G-100 Lectures 12 & 13 A riddle: **Clocks in Rocks**

"This thing all things devours:

Birds, beasts, trees, flowers;

Gnaws iron, bites steel,

Grinds hard stones to meal;

Slays king, ruins town,

And beats high mountains down".

J.R.R. Tolkein (1937) The Hobbit

Humankind has been obsessed with telling time since the beginning of recorded history

These phenomena have long been





appreciated as important to survival Serpent shadow at Vernal Equinox

Change of Season

• Chichen Itza (500-900 A.D.) Mayan pyramid; Timekeeping machine & Astronomical calendar





Hutton's Unconformity iccar Point, Scotland

of the Earth to be about 6,000 years, came a voice of reason:

> beginning-no prospect for

> > James Hutton (1788), Scotland

Clocks in Rocks

- Used to measure "deep time"
- Determine timing and rates of geological processes
- Relative time
 - Reconstructing geologic history from stratigraphic record
 - Observations: Fossils, stratigraphy, cross-cutting relationships
- "Absolute" time
 - Geologic clocks based on radioactive decay
 - A (current) geologic time scale

Geologic history from the stratigraphic record Principles of Stratigraphy

 original horizontality NORASSIENON • superposition



 Niels Stensen (1638-1686) Danish physician and anatomist

Research in Italy in 1660s, published geological conclusions in 1669 (Prodromus)

faunal succession

- William "Strata" Smith (1769-1839) English surveyor
 Practical observation that each individual rock layer contained its own specific assemblage of fossils (1796)
- Published first geologic map of England (1815)















Geologic history from stratigraphy

• Unconformities

- -Gaps in the stratigraphic record
 - Disconformity
 - Angular unconformity

• Cross-cutting relationships

- -Faults
- Igneous intrusions





















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TIME 2

TIME 3



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TIME 3

A dike from molten magma intruded the folded layers, cutting across them. Because the dike can be seen to cut a cross the folded layers, it is clear that sedimentation and folding preceded the intrusion.

TIME 4

Faulting displaced the layers and the intruding dike. Because both the sedimentary beds and the dike are displaced, faulting had to have taken place after their formation.

Figure 8-9 part 3 Understanding Earth, Fifth Edition © 2007 W. H. Freeman and Company



Fault











Henri Becquerel b. 1852 / d. 1908



Becquerel (1896) <u>Sur les radiations emises par</u> phosphorescence. Comptes Rendues Acad. Sci. Paris, v. 122, 420-21.

- Discovered natural radioactivity (x-rays fog photographic plate)
- Nobel Prize in Physics 1903 (with Pierre and Marie Curie)



Ernest Rutherford b. 1871 / d. 1937 Rutherford & Soddy (1903) <u>Radioactive Change</u>. *Phil. Mag. ser. 6, v. 576-91*.

Atomic "disintegration" theory of radioactivity

Nobel Prize in Chemistry 1908

Numerical Ages

- Isotopic Dating
 radioisotopic or radiometric dating
- Isotopes and Radioactive Decay
 - -Isotopes
 - Atoms of an element with differing number of neutrons, but same number of protons
 - -Radioactive Decay
 - Spontaneous nuclear disintegration of unstable isotopes



Numerical Ages

- Radioactive Decay
 - -Parent isotope decays to daughter product
 - rate of decay measured by physicists
 - decay process is "exponential", not linear
 - half-life
 - Time it takes for half the parent isotope to decay
 - After one half-life, equal amounts of parent and daughter isotopes are present in a mineral
 - decay constant
 - Portion of isotope that decays per unit time











•Arthur Holmes b. 1890 / d. 1965

Holmes (1913) The Age of the Earth, Harper & Brothers

· First geologist to apply radioactivity to dating rocks

- First numerical timescale (counters Lord Kelvin)
 - · Combined U-Pb date from Norway with Boltwood's results
 - Phanerozoic >400 million years long
 - Earth is >4 billion years old

Holmes (1928) <u>Radioactivity and Earth movements</u>.
Transactions Geological Society of Glasgow, v. 18, 559-606.
Suggested that mantle flows due to radioactive heating,

supporting Wegner's hypothesis of continental drift, 30 years before plate tectonic theory!

Isotopes		Half-Life	Effective Dating Panage	Minerals and Materials That Can	
Parent	Daughter	(years)	(years)	Be Dated	
Uranium-238	Lead-206	4.4 billion	10 million- 4.6 billion	Zircon Apatite	
Uranium-235	Lead-207	0.7 billion	10 million- 4.6 billion	Zircon Apatite	
Potassium-40	Argon-40	1.3 billion	10000- 4.6 billion	Muscovite, Biotite HornblendeK-feldspar	
Rubidium-87	Strontium-87	47 billion	10 million- 4.6 billion	Muscovite, Biotite Potassium feldspar	
Carbon-14	Nitrogen-14	5730	100- <mark>40</mark> ,000	Wood, charcoal, peat Bone and tissue	
				Shells and other calcium carbonates	

Why can Carbon-14 only be used over last 40,000 years of earth history ?

Numerical Ages

- · Uses of Isotopic Dating
 - -Age of eruption of lava, ash
 - ash fall deposits allow dating of sediments in paleolakes or oceans
 - -Age of intrusion
 - -Age of metamorphism
- Reliability of Isotopic Dating ?
 - -Multiple methods: U-Pb, Rb-Sr, K-Ar, etc.
 - Combine with Relative Dating Principles
 - Powerful means to understand time scales and rates of geological processes



Age of the Earth

- Early speculation
- Dating of meteorites
- U-Pb dating of zircon crystals –oldest rocks are 4.00 billion years old –oldest mineral grain found in sedimentary rock is 4.4 billion years old
- The Earth is 4.56 billion years old

4,560,000,000 years



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