

# Radiometric Dating:

## How Scientists Measure Earth's Age



How radioactive decay in rocks and meteorites measures Earth's age



Journey: atomic foundations, isochrons, dating systems, validation, results, limits



For students, adult learners, and educators seeking evidence-based vocabulary



Scientific ages = measurement + uncertainty + replication + cross-checks

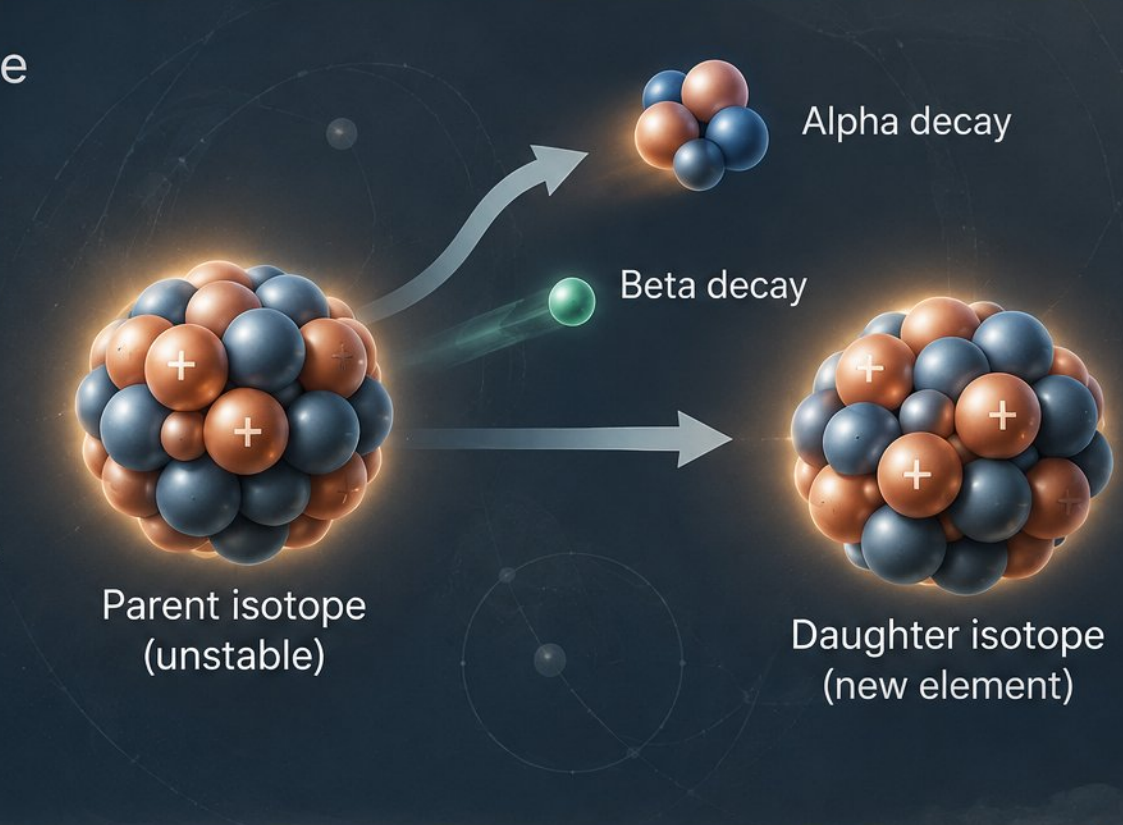


Consensus anchor: Earth is about  $4.54 \pm 0.05$  billion years old



# Atoms, Isotopes, and Why Radioactive Clocks Work

- **Isotopes:** same element, same protons, different neutrons.
- **Radioactive decay:** unstable parent becomes a daughter of a new element.
- **Decay modes:** alpha, beta, electron capture, fission tracks.
- **Half-life:** time for half a population to decay; fixed for each isotope.



