RADIOCARBON DATING: HOW THE GEOLOGICAL AND ARCHAEOLOGICAL SCIENCES DATE THE LAST 50,000 YEARS

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Geochronology: Quantification of the Geological and Paleontological Record

Eon	Era	Period	Epoch	Age (my)
Phanerozoic (13% of geologic time scale)	Cenozoic	Neogene	Holocene*	0.0115
			Pleistocene*	1.806
			Pliocene	5.332
			Miocene	23.03
		Paleogene	Oligocene	33.9
			Eocene	55.8
			Paleocene	65.5
	Mesozoic	Cretaceous		145.5
		Jurassic		199.6
		Triassic		251.0
	Paleozoic	Permian		299.0
		Carboniferous		359.2
		Devonian		416.0
		Silurian		443.7
		Ordovician		488.3
		Cambrian		542

* Holocene and Pleistocene traditionally combined to form Quaternary

Source: International Commission on Stratrigraphy

2004

Quaternary Geochronology

[Quaternary = last ~1.8 million years]

- **Major Data Sources**
  - Climatostratigraphy
  - Biostratigraphy
  - Paleomagnetic / Geophysical
  - Dating Methods

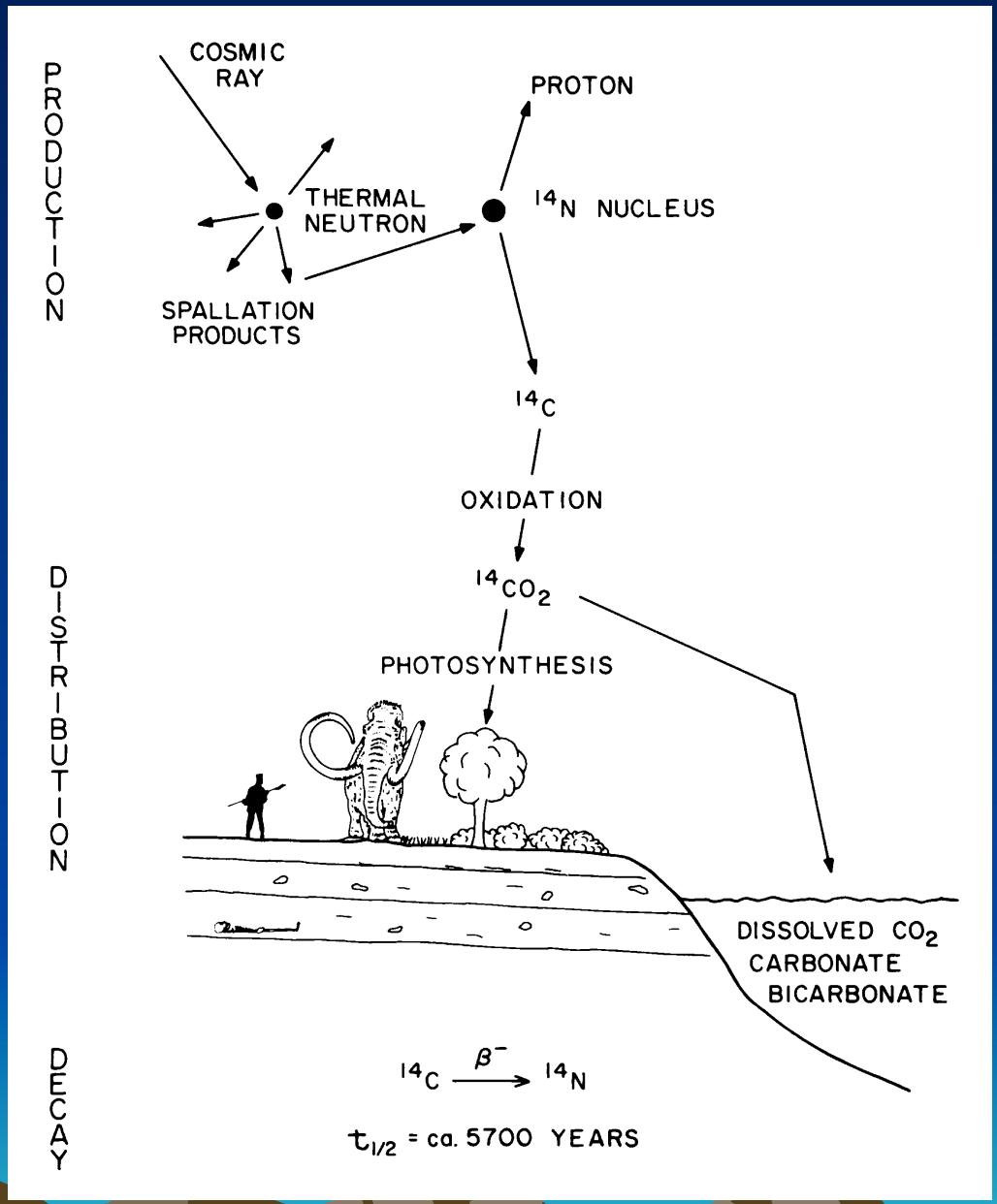
Quaternary Dating Methods

[Quaternary = last ~1.8 million years]

	process	
	rate dependent	pattern dependent
World-wide	radiocarbon (^{14}C)	geomagnetic
	potassium-argon / argon-argon	
	uranium-series	
	luminescence (TL/OSL)	
	electron spin resonance	
	fission track	
Regional	amino acid racemization	dendrochronology
	obsidian hydration	archaeomagnetic/ paleomagnetic
	fluorine	varve

