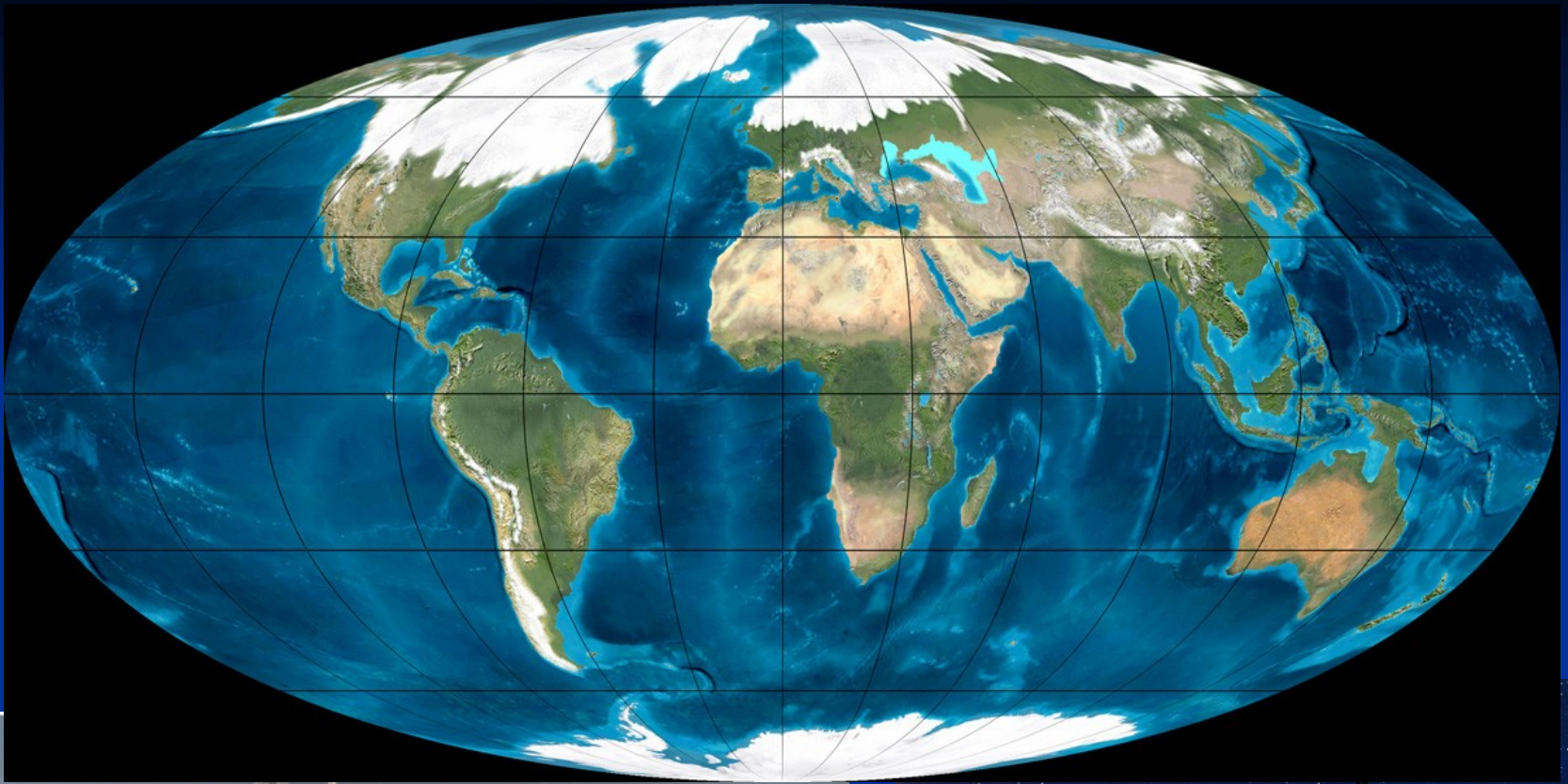


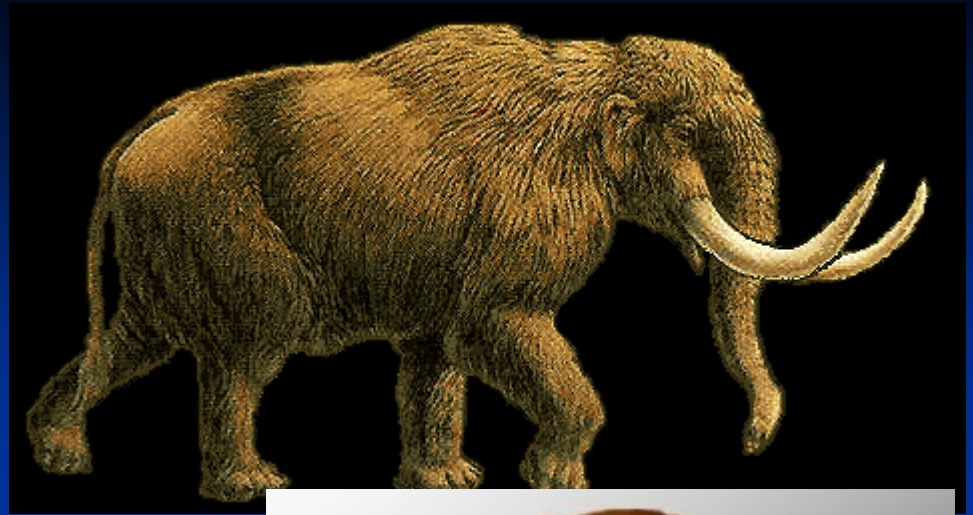
# Sedimenty kvartéru







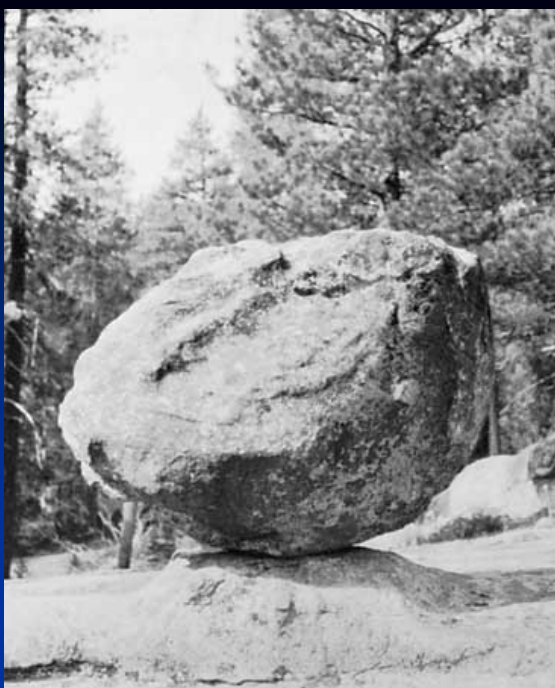












Private photo stored



Private photo stored  
in the Photoarchive  
of the Czech Geological Survey



# Plán

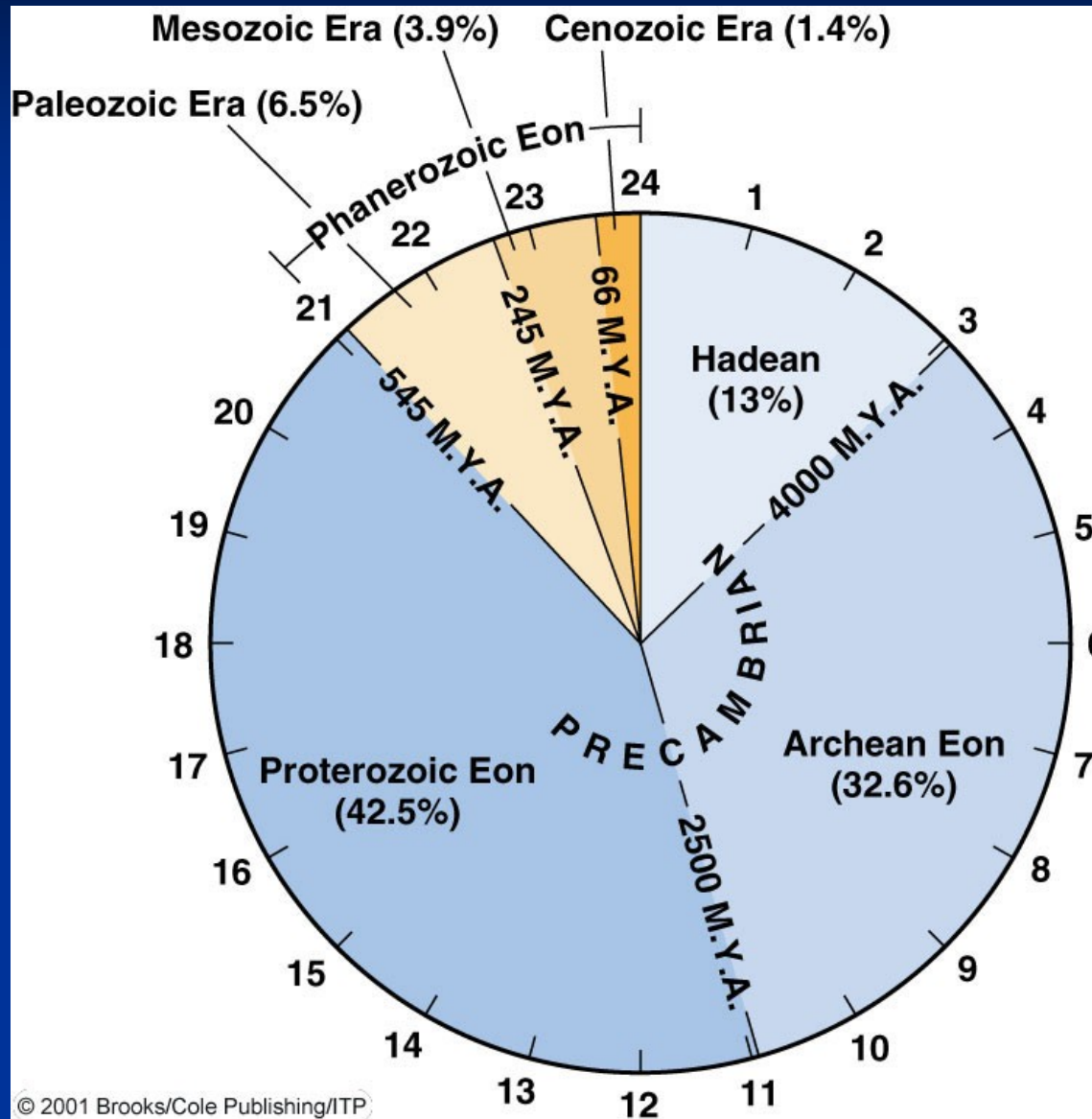
- Obecná charakteristika kvartéru: chronologie, klima, kolísání mořské hladiny
- Metody datování kvartérních sedimentů
  
- SEDIMENTY
- Glacigenní
- Eolické
- Fluviální
- Svahové (koluviální)
- Jeskynní sedimenty a speleotémy
- Mořské



# Kvartér: 38 vteřin

- Recall our analogy of all geologic time
  - represented by a 24-hour clock
- In this context, the Quaternary is only 38 seconds long,
  - but they are certainly important seconds,
  - because during this time our species evolved
    - *Homo sapiens*
- The Pleistocene deserves special attention
  - It is one of the few times in Earth history
  - when vast glaciers were present

# Geologický čas ve 24 hodinách



- the Quaternary
- is only 38 seconds long at this scale



# kvartér, co JE kvartér (!?!)

Gradstein, F.M., Ogg, J.G., Smith, A.G., Bleeker, W., Lourens, L. (2004): Episodes, 27, 2, p. 86.

„The “Quaternary“ is traditionally considered to be the interval of oscillating climatic extremes (glacial and interglacial episodes) that was initiated at about 2.6 Ma, therefore encompassed the Holocene and Pleistocene epochs and Gelasian stage of late Pliocene. This composite epoch **is not a formal unit in the chronostratigraphic hierarchy**“

= / ≠ NEOGÉN ?!



# Geologická časová škála 2004

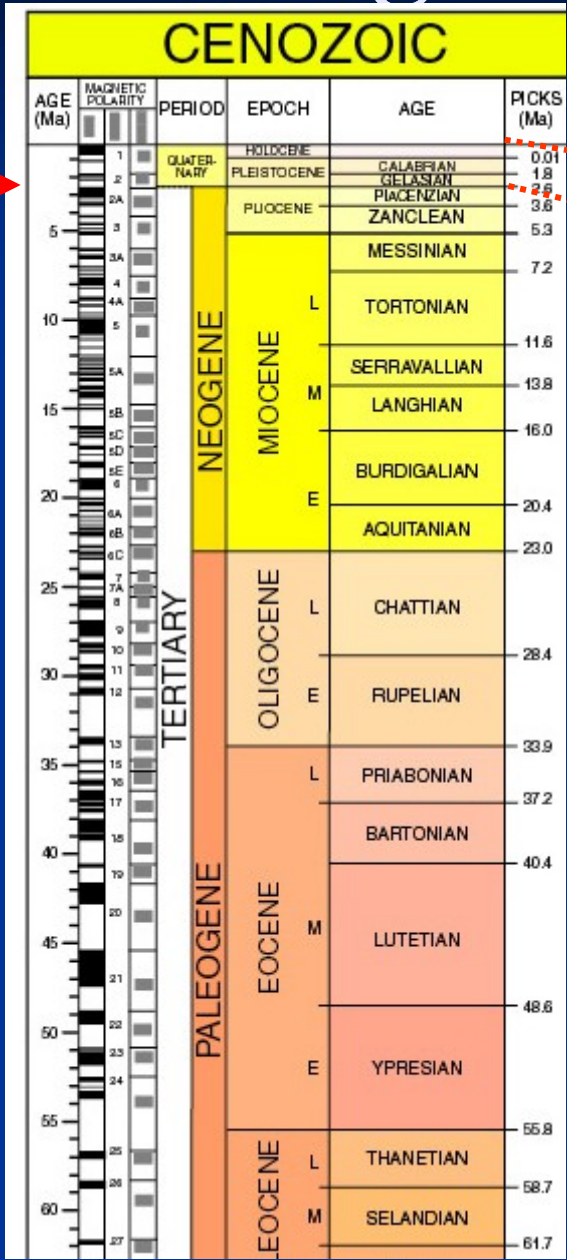
Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
Phanerozoic	Cenozoic	Quaternary*	Holocene		0.0118	
			Pleistocene	Upper	0.126	
				Middle	0.781	
		Lower		1.806	✓	
		Pliocene	Gelasian	2.588	✓	
			Piacenzian	3.600	✓	
			Zanclean	5.332	✓	
		Miocene	Messinian	7.246	✓	
			Tortonian	11.608	✓	
			Serravallian	13.65		
			Langhian	15.97		
			Burdigalian	20.43		
	Aquitanian		23.03	✓		
	Oligocene	Chattian	28.4 ±0.1			
		Rupelian	33.9 ±0.1	✓		
	Eocene	Priabonian	37.2 ±0.1			
		Bartonian	40.4 ±0.2			
		Lutetian	48.6 ±0.2			
		Ypresian	55.8 ±0.2	✓		
		Thanetian	58.7 ±0.2			
	Paleocene	Selandian	61.7 ±0.2			
		Danian	65.5 ±0.3	✓		
	Cretaceous	Upper	Maastrichtian	70.6 ±0.6	✓	
			Campanian	83.5 ±0.7		
			Santonian	85.8 ±0.7		
			Coniacian	89.3 ±1.0		
			Turonian	93.5 ±0.8	✓	
Cenomanian			99.6 ±0.9	✓		

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
Phanerozoic	Cenozoic	Quaternary*	Holocene		0.0118	
			Pleistocene	Upper	0.126	
				Middle	0.781	
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			Zanclean	5.332	✓	
		Miocene	Messinian	7.246	✓	
			Tortonian	11.608	✓	
			Serravallian	13.65		
			Langhian	15.97		
			Burdigalian	20.43		
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Oligocene	Chattian	28.4 ±0.1				
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	Ypresian	55.8 ±0.2	✓			
	Thanetian	58.7 ±0.2				
Paleocene	Selandian	61.7 ±0.2				
	Danian	65.5 ±0.3	✓			
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		Campanian	83.5 ±0.7			
		Santonian	85.8 ±0.7			
		Coniacian	89.3 ±1.0			
		Turonian	93.5 ±0.8	✓		
		Cenomanian	99.6 ±0.9	✓		





# Geologická časová škála 2009



PERIOD	EPOCH	AGE	PICKS (Ma)
QUATERNARY	HOLOCENE		0.01
	PLEISTOCENE	CALABRIAN	1.8
		GELASIAN	2.6
PLIOCENE	ZANCLEAN		3.6
		MESSINIAN	7.2
	MIOCENE	TORTONIAN	
SERRAVALLIAN			13.8
LANGHIAN			16.0

mezinárodní členění

EONOT.	ERAT.	ÚTVAR	ODDĚLENÍ	STUPEŇ	stáří (milióny let)	členění evropského kvartéru	
		kvartér	holocén		0,0117	členění kenozoika	
			pleistocén	tarant		0,126	Centrální Paratethys
				ion		0,781	
				calabr		1,806	
			pliocén	gelas		2,588	STUPEŇ
				piacenz		3,600	roman
			zancl		5,300	dac	

členění evropského kvartéru

ODDĚLENÍ
holocén
pleistocén
svrchní
střední
spodní

# Chronologie

## PLEISTOCÉN (1,8 Ma - 10 ka)

### Chronologie mořského pleistocénu:

terasové stupně - kalábr, emil, sicil, milazzo, tyrrhen, monastir, tapes (flandry)

### Chronologie glaciálů, alpské vysokohorské zalednění

glaciální stupně: donau, günz, mindel, riss, würm (názvy podle řek)

integraciální stupně: donau-güenz, güenz-mindel, atd.

### Chronologie glaciálů, severoevropské kontinentální zalednění

glaciály: pretegelen, eburon, menap, elster, saal, visla

interglaciály: tegelen, waal, bavel, cromer, holstein, eem (mořské transgrese)

### Chronologie glaciálů, severoamerické kontinentální zalednění

glaciály: nebraskan, kansan, illinoian a wisconsin

interglaciály: pre-nebraský, aftonský, yarmouthský, sangamonský

špatná korelace mezi severoamerickou a severoevropskou kontinentální stupnicí !

hranice pleistocén / holocén: 10 až 12 000 let - rychlý vzestup mořské hladiny

KVARTÉR				
oddělení	stupeň		polarita eventy	stáří (Ma)
	Severní Evropa	Alpy		
PLEISTOCÉN	pozdní glaciál	pozdní glaciál	M	0,110
	visla*	würm*		
	eem	riss/würm	E	
	saal*	riss*		
	holstein	mindel/riss	L	
	elster*	mindel*		
	cromer	güenz/mindel		
	bavel			
	menap*	güenz*	J	
	waal		Co	1,100
	eburon*	donau*	O	1,670
	tegelen		R	2,140
	pretegelen*	biber*		2,430

\* chladné nebo stepní období

Obr. 91. Základní členění pleistocénu (podle Musil, 1996).



# Chronologie

## HOLOCÉN (10 – 0 ka)

Éra po posledním  
zalednění

**mořské stupně:**

preboreál, boreál,  
atlantik, subborál,  
subatlantik

**kontinentální členění**

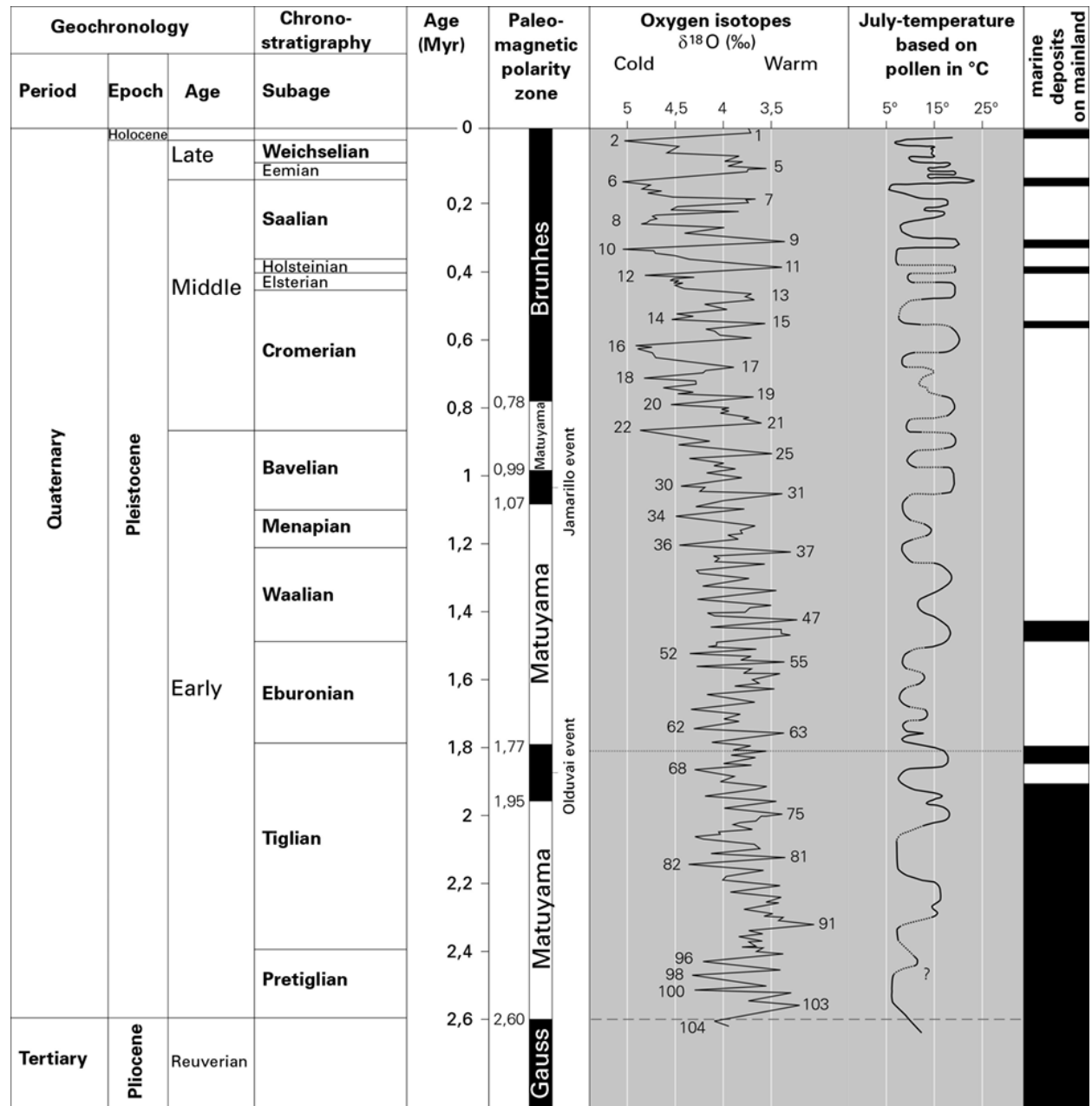
**podle kultur:**

mezolit, neolit,  
eneolit, atd.

K V A R T É R			
oddělení	stupeň	kultura	stáří (roky)
H O L O C É N	subatlantik	mladší	2 000
		starší	1 000
	subboreál		0
			1 000
	atlantik	mladší	2 000
		starší	3 000
	boreál		4 000
preboreál		5 000	
		6 000	
		7 000	
		8 300	

doba historická  
 doba železná  
 doba bronzová  
 halstatt  
 eneolit  
 neolit  
 mezolit  
 latén

# Marine isotope stages



..... 1,81 Ma time boundary  
 Plio-Pleistocene  
 cf. IUGS 2003

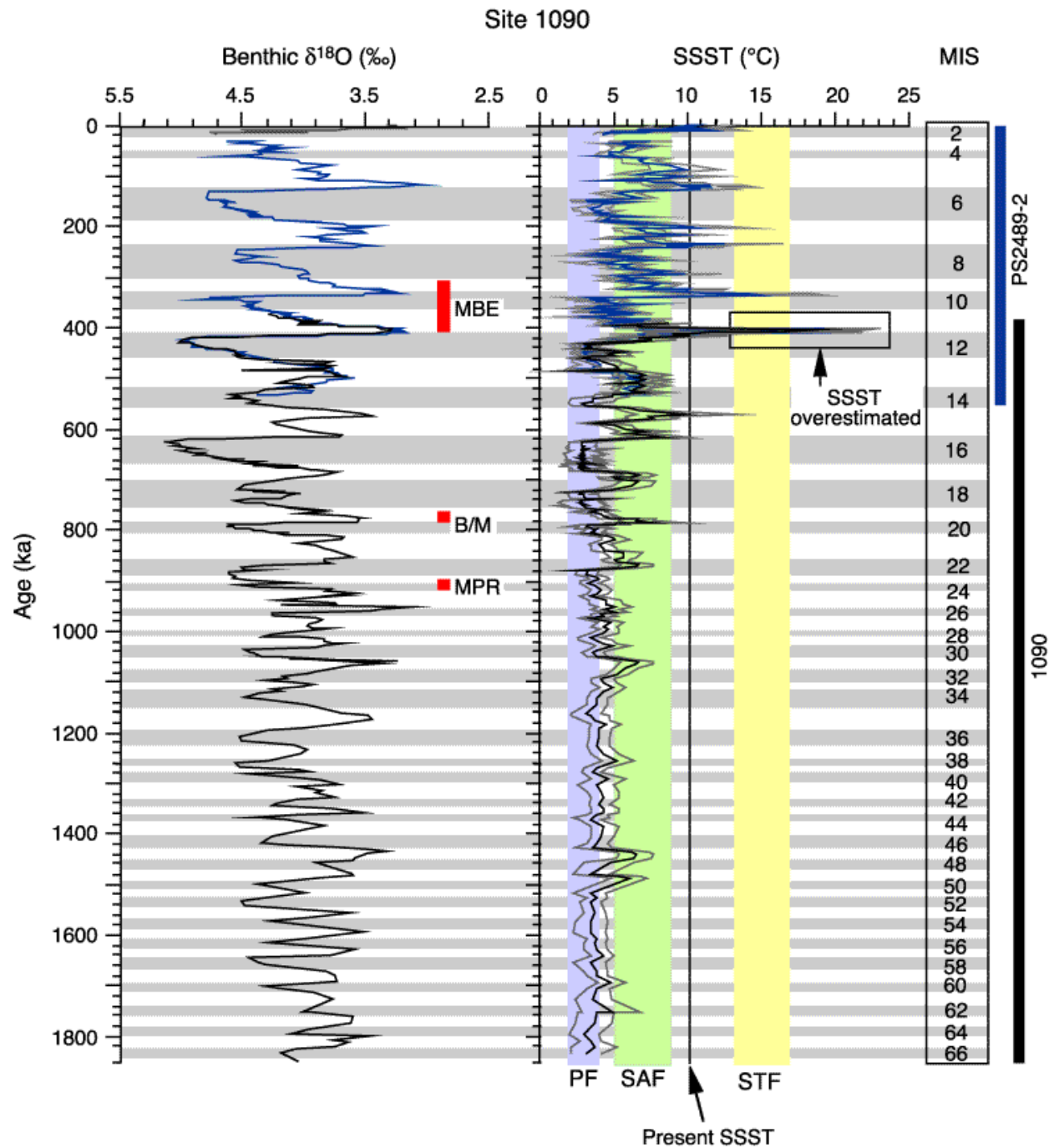
- - - - - Ca. 2,6 Ma time boundary  
 Plio-Pleistocene in  
 NW-Europe