## Key half-lives:

**C-14**  
5,730 yrs

**K-40**  
1.25 by

**U-235**  
704 my

**U-238**  
4.47 by

**Rb-87**  
48.8 by

# The Dating Equation: From Parent-Daughter Ratios to Ages

MINERALS • TIME • A DEEPER EARTH



Decay law: parent decreases and daughter accumulates over time



Simple age needs measured parent and daughter amounts



Initial daughter at formation must be known or corrected



Isochron method: measure minerals that formed together

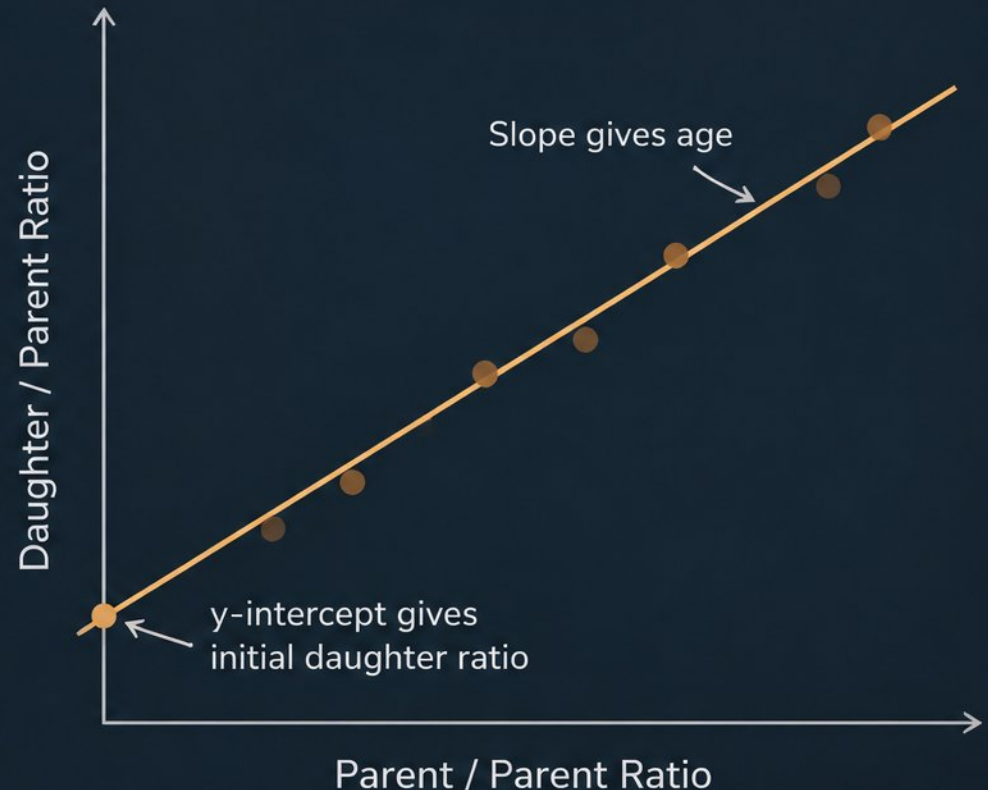


Slope gives age; y-intercept gives initial daughter ratio



Uncertainty from precision, decay constants, and geologic context

**Isochron Plot**



# Major Dating Systems and What Each One Dates

## Uranium-lead & lead-lead



zircon and uranium-bearing minerals; oldest terrestrial minerals, meteorites

## Potassium-argon & argon-argon



volcanic rocks, ash, feldspar, biotite; argon-argon handles disturbed samples

