotometer) we can relate the amount of energy released in an interval of time to the rate of decay.

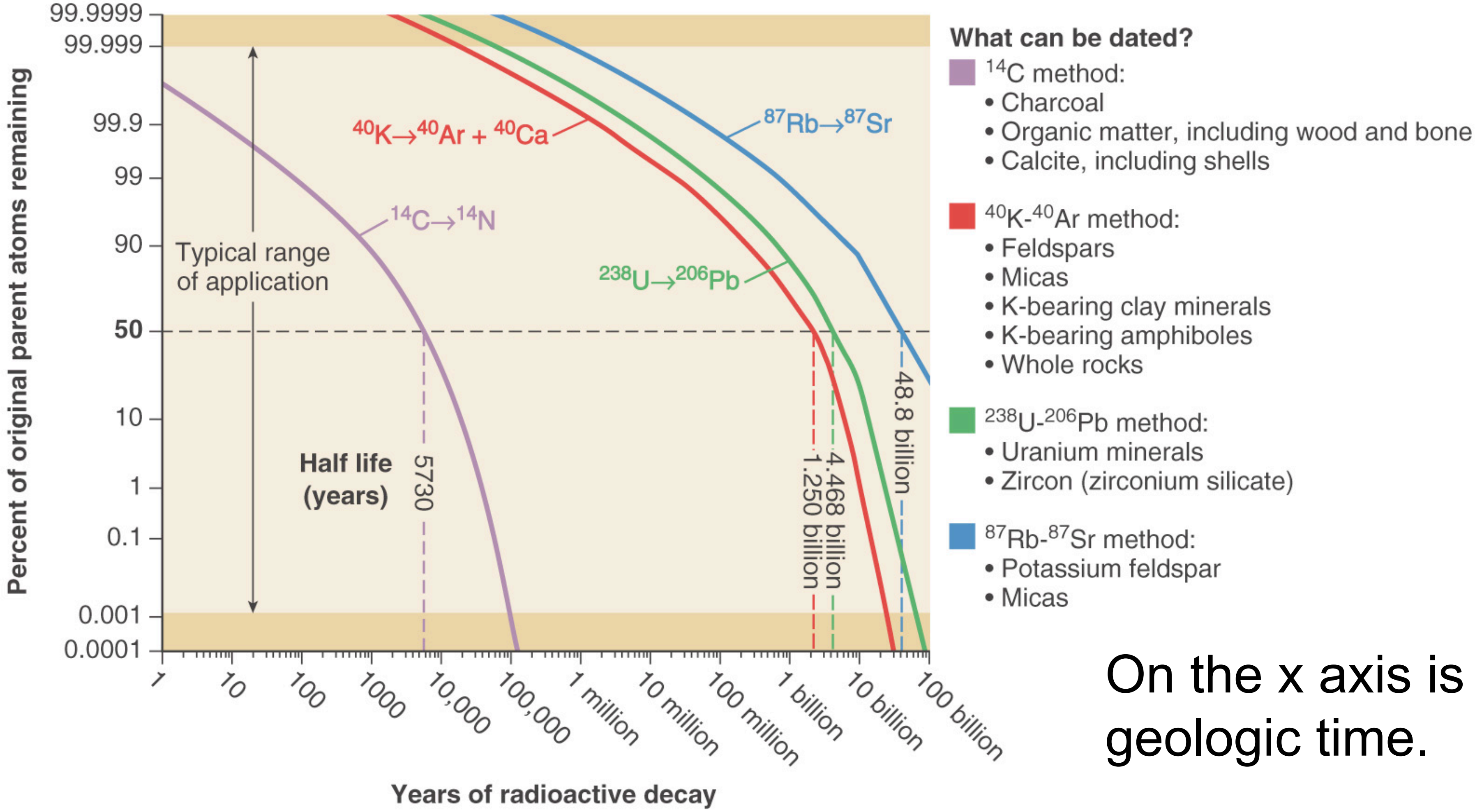


An example of how we use energy release to determine decay rate. On The X axis is measurement of the Xrays emitted per second as K_{40} decays to Ar_{40} (top) and K_{40} to Ca_{40} (bottom). The green bar represents the range of values, the circle is the mean value. After many, many measurements, the avg. values are determined. Improving instruments have Improved the precision of measurements (the error bars get smaller).

How reliable are these measurements?

