What Makes the Historical Sciences Tick? Geochronology and the Ontology of Scientific Methods

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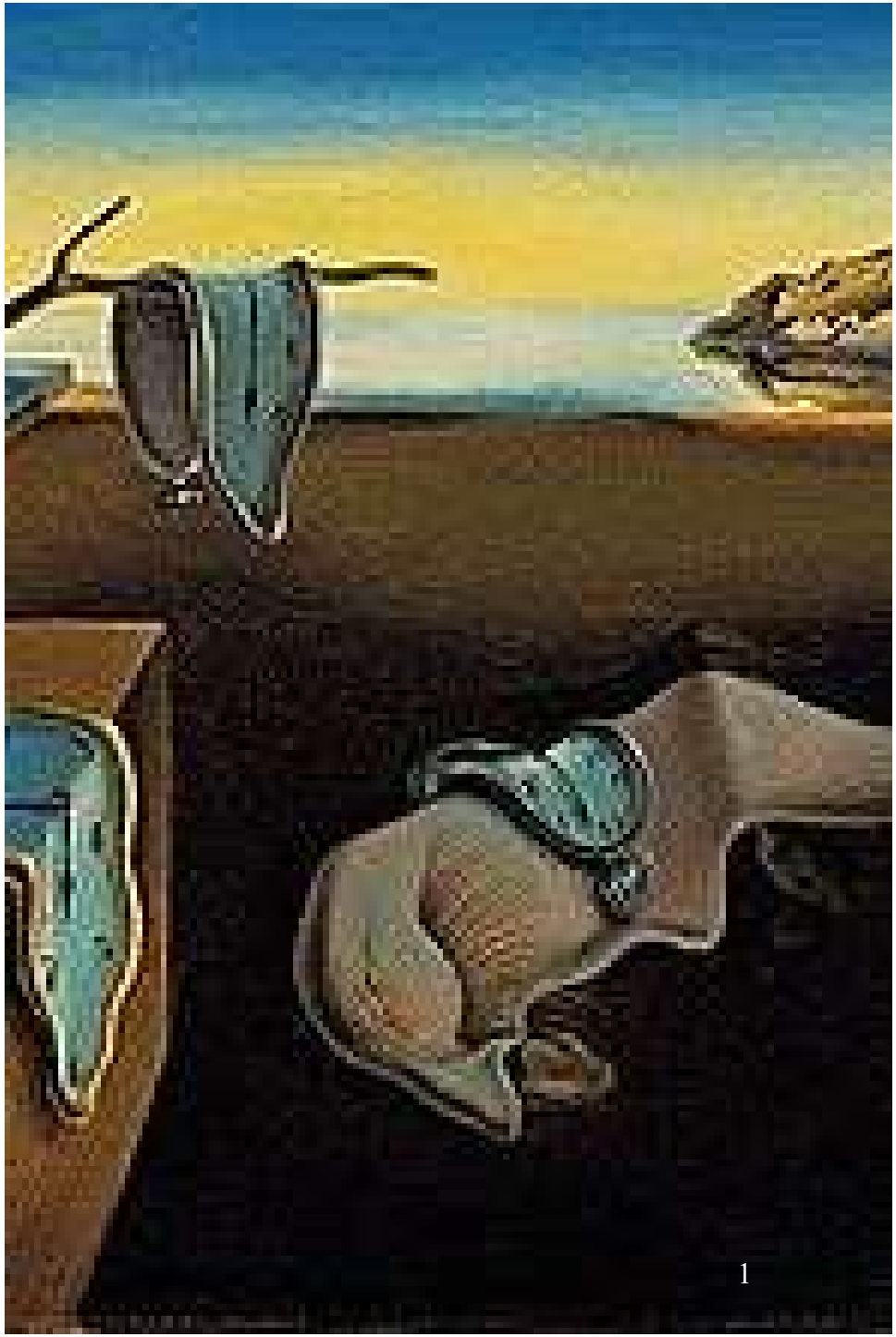

Measuring Geological Time

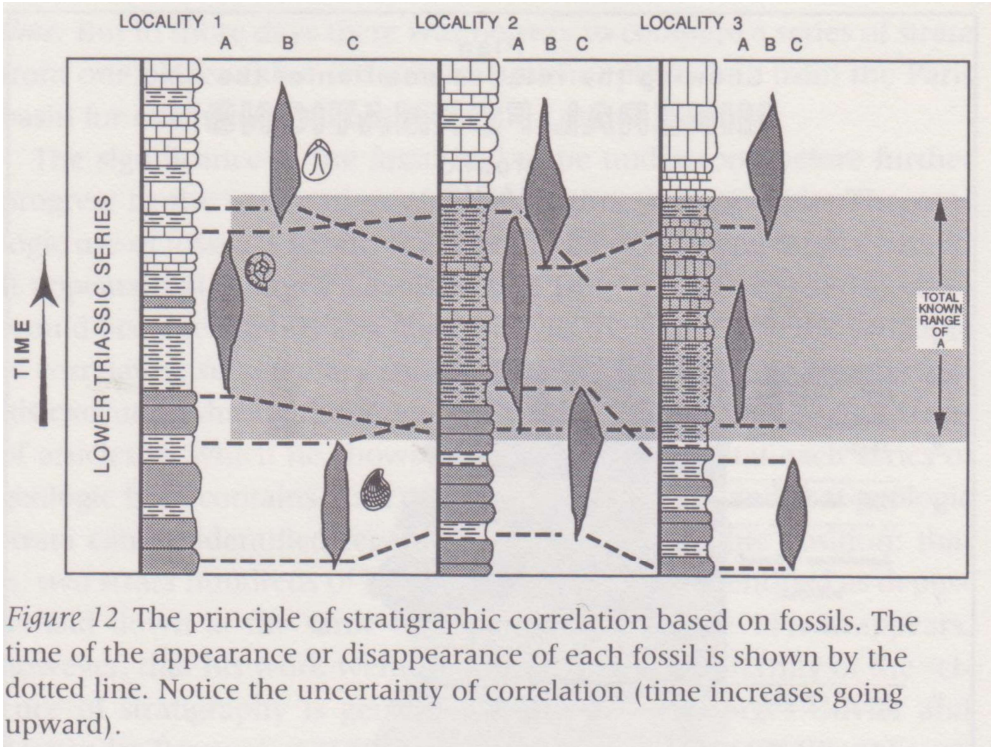

Figure 12 The principle of stratigraphic correlation based on fossils. The time of the appearance or disappearance of each fossil is shown by the dotted line. Notice the uncertainty of correlation (time increases going upward).