Sealevel (m) relative to present

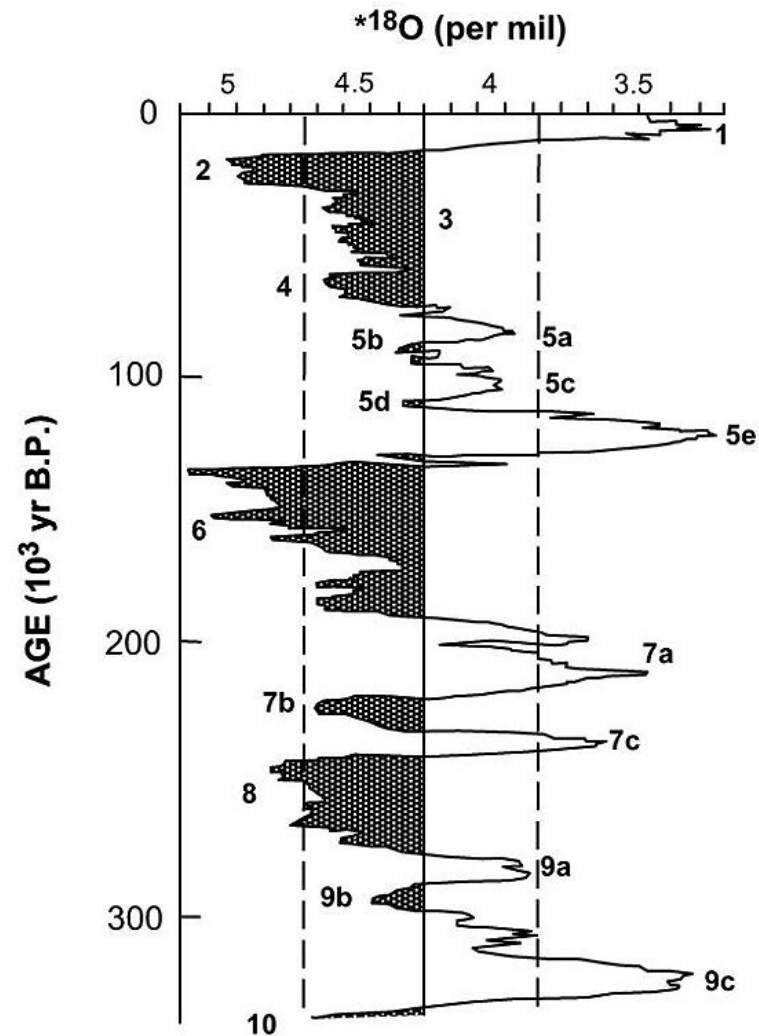
□ Reversed polarity  
 ■ Normal polarity



# Marine isotope stages



# Marine isotope stages



Marine oxygen isotope record. The peak of oxygen isotope stage 2 (about 20,000 years BP, or about 18,000 <sup>14</sup>C years BP) is generally considered the Last Glacial Maximum. The Pinedale, or Wisconsin glaciation spans stages 2-4 (and possibly to 5d), and the Bull Lake, or Illinoian glaciation is thought to be correlative with stage 6. This plot is a composite of oxygen isotope records of benthic foraminifera from several deep sea cores reflecting global ice volume, and was constructed using data from Shackleton and Pisias (1985) and Martinson et al. (1987). (After Porter, 1989)



# Doby „ledové“ a „meziledové“

## Glaciální a interglaciální stupně

- **GLACIÁLY** - snížená teplota, průměrná teplota na planetě výrazně nižší než dnes, průměrná roční teplota v našich z.š.: 0 stupňů C; průměrná teplota vod v oceánech zhruba o 4 až 7 stupňů celsia nižší než dnes
- interstadiály - drobné teplejší výkyvy v rámci glaciálu, průměrná teplota v našich šířkách zhruba o 4 stupně celsia nižší
- **INTERGLACIÁLY** - teplota zhruba odpovídající dnešní, roční průměr teplot zhruba o 2 až 3 stupně vyšší než dnes

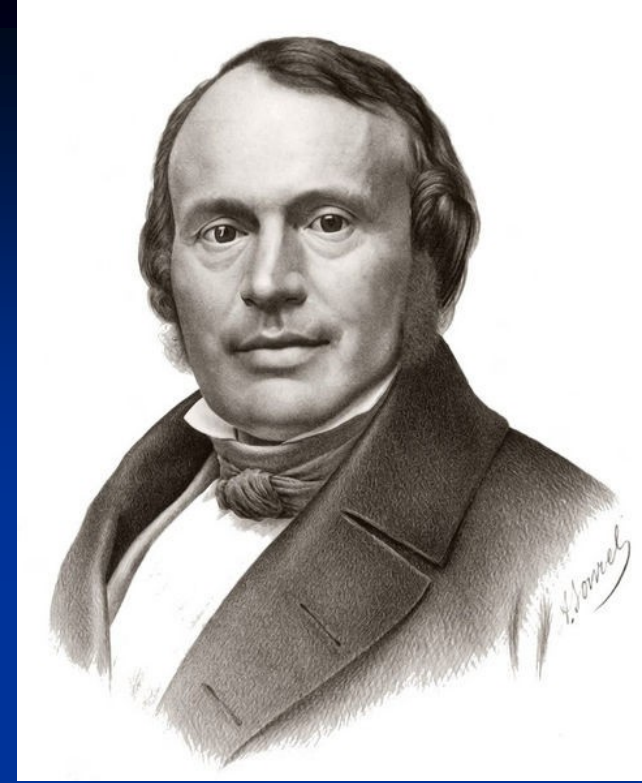


# Stadiál „starší Dryas“

- Velmi krátké chladné období (stadiál) v pozdním pleistocénu mezi interstadiály Bolling a Allerod; nejsilněji se projevuje v Eurasii
- Stáří 11700 – 12000 let BP
- Název podle alpské / tundrové trpasličí křoviny *Dryas*



# Louis Agassiz a doby ledové



- \*1837,
  - švýcarský přírodovědec Louis Agassiz
  - argued convincingly that the large displaced boulders as well as polished and striated bedrock and U-shaped valleys found throughout Europe and elsewhere resulted from huge masses of ice moving over the land

# Charakteristické rysy glaciace

- Features seen in areas once covered by glaciers
- glacial polish
  - the sheen
- striations
  - scratches
- These features are convincing evidence that
  - a glacier moved over these rocks
  - in Devil's Postpile National Monument, California





# Glacigenní sedimenty

- Glaciers typically deposit poorly sorted nonstratified sediment like this “TILL“
  - Other processes yield similar deposits
  - but their association with glacial polish, striations, and other features is definitive





# Globální zalednění v glaciálech

## GLOBALNÍ ÚČINKY ZALEDNĚNÍ

- **Severní Amerika** je pokryta laurentinským ledovcovým štítem. Při snížené hladině oceánů se vynořuje v pleistocénu nad hladinu i **Beringova úžina** a umožňuje migraci savců i později člověka na severoamerický kontinent.
- Během pleistocénu dosahuje maximálního rozšíření **kontinentální ledovec v Antarktidě**.

## ZALEDNĚNÍ V EVROPĚ

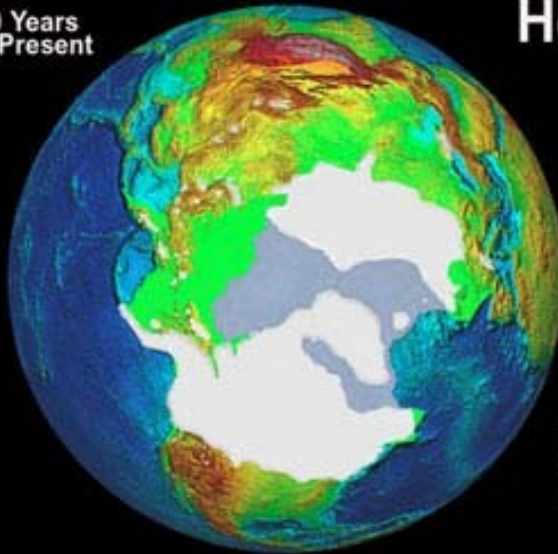
- V Evropě se sunuly masy kontinentálního ledu v několika vlnách ze **Skandinávie** k jihu až do **střední Evropy**. Zaledněna byla i větší část **britských ostrovů a západní Sibiř**. Ve vrcholném období chladného klimatu (glaciál elster) byly **pokryty až 2/3 Evropy ledovcem mocným přes 2.000 m**. Posuny ledových pokryvů způsobily i mimo oblast ledovců v nižších zeměpisných šířkách zvýraznění klimatických hranic a časté střídání suchých a vlhkých období.

# Povrch Země v době posledního glaciálního maxima

## Northern Hemisphere

Ice Coverage

18,000 Years Before Present

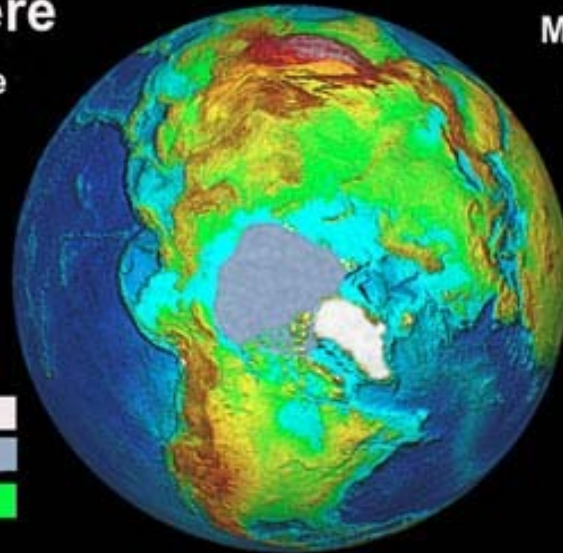


Legend

- Continental Ice
- Sea Ice
- Land Above Sea Level

Modern Day

(August)



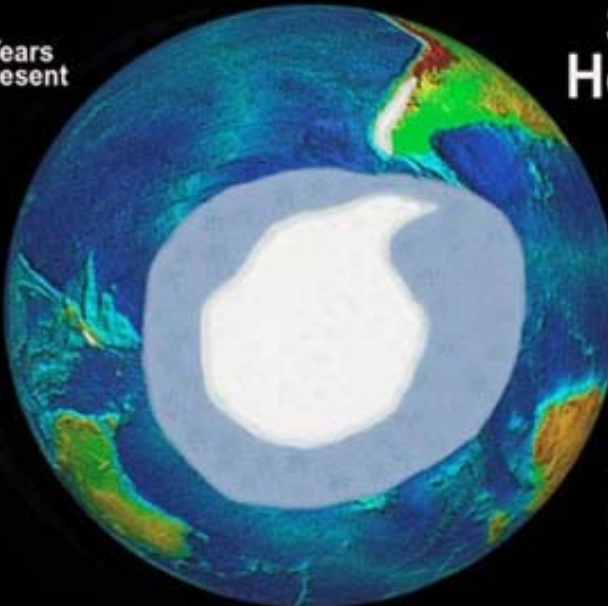
Note: Modern sea ice coverage represents summer months.



## Southern Hemisphere

Ice Coverage

18,000 Years Before Present

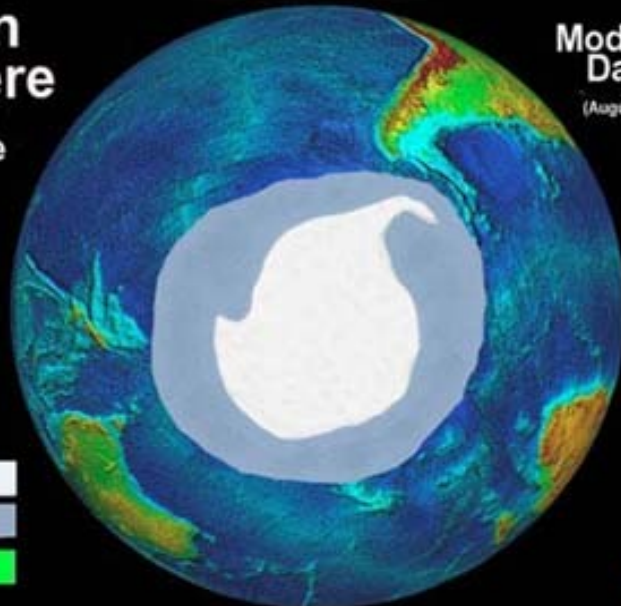


Legend

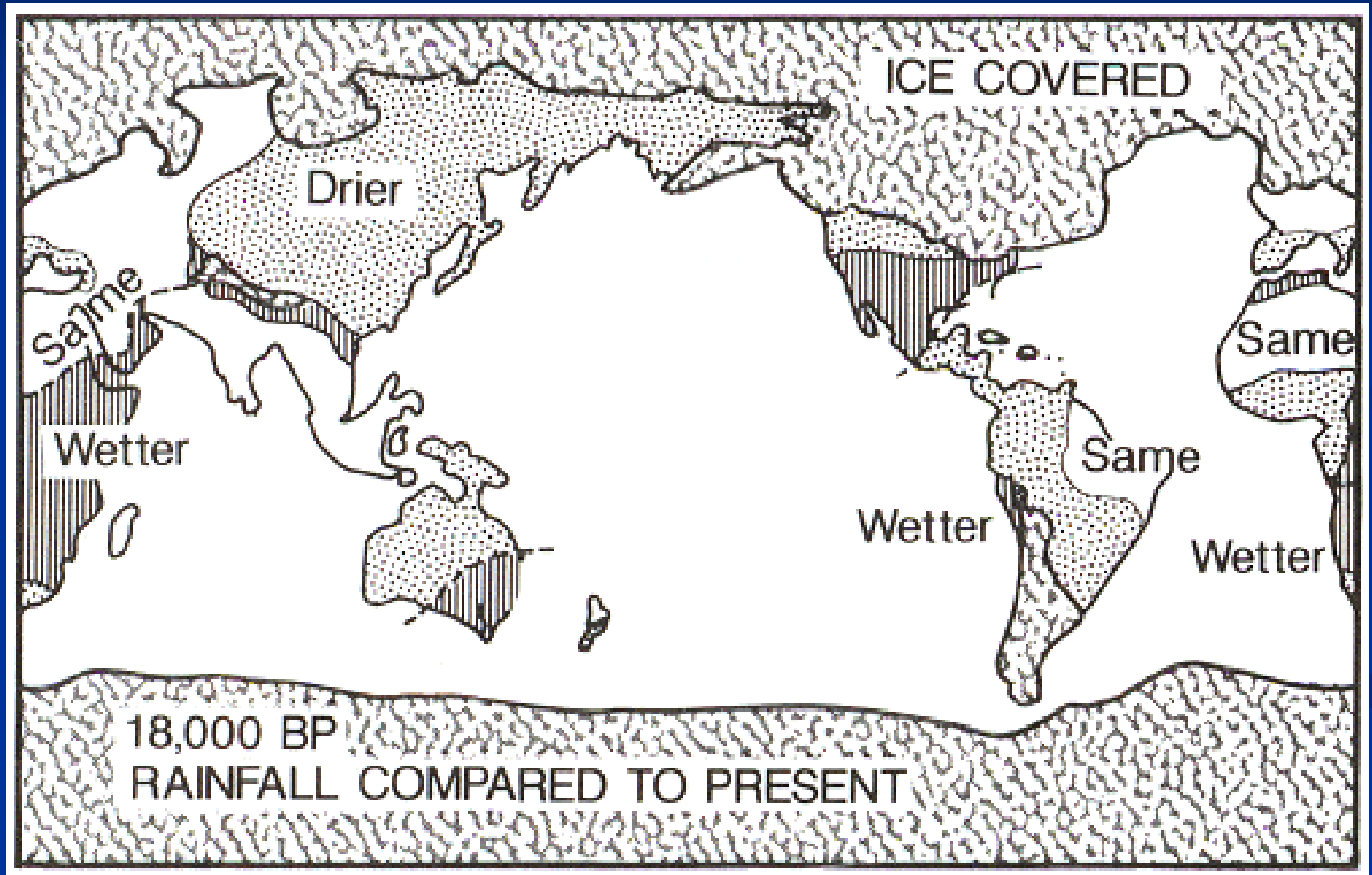
- Continental Ice
- Sea Ice
- Land Above Sea Level

Modern Day

(August)

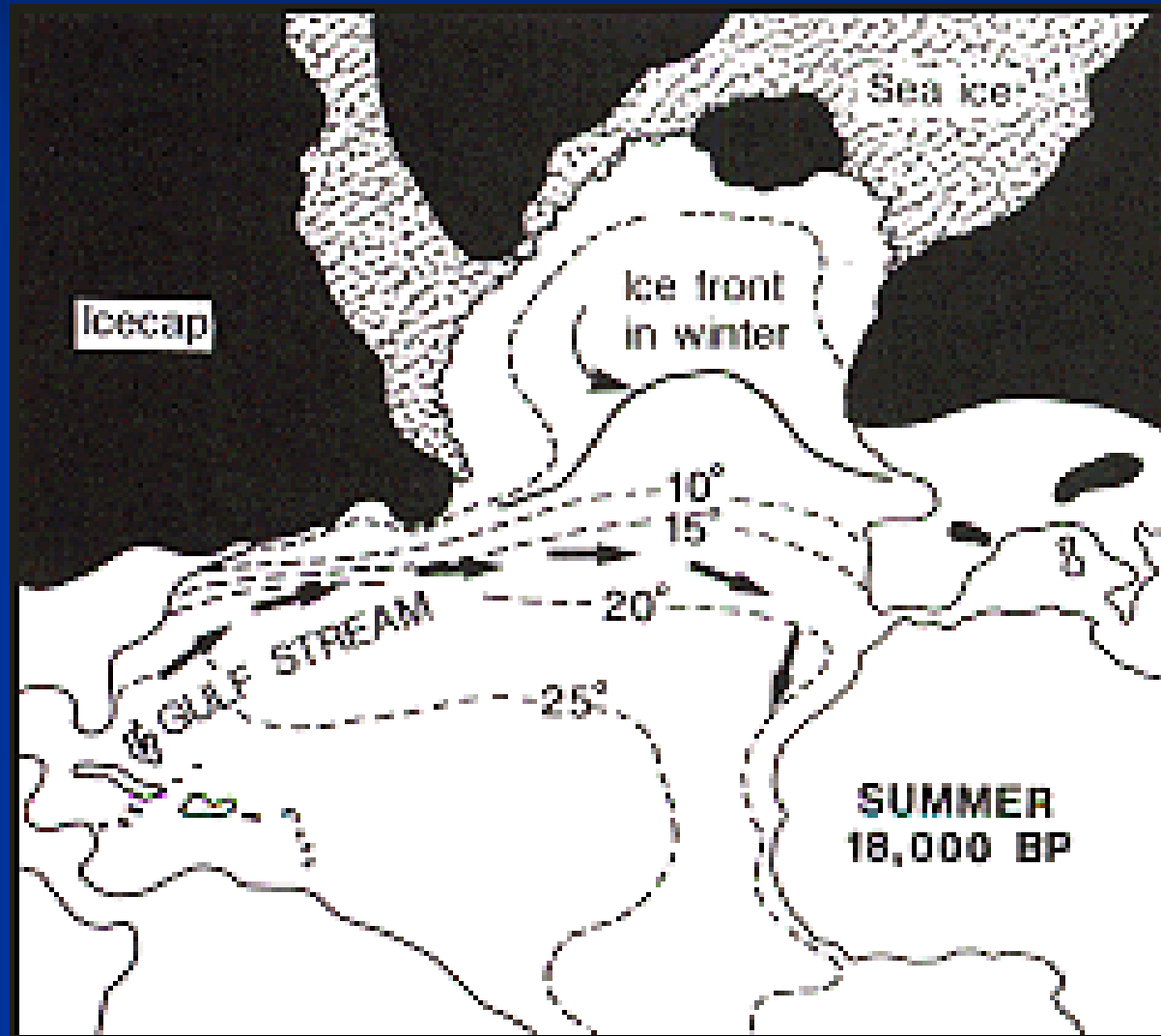


# Poslední glaciální maximum, 18ka





# Atlantický oceán během LGM, 18ka



# Evidence pro kolísání klimatu v kvartéru

- **kllická** kontinentální sedimentace - glacigenní a periglaciální sedimenty, **výskyt morén kontinentálních ledovců** v zeměpisných šířkách, kde se dnes nevyskytují (Český masív), minimálně 4 klimatické cykly v Severní Americe, min. 6 klimatických cyklů v Evropě
- poměry **izotopu O18/O16** v mořských sedimentech, min. 20 klimatických cyklů za posledních 20 mil. Let
- Vrtná jádra z ledu
- **pylové analýzy** - dokumentují pokles klimatu na základě změny vegetačního pokryvu
- **vinutí schránek Globorotálií, biogeografie planktonních foraminifer**
- **mořské terasy**, které dokumentují kolísání hladiny světového oceánu řádově o desítky metrů až okolo 100 m (středozevní oblast)
- **složení flóry a fauny** - přítomnost savců v Evropě, kteří jsou dnes výskytem vázáni na teplejší oblasti (opice, lvi)

# Kontinentální a horské zalednění: morény

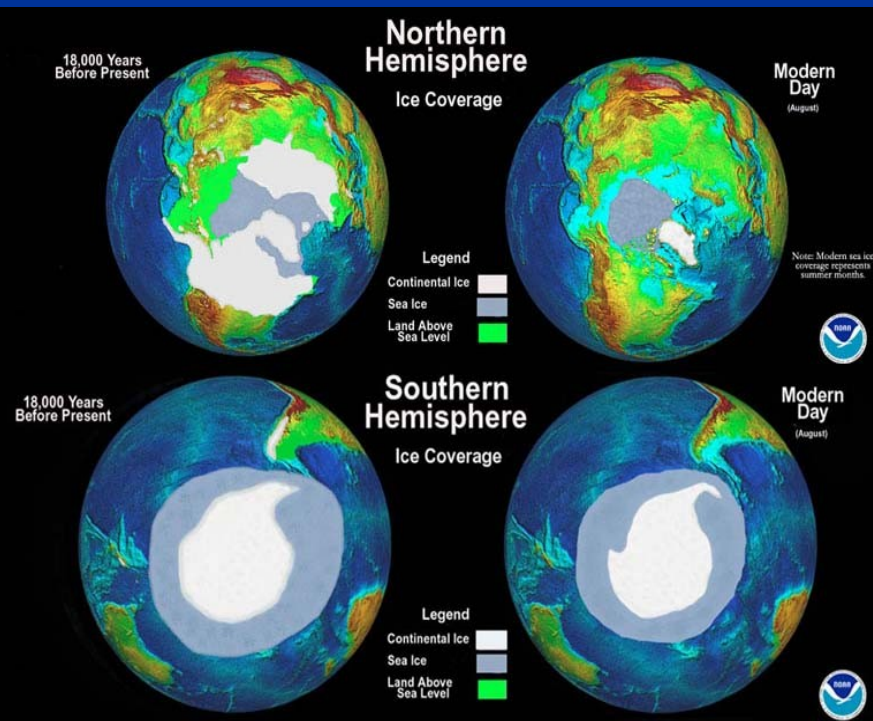
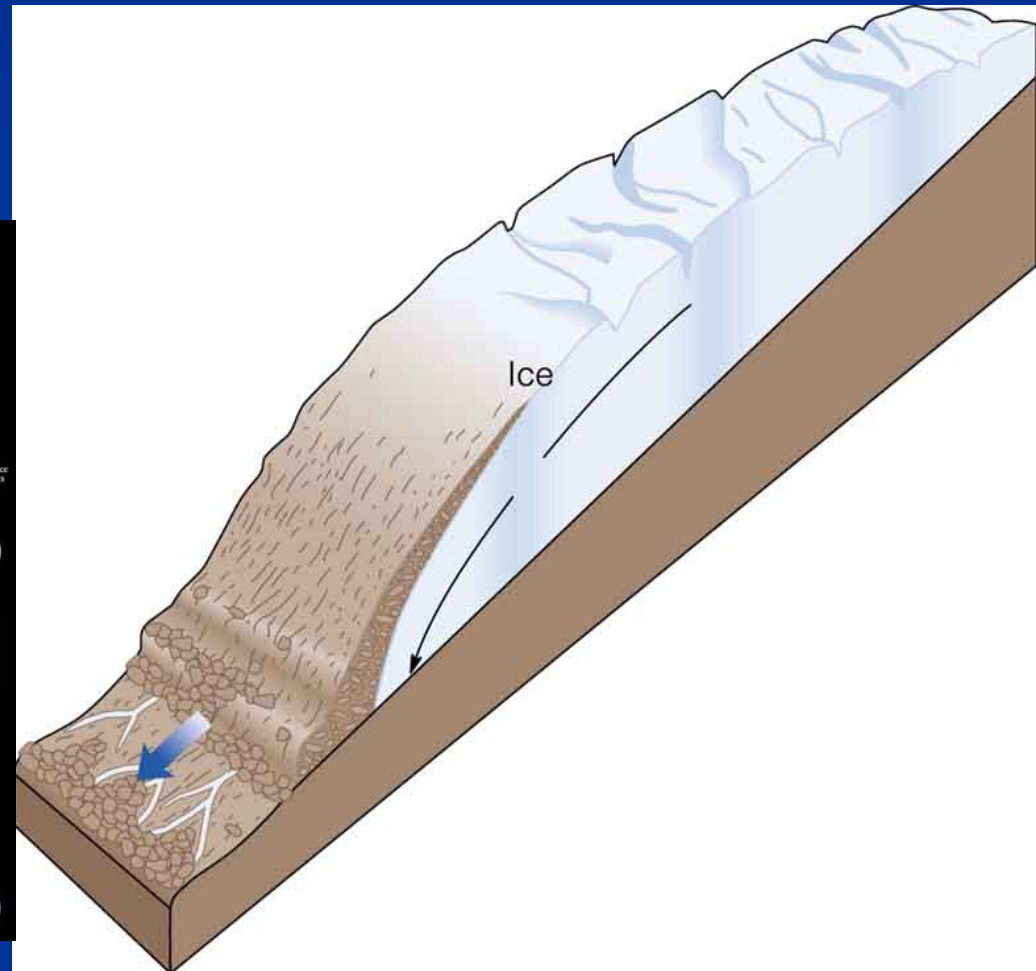
- As a glacier advances, its leading edge acts like the blade of a bulldozer, pushing rock and debris in advance.
- These remnants of glaciation, called end moraines (čelní morény), mark the location of maximum ice extent.