- If you examine the previous figure, you can see that improvements in the quality of instrumentation has resulted in progressively increasing precision of measurements (between 1950 and 1965 the precision increased by more than 100%)…the statistical degree of certainty for these measurements is now less than 1/2 of 1% (<0.5%).
- Studies are ongoing to see if there are physical effects, such as pressure, on decay rate. No results have shown any variation.

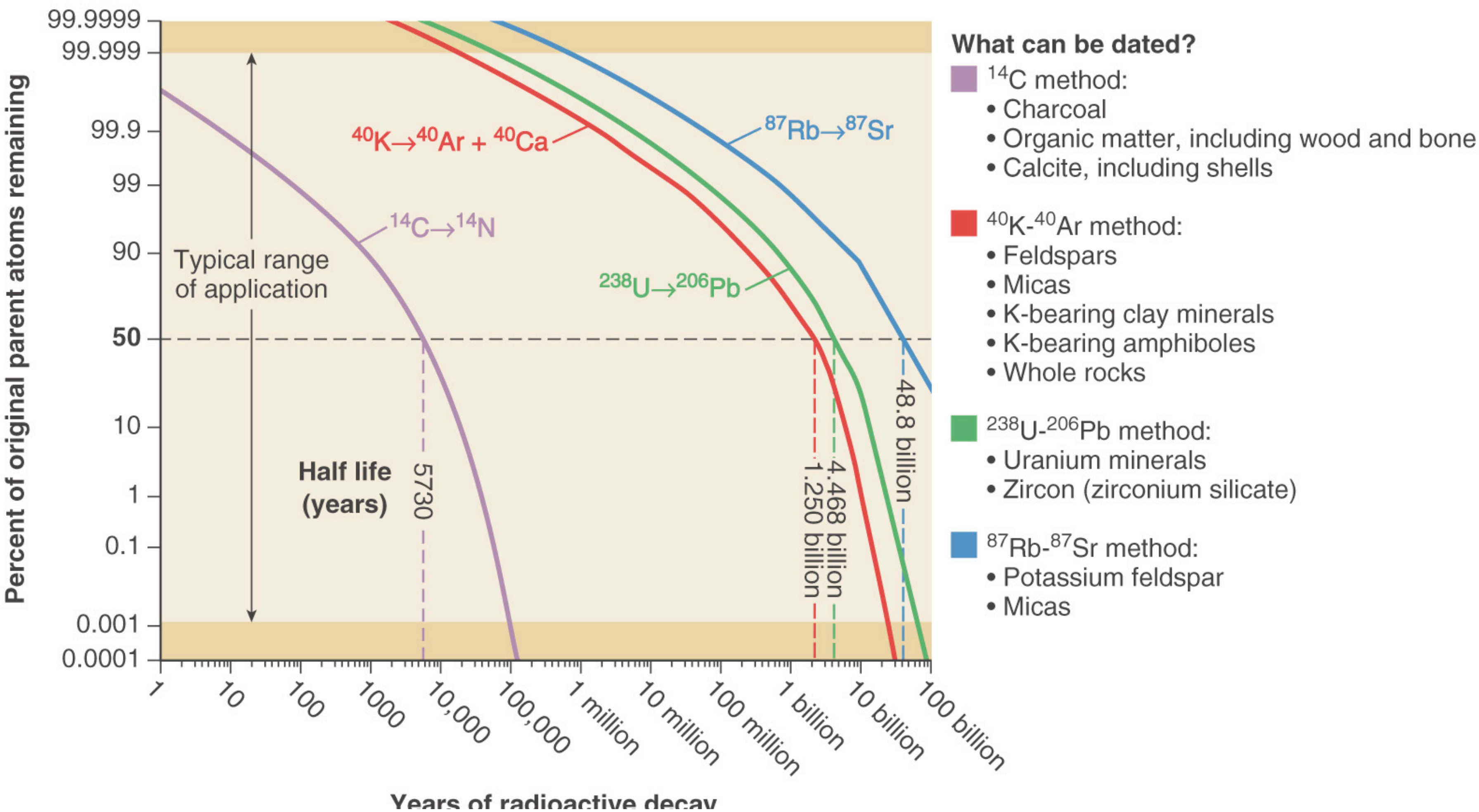
What are commonly used isotopes for dating rocks?



On the x axis is geologic time.

On the y axis is the % of parent isotope remaining in a sample. the 4 colored lines represent 4 different isotopes.