Radiocarbon Dating

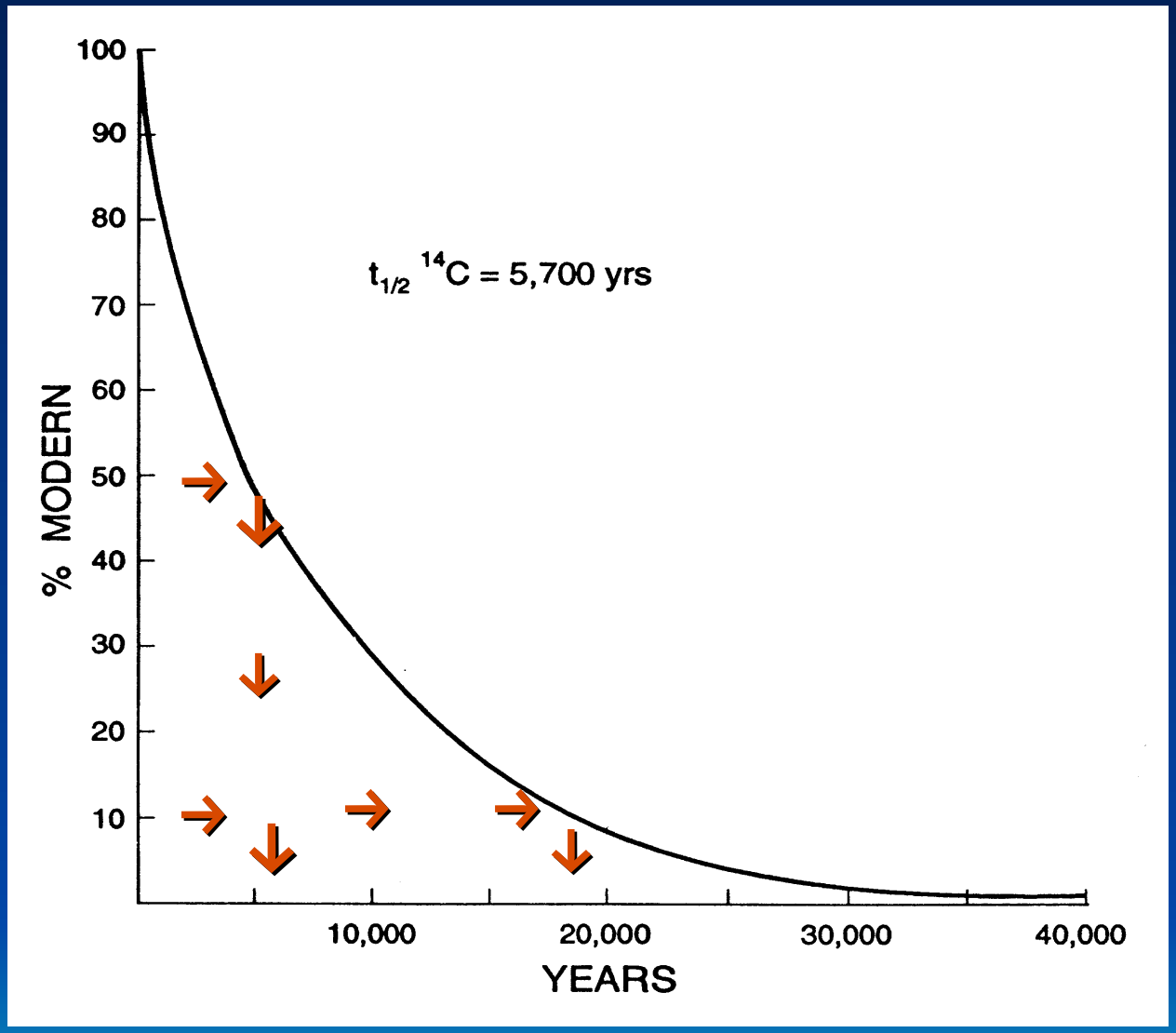
- ✓ **Principal isotopic dating method for the period from ~300 to ~50,000 years**
- ✓ **Gold Standard** for chronometric [time placement] dating in prehistoric archaeology, paleoclimate / paleoenvironmental research, Quaternary geology, authenticity of historic materials (e.g., Shroud of Turin, Noah s Ark)
- ✓ **60 years of experimentation and research** with scrutiny of data by many investigators and laboratories
- ✓ **Anomalies studied in detail** and reasons for most problematical results generally understood



Radiocarbon Dating: Physical Model

ACCURATE / PRECISE RADIOCARBON AGES: PHYSICAL ASSUMPTIONS

- ✓ **Zero age ^{14}C concentrations constant over ^{14}C time scale**
- ✓ **Complete and rapid mixing of ^{14}C in active carbon reservoirs**
- ✓ **Except for ^{14}C decay, carbon isotope ratios have not been altered in a sample since metabolism ceased**
- ✓ **^{14}C half-life/decay constant known to reasonable precision**
- ✓ **^{14}C concentrations can be measured to reasonable**



Radiocarbon Dating:
Residual ^{14}C Content (% Modern) to Conventional ^{14}C Age (Years BP)

Basis of Radiocarbon Ages

- **Radiocarbon age estimates are**
  - ✓ **Inferred** from the measurement of residual ^{14}C activity in a sample, by
  - ✓ Making a set of **assumptions**, and
  - ✓ **Expressing** the age estimate in terms of a set of conventions to yield an age in ^{14}C years, and
  - ✓ **Correcting, normalizing**, and/or **calibrating** to yield an age in solar/calendar years

ACCURATE / PRECISE RADIOCARBON AGES: CONTEXUAL ASSUMPTION

" Documented relationship between

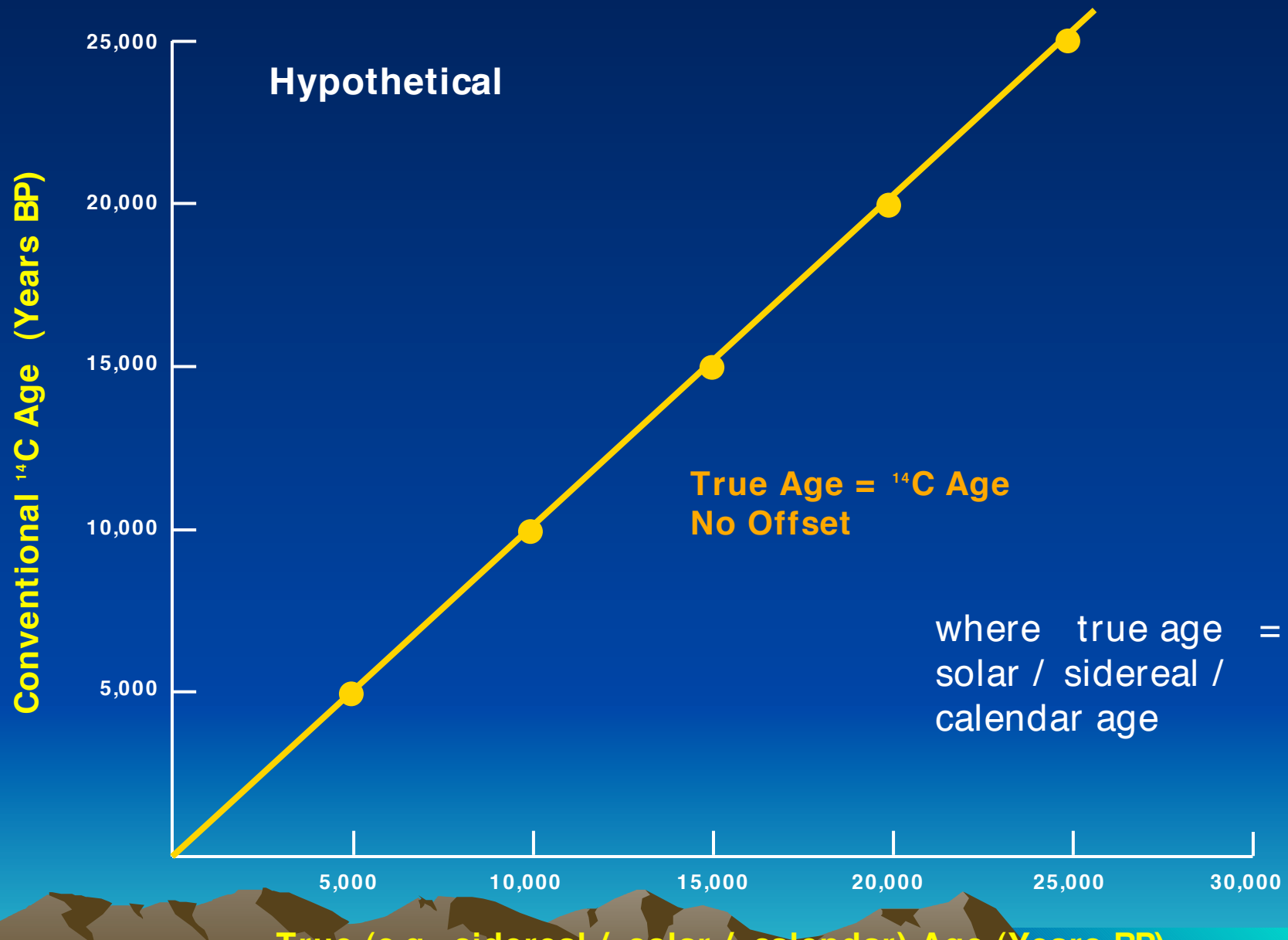
- ✓ an organic sample whose residual ^{14}C content is used to infer age, and
- ✓ a specific event or phenomenon for which temporal placement is desired