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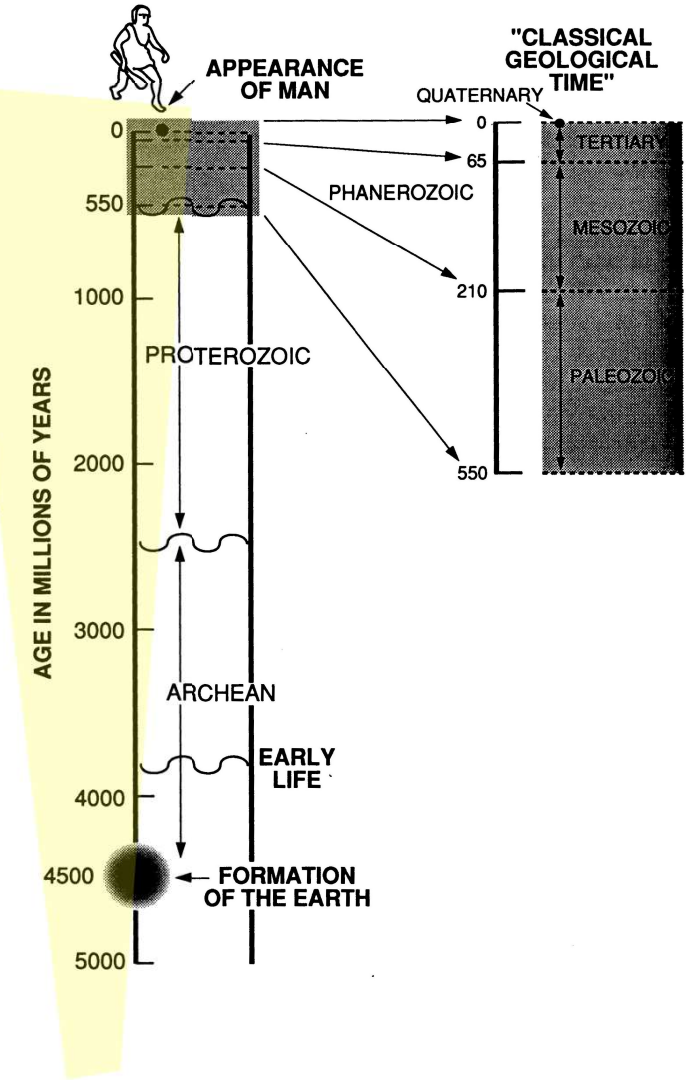

How was an absolute geological timescale established?

How was a timekeeper found?

Technology in the Historical Sciences

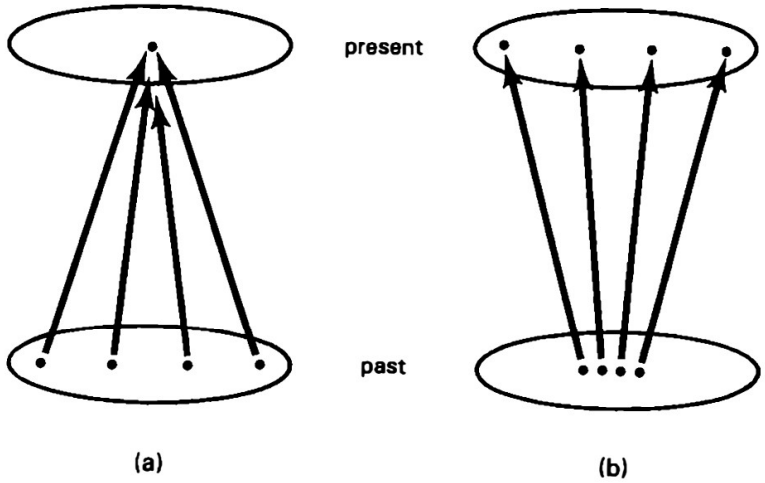

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Figure 1.
Whether observing the present state of a system provides evidence about its past depends on whether the process linking past to present is (a) information destroying or (b) information preserving. .

In general, the role of technological progress has been construed as one of enabling historical scientists to mitigate information destruction

Productivity in Geochronology

How do we make a concept measurable in a new domain?

Scientific techniques:

- ***Spell out what the concept means in a specific research context***

- ***Determine the concept's range of application***

Proposal: Radiometric techniques play this role for the concept of* age *in isotope geochronology

$$t = \frac{1}{\lambda}\ln\left\{\left[\frac{D - D_0}{N}\right] + 1\right\}$$

interpretation → ***Geological age***

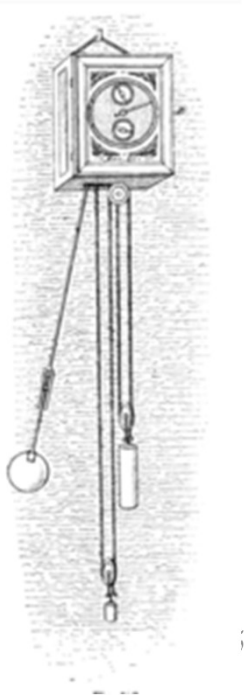
'Apparent age'

Measuring Time

- ***Continuous flow processes***
- ***Oscillatory processes***

Exhibit constancy (and irreversibility)

Problem for historical scientists: 'Asymmetry of manipulability' (Turner)



Need a process that is constant, theoretically tractable, and leaves traces

19th-Early 20th c.: "Classical" Geochronometers

- ***Tree-rings (O)***
- ***Sediment deposits in lakes (varves) (O)***
- ***Correlation of glacial and interglacial periods with astronomical cycles (O)***
- ***rates of morphological evolution (C)***
- ***Rock strata (O/C)***
- ***Ocean salt accumulation (C)***
- ***Alleged cooling of the Earth (C)***
- ***Slowing of the Earth's rotation (C)***