## Rubidium-strontium & samarium-neodymium



igneous and metamorphic rocks; very old materials like meteorites

## Carbon-14



once-living organic material and some carbonates; limit ~50,000–60,000 years



**Match the method to the sample:** each system has its own age range and limits



# Assumptions, Closed Systems, and How Methods Are Validated

## Open System

Parent and daughter loss



## Closed System

Isotopes retained



## Cross-check with independent methods

Compare to known-age samples



Core requirement: a closed system with no parent or daughter loss



Heating, weathering, metamorphism, and fluids can reset radiometric clocks



Cross-checks with independent methods and known-age samples build confidence



Interlaboratory comparisons test whether labs agree on the same material

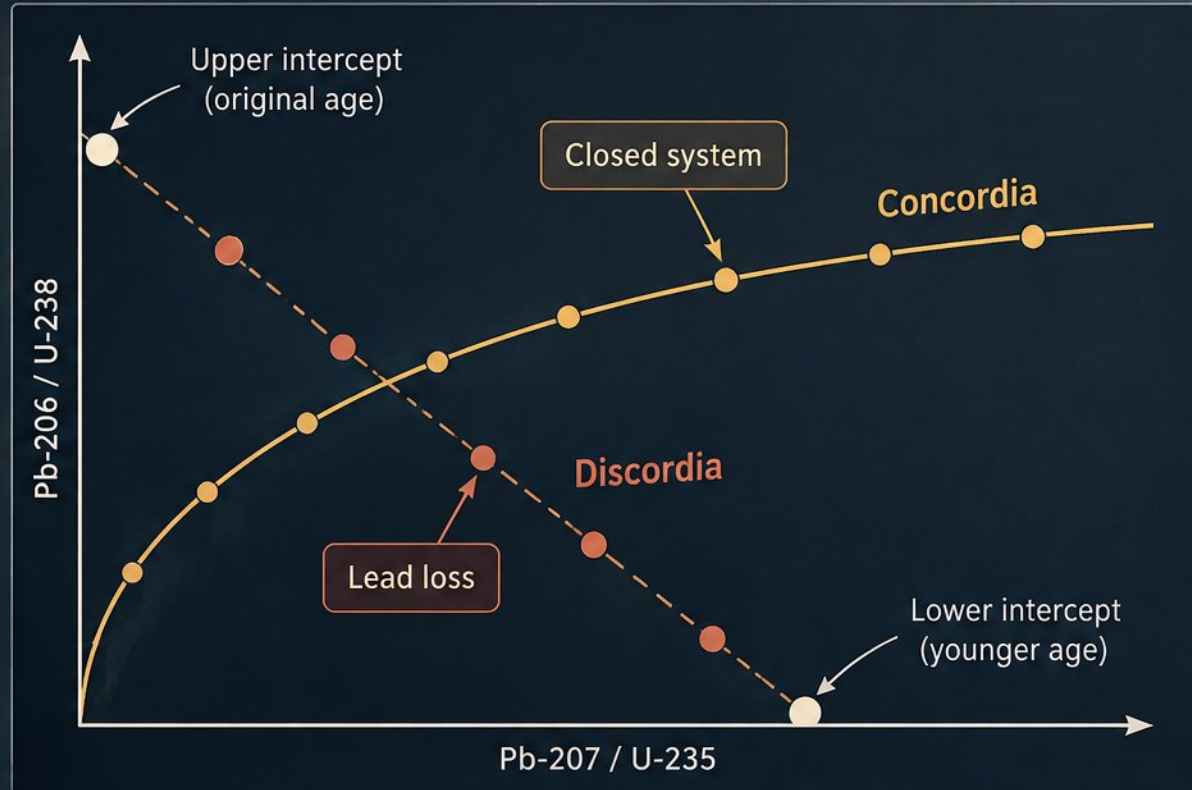


A disturbed sample signals its history needs care, not method failure

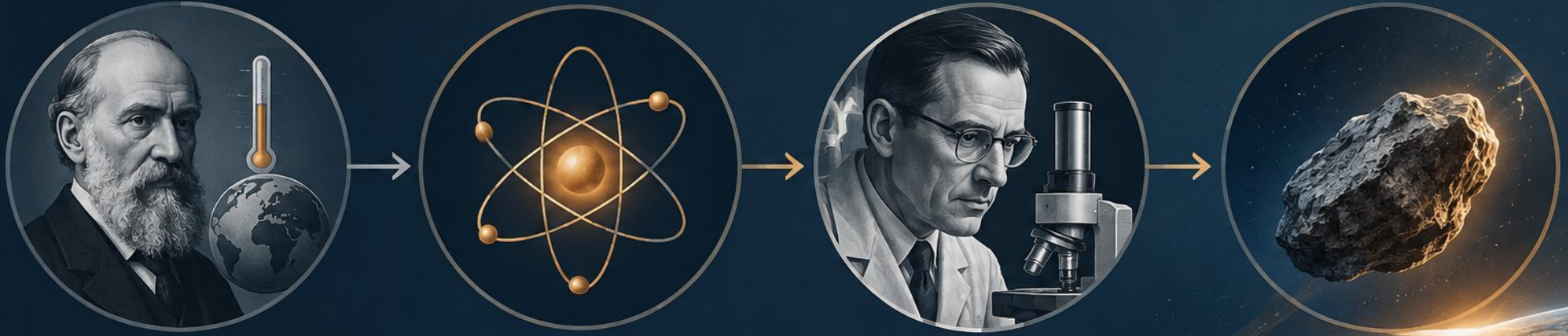
# Reading Disturbed Data: Concordia, Discordia, and Open Systems