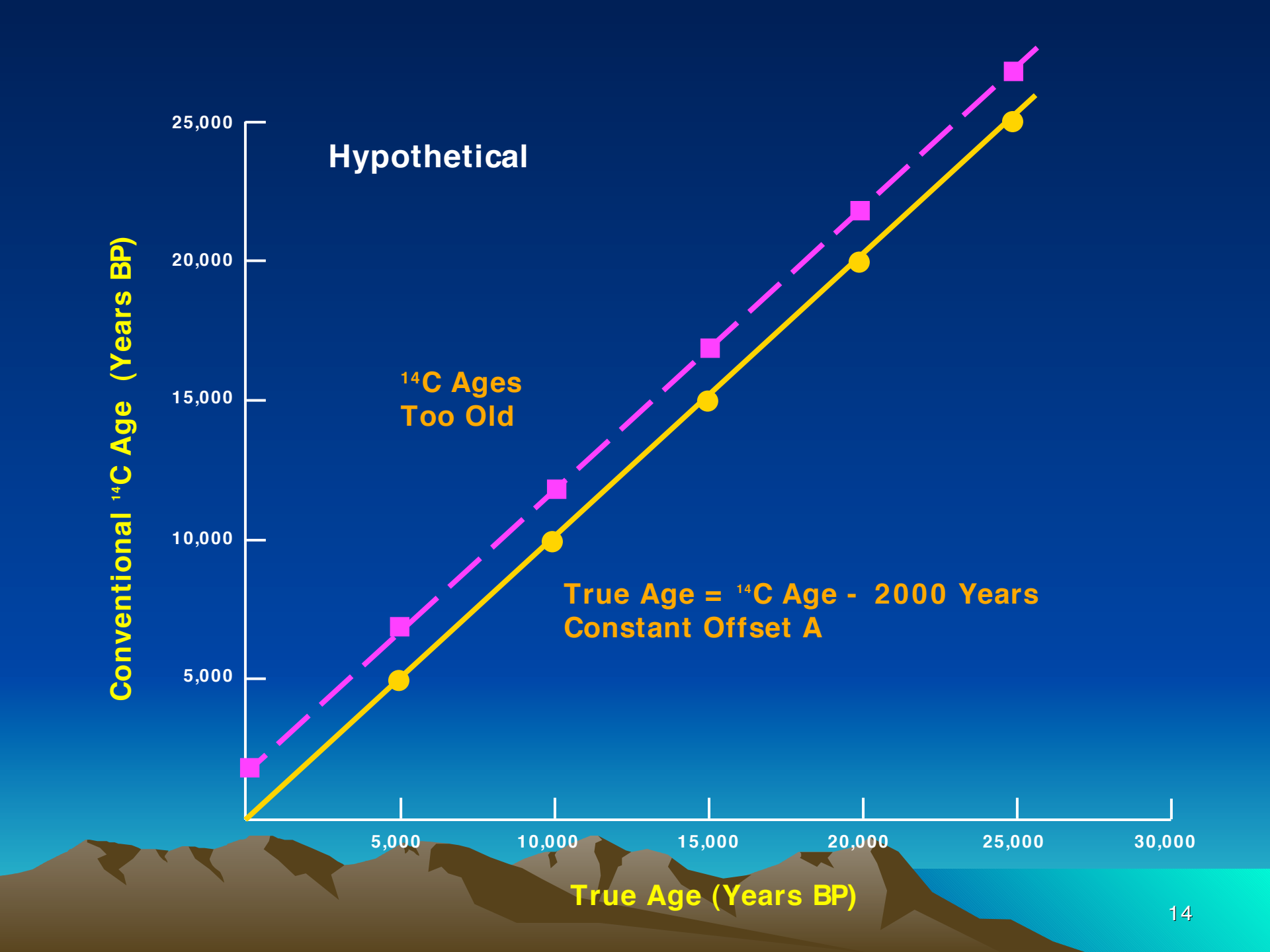
ACCURATE / PRECISE RADIOCARBON AGES: MAJOR FACTORS CREATING ANOMALIES

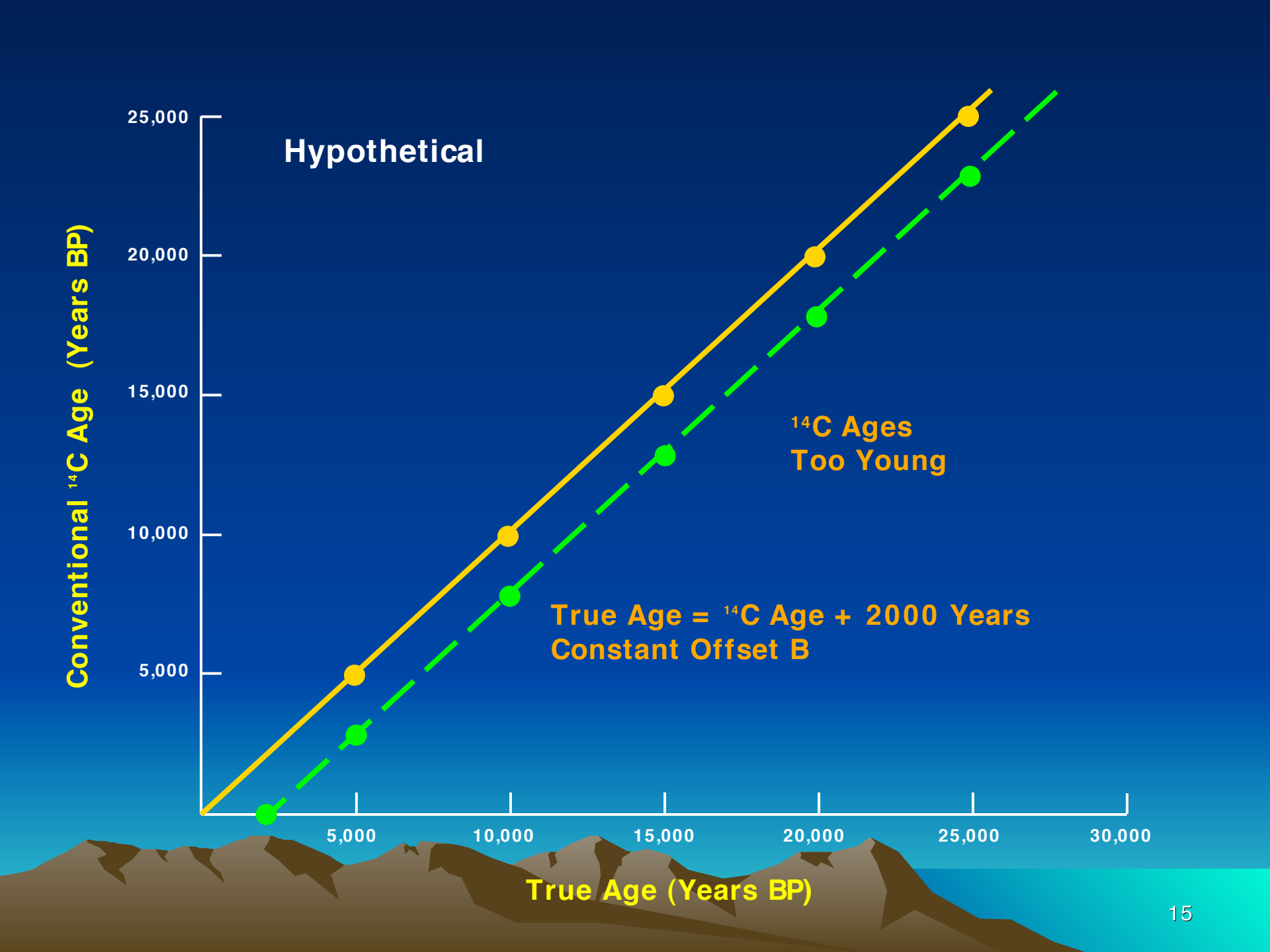
- Sample contextual factors
  - ✓ Stratigraphic resolution issues
- Sample composition factors
  - ✓ Contamination and fractionation effects
- Statistical and experimental factors
  - ✓ Accuracy and precision issues
- Systemic factors
  - ✓ Reservoir effects
  - ✓ Secular variation effects