Lack of constancy, irreversibility

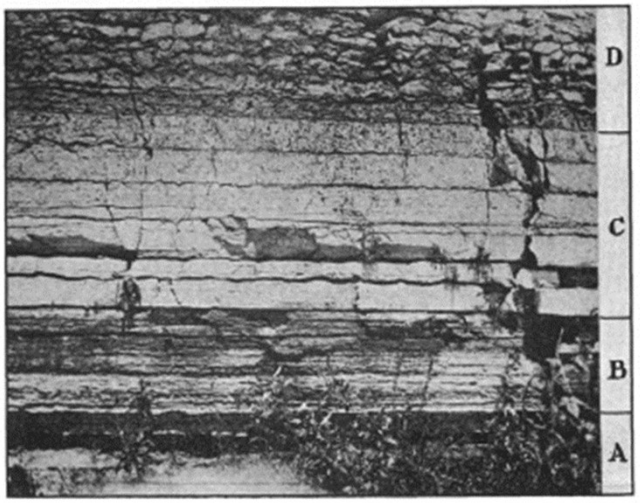
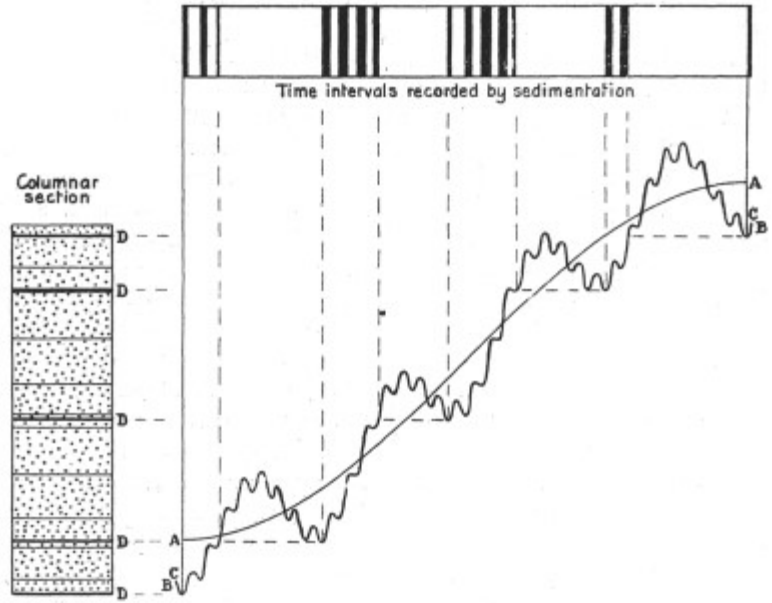


FIGURE 2.—CONTACT OF LOWVILLE AND BLACK RIVER LIMESTONES, NEWPORT, NEW YORK
Photograph by P. E. Raymond

LIMESTONE EXPOSURES IN PENNSYLVANIA AND NEW YORK



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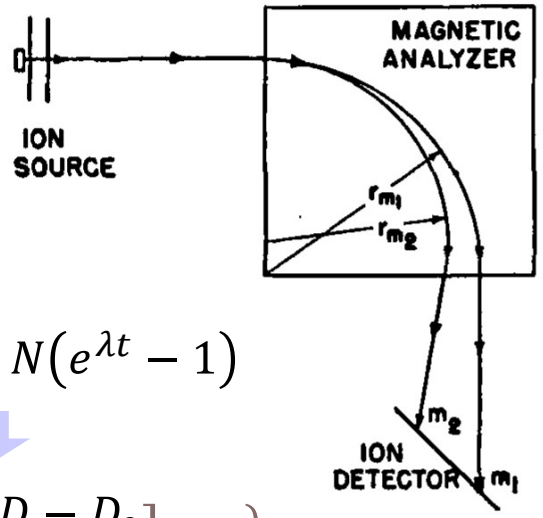
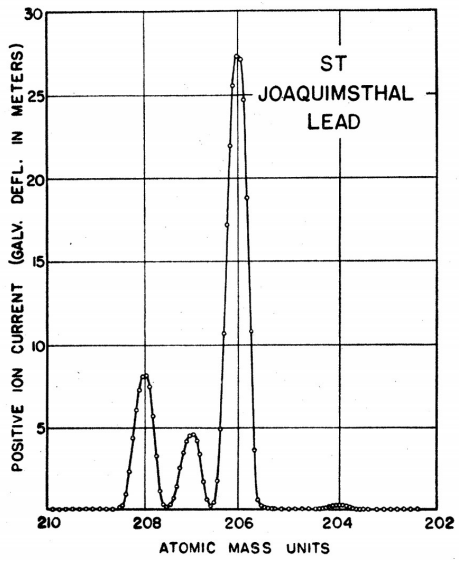
A-A. Primary curve of rising baselevel.
B-B. Diastrophic oscillations, giving disconformities D-D.
C-C. Minor oscillations, exaggerated and simplified, due largely to climatic rhythms. Equation of curve C-C: $y = \sin x - .25 \cos 8x - .05 \cos 64x$.

1896-mid-20th c.: Birth of Radiometric Geochronology



$$D = D_0 + N\left(e^{\lambda t} - 1\right)$$

$$t = \frac{1}{\lambda}\ln\left\{\left[\frac{D - D_0}{N}\right] + 1\right\}$$



Ernest Rutherford
1871-1937

Alfred Nier
1911-1994

Arthur Holmes
1890-1965

$^{238}U \rightarrow {}^{206}Pb$
$^{235}U \rightarrow {}^{207}Pb$

The basic method, ca. 1940s:

1. ***Analyze, chemically, elemental Pb and U***
2. ***Separate Pb isotopes by mass spectrometry***
3. ***Measure relative proportions from spectrum***
4. ***Calculate apparent age***
5. ***Correct and interpret to get geological age***

A More Promising Geochronometer

$$t = \frac{1}{\lambda}\ln\left\{\left[\frac{D - D_0}{N}\right] + 1\right\} = \frac{1}{\lambda}\ln\left[\frac{N_0}{N}\right]$$

Fractional rate of decay (λ) extremely stable

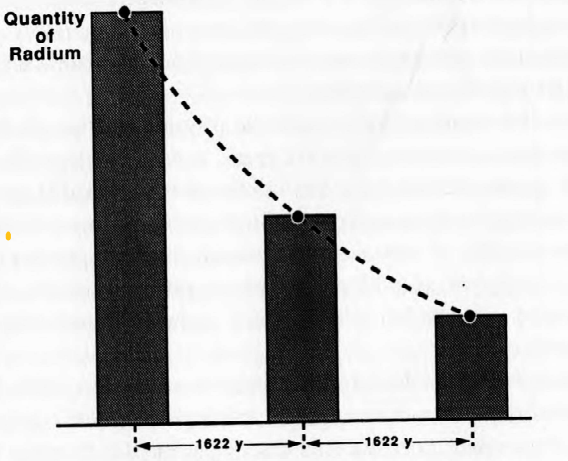


Figure 13 The principle of radioactivity. During each period the quantity of radium has decayed by half.