Note that C_{14} has the shortest half life: 5,730 years. Rubidium 87 decaying to Strontium 87 has the longest, 4.8 billion years. So, carbon is used for dating recent organic material (bone) while the other minerals date minerals that can be as old as the formation of the Earth



How do we date a rock?

We need to find a rock that contains minerals that will have unstable isotopes in them, like K_{40} or U_{238}. These isotopes are contained in minerals (decay begins with crystallization). Good candidate rocks are therefore igneous rocks, like this dike. We collect rock samples, return to the lab and crush the rock and remove the isotope-bearing minerals. These minerals are further processed and then analyzed in the mass spectrophotometer

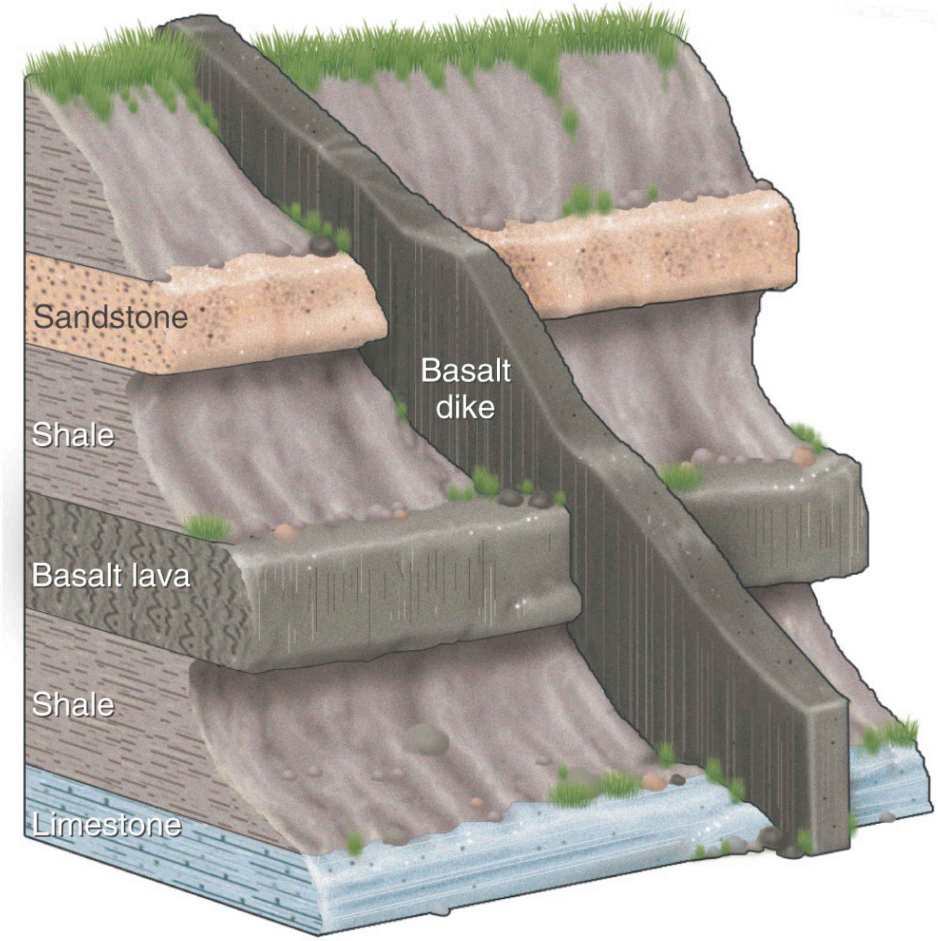
There's more:

- We need to be able to demonstrate that we have a "closed system" - which means that no isotopic material has entered or left. Loss of daughter is common if a rock is re-heated; fluids moving through the hot rock can add parent.

Another useful method of radiometric dating involves fission tracks. As a radioactive atom in a mineral crystal decays, it emits a particle that travels through the crystal and disrupts its structure. The tiny trail is termed a ***fission track***.

By counting fission tracks, we can determine how many radioactive atoms have decayed. We bombard the remaining atoms with neutrons, causing the rest of the parent atoms to decay. When you recount the number of fission tracks, the proportion of parent to daughter atoms can be determined, and from this, its age

Putting ages on the geologic time scale:



Relative ages:

Sandstone is younger than basalt lava by principle of superposition.

Basalt dike is younger than sandstone by principle of cross-cutting relationships.

Radioactive isotope absolute ages:

Basalt lava is 25 million years old.