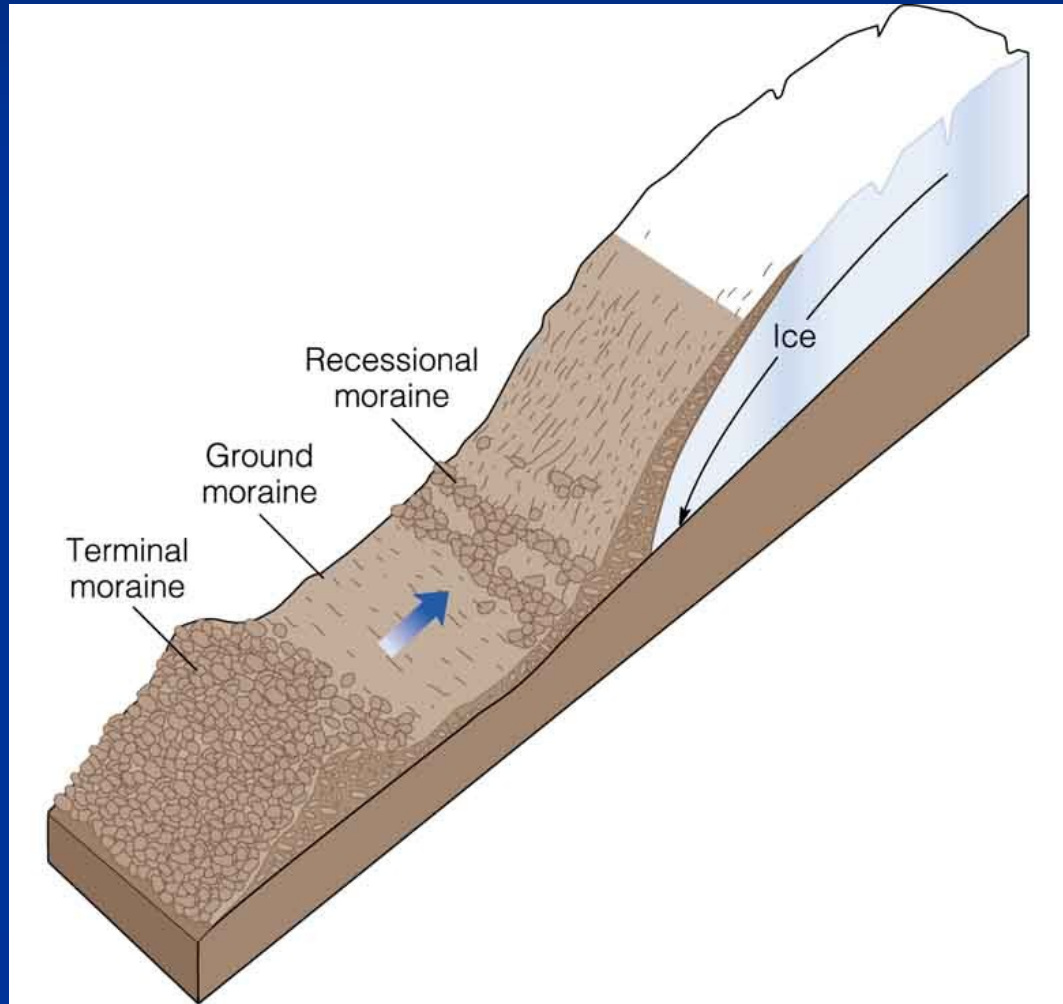
# Kontinentální zalednění: terminální morény

- Čelní moréna, která označuje maximální vzdálenost dosahu ledovce od svého centra se nazývá terminální moréna



# ústupová moréna

- If the glacier's terminus should recede and then stabilize once again another end moraine forms known as a *recessional moraine* (*ústupová moréna*)



# Morény

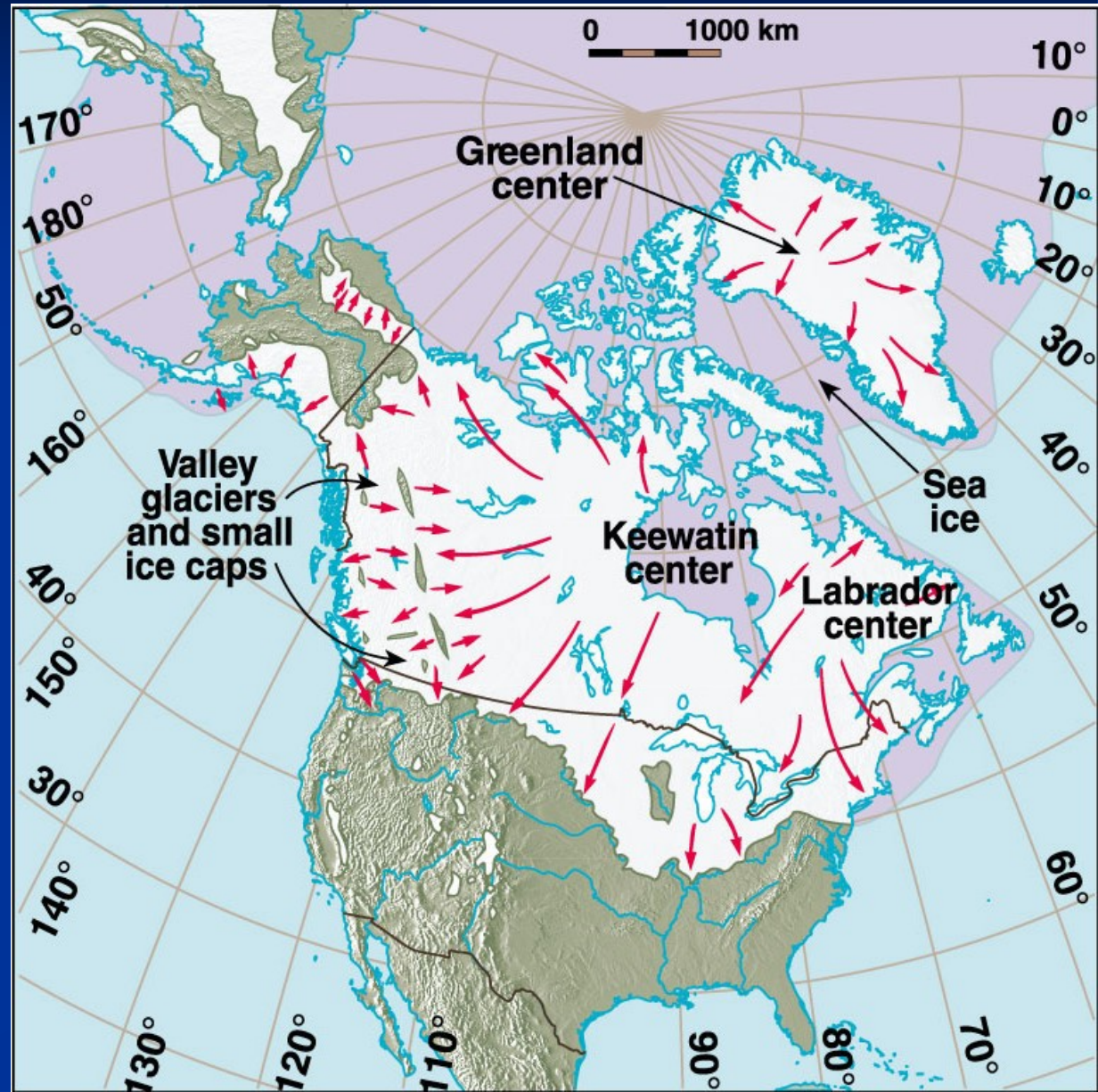
- Mapa oblasti Velkých Jezer (S.A.) showing **terminal moraines** (16,000 years old) and **recessional moraines** of the most recent continental glacier to cover this region





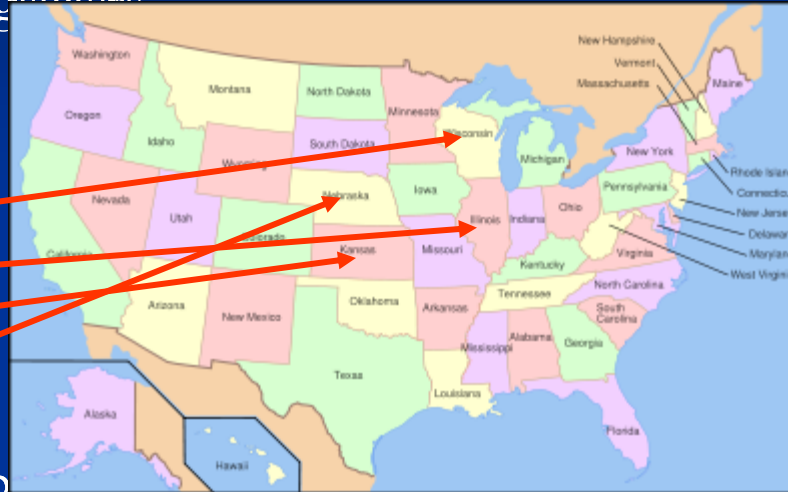
# Zalednění Severní Ameriky

- Centers of ice accumulation and maximum extent of Pleistocene glaciers in North America



# Čtyři glaciální stupně

- Each glacial advance
  - was followed by retreating glaciers
  - and warmer climates
- The four **glacial stages**,
  - the *Wisconsinan*,
  - *Illinoian*,
  - *Kansan*,
  - and *Nebraskan*,
  - are named for the states representing the southernmost advance
  - where deposits are well exposed
- The three **interglacial stages**,
  - the *Sangamon*, *Yarmouth*, and *Aftonian*,
  - are named for localities
  - of well exposed interglacial soil and other deposits



Wisconsinan  
Glaciation

Sangamon  
Interglacial

Illinoian  
Glaciation

Yarmouth  
Interglacial

Kansan  
Glaciation

Aftonian  
Interglacial

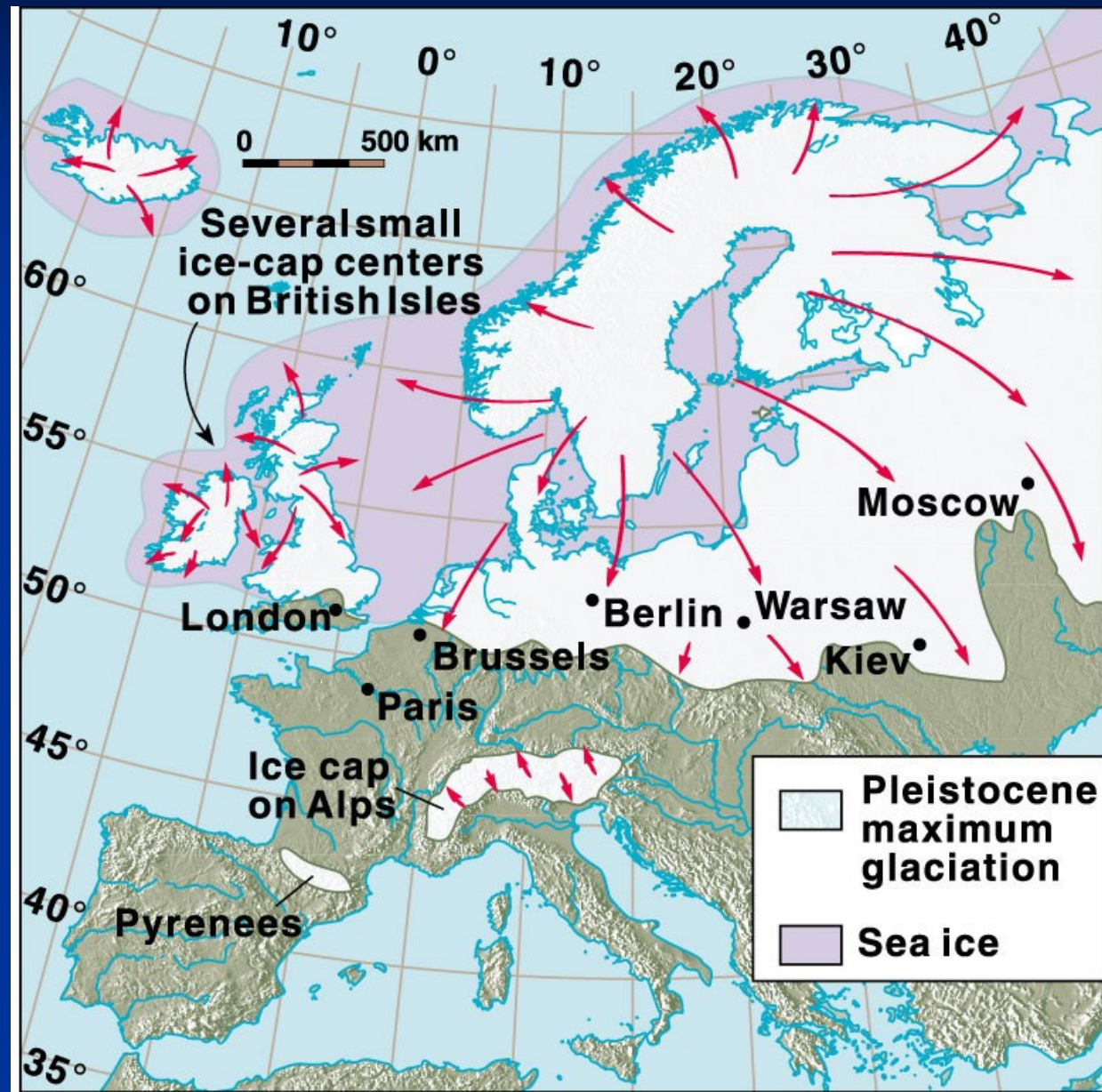
Nebraskan  
Glaciation

Pre-Nebraskan



# Zalednění v Evropě

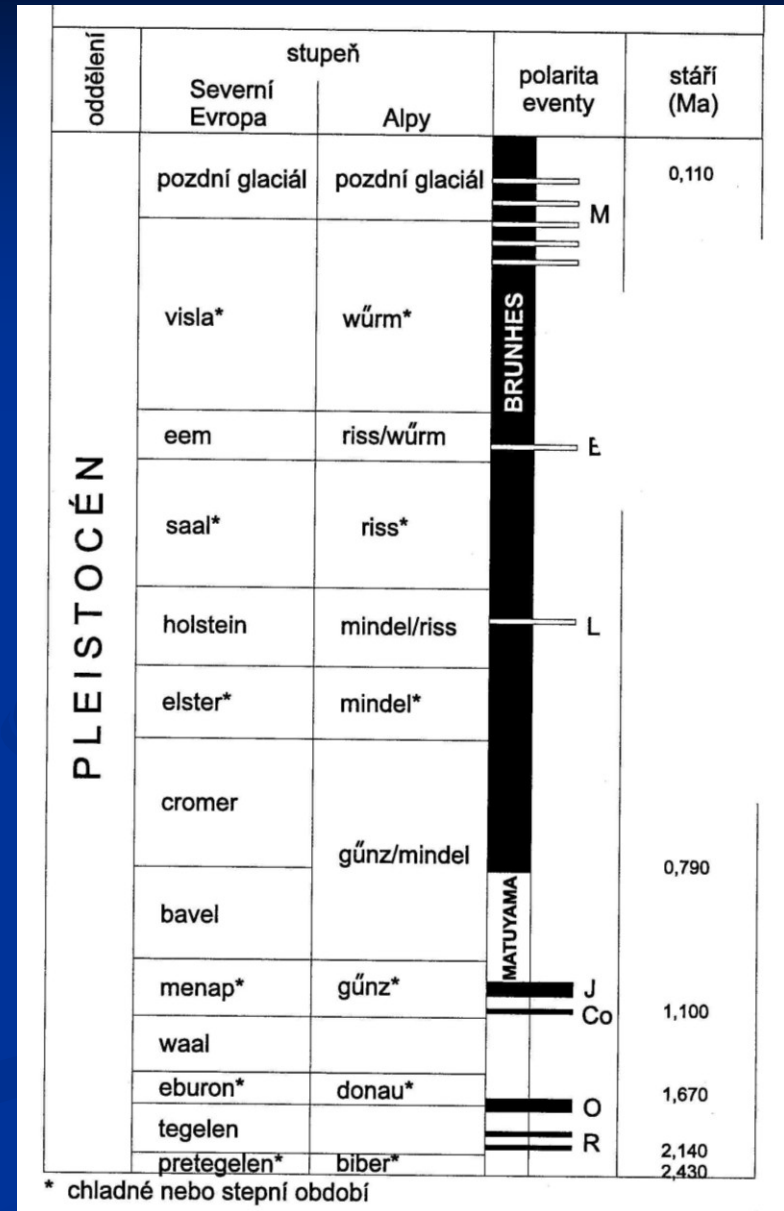
- Centers of ice accumulation and directions of ice movement during the maximum extent of Pleistocene glaciers in Europe





# Glaciály v Evropě

- Six or seven major glacial advances and retreats
  - are recognized in Europe, and at least 20 major warm–cold cycles can be detected in deep-sea cores
- Why isn't there better correlation
  - among the different areas if glaciation was such a widespread event?
- Part of the problem is that
  - glacial deposits are typically chaotic mixtures of coarse materials that are difficult to correlate



# Mořské terasy

Marine terraces

covered with Pleistocene sediments attest to periodic uplift in southern California

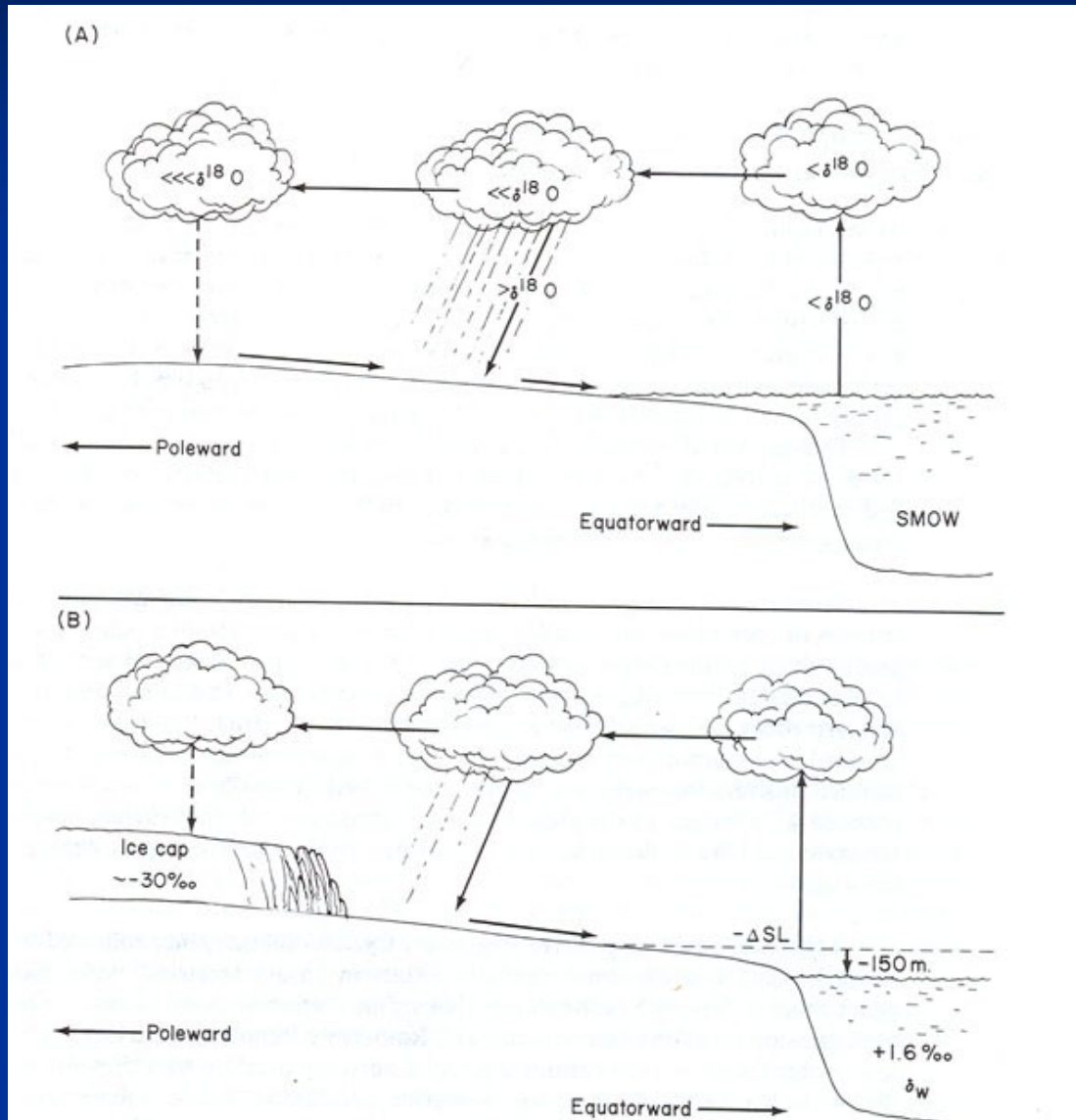


# Izotopy kyslíku

- A small fraction of water molecules contain the heavy isotope  $^{18}\text{O}$  instead of  $^{16}\text{O}$ .
- $^{18}\text{O}/^{16}\text{O} \approx 1/500$
- This **ratio is not constant**, but varies over a range of several percent.
- Vapor pressure of  $\text{H}_2^{18}\text{O}$  is lower than that of  $\text{H}_2^{16}\text{O}$ , thus  **$\text{H}_2^{16}\text{O}$  is more easily evaporated.**



# Frakcionace $^{18}\text{O}/^{16}\text{O}$ v koloběhu vody



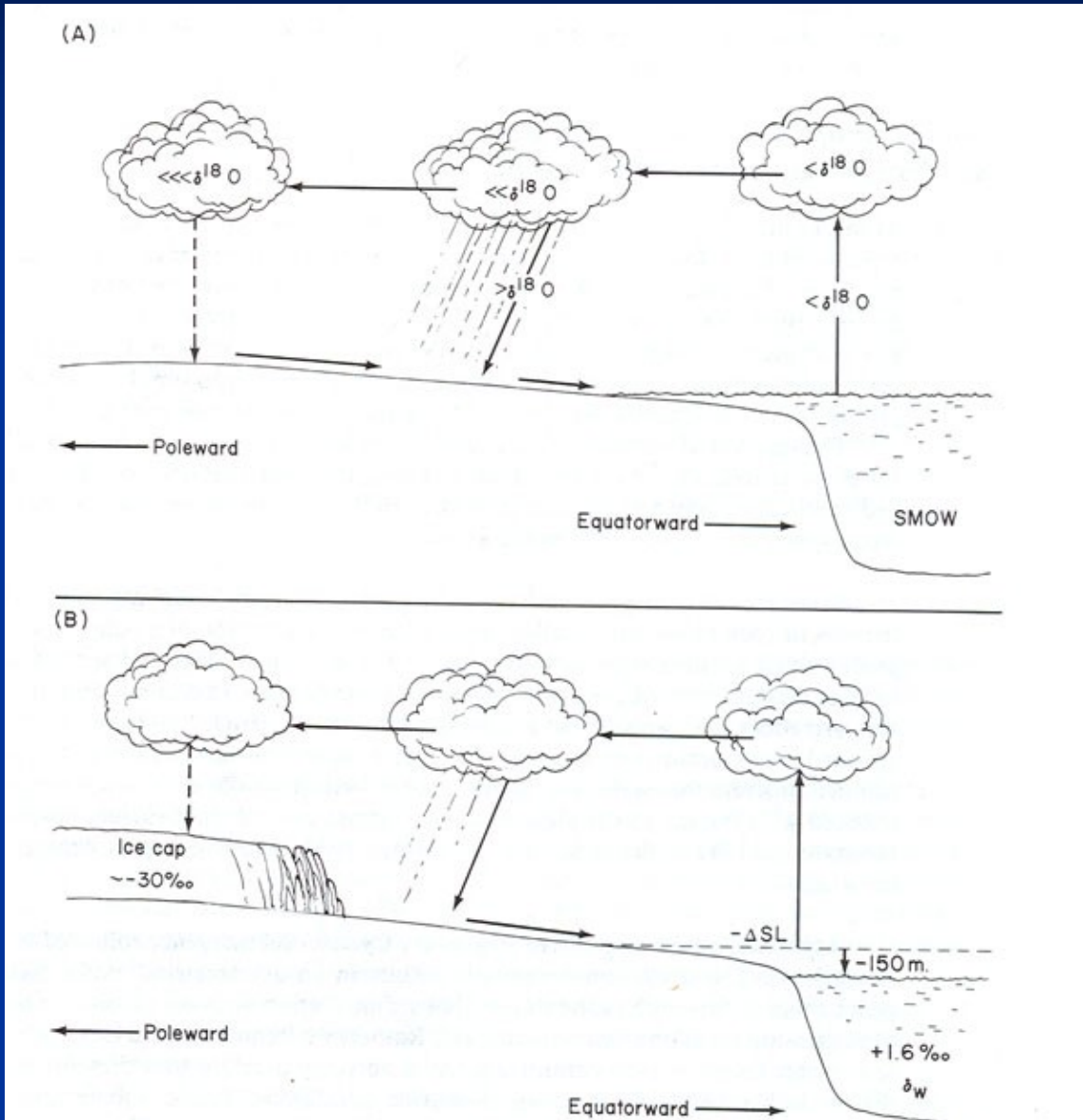
$\text{H}_2\text{O}$  is evaporated from sea water. The oxygen in the  $\text{H}_2\text{O}$  is enriched in the lighter  $\text{O}_{16}$ .

This  $\text{H}_2\text{O}$  condenses in clouds, falling on land as precipitation.

Thus,  $\text{H}_2\text{O}$  that is part of the terrestrial water cycle is enriched in the light  $\text{O}_{16}$  isotope and

Sea water is enriched in the heavier  $\text{O}_{18}$  isotope

# Klimatický význam frakcionace $^{18}\text{O}/^{16}\text{O}$



Glacial ice is therefore made up primarily of water with the light  $\text{O}_{16}$  isotope. This leaves the oceans enriched in the heavier  $\text{O}_{18}$ , or “more positive.”

During glacial periods, more  $\text{O}_{16}$  is trapped in glacial ice and the oceans become even more enriched in  $\text{O}_{18}$ .

During interglacial periods,  $\text{O}_{16}$  melts out of ice and the oceans become less  $\text{O}_{18}$  rich, or “more negative” in  $\text{O}_{18}$ .

# $^{18}\text{O}/^{16}\text{O}$ a globální objem ledu

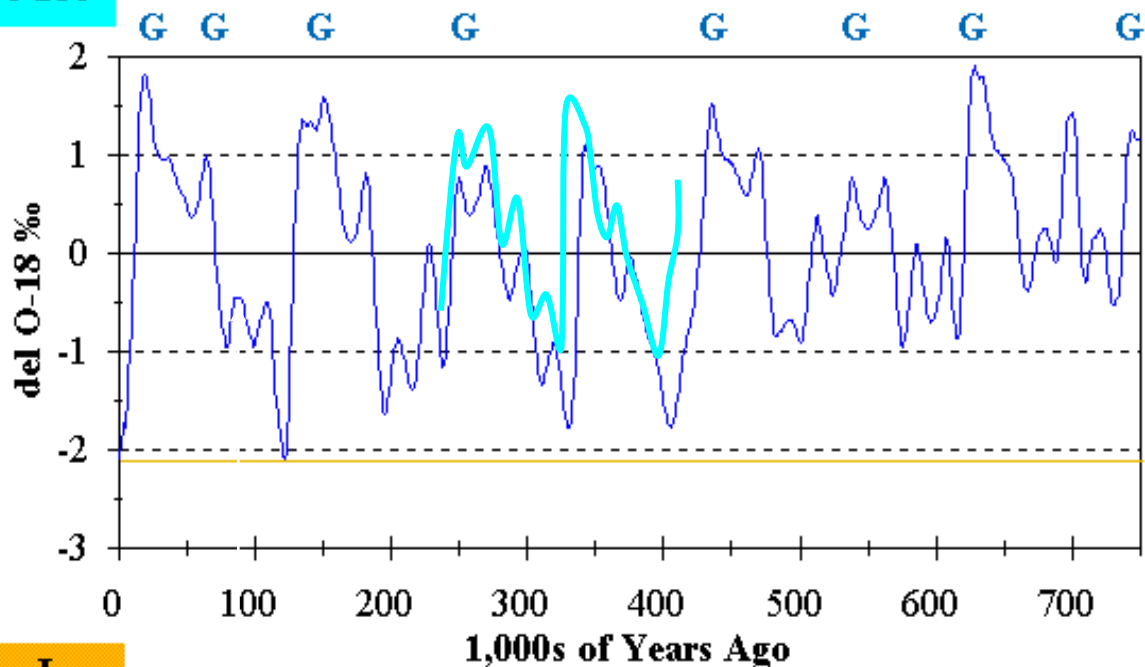
- As ice sheets grow, the water removed from the ocean has lower  $^{18}\text{O}$  than the water that remains.
- Thus the  $\delta^{18}\text{O}$  value of sea water in the global ocean is linearly correlated with ice volume (larger  $\delta^{18}\text{O}$   $\rightarrow$  larger ice sheets).
- A time series of global ocean  $^{18}\text{O}$  is equivalent to a time series of ice volume.