Decay irreversible

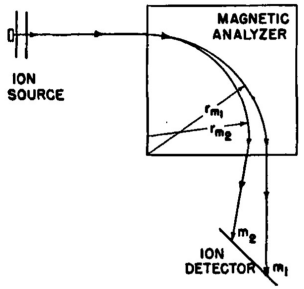
- ***Decay law satisfied conditions of constancy and irreversibility***
- ***The apparent age depends only on the chemical and isotopic composition of the sample***
- ***Certain conditions required for it to have full physical and geological significance***
- ***Derivation of decay law expresses the fact that decay is constant regardless of environmental conditions***
- ***Implies extremely broad range of application (subject to conditions)***

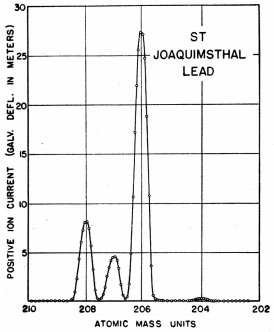
Decompositionism

Rock or mineral

analysis

“pure” element



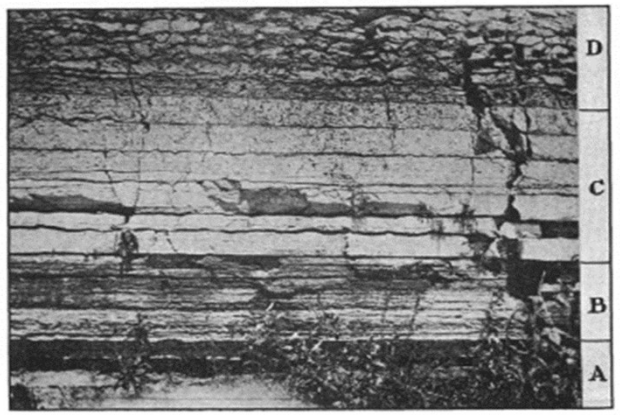


isotopes

- ***An ontological commitment: a world structured by compositional levels of organization***
- ***“Hierachical divisions of stuff … organized by part-whole relations, in which wholes at one level function as parts at the next (and at all higher) levels” (Wimsatt)***
- ***Shift to a different level typically involves a change of the size or size ranges of the entities, as well as a change of the regularities of their behavior***
- ***Entails possibility that the constituents may have radically different properties than the object they constitute***
- ***Claim: Success of radiometric methods resulted (in part) from an ontological shift to a lower level of organization***

Level-switching

- ***Historical processes unfold within a context, and a process at a given level of organization will be affected by its context to a greater or lesser degree***



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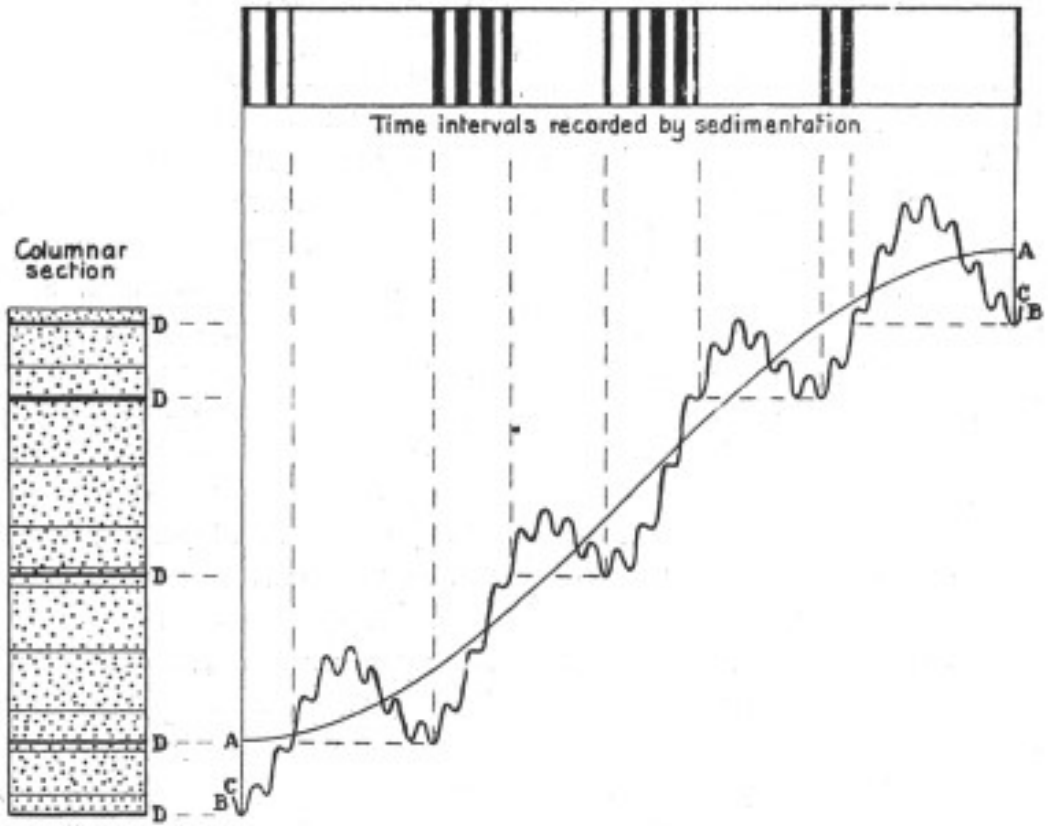