ISOTOPES  
ROCKS  
DEEP TIME

- Uranium-lead dating pairs two decay chains: U-238 to Pb-206 and U-235 to Pb-207
- Concordia marks where both U-Pb ages agree, indicating a closed system
- Discordia forms when lead or uranium is lost or gained after crystallization
- The upper intercept can still preserve the original crystallization age
- Chemical abrasion and imaging remove disturbed domains before dating



# Measuring Earth's Age: From Early Estimates to Patterson's Breakthrough



- Before radioactivity, Kelvin's cooling model gave a wide, uncertain range of ages
- Early 1900s: radioactivity revealed a physical clock inside rocks
- Clair Patterson, 1956: lead-isotope dating of meteorites gave  $4.55 \pm 0.07$  billion years
- Key insight: meteorites and Earth formed from one shared reservoir of material
- Hundreds of later determinations refined this to  $4.54 \pm 0.05$  billion years

# Why 4.54 Billion Years Is the Accepted Value

- Oldest Earth rocks recycled by plate tectonics, erasing direct evidence
- Meteorites fill the gap: ages cluster **4.53–4.58 billion years**
- That 50-million-year spread marks solar system formation duration
- Jack Hills zircons, Western Australia: oldest terrestrial minerals, **about 4.4 billion years**
- Multiple isotope systems and labs converge on **4.54 +/- 0.05 billion years**
- Uncertainty reflects measurement precision and planetary accretion duration

DIFFERENT EVIDENCE. A CONSISTENT STORY.

## Meteorite Ages

Ages cluster 4.53–4.58 billion years



## Jack Hills Zircons

Western Australia: oldest terrestrial minerals, **about 4.4 billion years**



## Accepted Value

Multiple isotope systems and labs converge on **4.54 +/- 0.05 billion years**



## Radiometric Decay (conceptual)



OUR PLANET.  
A DEEPER PAST.

# Case Study:

## Dating Volcanic Ash to Calibrate the Human Fossil Record

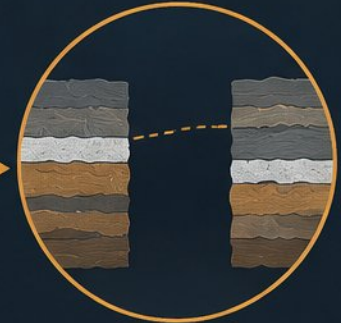
- Fossils are rarely dated directly; ash layers above and below bracket their age
- Single-crystal argon-argon dating of feldspar gives volcanic ash its age
- Omo-Kibish fossils: KHS Tuff dated to  $233 \pm 22$  thousand years
- Tephrochronology matches ash chemistry to correlate distant deposits
- Ash layers act as time markers tying fossils to the radiometric timescale