# Záznam izotopů kyslíku v mořských sedimentech za posledních 700 tisíc let

Ice Volume  
Planktonic Foram O-18 as Proxy

More Ice



Less Ice

Vrtné projekty  
DSDP a ODP

Pelagické  
sedimenty, cca  
konstantní rychlost  
sedimentace,  
datování

$^{18}\text{O}$  v schránkách  
plaktonních  
foraminifer ( $\text{CaCO}_3$ )

Časové řady

# Paleoklimatologie z vrtných jader ledu

- As snow falls on very cold glaciers or ice sheets and gradually is converted to ice, air is trapped in bubbles.
- This “fossil air” can be chemically analyzed to determine past atmospheric composition.
- Other paleoclimatic proxies (isotopes, dust, acidity) can also be determined from the ice, providing information about temperature, sulfate aerosols, precipitation.

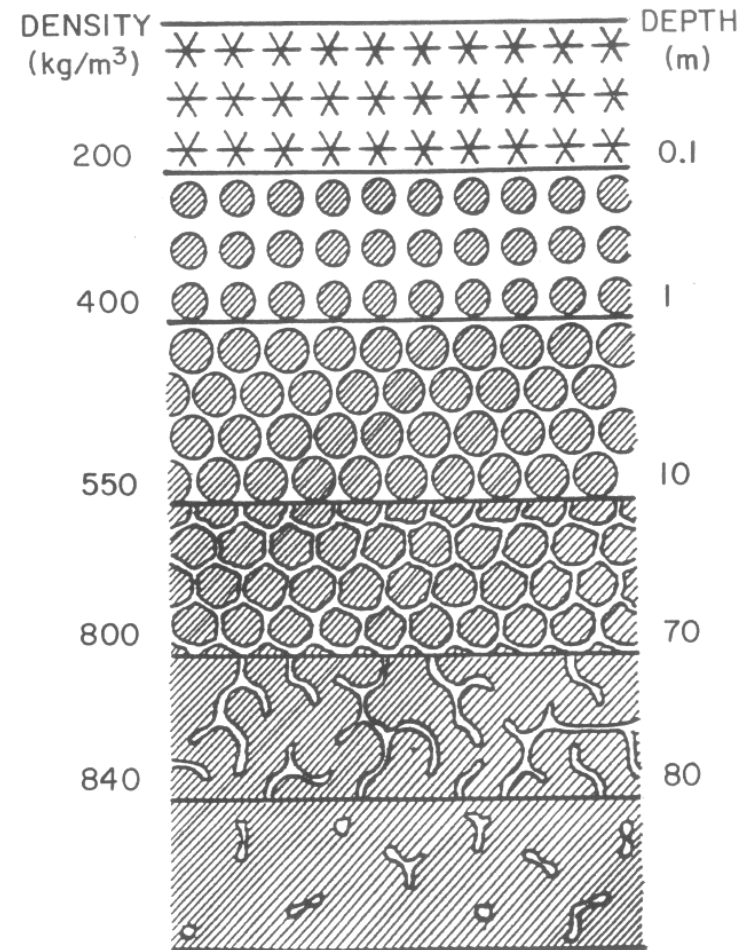
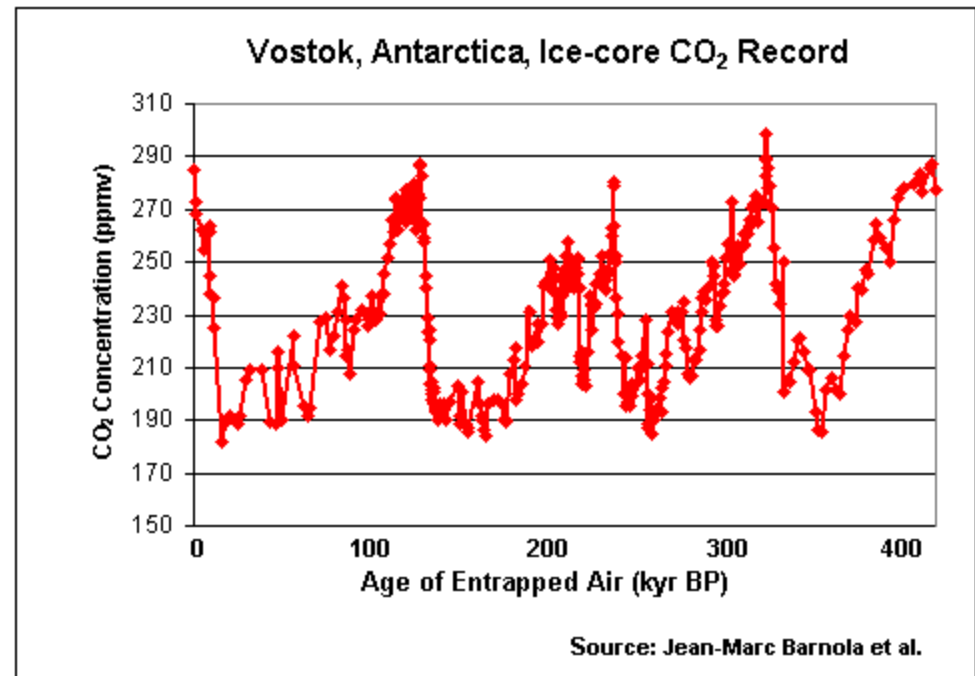


Figure 14. Diagrammatic depiction of the gradual lithification of the snow which falls on polar ice caps. The snow recrystallizes to firm which has passages through which air can circulate. When the firm is fully lithified, the air passages are sealed off becoming bubbles.

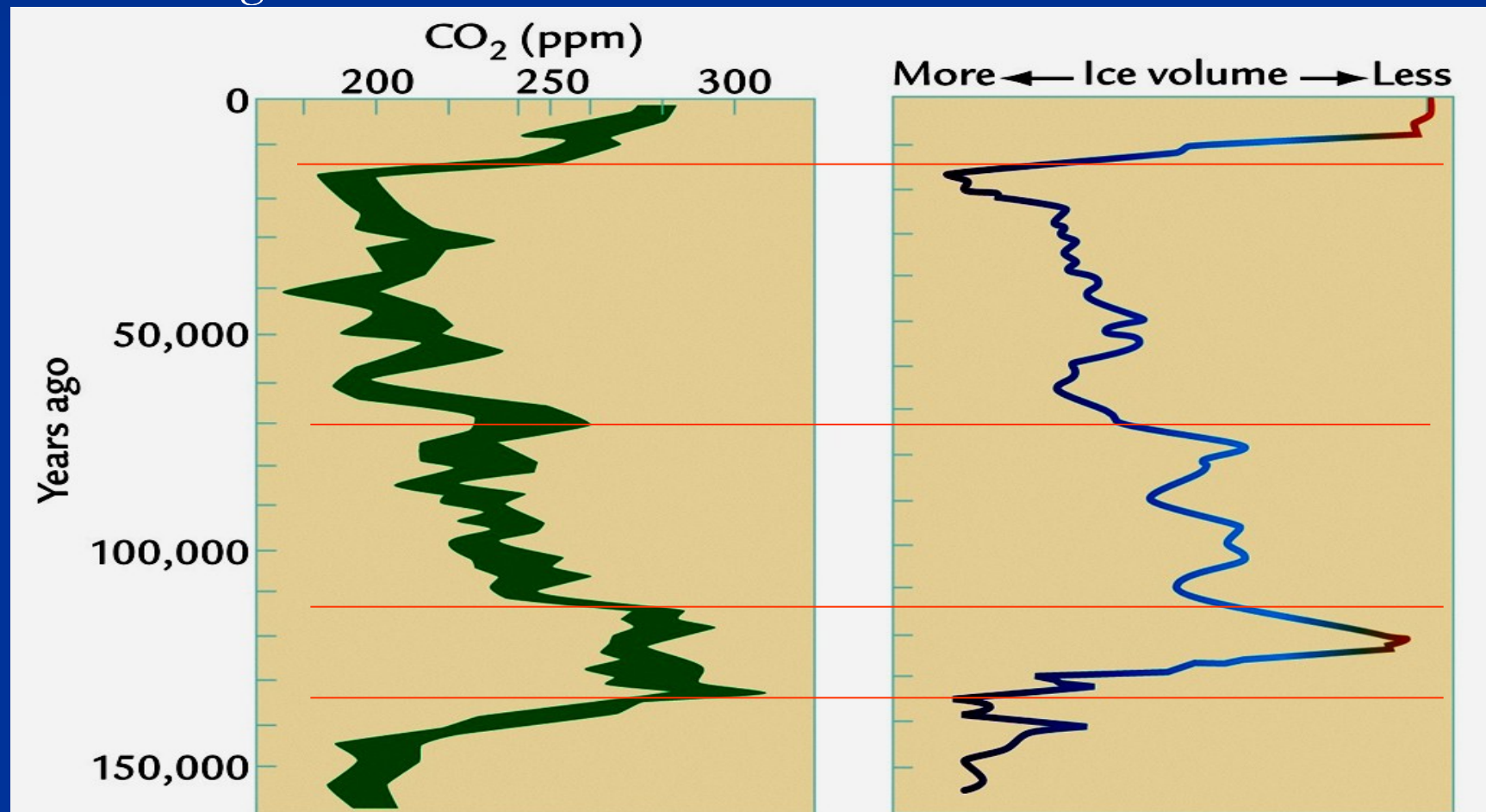
# Vrt Vostok, Antarktida





# CO<sub>2</sub> v atmosféře a objem ledovců

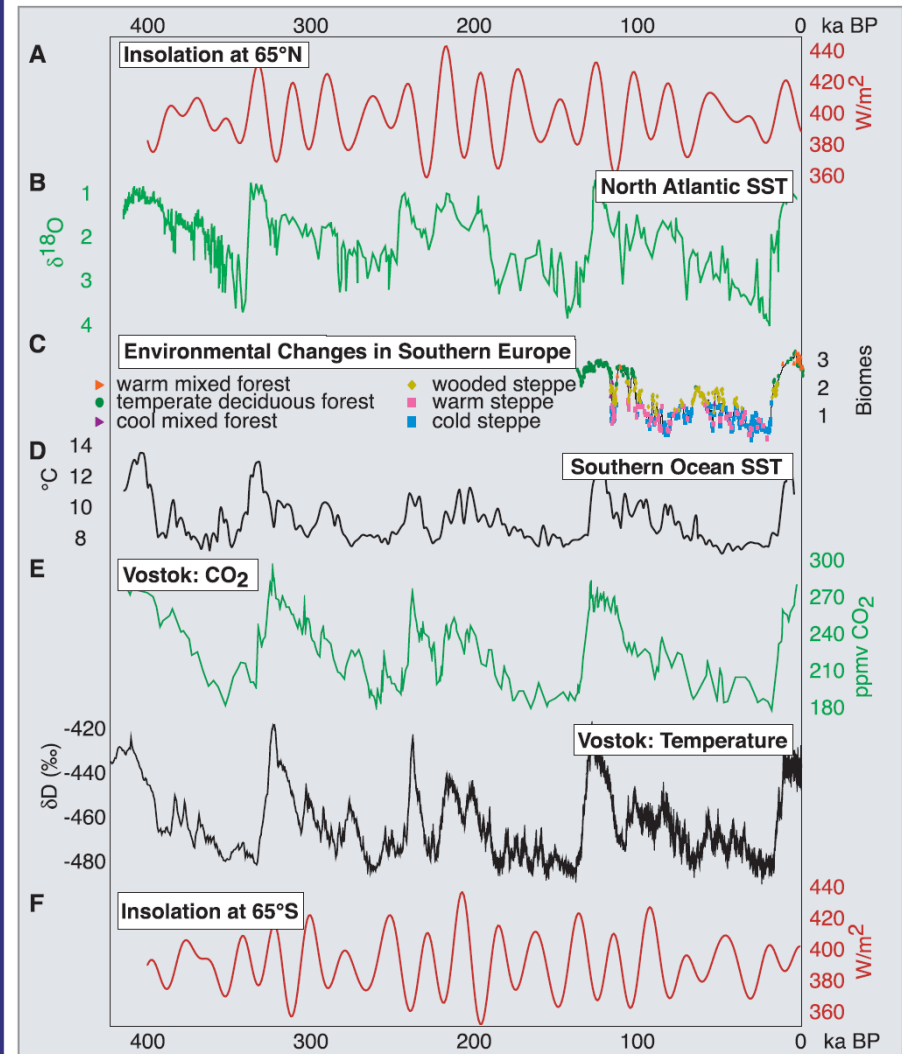
- Records of CO<sub>2</sub> and ice volume well correlated
  - Both must be related ultimately to orbital changes
  - Strong correlation



# Multiproxy Analysis of Glacial Cycles

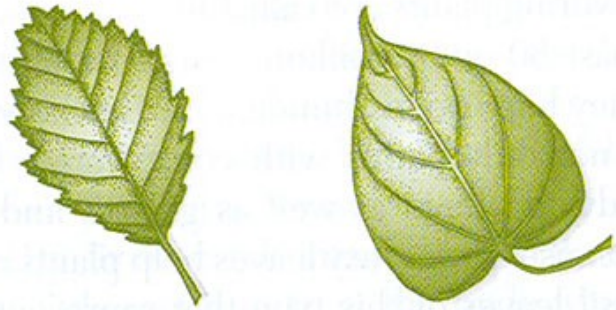
- Glacial-interglacial cycles are evident in a variety of paleoclimatic and paleoceanographic proxies.
- The shapes of the cycles vary somewhat among the different proxies.
- Glacial-interglacial variations in atmospheric CO<sub>2</sub> concentration are substantial. (But what causes them?)
- There are uncertainties in time scales.

## Climatic Proxies From Both Hemispheres Over Four Glacial Cycles



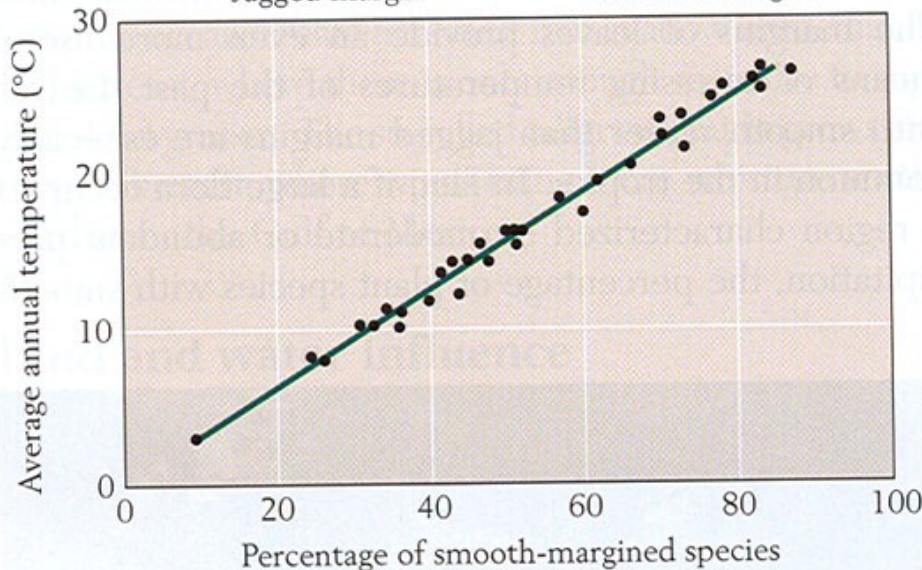
Paleoclimate, Global Change and the Future  
Alverson, Bradley and Pederson eds., 2002

# Záznam klimatických změn v morfologii listů krytosemenných rostlin



Jagged margin

Smooth margin



Serrations (zoubkování) on leaf margins indicate temperature: jagged edges (zoubkované okraje) indicate cooler climate

Leaf waxiness is an indicator of moisture retention



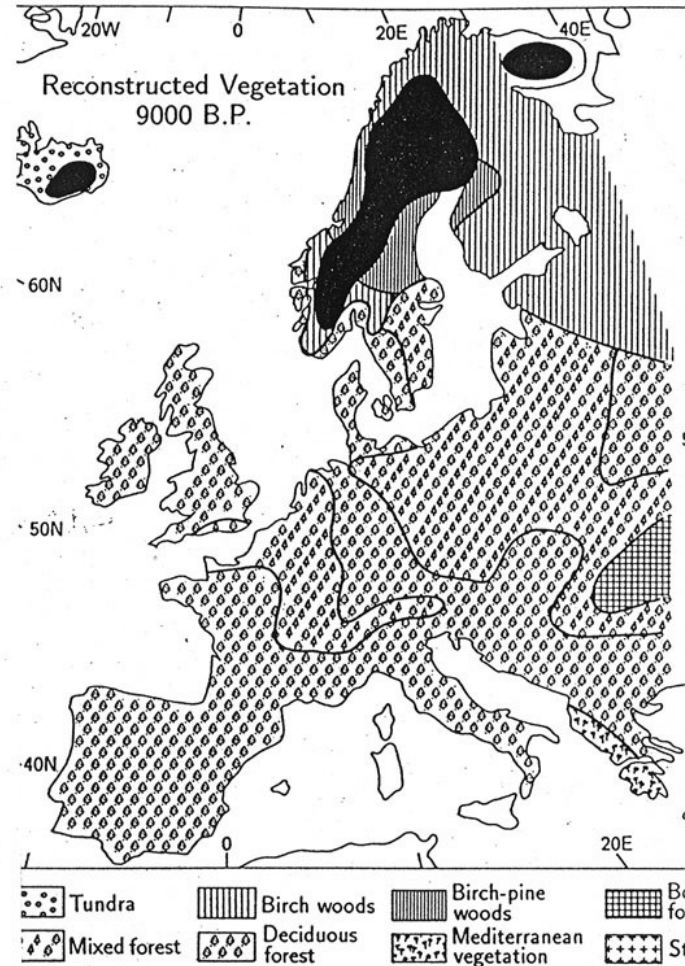
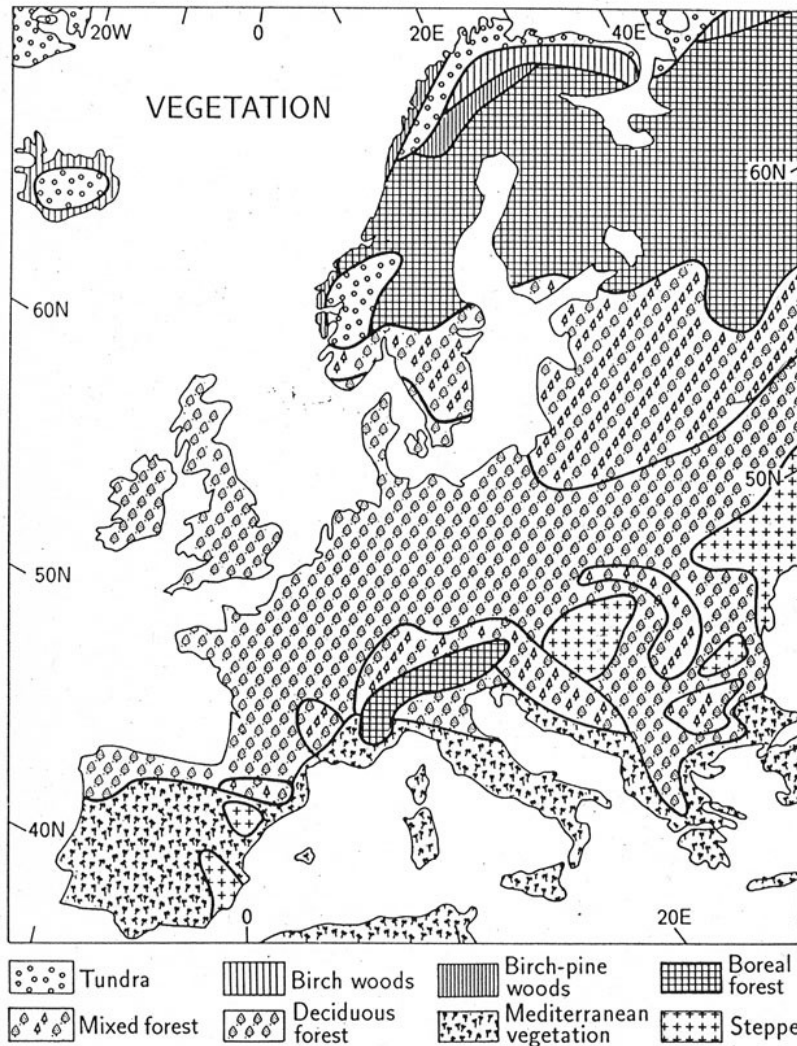
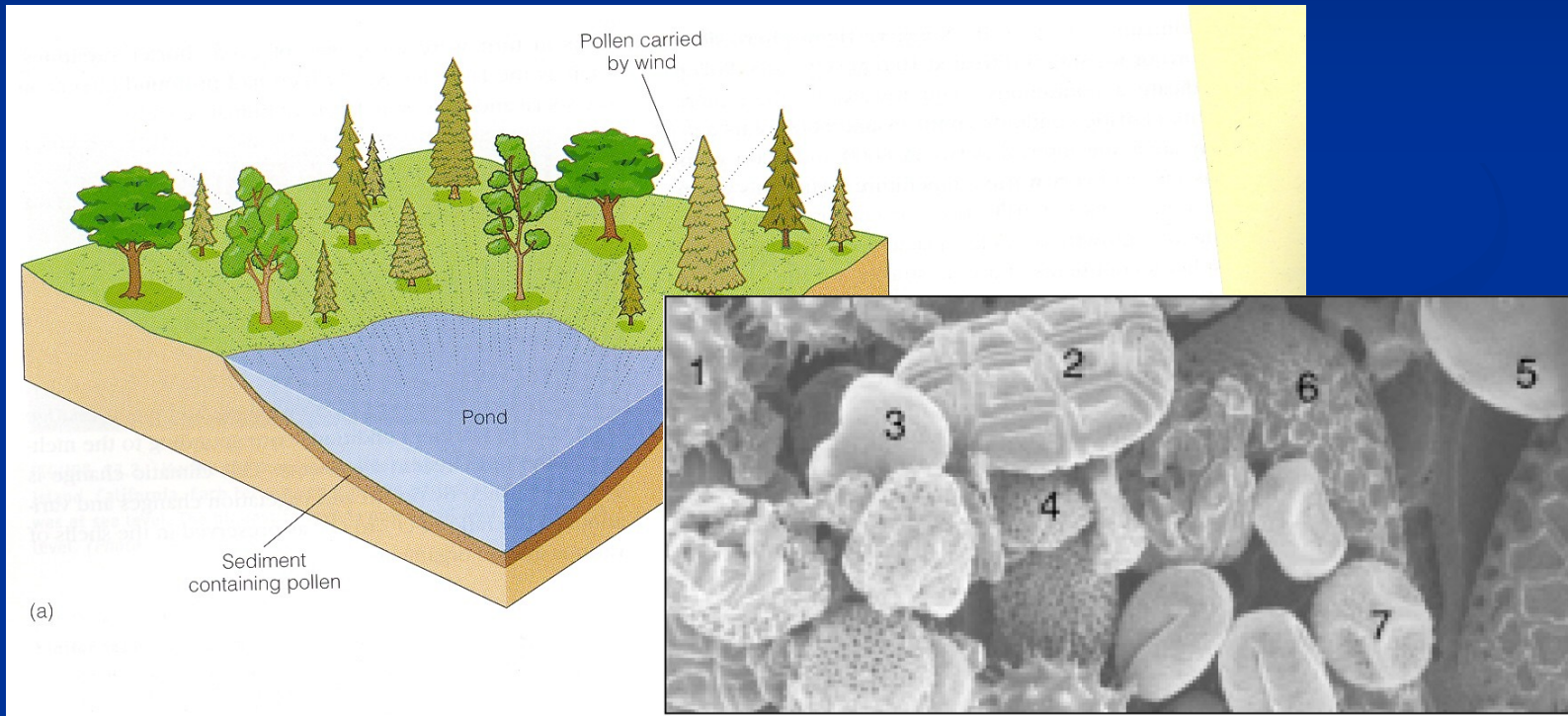


Fig. 73. European vegetation regions (data from Fullard and

Vegetation zones in Europe parallel latitude now and 9,000 yr before present

# Pyly

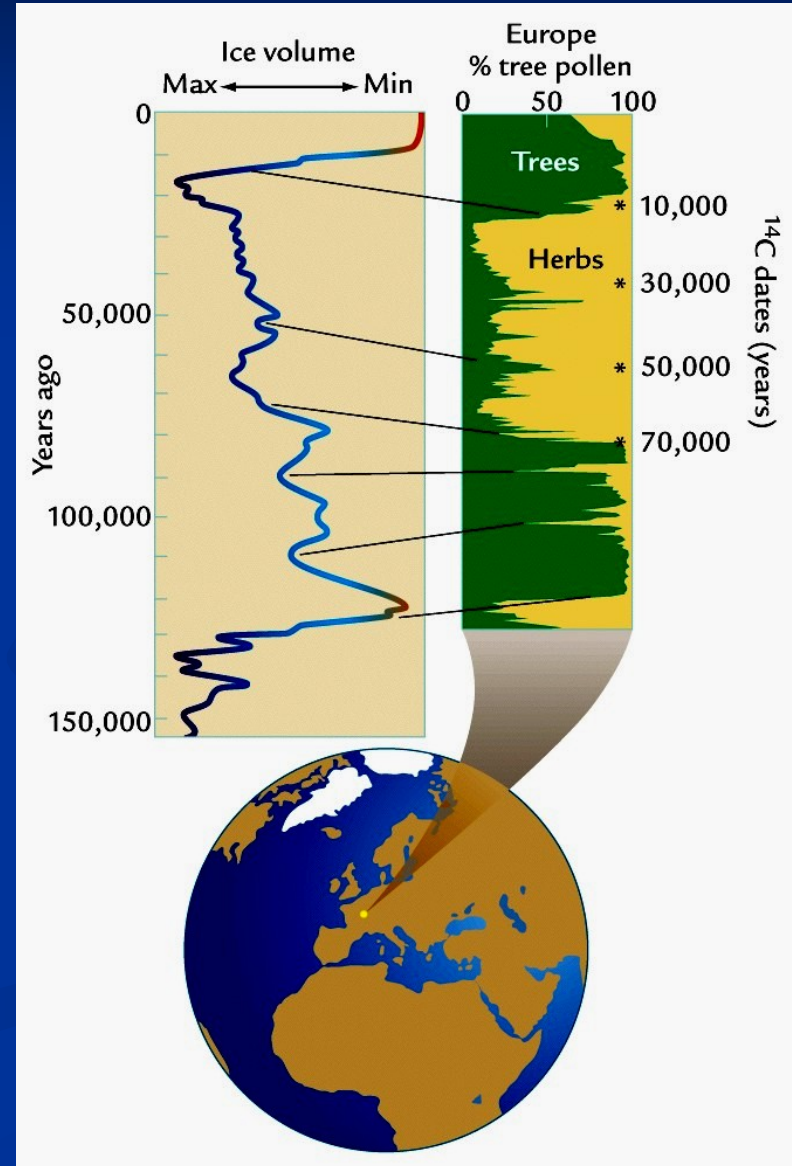
- Scanning electron microscope view of present-day pollen grains, including