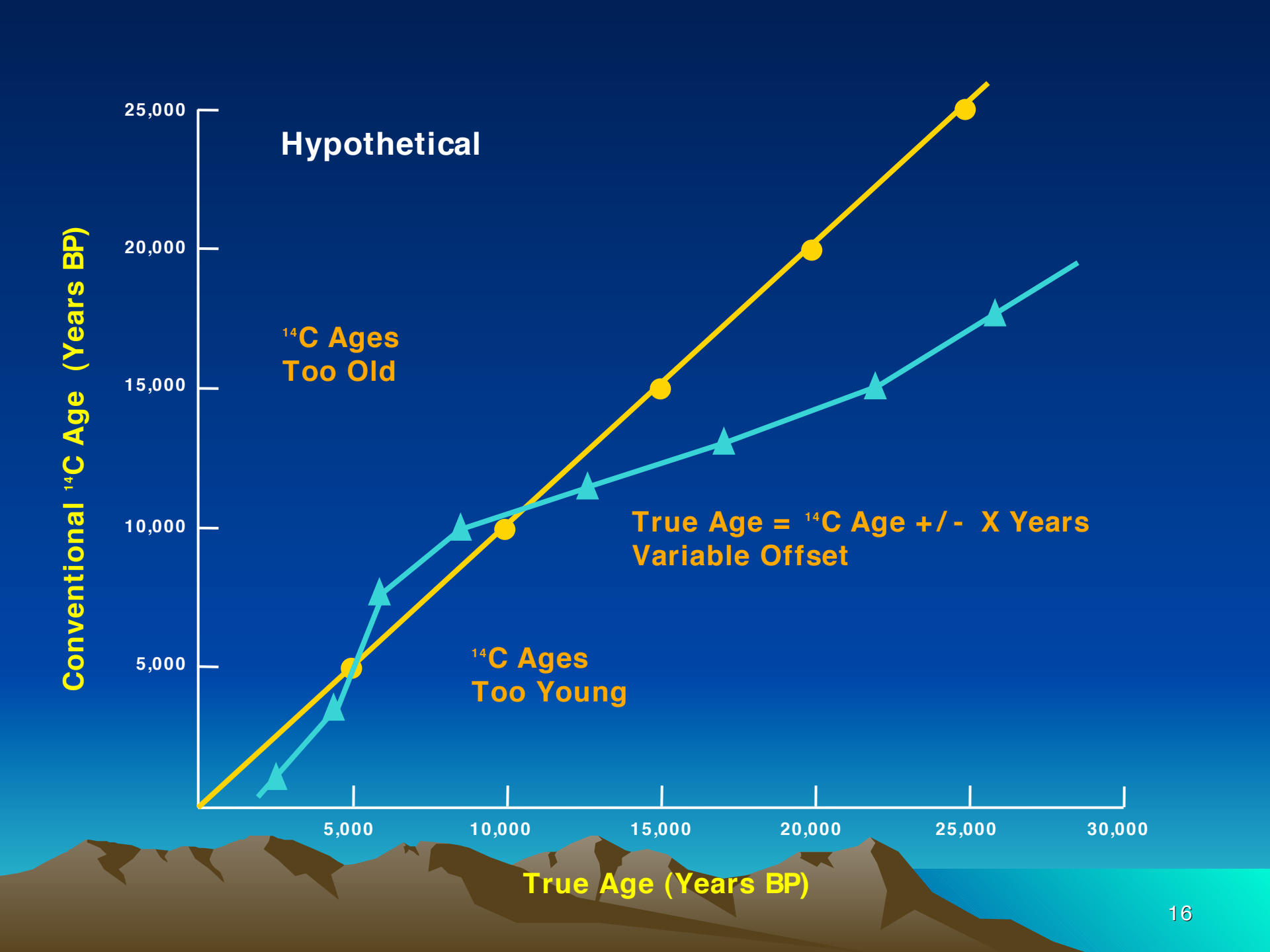
RADIOCARBON DATING: MAJOR ANOMALIES

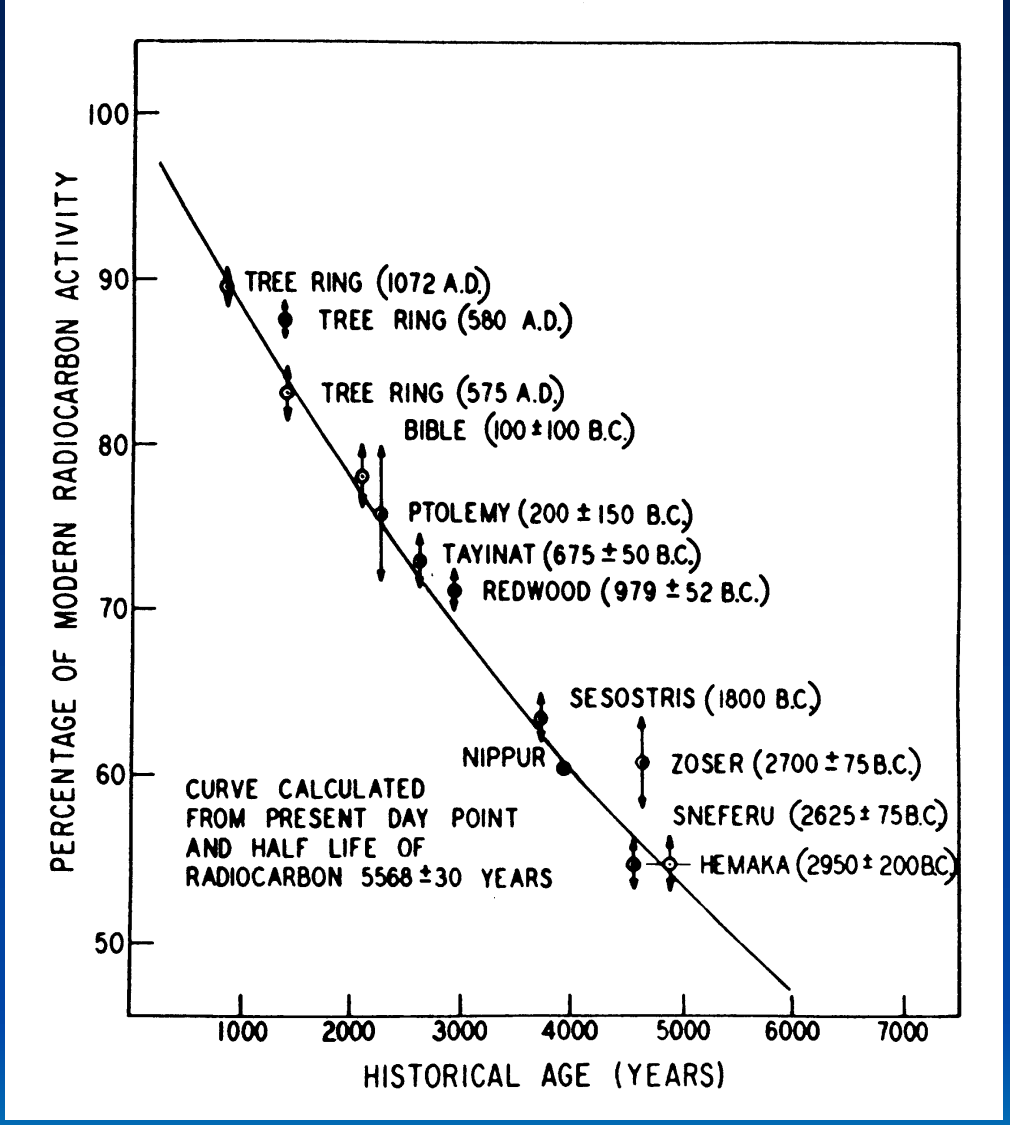
Assumption	Anomaly	Correction
	Systemic (world-wide)	
Constant zero-age Calibration Temporal	Natural Secular ^{14}C concentration	Variation
	Offsets	
	Anthropogenic Temporal Offsets	
	Suess/ Industrial/ Fossil Fuel effect	
	Libby/ Atomic bomb/ Nuclear effect	


Hypothetical
Conventional ^{14}C Age (Years BP)
25,000
20,000
15,000
10,000
5,000
True Age = ^{14}C Age
No Offset
where true age = solar / sidereal / calendar age
5,000
10,000
15,000
20,000
25,000
30,000
True (e.g., sidereal / solar / calendar) Age (Years BP)


Hypothetical
^{14}C Ages
Too Old