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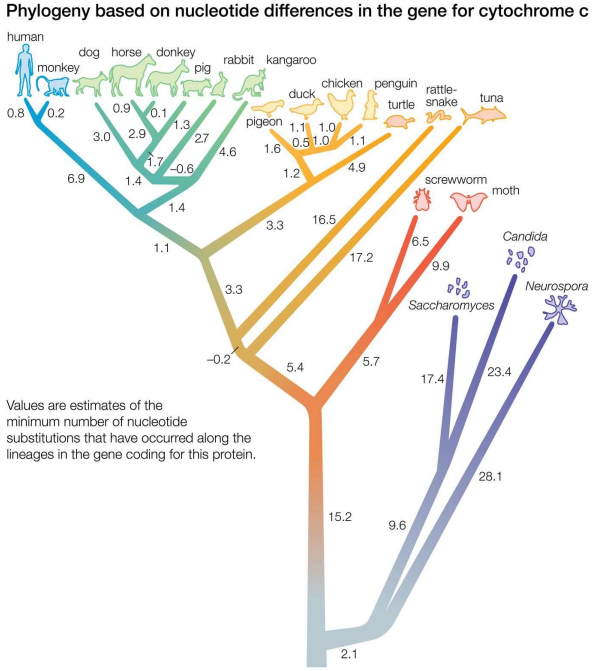
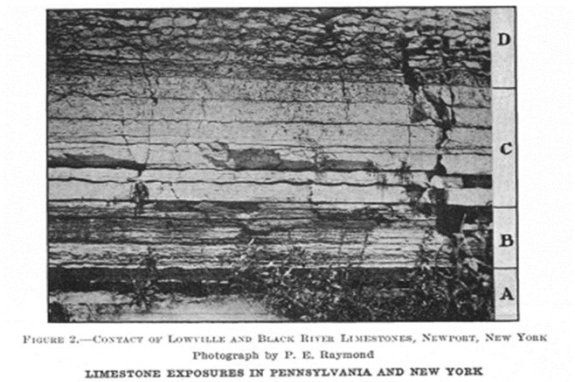
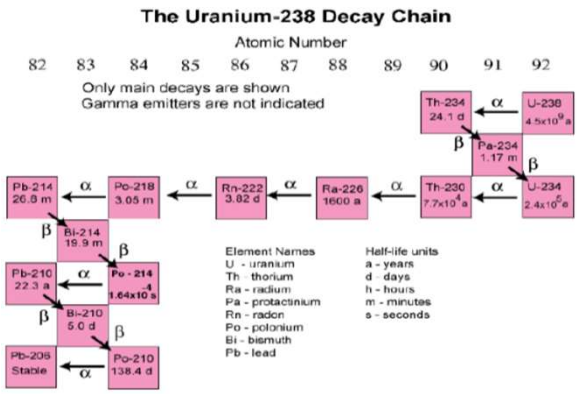
Level-switching







organization

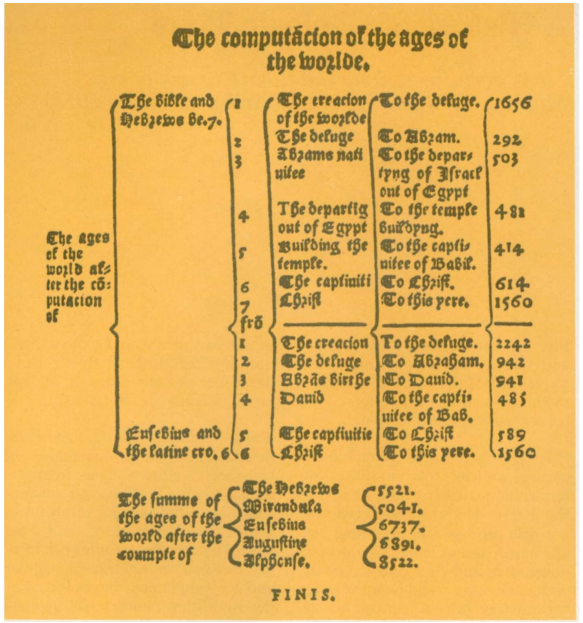
- ***Heuristic: if a process at a given level is too context-dependent to be reliable, then look for a lower-level process that can accomplish the same goal.***

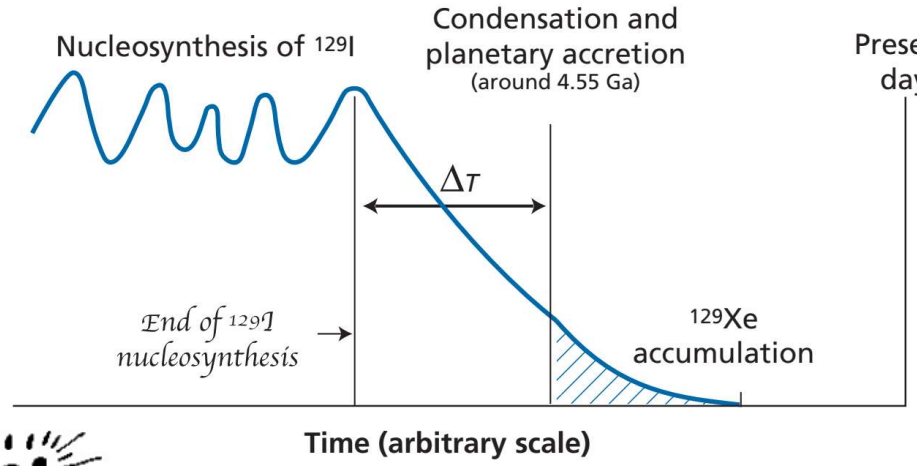
- ***The behavior of entities at higher levels of organization tends to be more context-dependent than that of entities at lower levels.***

- ***Hope: Information-destroying processes at the higher level will be avoided at the lower***