- (1) slunečnice, (2) akácie, (3) dub, (4) hořčice, (5) ořech, (6) agáve, (7) jasan

# Pylové analýzy – směry proudění vzduchu

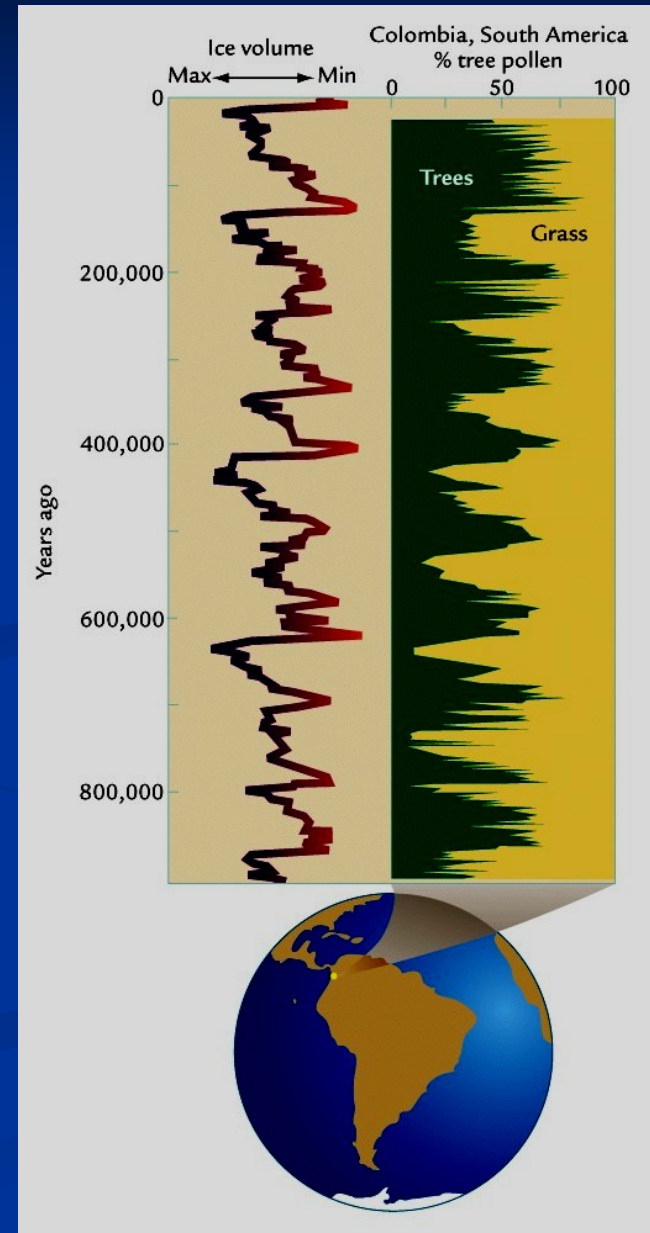
- Pollen changes in France
  - N. Europe's climate changed
    - Warm and moist (trees)
    - Cold and dry (herbs)
  - Changes correlate with ice volume
  - Cold winds from Scandinavian ice sheets
  - N. Atlantic ocean colder than today
    - Relative warm N. Atlantic moderates Europe's winter weather





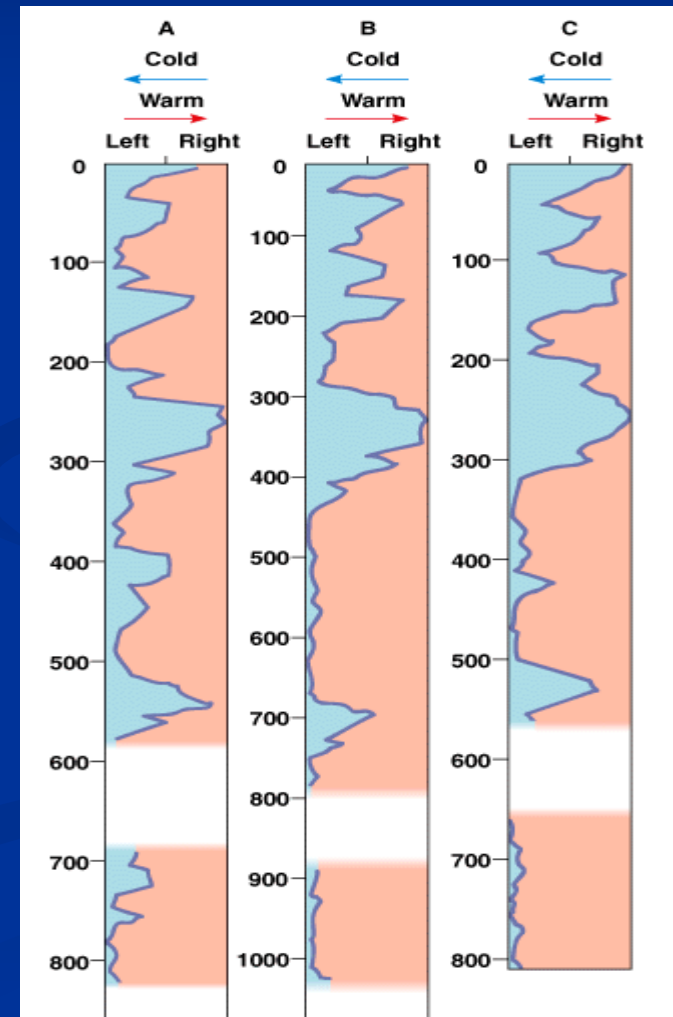
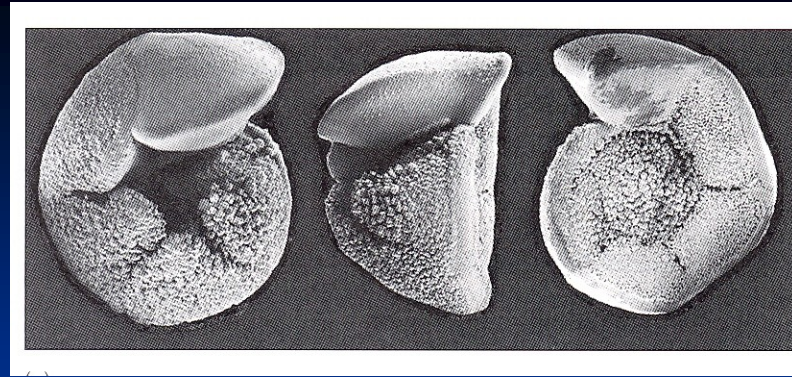
# Pylové analýzy v Jižní Americe

- Long cores from eastern Columbian lakes
  - Pollen records that **alternate between grass and trees**
  - 100,000 year cycles
    - **Trees** grew **during rapid warming**
    - **Grassland** dominated **during slow cooling** intervals



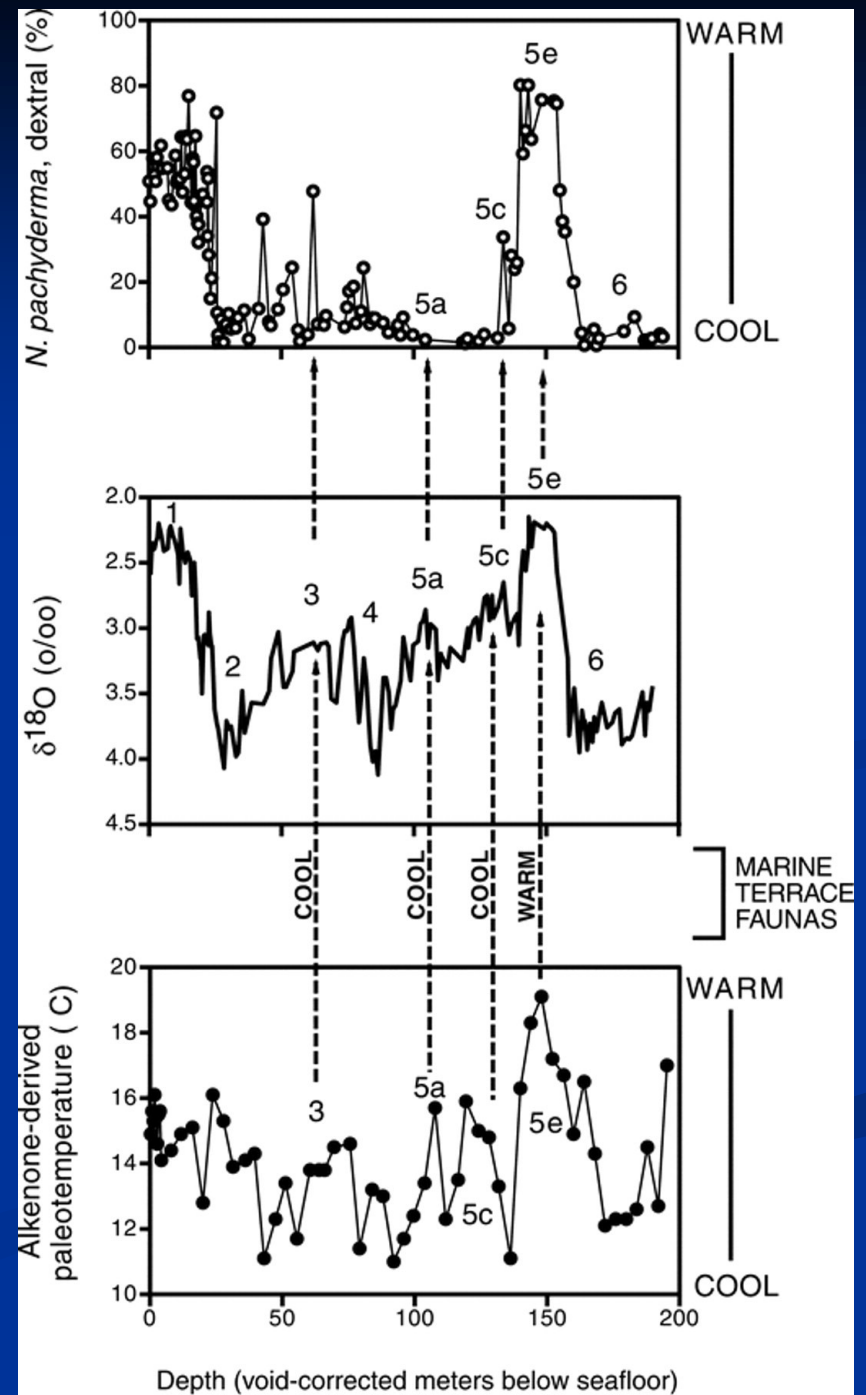
# Směr vinutí schránek planktonních foraminifer

- Some planktonic foraminifera species change the direction they coil (vinout se) during growth in response to temperature fluctuations
- The Pleistocene species *Globorotalia truncatulinoides* coils predominantly to the right in water temperatures above 10°C but coils mostly to the left in water below 8°-10°C
- On the basis of changing coiling ratios, geologists have constructed detailed climatic curves for the Pleistocene and earlier epochs



Graphs illustrating the percentages of right-coiling and left-coiling foraminifera, *Globorotalia truncatulinoides*. The vertical scale is depth in deep sea sediment cores, in centimeters

- Paleoclimatic records from sediments of Santa Barbara Basin compared to marine-terrace faunas from this study.
- Middle panel: Oxygen isotope record of benthic foraminifera and isotope substages (data from Kennett, 1995).
- Upper panel: Abundances of warm-water planktonic foraminifer *Neogloboquadrina pachyderma*, dextral-coiling (data from Kennett and Venz, 1995).
- Lower panel: Surface-water paleotemperature estimates derived from alkenone-unsaturation index from phytoplankton (data from Herbert et al., 1995). Marine-terrace–fauna temperature aspect derived from paleozoogeographic inferences and U-series ages herein (see text for references).

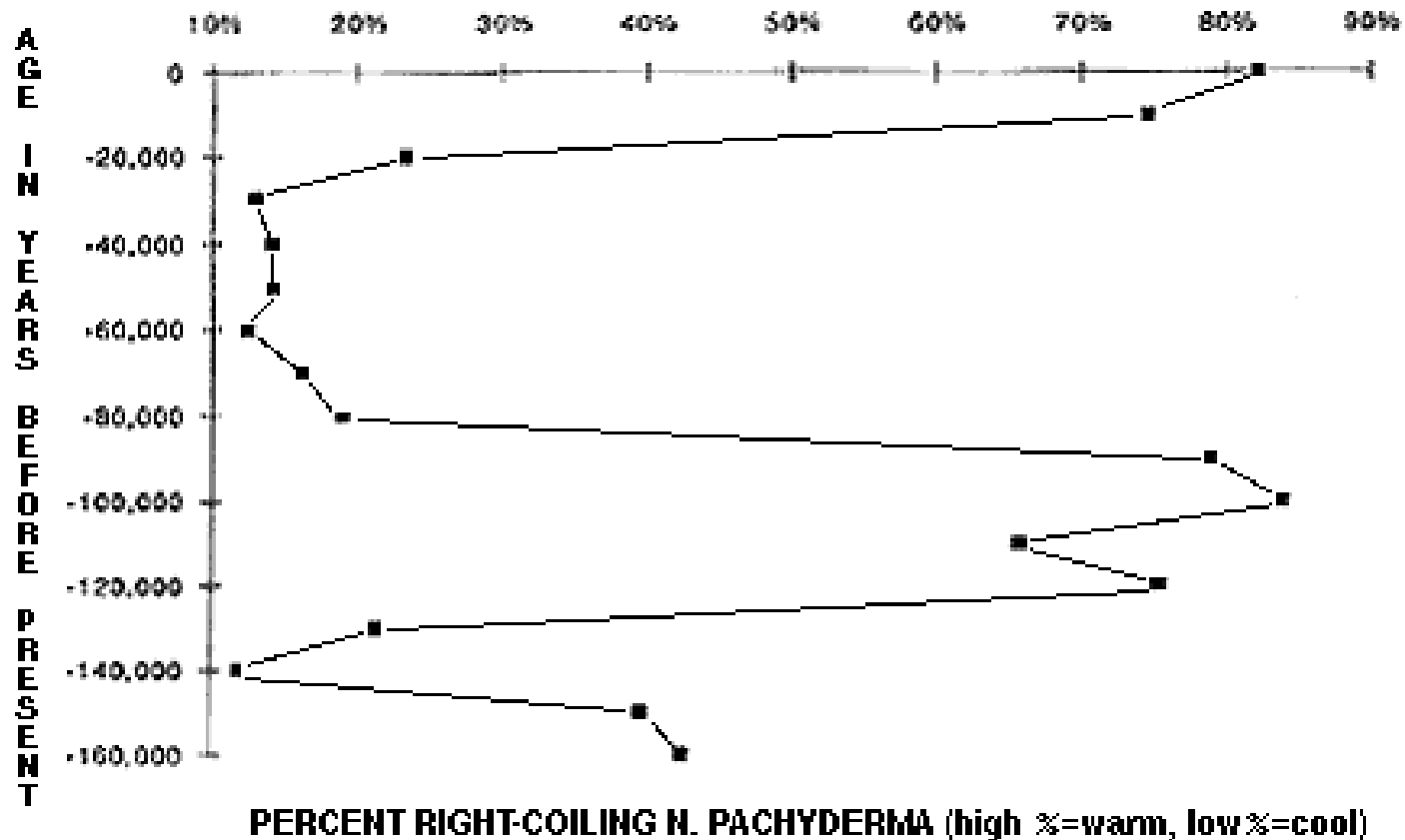




# *Neogloboquadrina pachyderma*

- *Neogloboquadrina pachyderma* is an excellent recorder of climatic temperatures through geologic time. When the earth experiences periods of relatively cold temperatures, ocean waters are cooler and *Neogloboquadrina pachyderma* forms its test (shell) such that it coils to the left. Alternatively, during periods of relatively warm temperatures when ocean waters are warmer, *Neogloboquadrina pachyderma* constructs its test with a coiling direction to the right.

Figure 1. Climatic signal derived from coiling ratios of *Neogloboquadrina pachyderma*.



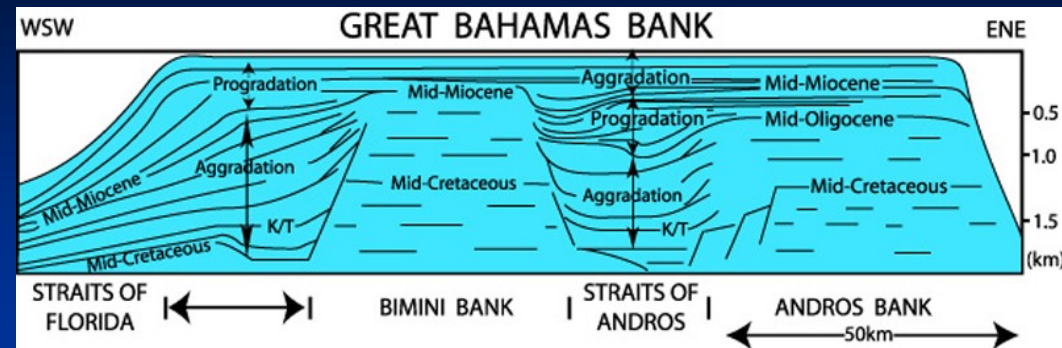
# Biogeografie planktonních foraminifer

- Many are sensitive to variations in temperature
  - and migrate to different latitudes when the surface water temperature changes
- For example, the tropical species
  - *Globorotalia menardii* is present or absent within Pleistocene sediment samples, depending on what the surface water temperature was at the time
- During periods of cooler climate,
  - it is found only near the equator, while during times of warming its range extends into the higher latitudes

# Klima a kolísání mořské hladiny

## Velká bahamská lavice

- Plochý povrch
- Malá hloubka
- Záznam oscilací mořské hladiny  
(GLACIEUSTATICKÉ CYKLY)

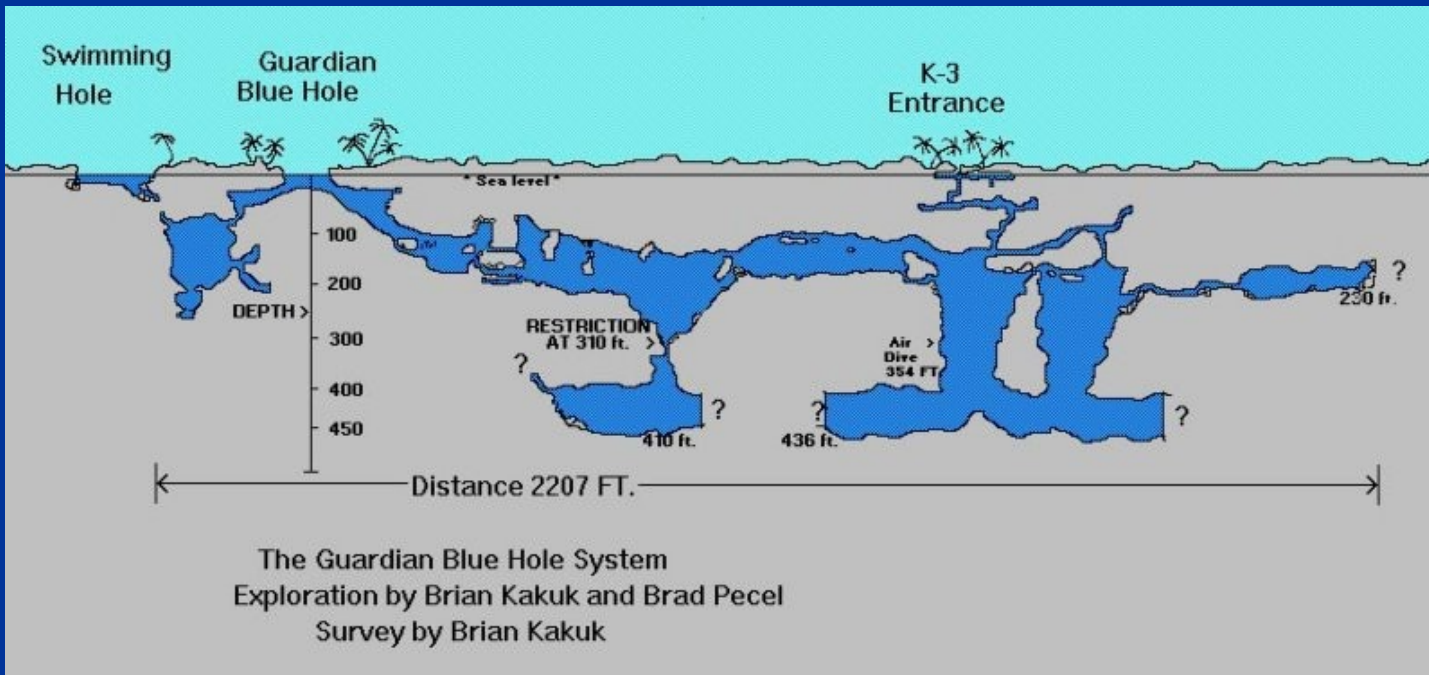




# Klima a kolísání mořské hladiny

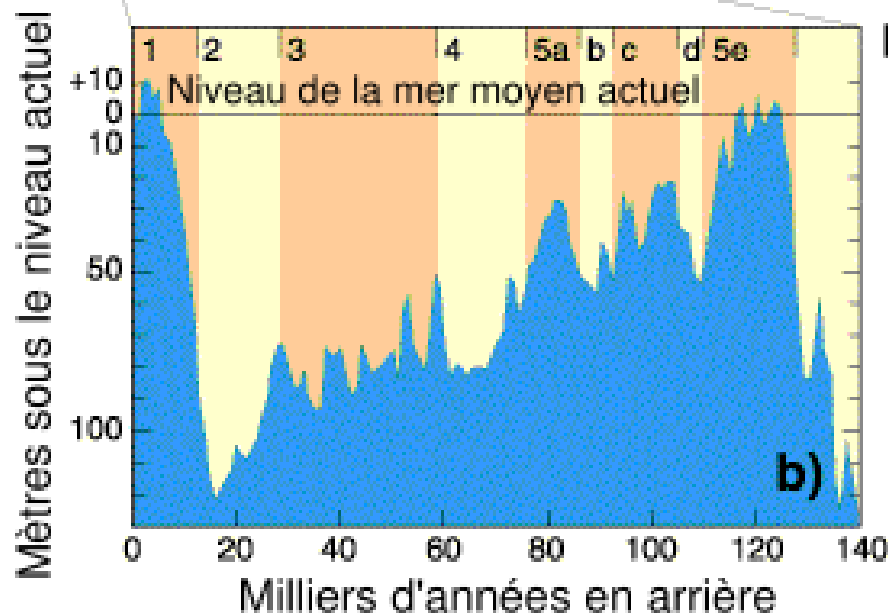
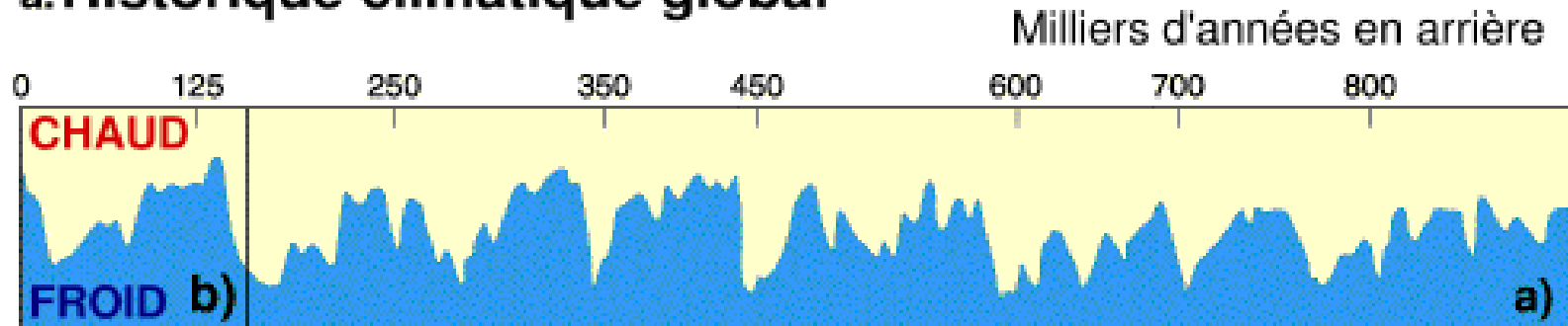


- Modré díry (blue holes), Bahamy, Belize: jeskynní systémy
- **Glaciál**: nízká hladina oceánu, vynoření VBL nad hladinu + krasovění (blue holes)
- **Interglaciál**: vysoká hladina oceánu, zalití VBL vodou + obnovená mořská sedimentace
- Střídání mořské sedimentace (depoziční sekvence) a subaerické eroze (sekvenční hranice):  
**GLACIEUSTATICKÁ CYKLICITA**



# Kolísání mořské hladiny

## a. Historique climatique global



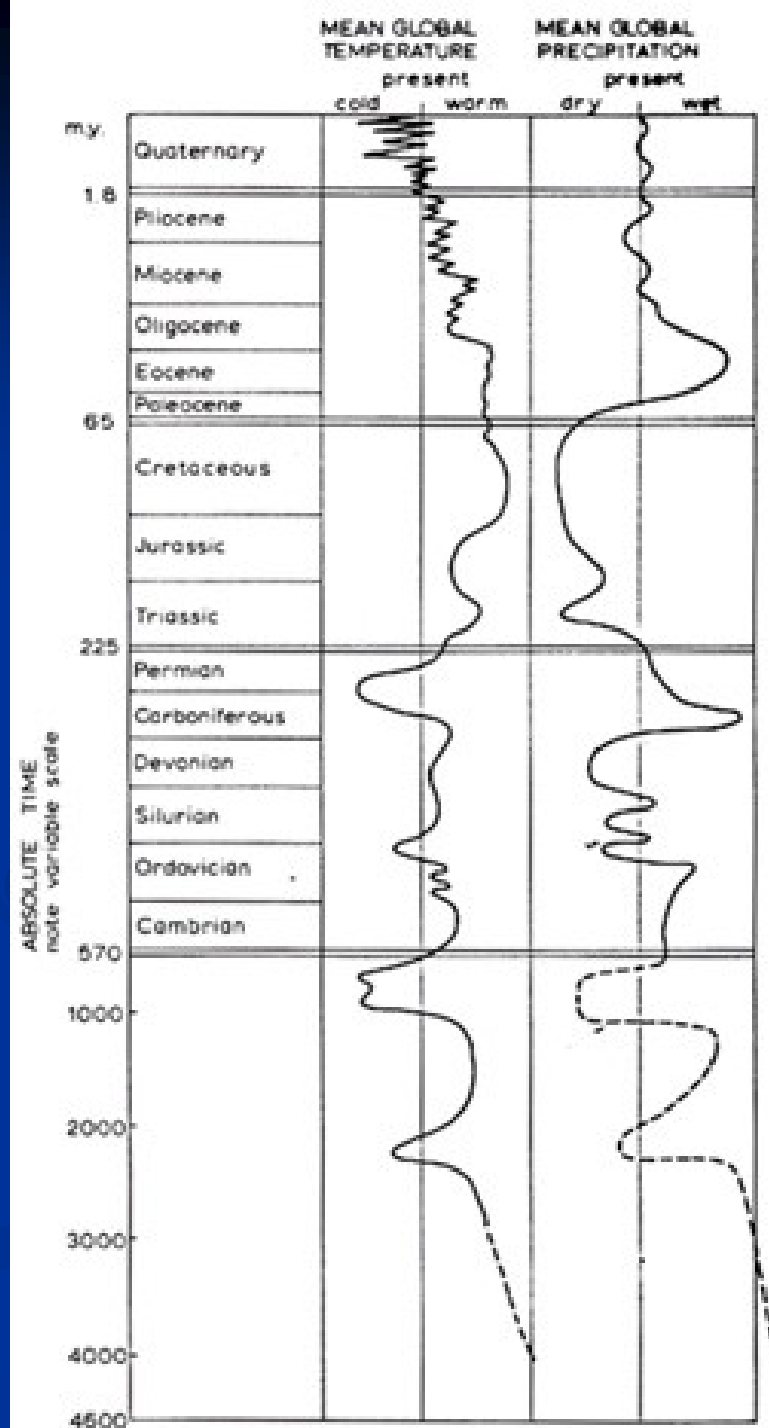
## b. Historique du niveau de la mer à la fin du Quaternaire