True Age = ^{14}C Age - 2000 Years
Constant Offset A
Conventional ^{14}C Age (Years BP)
25,000
20,000
15,000
10,000
5,000
5,000
10,000
15,000
20,000
25,000
30,000
True Age (Years BP)


Hypothetical
Conventional ^{14}C Age (Years BP)
25,000
20,000
15,000
10,000
5,000
^{14}C Ages
Too Young
True Age = ^{14}C Age + 2000 Years
Constant Offset B
5,000
10,000
15,000
20,000
25,000
30,000
True Age (Years BP)

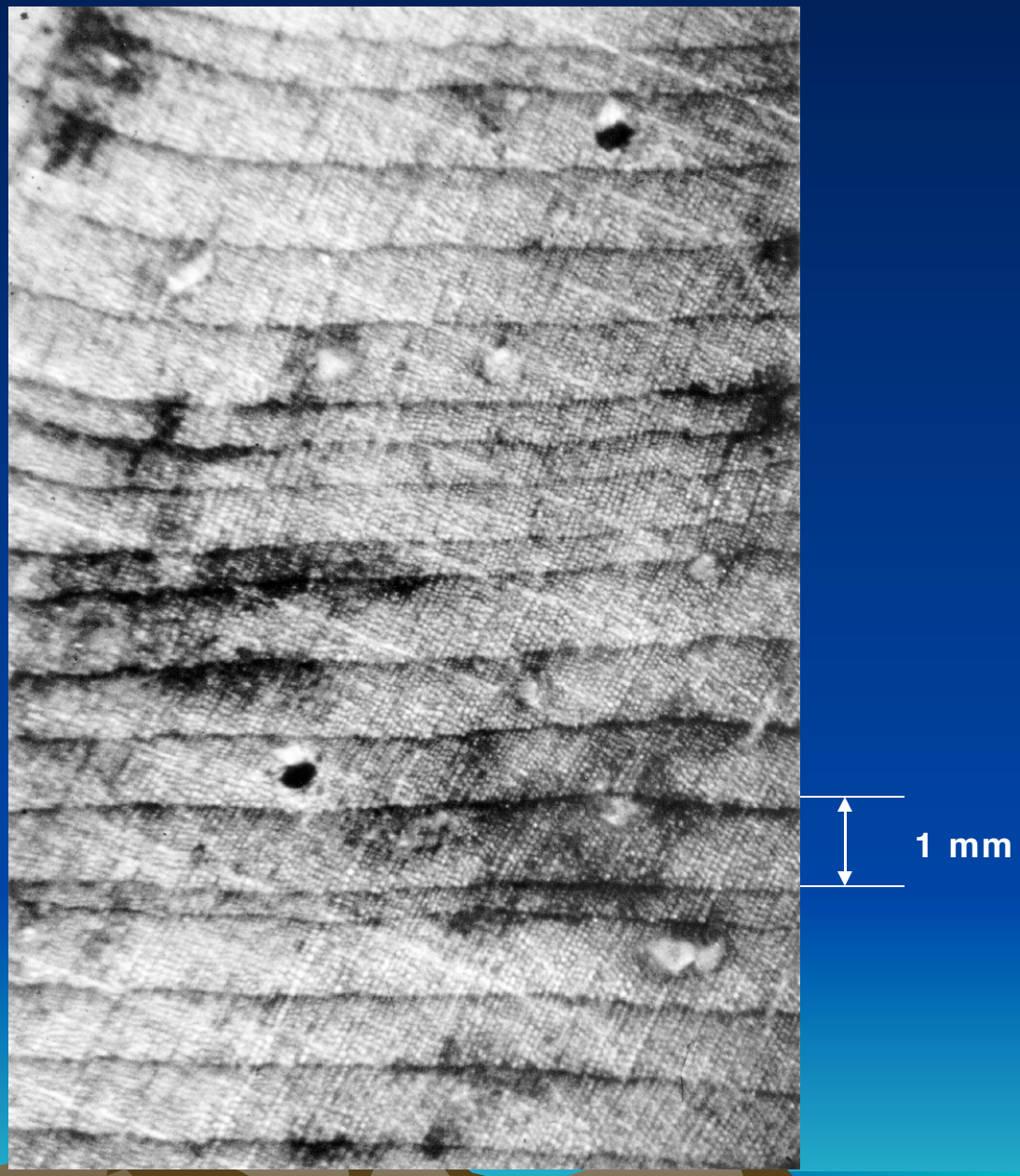

Hypothetical
Conventional ^{14}C Age (Years BP)
25,000
20,000
15,000
10,000
5,000
^{14}C Ages
Too Old
True Age = ^{14}C Age +/- X Years
Variable Offset
^{14}C Ages
Too Young
5,000
10,000
15,000
20,000
25,000
30,000
True Age (Years BP)