Single-crystal  
argon-argon dating  
of feldspar



Omo-Kibish fossils:  
KHS Tuff dated to  
 **$233 \pm 22$**  thousand years

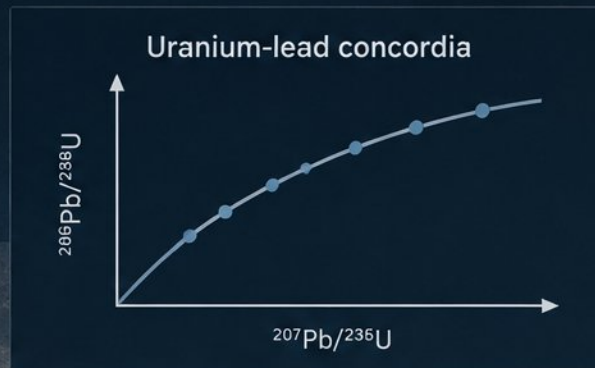
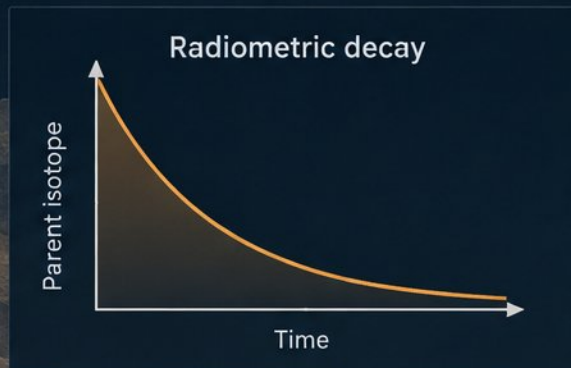
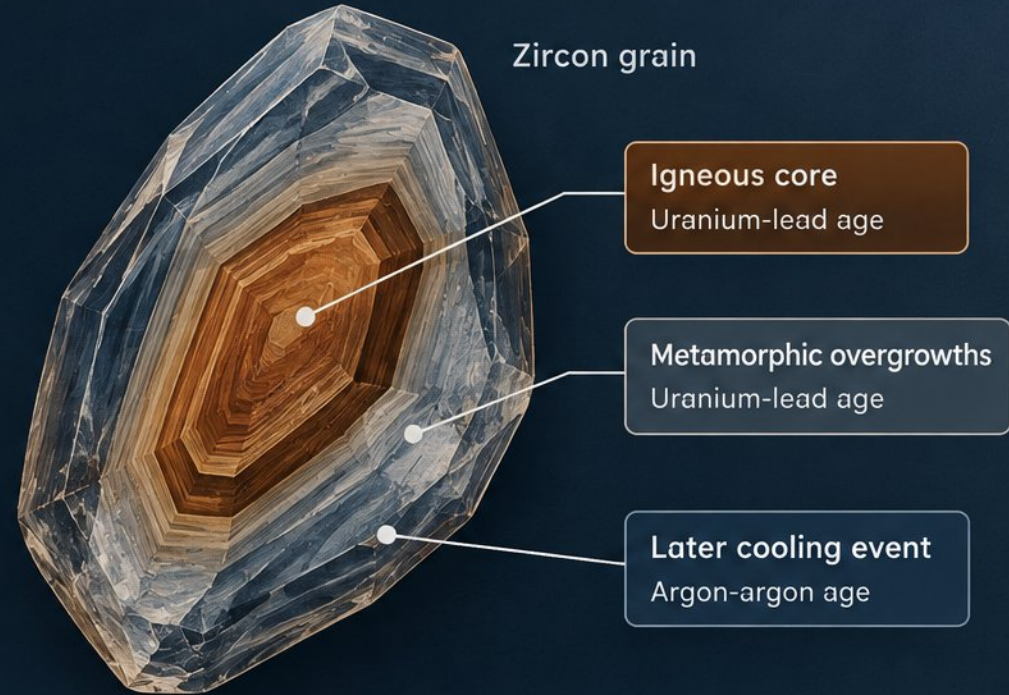


Tephrochronology  
matches ash chemistry  
to correlate distant  
deposits

# How a Single Rock Records Multiple Events

DIFFERENT SYSTEMS. A DEEPER STORY.

- Different isotope systems close at different temperatures, preserving distinct ages in one rock
- Zircon can keep an igneous core plus later metamorphic overgrowths — multiple events in a single grain
- Argon-argon step heating and uranium-lead concordia separate crystallization from later disturbance
- A radiometric date marks an event, not the object itself
- Ask not "how old is this rock?" but "what event does this measurement date?"



ROCKS REMEMBER  
MORE THAN ONE MOMENT

# What Radiometric Dating **Cannot Do** and Why That Matters



## WHAT RADIOMETRIC DATING CANNOT DO



Carbon-14 fails beyond ~50,000–60,000 years: too little remains to measure.



Sedimentary rocks are hard to date directly; their grains come from older source rocks.



Geologists instead date igneous layers that bracket sedimentary sequences and fossils.



Heating, weathering, or fluid flow can disturb a rock's clock and reset its age.