The Flourishing of Post-WWII Isotope Studies

The age of the Earth





The history of the solar system

The Flourishing of Post-War Isotope Studies

The history of the climate

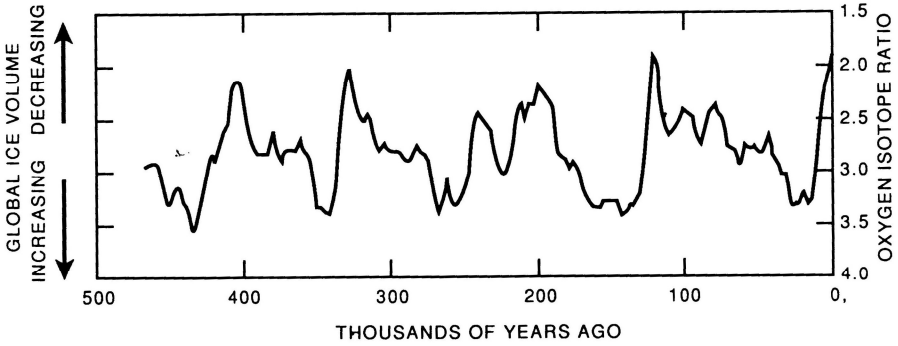
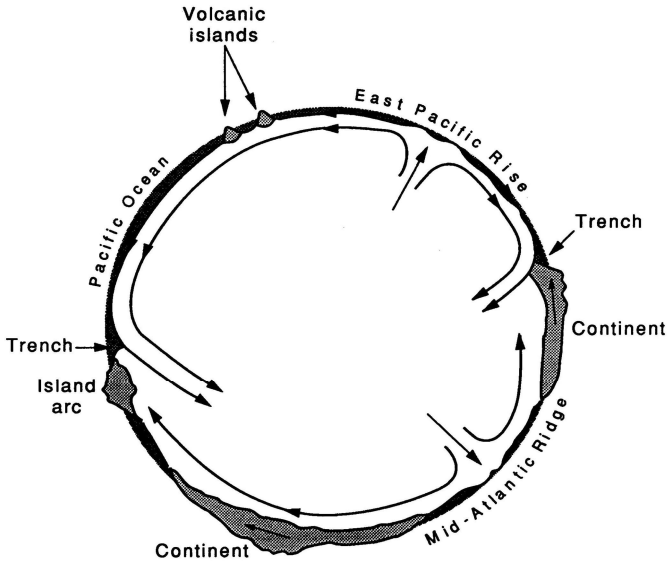


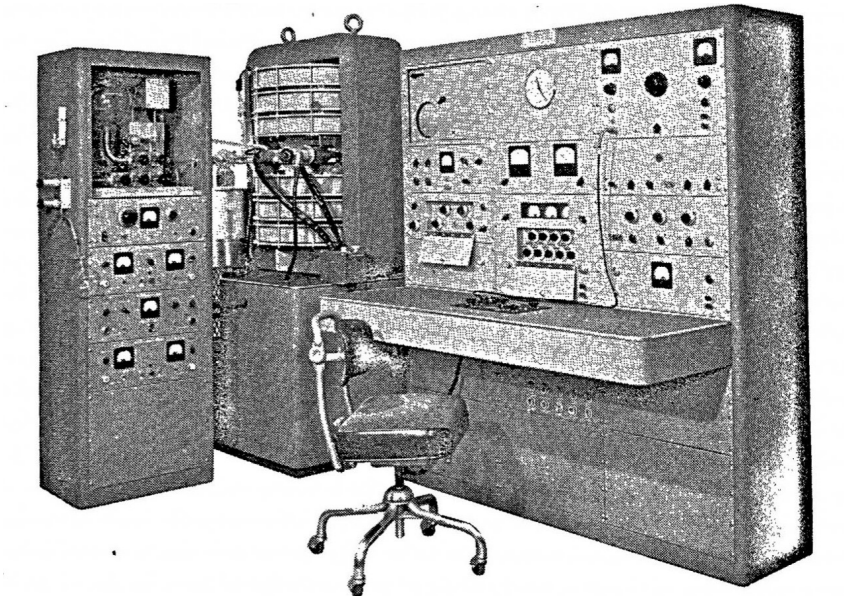
Figure 64 The variation in oxygen isotopes in seawater over the last million years, which reflects the variations in the average temperature of the surface as represented by the volume of ice in the ice cap.

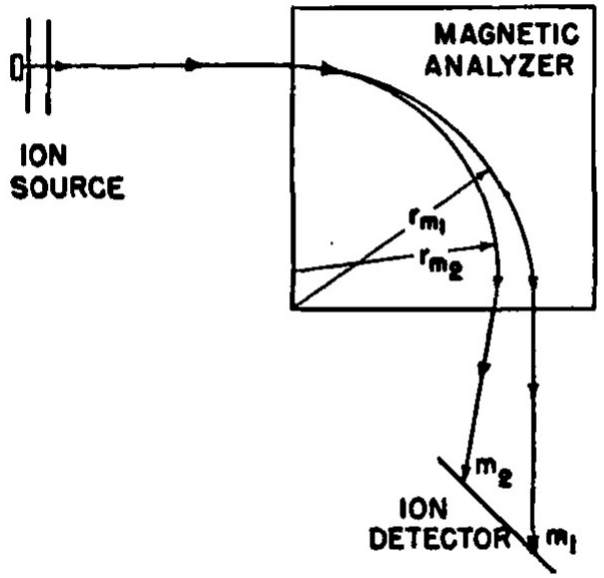
Tectonics and terrestrial evolution



- ***Overall impact: Isotope methods shattered spatial and temporal limits of traditional geology***
- ***Also expanded number of parameters whose history could be studied***

Role of Mass Spectrometry in Level-Switching

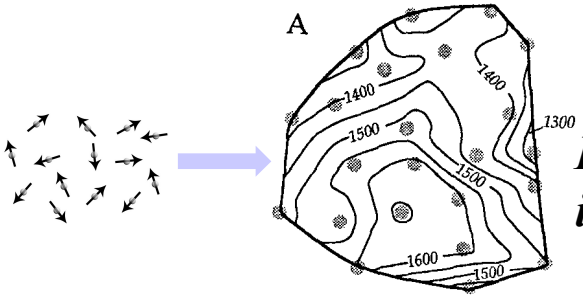




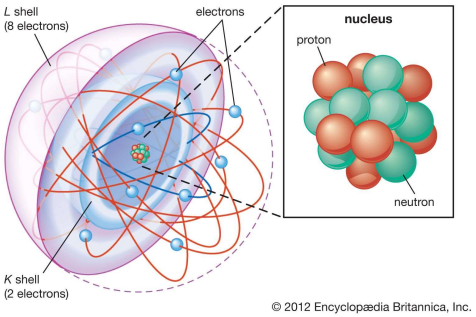
- ***Required for isotope separation***
- ***Complements decay law: use of MS not associated with any specific kind of geologic context, and so can take samples from widely different sources***
- ***More generally, techniques enables scientists to access desired levels in a level-switching strategy***
- ***Need flexibility of technology to access levels with sufficiently different properties to solve the problem***