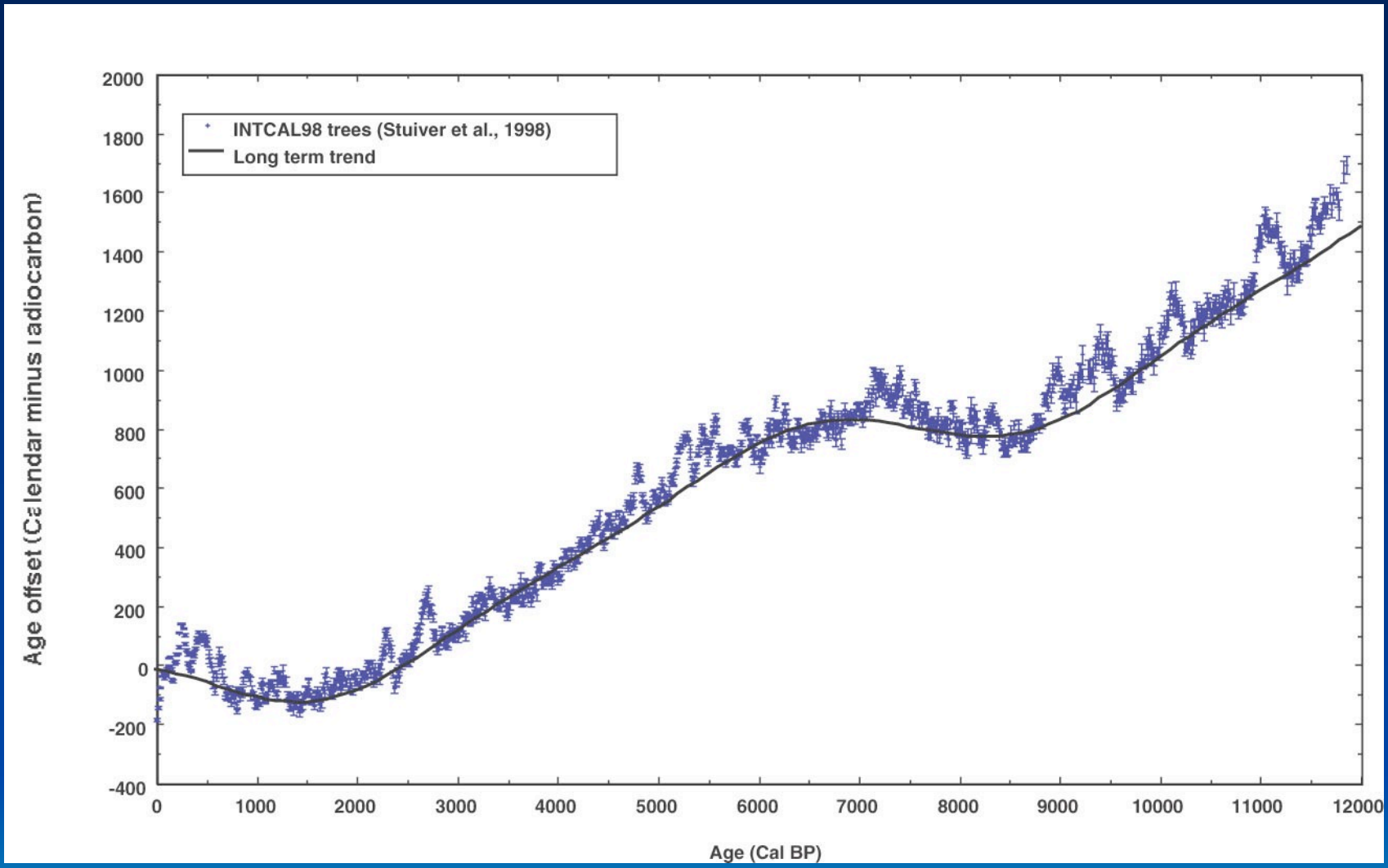
Radiocarbon Dating:
Second Libby Curve of Knowns (1955) Using
$t_{1/2}$ = 5568±30 Years

Bristlecone Pine (*Pinus longaeva*), White Mountains, California

Numerous studies have demonstrated that **individual tree- rings in certain species of trees in certain environments are isotopic isolates** i.e., each ring contains carbon that derives from the successive annual sampling of atmospheric CO_2 with no evidence of cross- talk between Individual rings