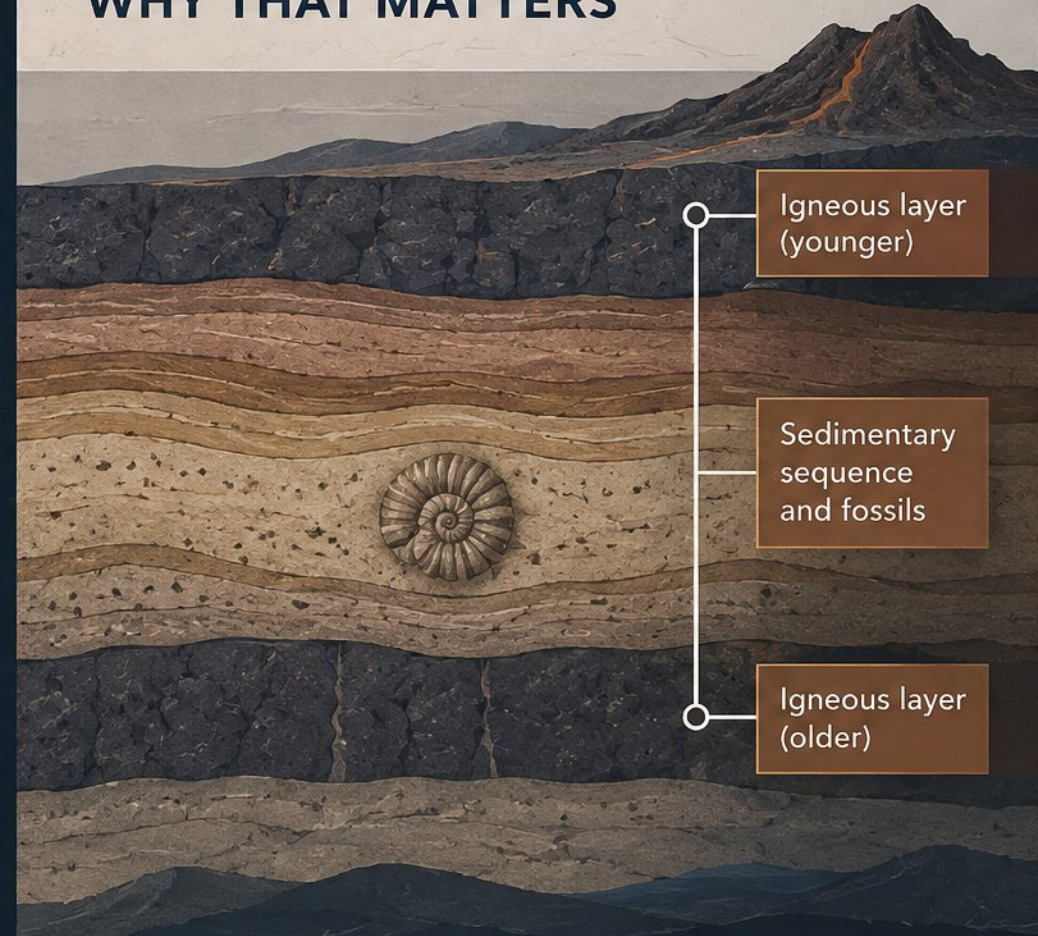


An anomalous result signals contamination or open-system behavior, not a failed method.



Ages are estimates with stated ranges, not exact numbers or arbitrary guesses.

## WHY THAT MATTERS



Understanding the limits helps us use radiometric dating correctly—and draw more reliable conclusions about Earth's history.

# Practical Takeaways for Learners and Educators

## BUILDING CONFIDENCE IN GEOCHRONOLOGY



**Checklist:** method, sample context, closed-system evidence, uncertainty, validation



**Classroom:** model decay with dice; plot a real isochron dataset



**Match methods to materials:** argon-argon on ash, U-Pb on zircon



**Trusted sources:** USGS, NASA, NIST, peer-reviewed geochronology journals



**Teach honestly:** ages are estimates with uncertainty, not guesses



**Key terms:** isotope, half-life, isochron, concordia, closure temperature



# Summary and Key Numbers to Remember

DATING OUR PLANET



**Earth is  $4.54 \pm 0.05$  billion years old,**  
from meteorites, lunar samples, and oldest minerals



**Carbon-14:** half-life ~5,730 years;  
useful to ~50,000-60,000 years



**Potassium-40:** half-life ~1.25 billion years;  
powers argon-argon dating



**Uranium-238 ~4.47 billion years and  
uranium-235 ~704 million years** enable U-Pb concordia



**Radiometric dating is self-checking:**  
independent methods and interlaboratory  
comparisons agree



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