Example: A crystal

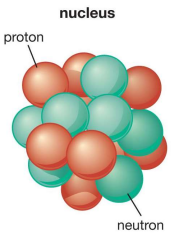
Crystal



Ensemble of isotopes



Atom



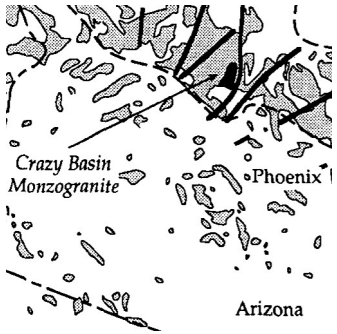
Nucleus → *nuclear force*

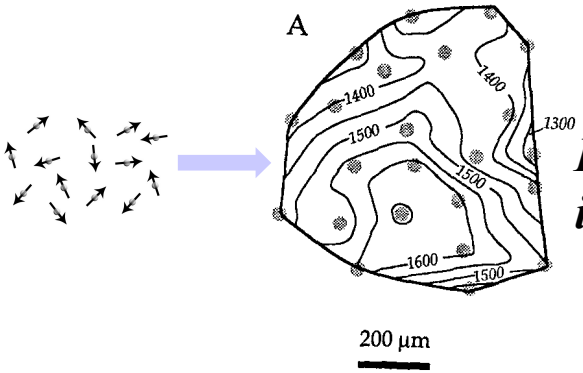
organization

"The quantum theory provides a reason for this insensibility of the radioactive elements to external influences. It is not difficult to remove electrons from the outer part of an atom, but radioactivity is a property of the nucleus, and the latter cannot be affected except by the application of radiation as energetic as its own. In the case of uranium the radiation emitted corresponds … to the unimaginable temperature of 5,800,000,000°C. Evidently the conditions encountered by rocks in the earth's crust are unlikely to affect atomic nuclei."

-Arthur Holmes, 1937

Role of Context is Level-Dependent





Ensemble of isotopes

organization

Two key assumptions:

i. No migration of parent or daughter elements into or out of system since solidification

ii. Distribution of isotopes was homogeneous at time of solidification

$$t = \frac{1}{\lambda}\ln\left\{\left[\frac{D - D_0}{N}\right] + 1\right\} = \frac{1}{\lambda}\ln\left[\frac{N_0}{N}\right]$$

- ***Homogeneity depends on diffusion of elements between subsystems of the sample, and between subsystems and the sample's environment***
- ***Not all levels equally affected: nuclear level largely shielded from contextual factors, whereas ensemble level subject to migration and homogeneity worries***

Comparison

"For the successful application of a method based on a progressive [continuous flow] process, it is necessary to know:

a) The rate of the process at the present time;

b) The law expressing the variation of the rate during the interval to be measured; and

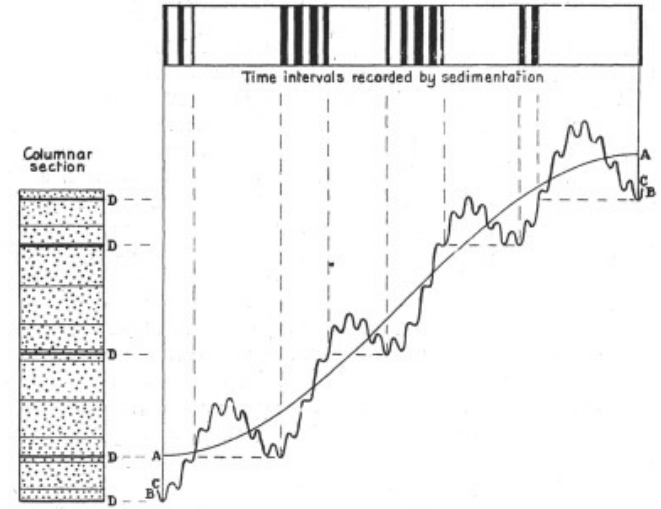
c) The total change effected by the process during that interval.

The accumulation in minerals of the end-products of radioactive decay constitutes the only progressive process so far recognised in which these conditions are satisfactorily fulfilled over the whole range of geological time."