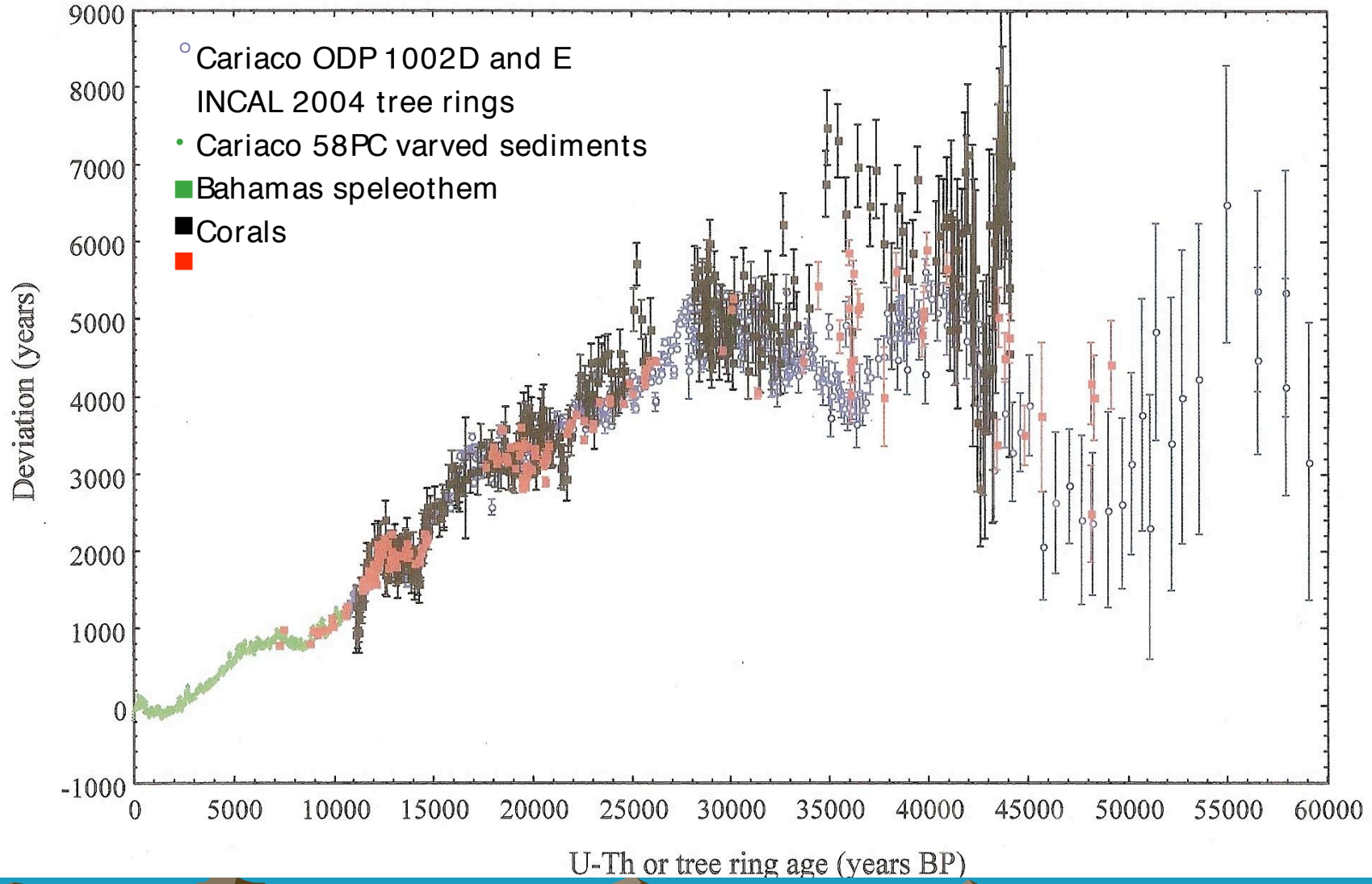


Bristlecone Pine Tree Ring Section, magnified



Deviation of ^{14}C- from dendrochronological- inferred ages

Radiocarbon time scale: Age offsets to 60 ka



Sources: Hughen *et al.* 2004; Reimer *et al.* 2004; Hughen *et al.* 2000; Beck *et al.* 2006; Fairbanks *et al* 2005; J. Southon, personal communication, 2007.

RADIOCARBON TIME SCALE: MAJOR CAUSES OF ^{14}C AGE OFFSETS

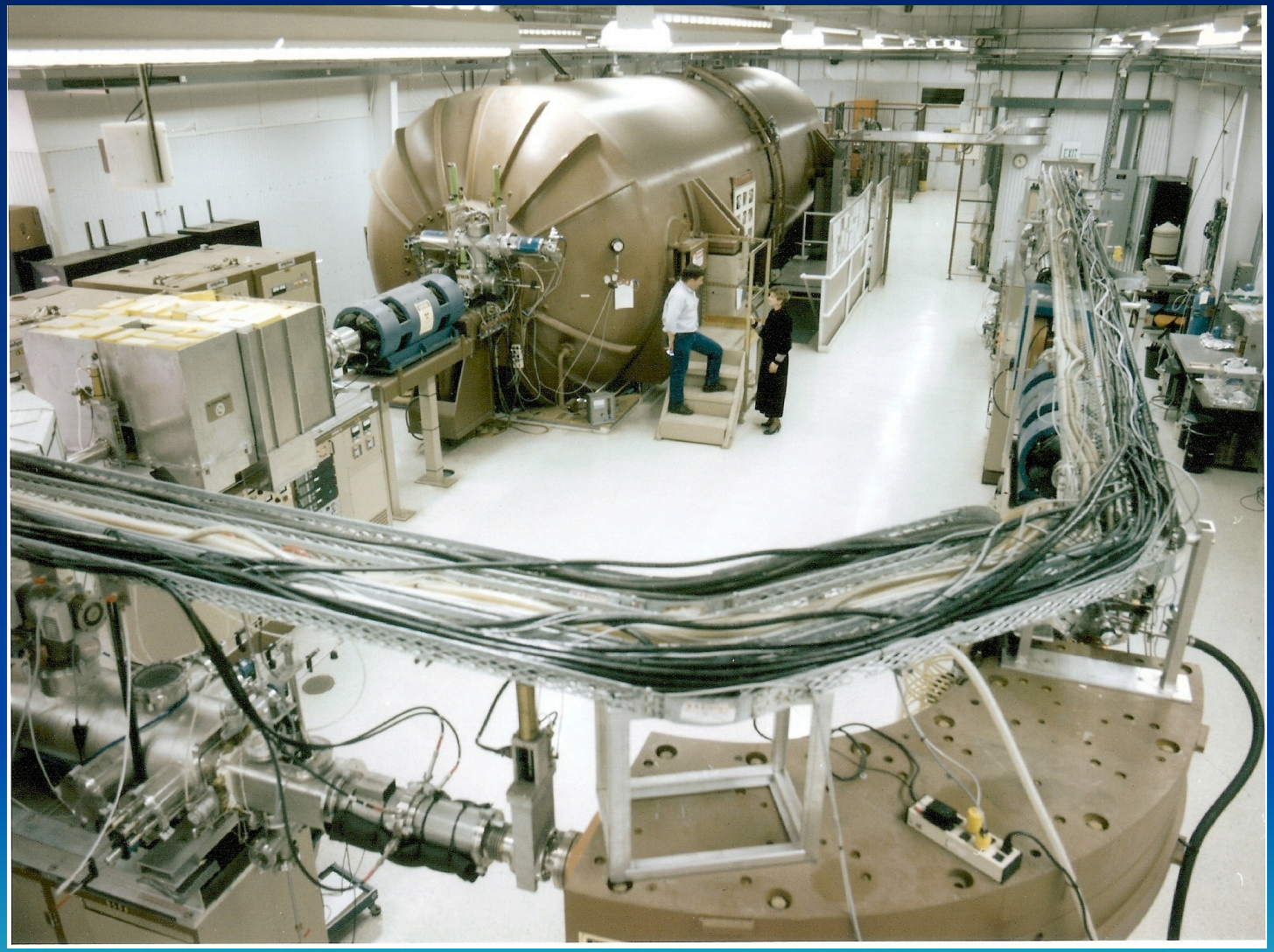
- **Main Trend (long-term cycles)**
  - ✓ 7000- and 3500-year sinusoidal geomagnetic intensity modulation of ^{14}C production

- **Fine Structure (short-term cycles [de Vries effects])**
  - ✓ Solar magnetic field modulation of ^{14}C production
  - ✓ Paleoclimate modulation of carbon cycle parameters
    - Variation in exchange rates between atmospheric

RADIOCARBON MEASUREMENT TECHNOLOGY: COMPARISON OF DECAY AND DIRECT (ION) COUNTING

age Counting	GP/LS Beta Detector Decay Counting (1946- present)	Accelerator Mass Spectrometry Direct/Ion (1977-present)
Modern carbon	13.5 dpm/gm carbon	5.9 x 10^{10} atoms ^{14}C/gm
50,000 ^{14}C/gm carbon	0.03 dpm/gm carbon	1.4 x 10^{8} atoms
100,000 atoms ^{14}C/gm carbon	0.00007 dpm/gm carbon	3.2 x 10^{5}

Direct / Ion Counting: Accelerator Mass Spectrometry



Center for Accelerator Mass Spectrometry
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University of California