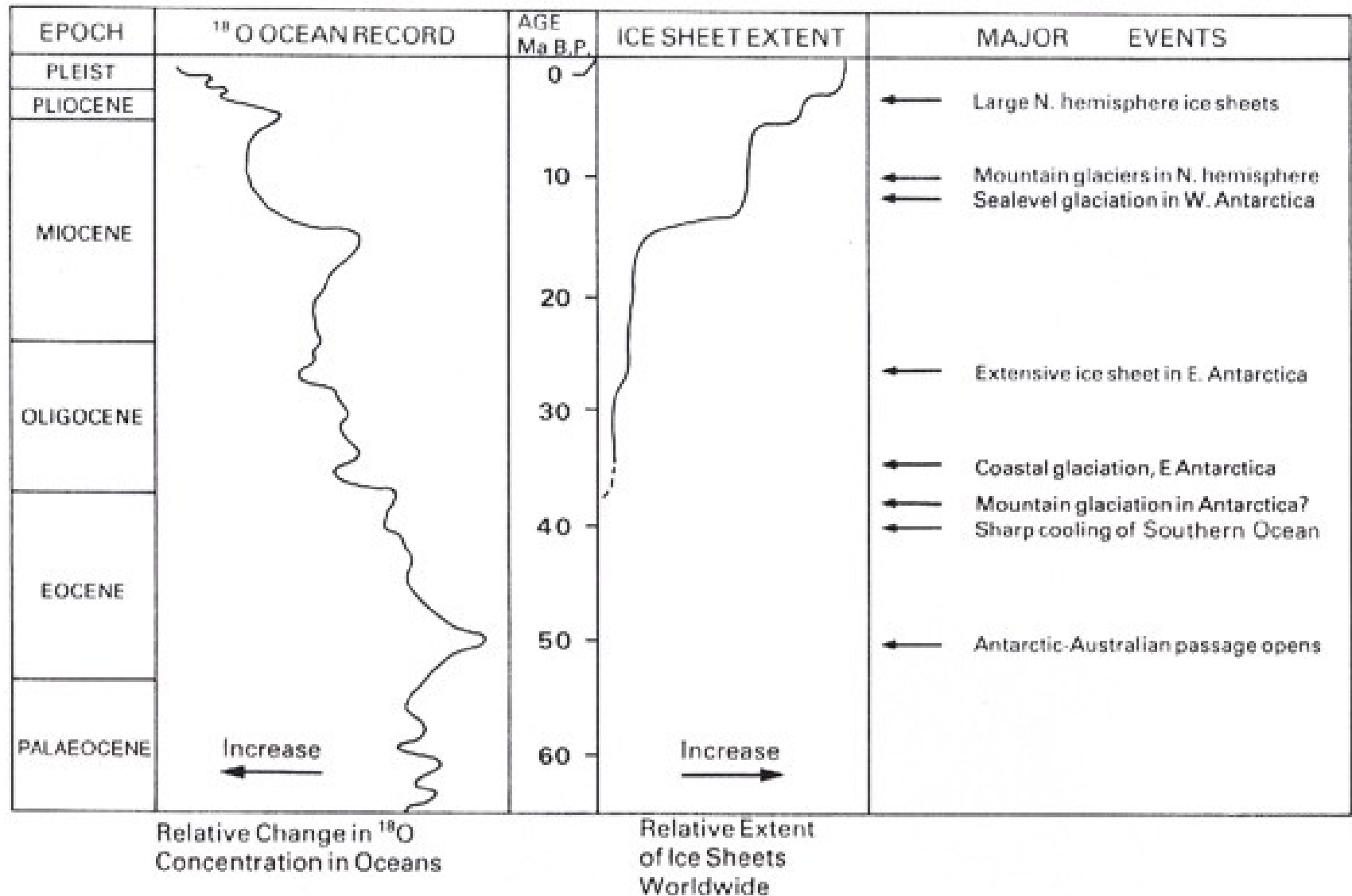


# Počátek cyklického střídání glaciálů

- The onset of glacial conditions
  - actually began about 40 million years ago
  - when surface ocean waters at high southern latitudes rapidly cooled, and the water in the deep-ocean became much colder than it had been previously
- The gradual closure of the Tethys Sea
  - during the Oligocene
  - limited the flow of warm water to higher latitudes



# Počátek cyklického střídání glaciálů



# Před pleistocénem

- Střední miocén,
  - an Antarctic ice sheet had formed,
  - accelerating the formation of very cold oceanic waters
- Oteplení v Pliocénu
- Ochlazení koncem pliocénu
  - continental glaciers
  - began forming in the Northern Hemisphere
  - about 1.6 million years ago

# Klima v pleistocénu

- The climatic conditions
  - leading to Pleistocene glaciation were, as you would expect, worldwide
- But contrary to popular belief
  - and depictions in cartoons and movies, Earth was not as frigid as it is commonly portrayed
- In fact, evidence of various kinds
  - indicates that the world's climate gradually cooled from Eocene through Pleistocene time



# Late Wisconsin Environment

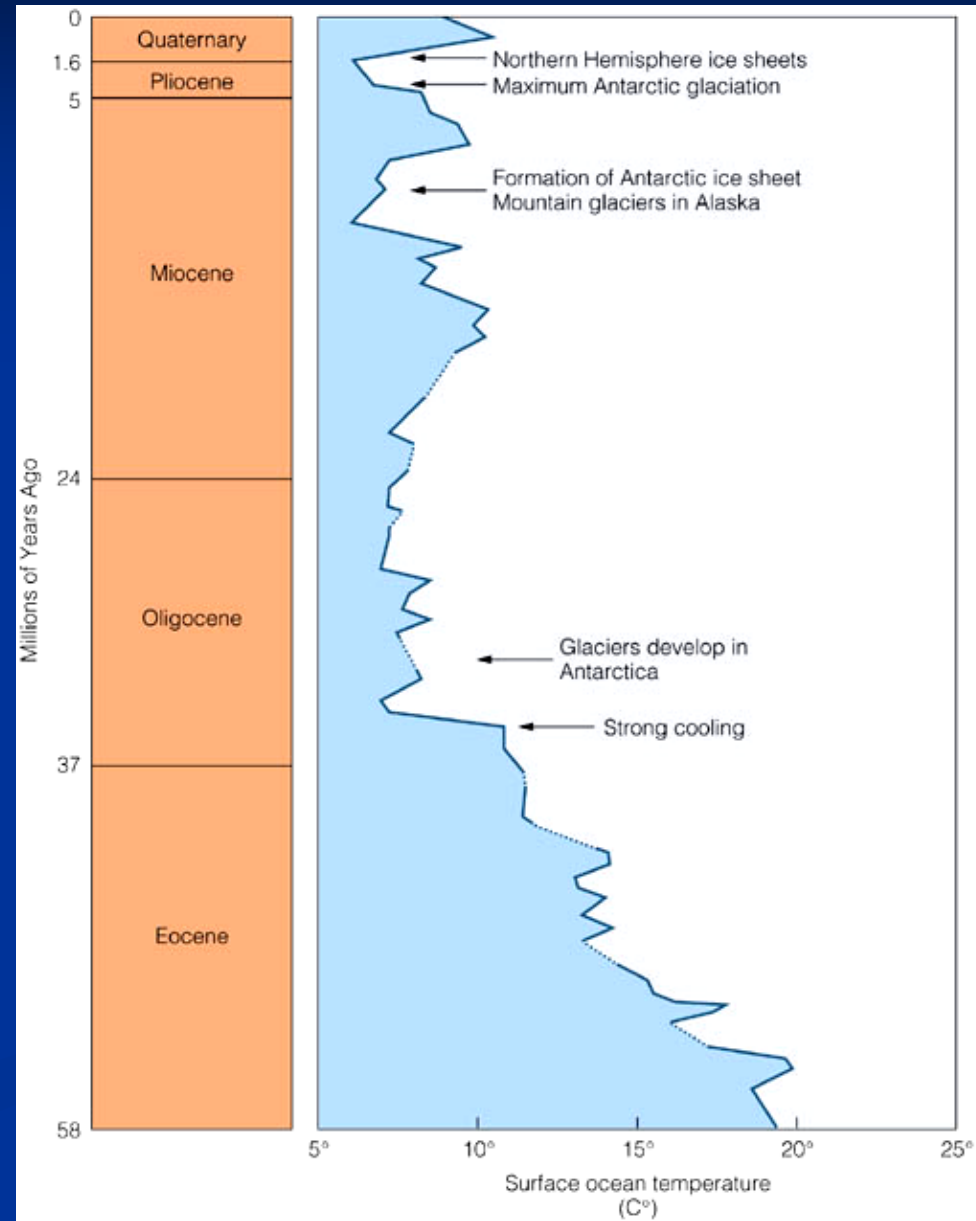


# Kolik těch dob ledových vlastně bylo ?

- Oxygen isotope ratios ( $O^{18}$  to  $O^{16}$ )
  - from deep-sea cores reveal that
  - Earth has had 20 major warm-cold cycles during the last 2 million years
  - during which the temperature fluctuated by as much as  $10^{\circ}\text{C}$
- Studies of glacial deposits
  - attest to at least four major episodes of glaciation in North America
  - and six or seven similar events in Europe

# Povrchová teplota oceánu

- Fluctuations in  $O^{18}$ -to- $O^{16}$  isotope ratios
  - from a sediment core in the western Pacific Ocean
  - reveal changes in ocean surface temperatures during the last 58 million years
  - A change from warm to colder conditions took place 35 million years ago



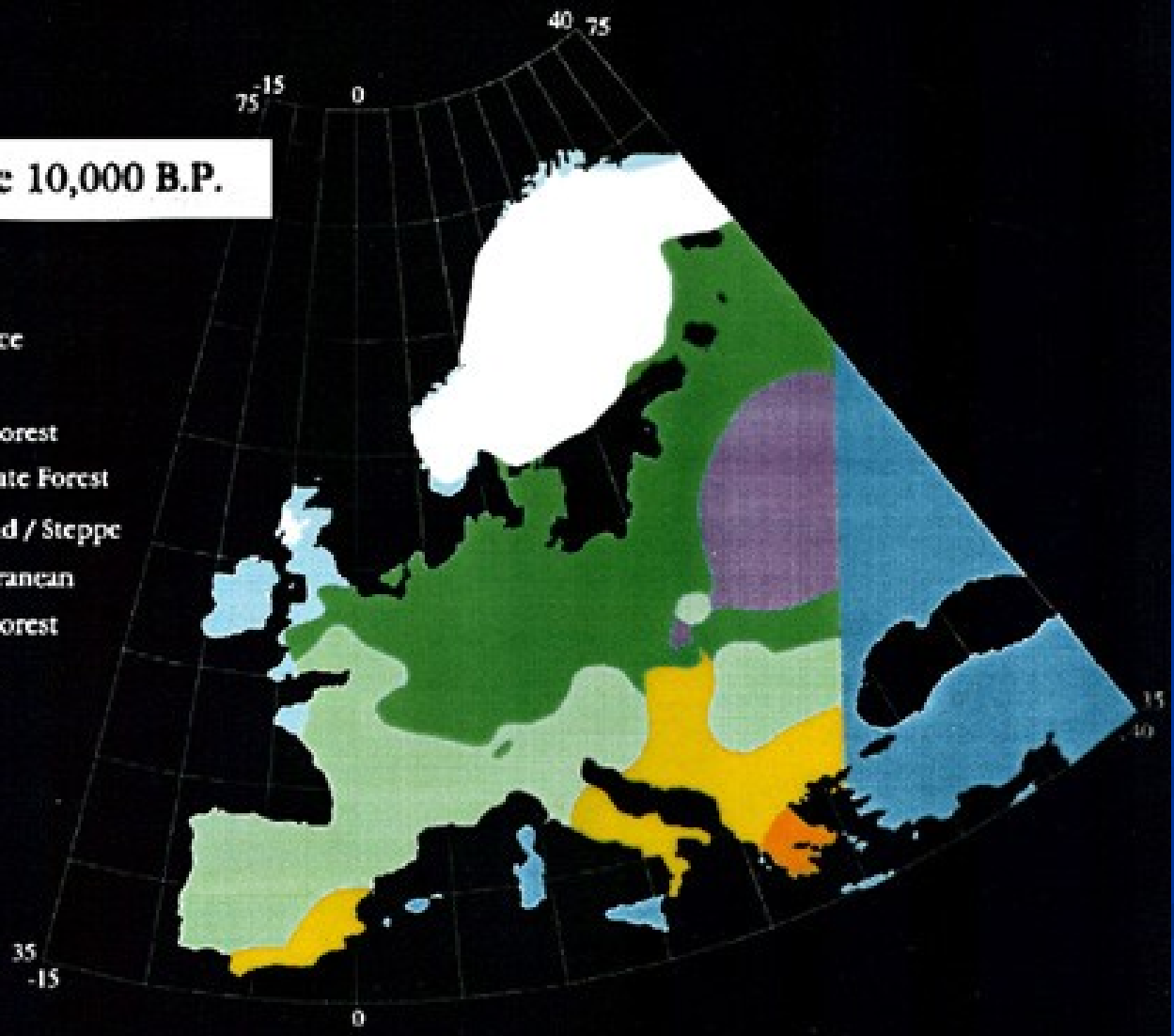
# Chladná léta, vlhké zimy

- během růstu ledovců
  - those areas covered by, or near glaciers experienced short, cool summers and long, wet winters
  - but areas distant from glaciers had varied climates
- Během postupu ledovců,
  - lower ocean temperatures
  - reduced evaporation rates
  - so most of the world was drier than it is now
- But some now arid areas were much wetter during the Ice Age



# Europe 10,000 B.P.

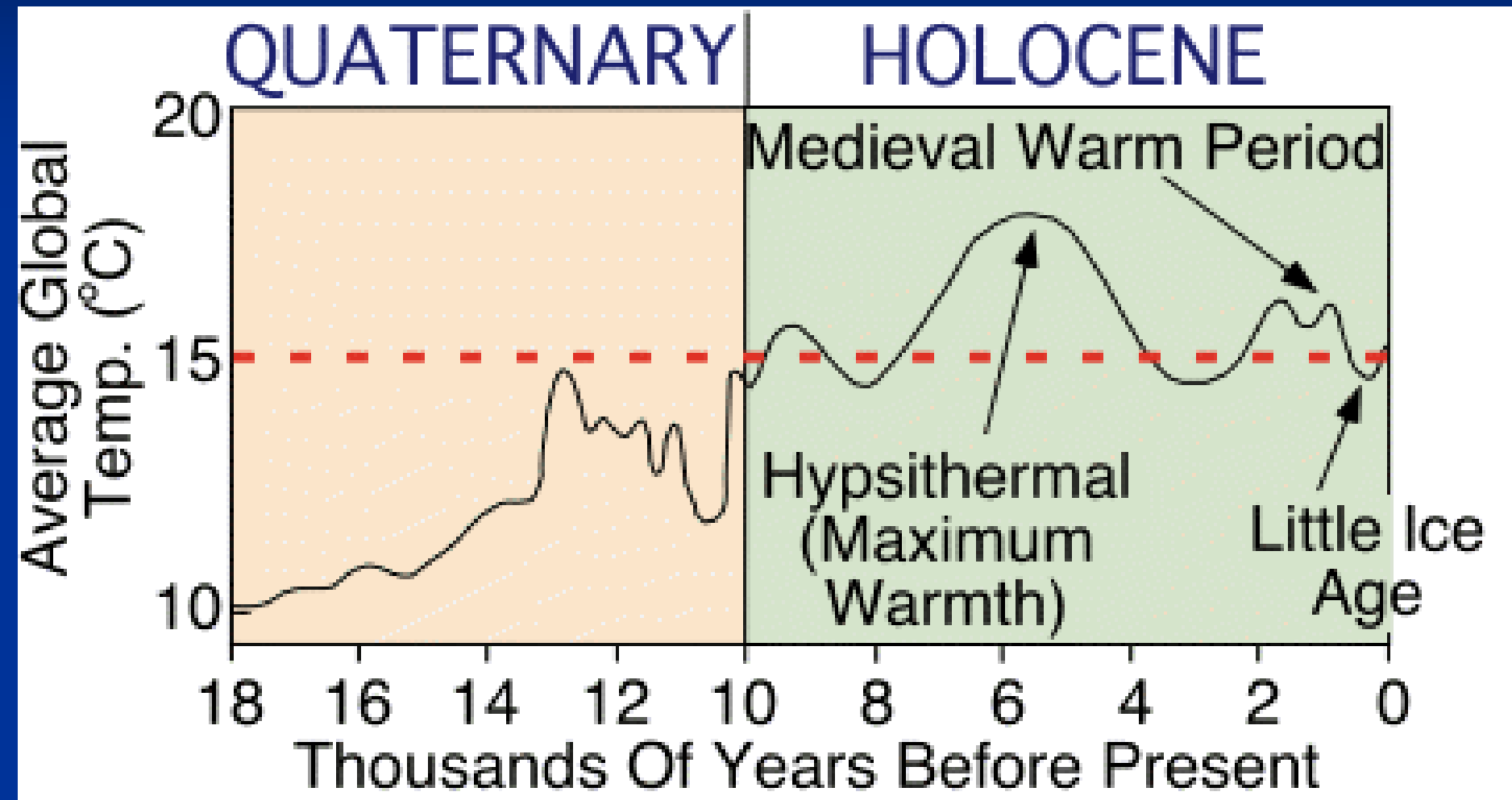
- Glacial Ice
- Tundra
- Boreal Forest
- Temperate Forest
- Grassland / Steppe
- Mediterranean
- Mixed Forest
- No Data



# Holocén

- Klimatické fluktuace
  - have certainly occurred since the Pleistocene,
  - the most recent significant one being the Little Ice Age (malá doba ledová)
    - from about A.D. 1500 until some time in the 1800s
- Malá doba ledová byla obdobím
  - of glacial expansion in mountain valleys,
  - as well as of cooler, wetter summers with shorter growing seasons

# Holocenní teplá období







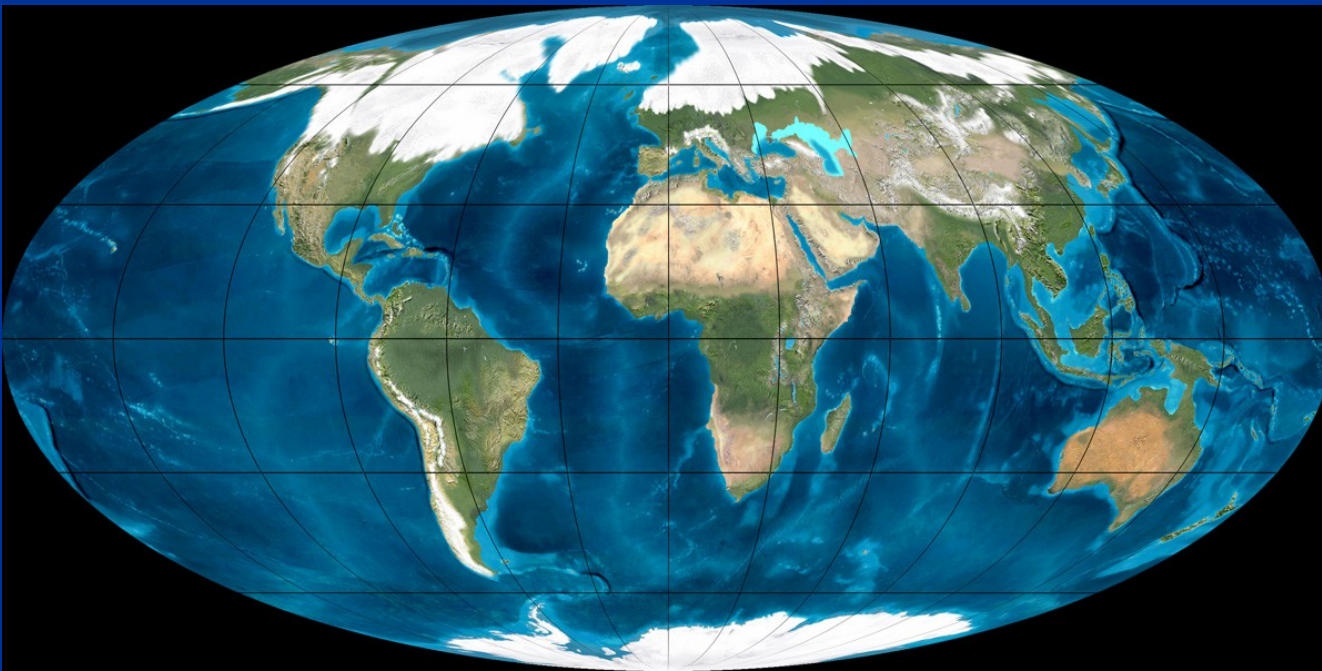
# Malá doba ledová

- During the Little Ice Age,
  - many glaciers in Europe extended much farther down their valleys than they do now

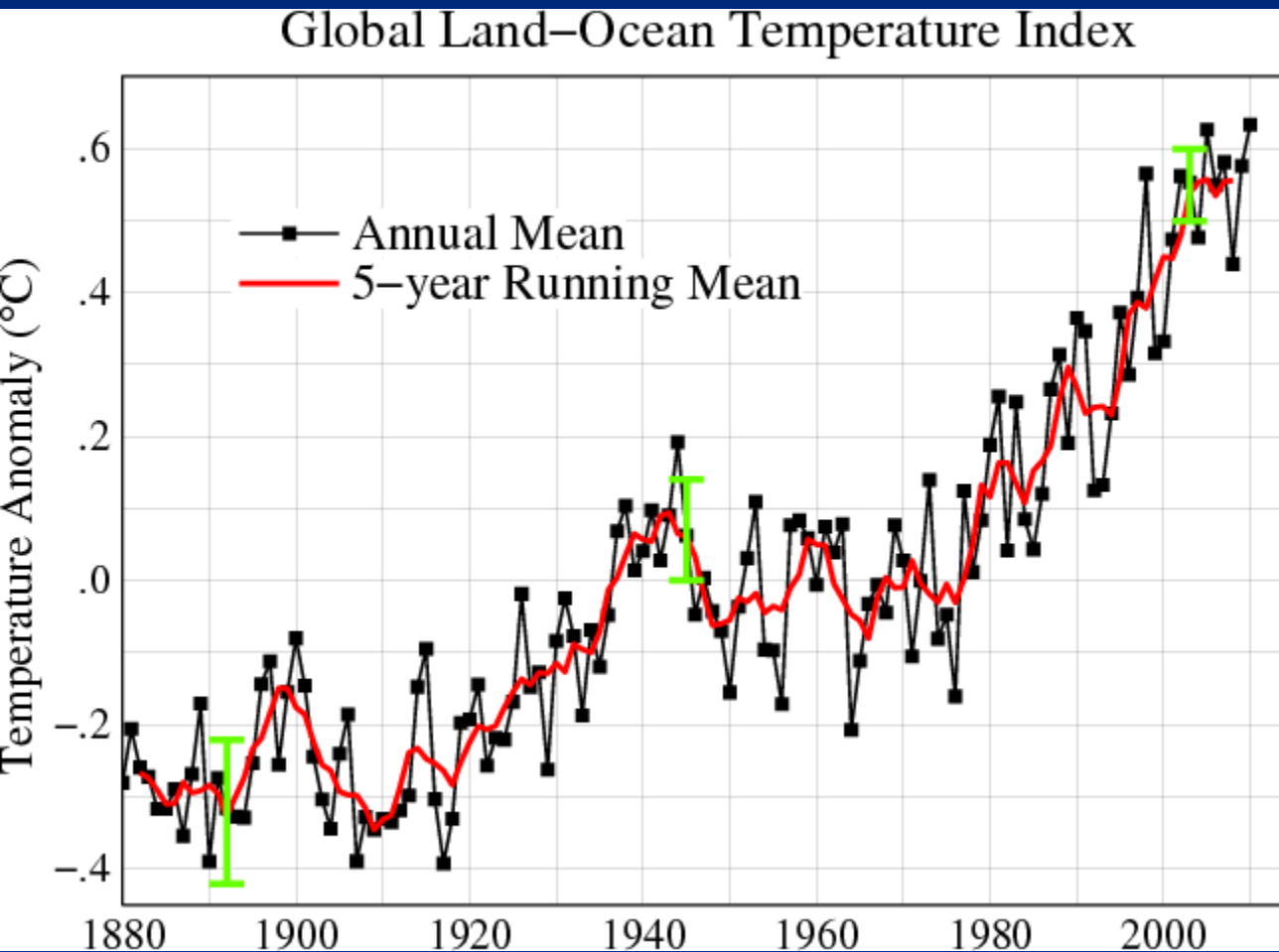


# Klimatická změna

- Globální změna klimatu
- Časové řady měření a odhad vývoje
- Sedimentární archívy: “čtení“ dlouhodobého vývoje pomocí zástupných („proxy“) údajů