-Arthur Holmes, 1947

$$Age \sim \frac{total\ change\ effected}{rate\ of\ process}$$

Comparison



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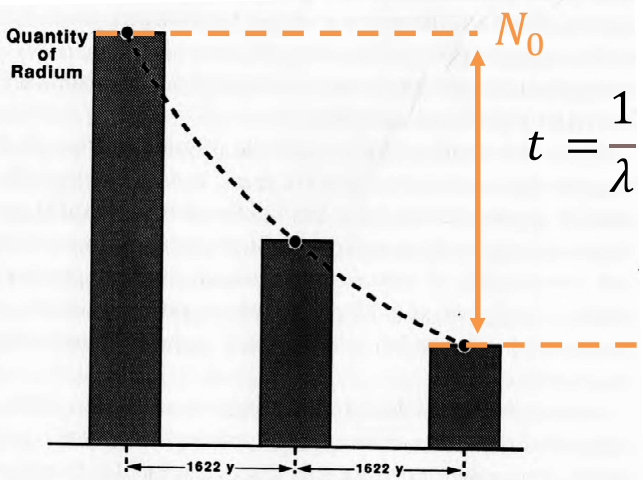
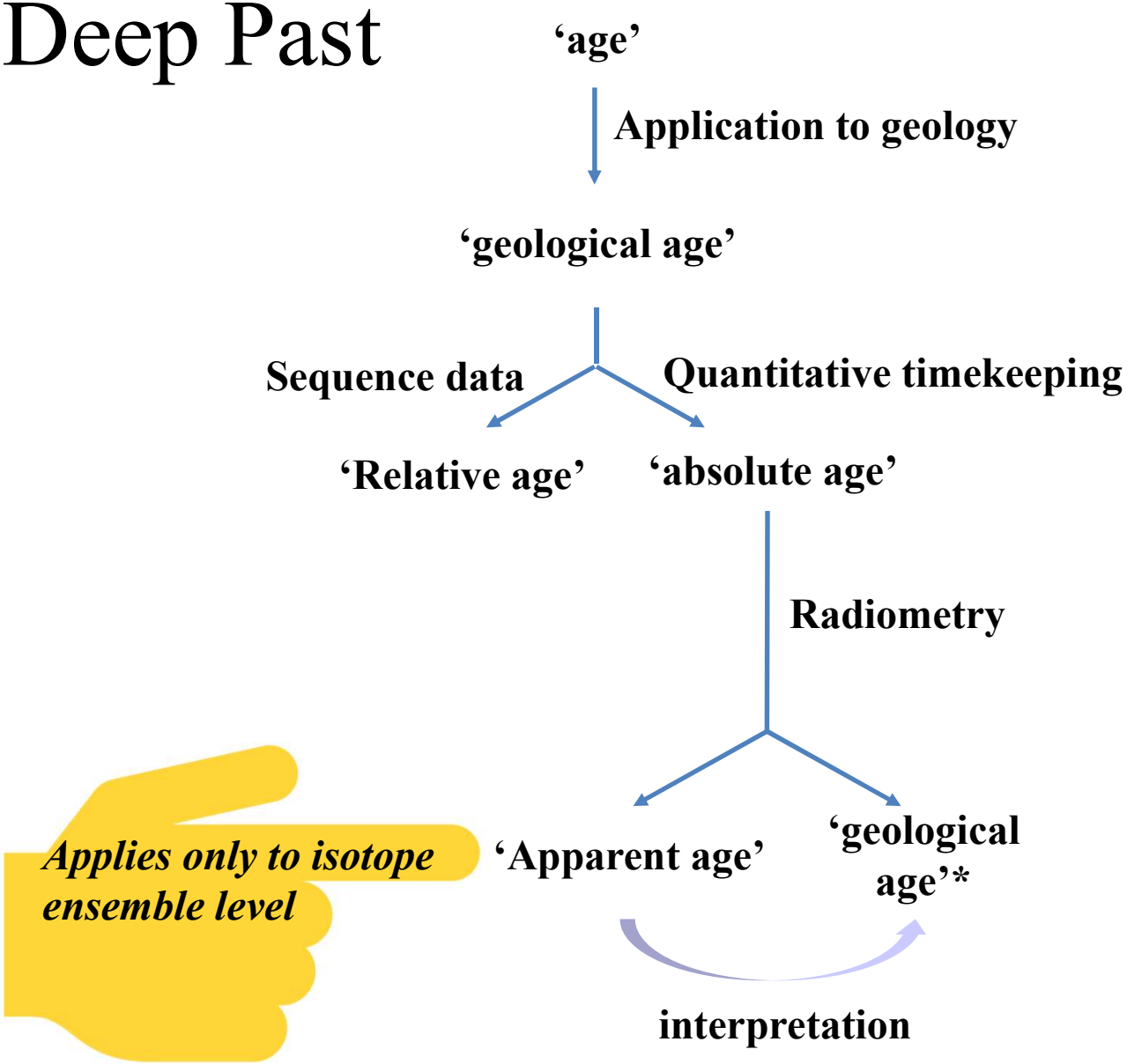


Figure 13 The principle of radioactivity. During each period the quantity of radium has decayed by half.

condition	Sediment accumulation	Radioactive decay
a) Present rate of process	*Context-dependent*	*Context-independent*
b) Law of variation of rate	*Context-dependent*	*Context-independent*
c) Total change	*Context-dependent*	*Context-dependent*

Conclusion: Making Time Measurable in the Deep Past



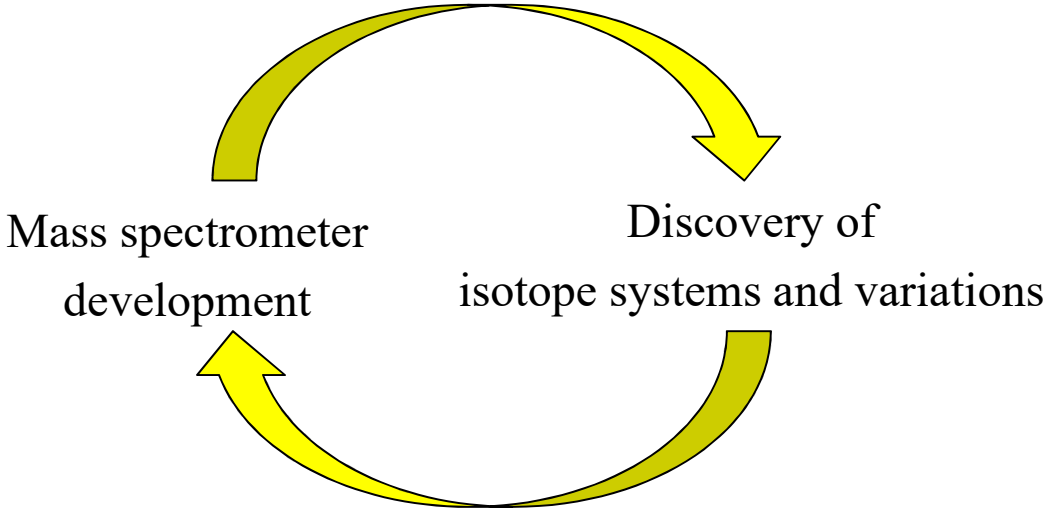
Conclusion: Productivity in Geochronology

The productivity of isotope geochronology is based on

a. Mereological decomposition in order to

b. exploit regularities at a lower level, and

c. an exceptional complementarity between the instrument and those regularities, allowing application to a plethora of geological contexts



Conclusion: Technology in geochronology

- ***The isotope-MS couple allows information destruction, concerning the age of geological objects, to be attenuated,*** **but also**

- ***further articulates the meaning of the concept of age in the geochronological context, and***

- ***determines the range of application of the concept***

- ***making possible an explosion of the research agenda of 20th c. geology, having started from the initial quest for a method of measuring time.***

- ***The metaphysical structure of a domain of scientific inquiry opens up methodological opportunities that can be exploited with the aid of technology.***

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