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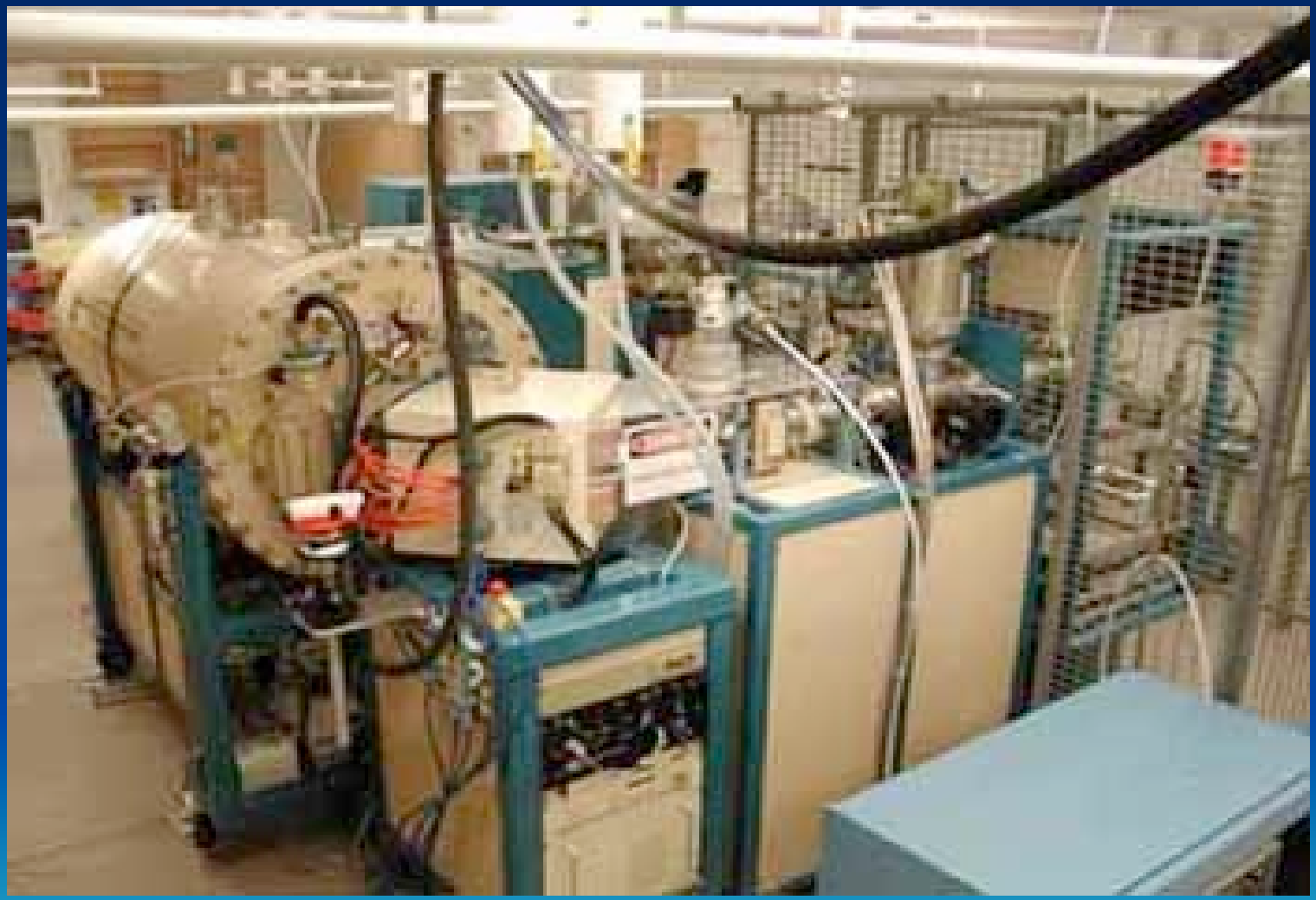

Keck Carbon Cycle Mass Spectrometry Laboratory
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Radiocarbon Dating: Identifying Fakes

- **Shroud of Turin**
  - If associated with Jesus of Nazareth = ~2,000 BP
  - If associated with first historical reference = ~600 BP

Radiocarbon Dating: Identifying Fakes

Shroud of Turin AMS-based ^{14}C ages (Damon et al. 1989)

	Egyptian linen Known age = 2010±80 (yrs. BP)	Shroud linen (yrs. BP)
Arizona AMS	1,838±47	591±30
	2,041±43	690±35
	1,960±55	606±41
	1,983±37	701±33
	2,137±46	
	Mean=1,995±46	Mean= 646±24
Oxford AMS	1,955±70	795±65
	1,975±55	730±45
	1,990±50	745±55
	Mean=1,980±35	Mean= 750±30
Zurich AMS	1,984±50	733±61
	1,886±48	722±56
	1,954±50	635±57
		639±45
		679±51
	Mean= 1,940±30	Mean= 676±24

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	fission track	
Regional	amino acid racemization	dendrochronology
	obsidian hydration	archaeomagnetic/ paleomagnetic
	fluorine	varve

Geochronology and Evolution

Scientific data and arguments supporting the conventional geological time scale have little to do with data and arguments in support of (or, for that matter, in opposition to) current scientific consensus concerning biological evolution

end

Adventist Biblical Creationism(s): Science / Theology Faculty Views

Results of 1994 and 2003 SDA Science and Theology Faculty Surveys

	1994 Science Faculty (%)	2003 Science Faculty (%)	2003 Theology Faculty (%)
God created all living organisms during a literal six- day period			
less than 10,000 yrs ago	43.0	30.0	46.8
less than 20,000 yrs ago	-	10.0	

Adventist Biblical Creationism(s): Science and Theology Faculty Views

Results of 1994 and 2003 SDA Science and Theology Faculty Surveys

2003 Theology Faculty	1994 Science Faculty (%)	2003 Science Faculty (%)	(%)
God created all living organisms over an indeterminate length of time over the last 100,000 years	6.6	6.6	4.9
God created life millions of years ago and over this period guided its development	18.2	18.3	12.2
Life as recorded in the fossil record has evolved over several billions of years exclusively by natural means	3.3	10.0	2.4

Age of earth and life: Seven responses to conflict between theological- based and scientific- based views- 1

- ✓ 1. **Reject scientific consensus**: key data and interpretations biased by **evolutionary assumptions**
- ✓ 2. **Reject scientific consensus**: key data and interpretations can be disputed **focus on the relatively small number of anomalies in data**
- ✓ 3. **Examine assumptions**: both theology- based and science- based views determine precisely how theological and scientific assumptions condition understandings and conclusions`

Age of earth and life: Seven responses to conflict between theology- based and science- based views- 2

- **4. Accept two ways of knowing : theological** (authority- based) and **scientific** (empirically- based). ***Both provide equally valid inferences in their different and distinct areas of knowing***
- **5. Accept scientific consensus**: accept overwhelming weight of empirical evidence; theological- based traditional views have misunderstood nature of Biblical statements
- **6. Suspend judgment**: We will never really know so let's just all get along.
-

Age of earth and life: Seven responses to conflict between theology- based and science- based views- 3

- ✓ 7. **Ignore the conflict**: What difference does it make?

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