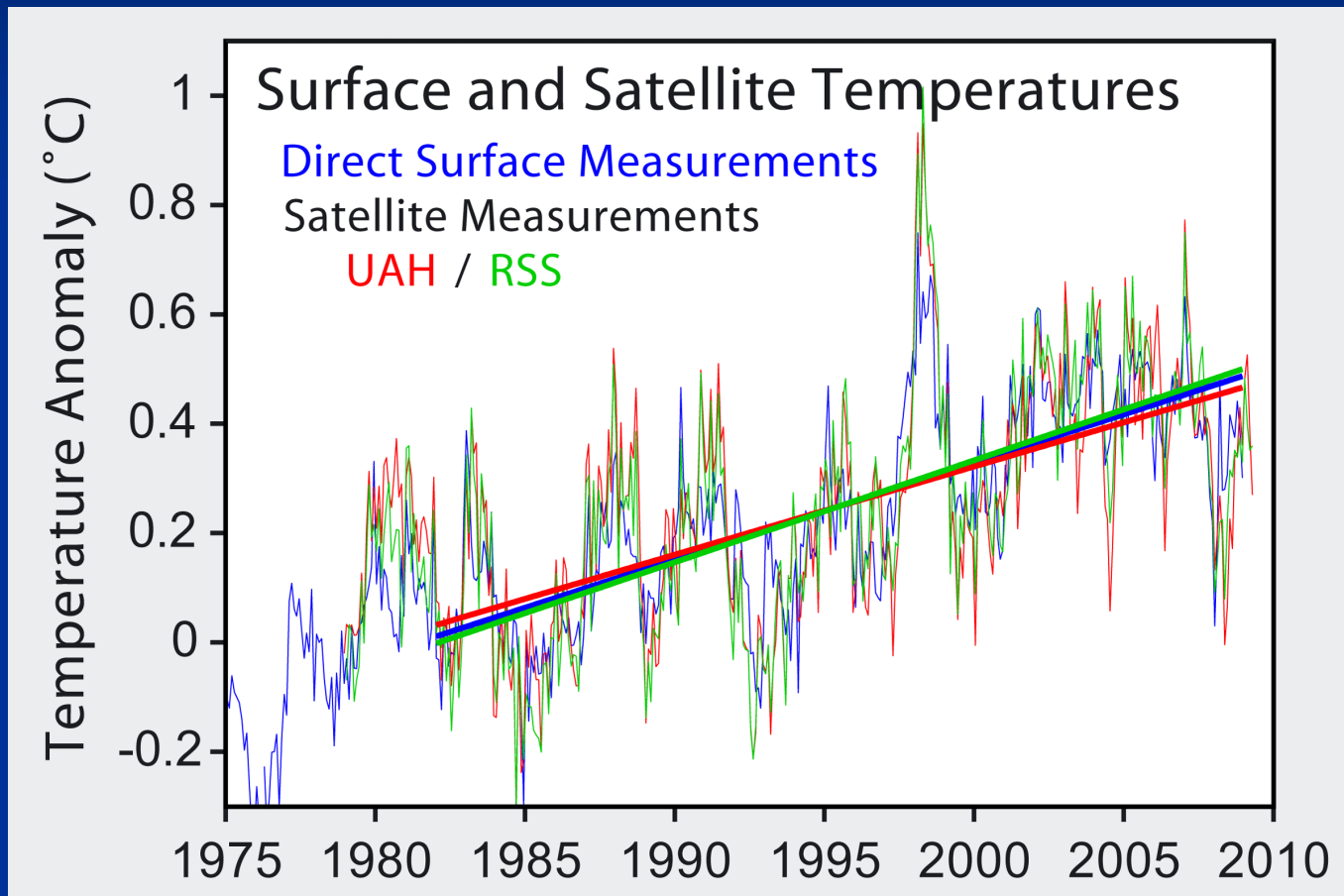


# Vývoj průměrné globální teploty (oceány + kontinenty) od r. 1880 (NASA)





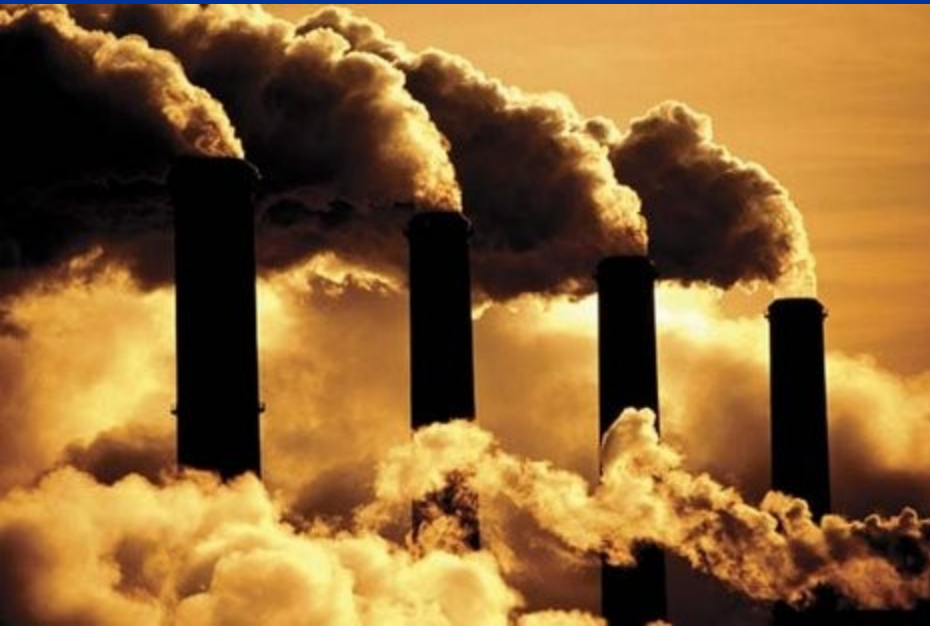
# Vývoj globální teploty z povrchových a satelitních měření za posledních 35 let





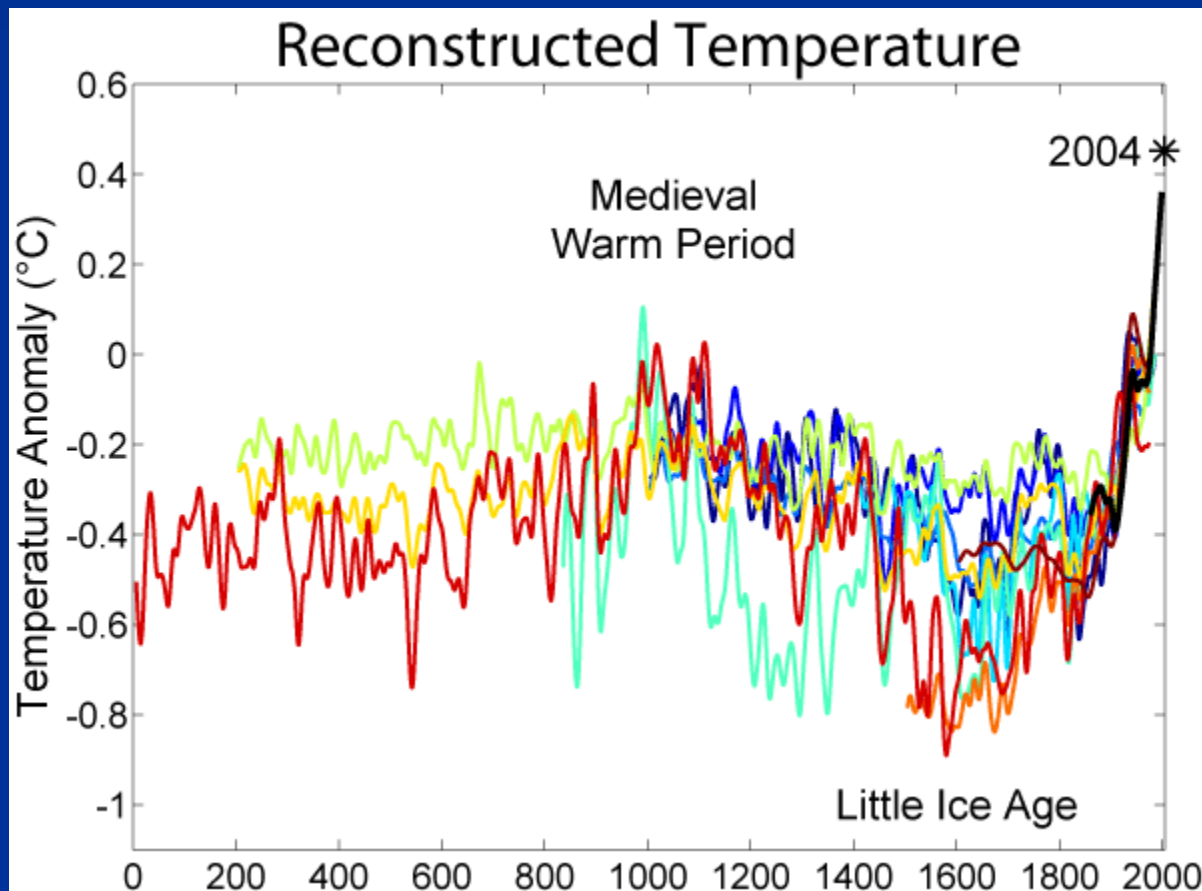
# Skleníkové plyny

- Vodní páry (způsobují cca 36 - 70 procent skleníkového efektu)
  - Oxid uhličitý (způsobuje cca 9 - 26 procent skleníkového efektu)
  - Metan (způsobuje cca 4 - 9 procent skleníkového efektu)
  - Ozón (způsobuje cca 3 - 7 procent skleníkového efektu)
- Během průmyslové revoluce se zvýšily emise skleníkových plynů do atmosféry. Od roku 1750 se koncentrace  $\text{CO}_2$  zvýšily o 36% a metanu o 148%

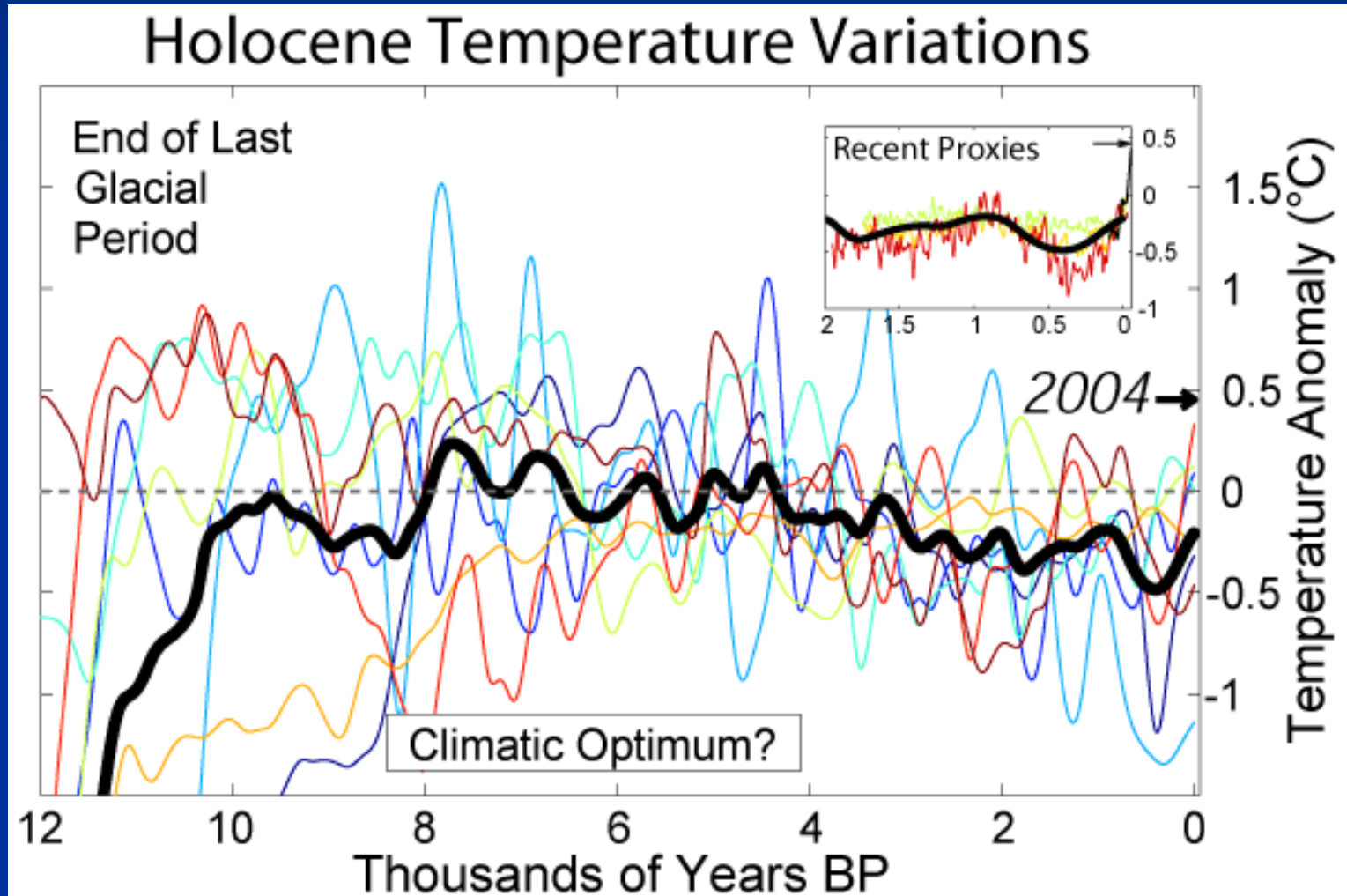


# Vývoje globální teploty: posledních 2000 let

- Průměrná povrchová teplota podle různých rekonstrukcí (křivky vyhlazené na dekády), černá čára: instrumentální měření teploty



# Rekonstruovaný vývoj teploty v holocénu (posledních 12 000 let)

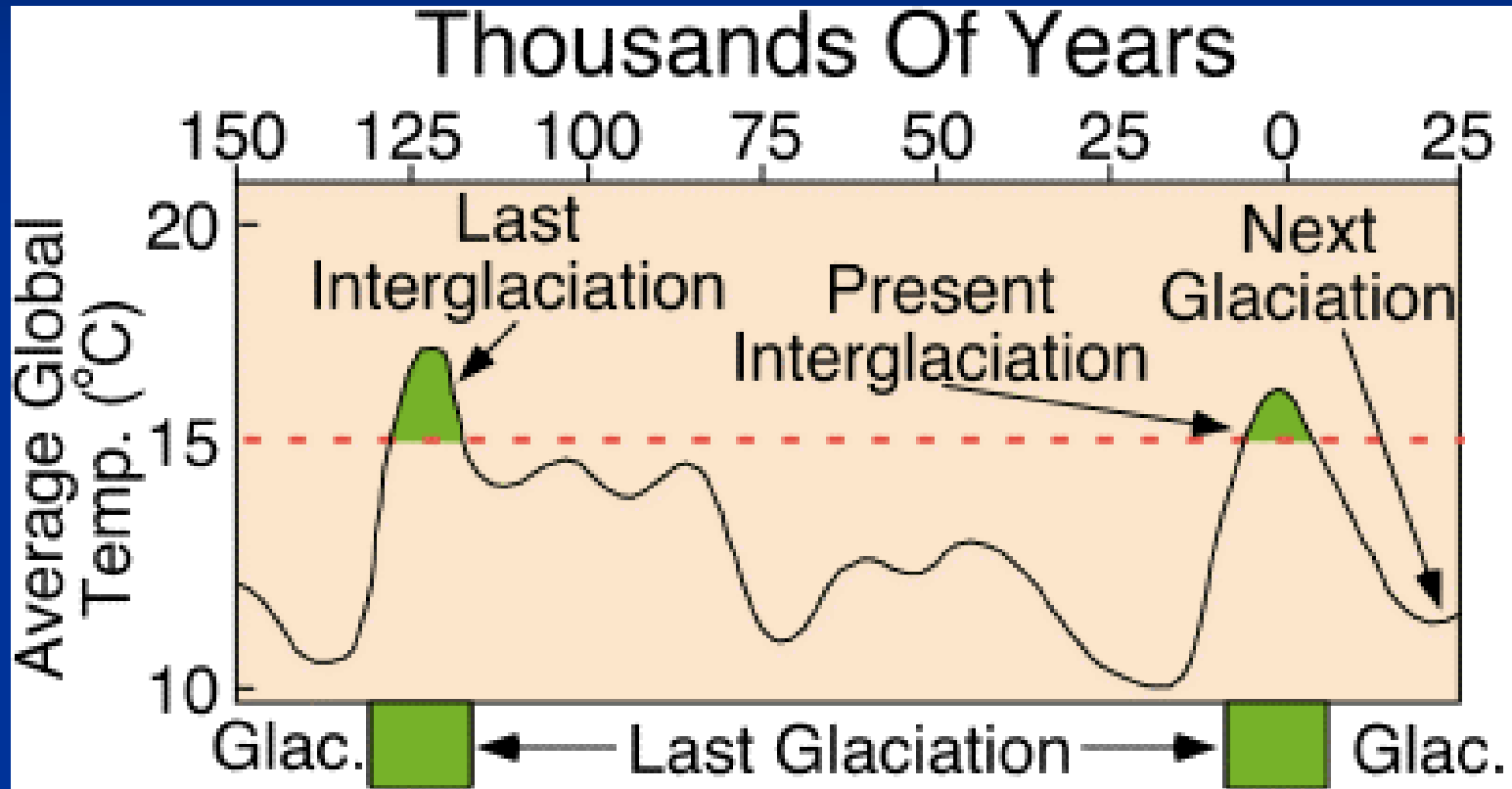


# Co bude dál ?

- Is the Ice Age is truly over?
- Or are we in an interglacial period
  - that will be followed by renewed glaciation?



# Jedna z odpovědí: jsme stále v pleistocénu !



# ... až roztají všechny polární ledovce



Pokud se roztaví všechny ledovce a ledové pokrivy, vzroste hladina oceánu o ~65 m



# Příčiny kolísání klimatu

- Terestrické faktory
  - Změna směrů a intenzity mořského proudění, výzdvih pohoří v důsledku kolizních událostí, zvětrávání vyzdvižených orogénů a změny v parciální tlaku CO<sub>2</sub> v atmosféře, znečištění atmosféry produkty vulkanismu
  - **relativně dlouhodobé**
- Extraterestrické faktory:
  - výchylky úhlu sklonu zemské osy, rotace zemské osy (precese) a orbitální excentricita Země okolo Slunce - milankovičovy cykly
  - **relativně krátkodobé**



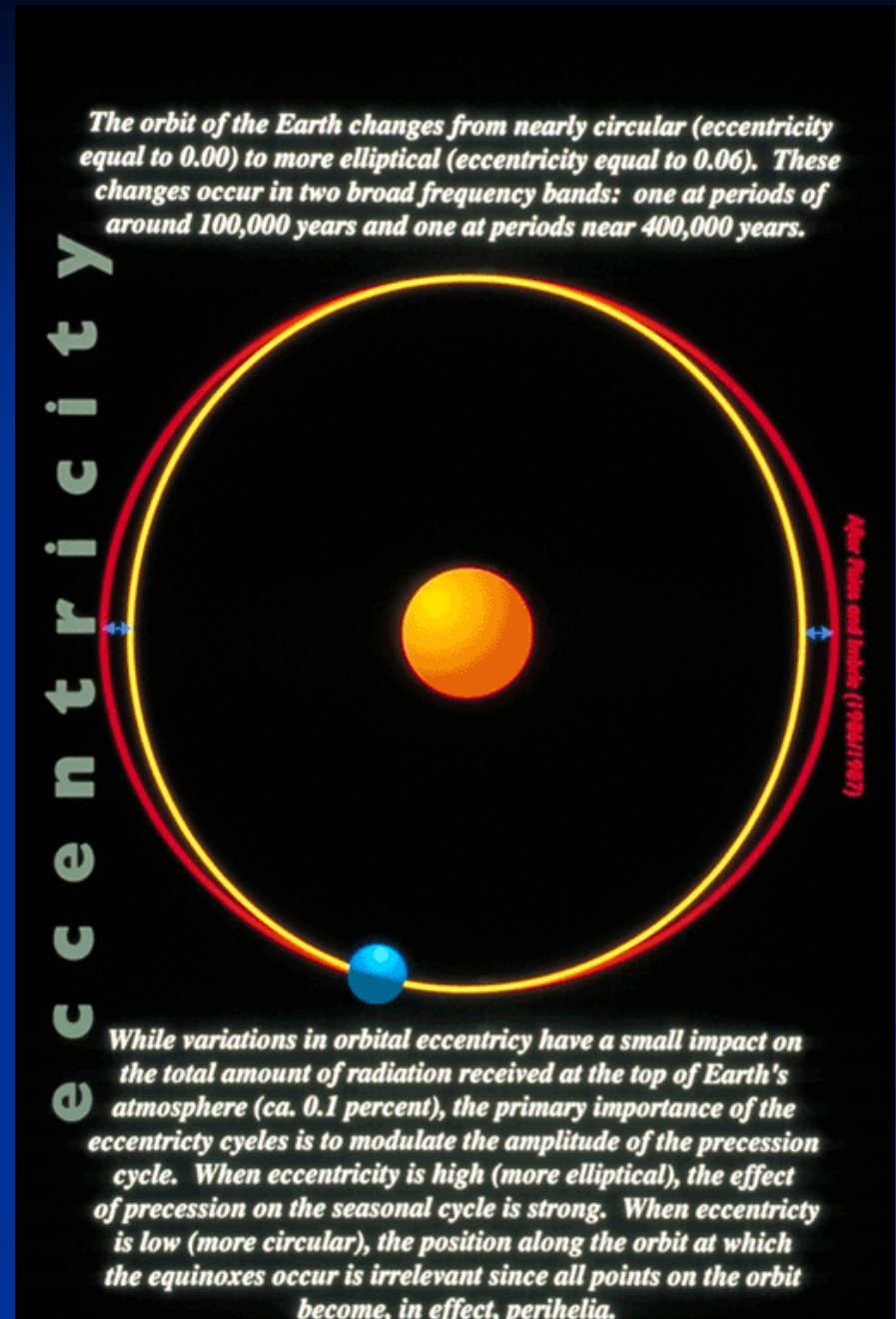
# Extraterestrické faktory

- Excentricita eliptické dráhy Země kolem slunce
- Náklon zemské osy
- Precese (kmitání zemské osy)

# Excentricita

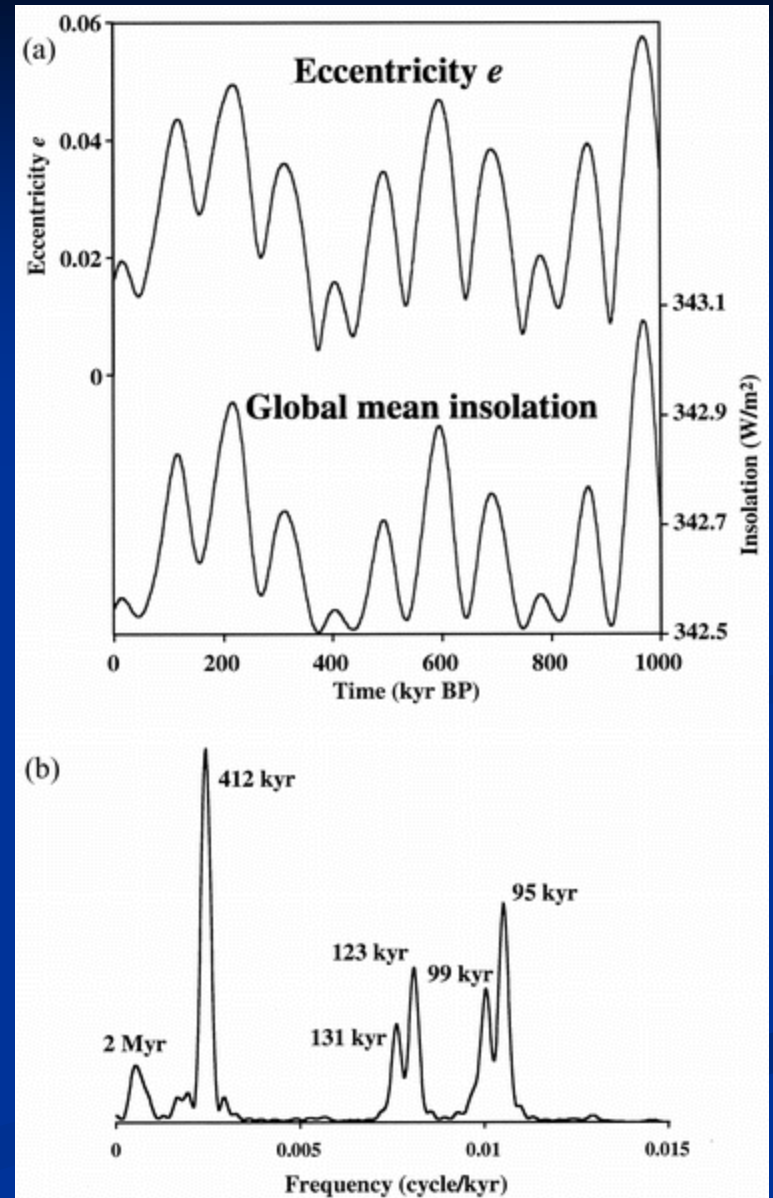
Excentricita =  
(vzdálenost mezi ohniskem a  
středem elipsy) / (délka vedlejší  
osy)

Excentricita dráhy Země kolem  
slunce kolísá od 0 do 0.05, s  
periodou 100 tis. let, 400 tis. let  
a 2 mil let.



## Excentricita

- Časová řada
  - Excentricita
  - Oslunění (W/m<sup>2</sup>)
- Frekvenční spektrum



# Náklon zemské osy

*Earth's axial tilt varies from 24.5 degrees to 22.1 degrees at periods of close to 41,000 years.*



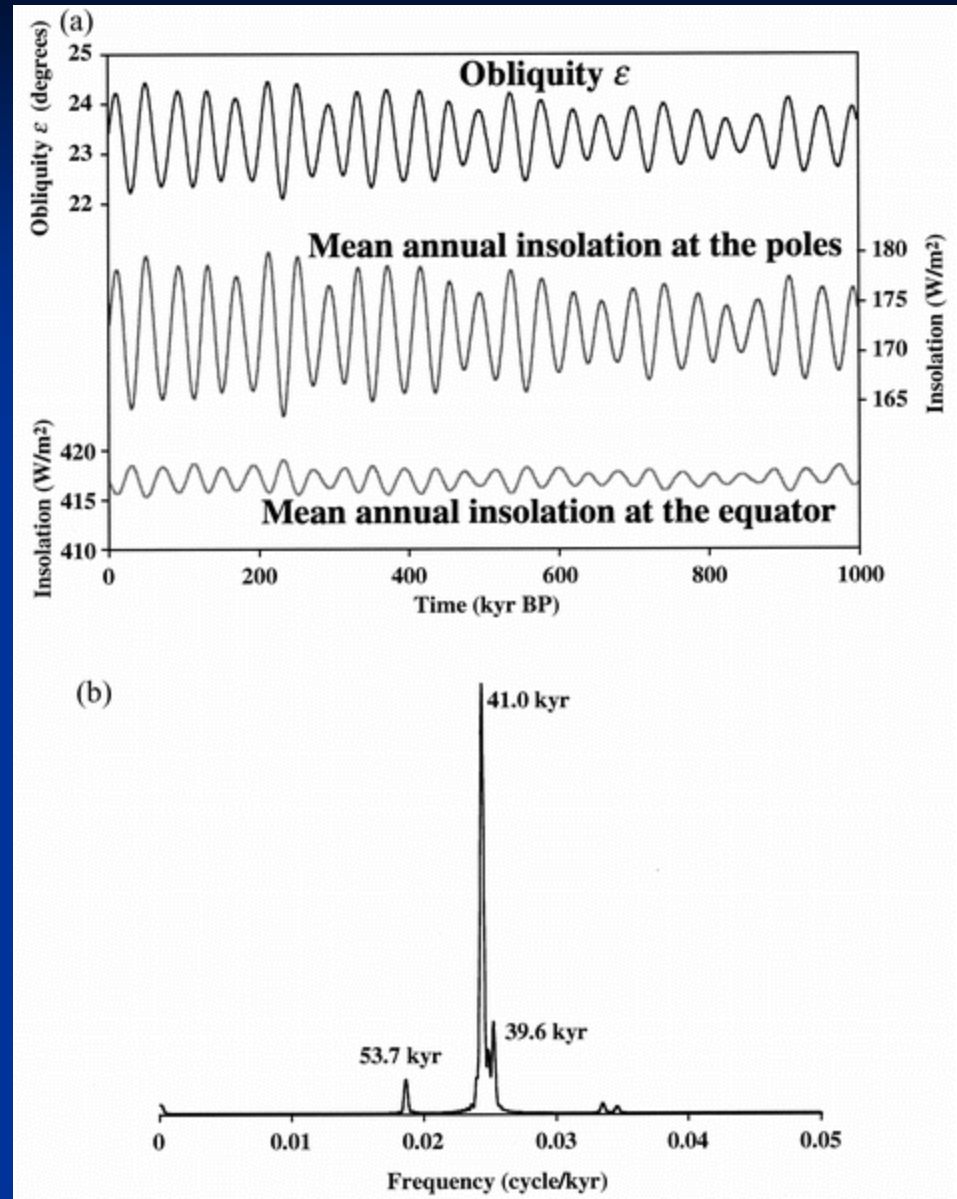
*Axial tilt affects the distribution of solar radiation on Earth's surface. When the tilt is decreased, polar regions receive less sunlight; when it is increased, polar regions receive more sunlight.*

Šikmost (i.e., náklon) zemské osy kolísá od 22 do 24,5 , s periodou 41 tis. let.