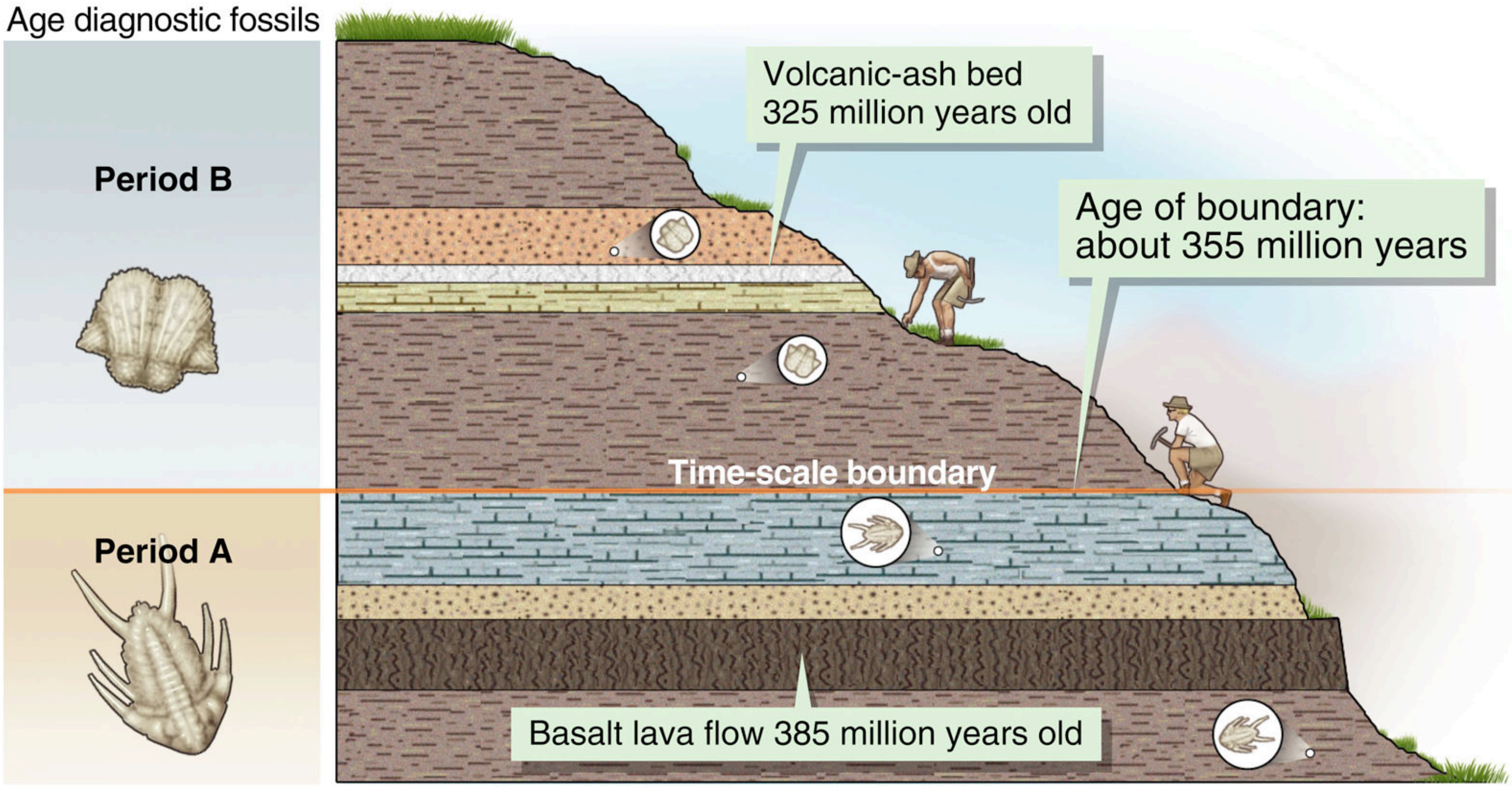
Basalt dike is 20 million years old.

Approximate absolute age of sandstone:

Sandstone deposited between 25 million and 20 million years ago.

The dike cuts through sedimentary layers. We use Steno's Laws to date the relative ages of the layers and an absolute date on the igneous dike. This tells us that the sedimentary layers have to be older than the age of the dike.

The Geologic Periods are characterized by their different fossils



Determining an absolute age for the igneous rock immediately below the transition from one time period to another, as well as the volcanic ash bed above the transition helps us to bracket the age of the transition from the Devonian to the Carboniferous Periods.