## Náklon zemské osy

- Časová řada
  - Oslunění ( $\text{W}/\text{m}^2$ )
  - Náklon (stupně)
- Frekvenční spektrum



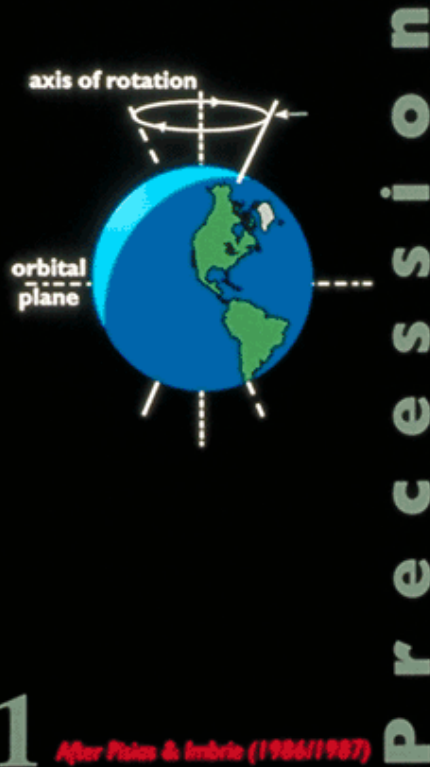
# Precese

Modulace záznamu precese excentricitou:

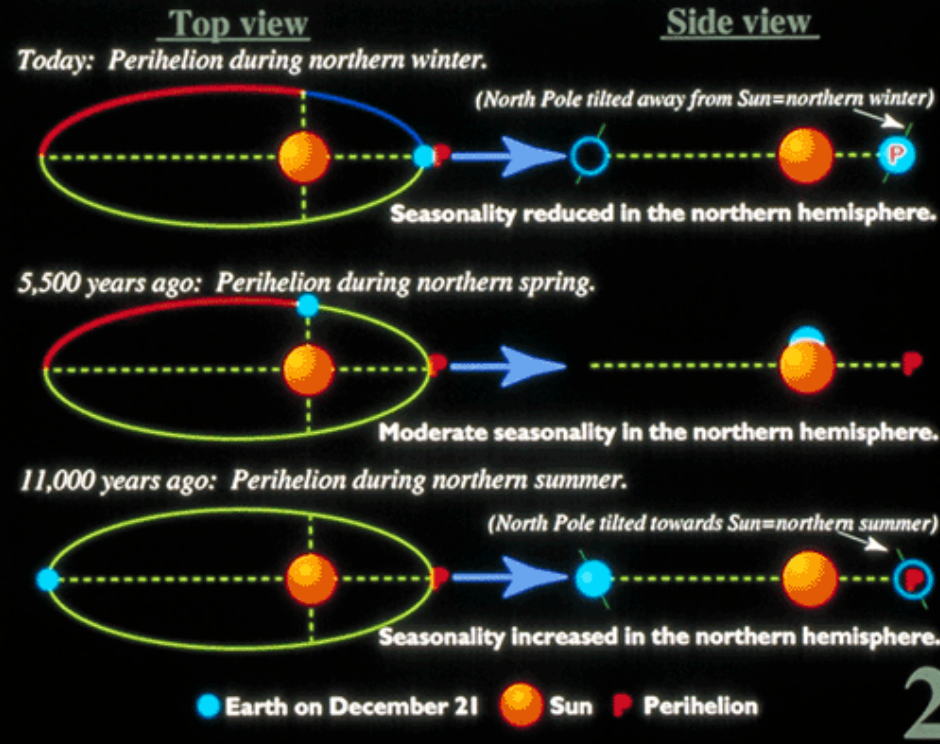
Zima na S. polokouli v perihéliu, léto v aféliu: **zmírněné sezónní výkyvy** (DNEŠEK)

Zima na S. polokouli v aféliu, léto v perihéliu: **zesílené sezónní výkyvy** (KONEC POSLEDNÍHO GLACIÁLU)

Like a spinning top, Earth's axis of rotation "wobbles," so that the North Pole describes a circle in space



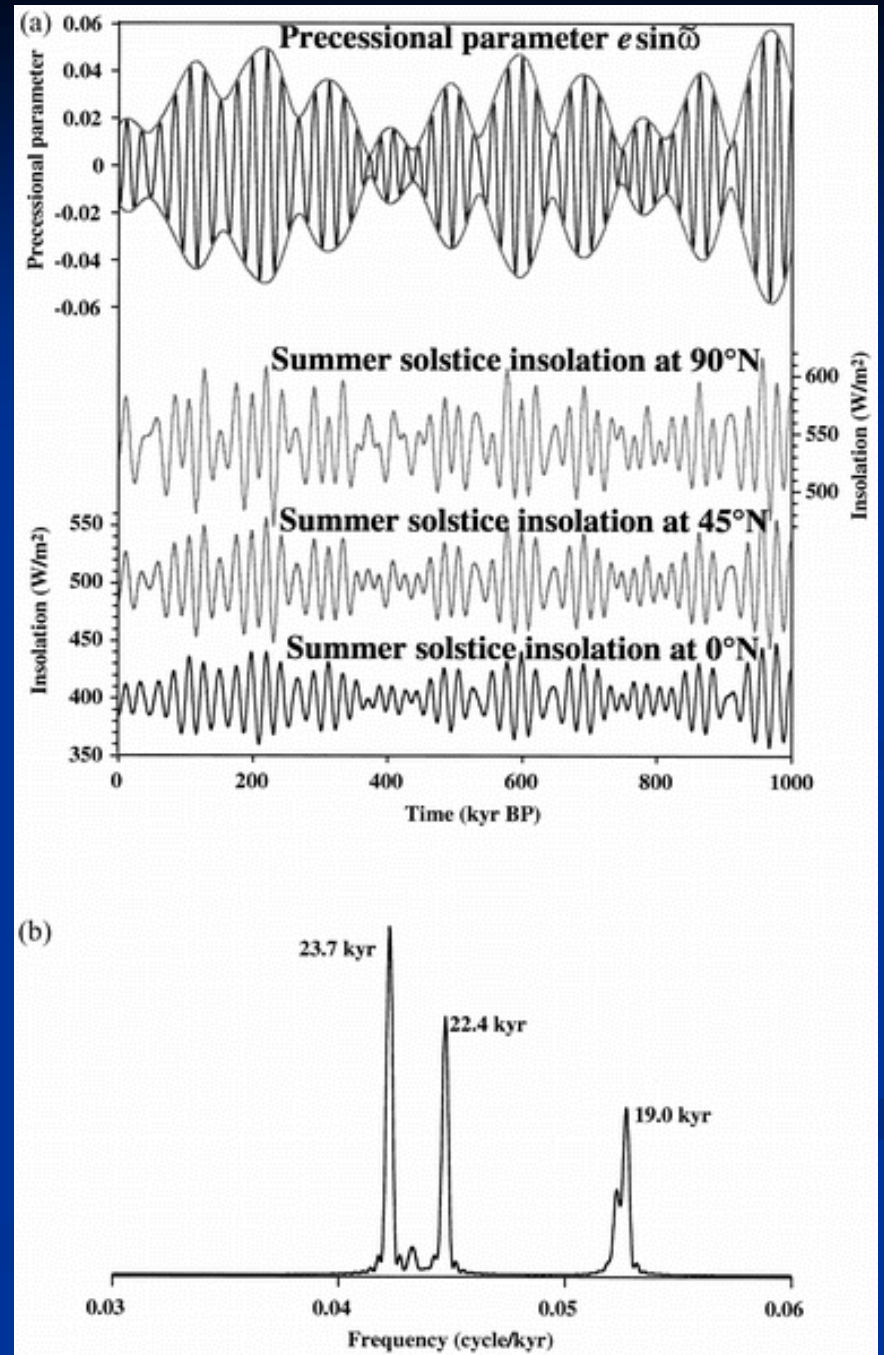
The 'wobble' of the Earth's axis causes the precession of the equinoxes. As shown in this figure, the positions of the equinoxes and solstices shift slowly around the Earth's elliptical orbit, completing one full cycle every 22,000 years. Precession changes the time at which the Earth reaches its perihelion (the point on the orbital path closest to the Sun), serving to amplify or soften climatic seasonality.



Kolísání zemské osy s periodou 19 tis. let a 23 tis. let.

## Precese

- Časová řada
  - Precese
  - Oslunění ( $\text{W/m}^2$ )
- Frekvenční spektrum



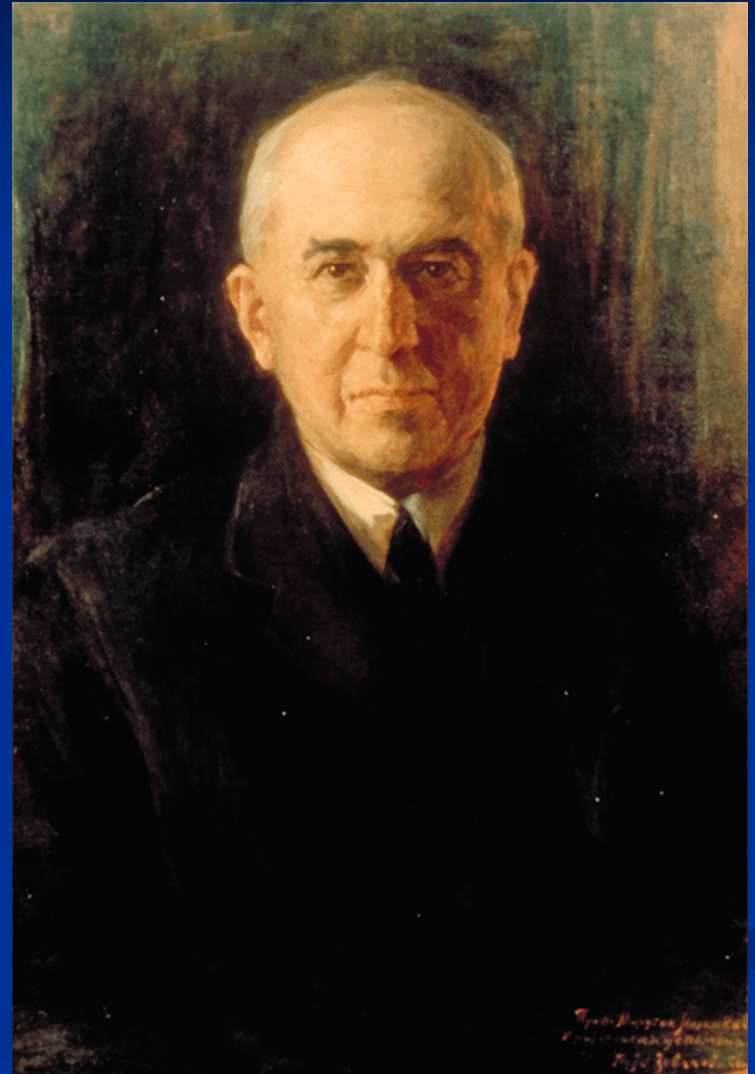
# Astronomická teorie ledových dob

- In 1842, J. Adhémar suggested that **slow variations in Earth's orbit** could be responsible for climatic changes by **altering the lengths of the seasons**.
- In 1875, J. Croll hypothesized that orbital variations might lead to substantial changes in climate. (**Colder winters → larger snow cover → glaciation**)



# M. Milankovič

- Renewed interest in orbital forcing of glacial cycles occurred when M. Milankovitch (1941) computed long-term variations in insolation.
- Milankovitch believed that cold summers led to glaciation by allowing snow to survive into the next year.



# Oslunění na 65 N

- High latitude summer insolation (June, 65 N) has been regarded as an index of orbital forcing of glaciation. (This is the **original Milankovitch hypothesis: Cool summers are beneficial to ice growth.**)
- Note that the effects of precession are modulated by eccentricity.
- For low summer insolation: Aphelion in summer (esp. with high eccentricity), low obliquity.

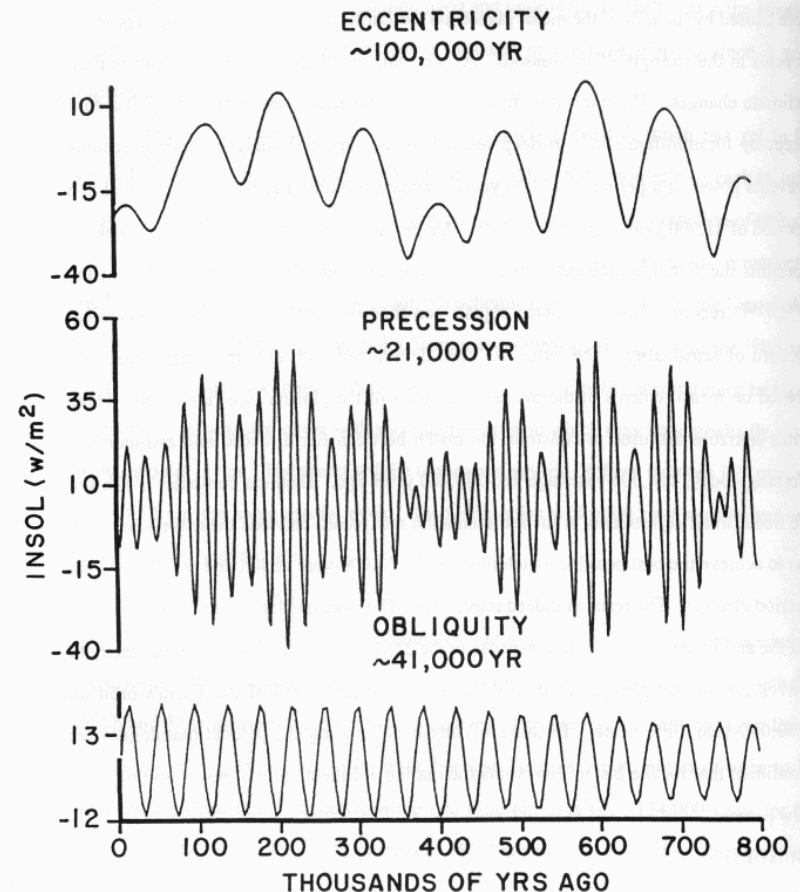
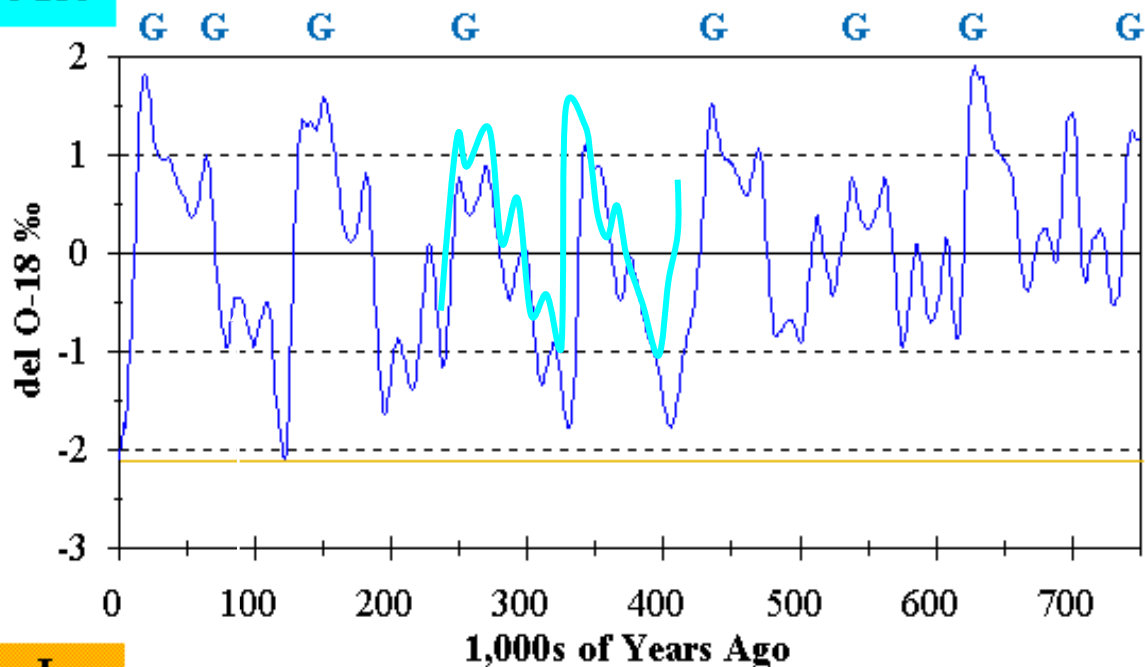


Figure 16. June insolation changes at 65°N caused by changes in the eccentricity of the Earth's orbit (100,000 and 450,000 year cycles), by changes in the phasing between the Earth's distance and tilt seasonality (19,000 and 23,000 year cycles) and by changes in the tilt of the Earth's axis (41,000 year cycle).

# Záznam izotopů kyslíku v mořských sedimentech za posledních 700 tisíc let

Ice Volume  
Planktonic Foram O-18 as Proxy

More Ice



Less Ice

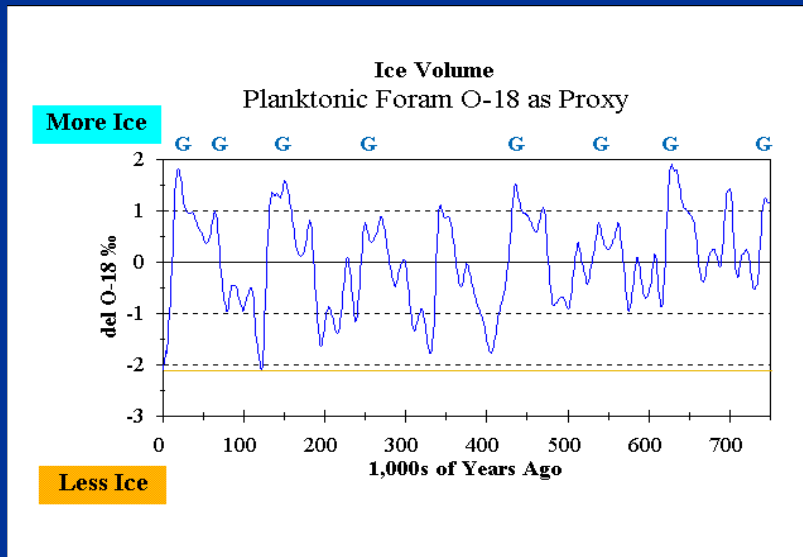
Vrtné projekty  
DSDP a ODP

Pelagické  
sedimenty, cca  
konstantní rychlost  
sedimentace,  
datování

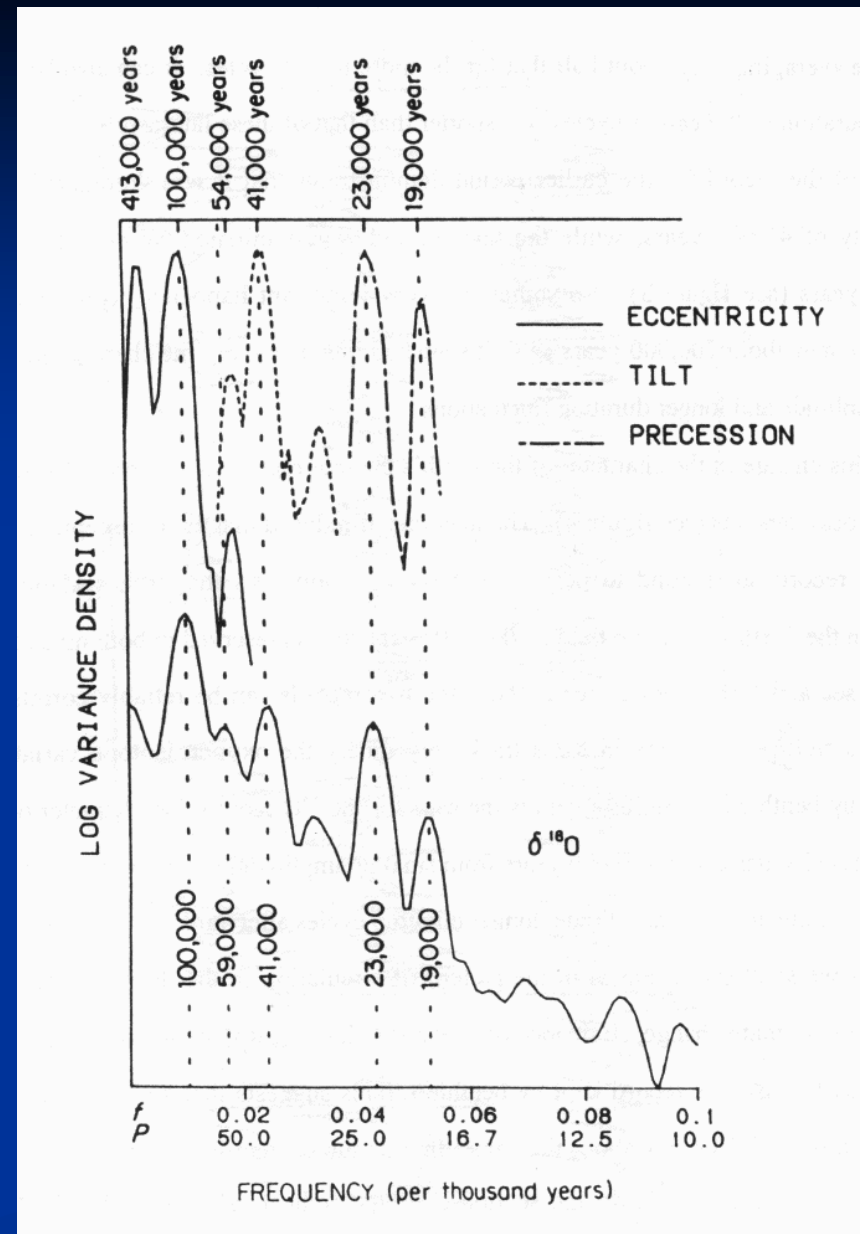
$^{18}\text{O}$  v schránkách  
plaktonních  
foraminifer ( $\text{CaCO}_3$ )

Časové řady

# Peaks in $\delta^{18}O$ Spectrum Correspond to Orbital Frequencies



Variance spectra for marine oxygen isotopes for the last 700 kyr (lower curve) compared with spectra for Earth's orbital parameters (Imbrie, 1985). (From Broecker, 2002)







# Metody datování kvartéru

## ■ ‘Absolutní’ (číselné) datování

Attempt to establish the age of an event in years before the present.

E.g. **radiometrické metody** ( $^{40}\text{K}/^{40}\text{Ar}$  or  $^{14}\text{C}$ ) and **přirůstkové metody** (dendrochronologie).

## ■ Relativní datování

Establishes the relative age (e.g. this event is oldest, this event next oldest, this event is youngest, etc.).

E.g. **superpozice** of sediments is one example (oldest at base of sequence) or **stupeň zvětrávání** of a rock surface.

## ■ Metody časové ekvivalence

Distinctive ‘**marker**’ events can indicate the age-equivalence of particular points within sediment sequences (e.g. tephra layers).

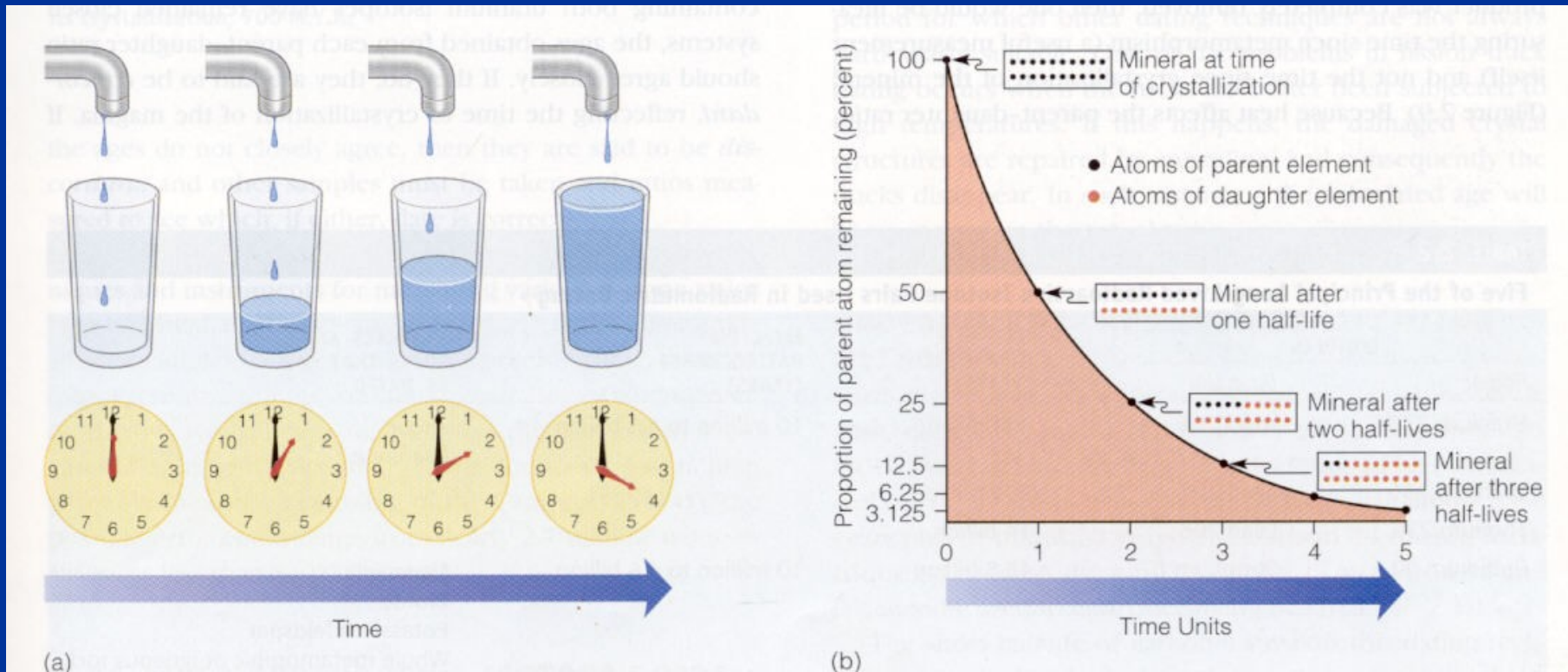
Often possible to then find absolute age of the ‘marker’ event at one location and therefore infer date of same event at other locations.

# Radiometrické datování: metoda

Číselné měření času:

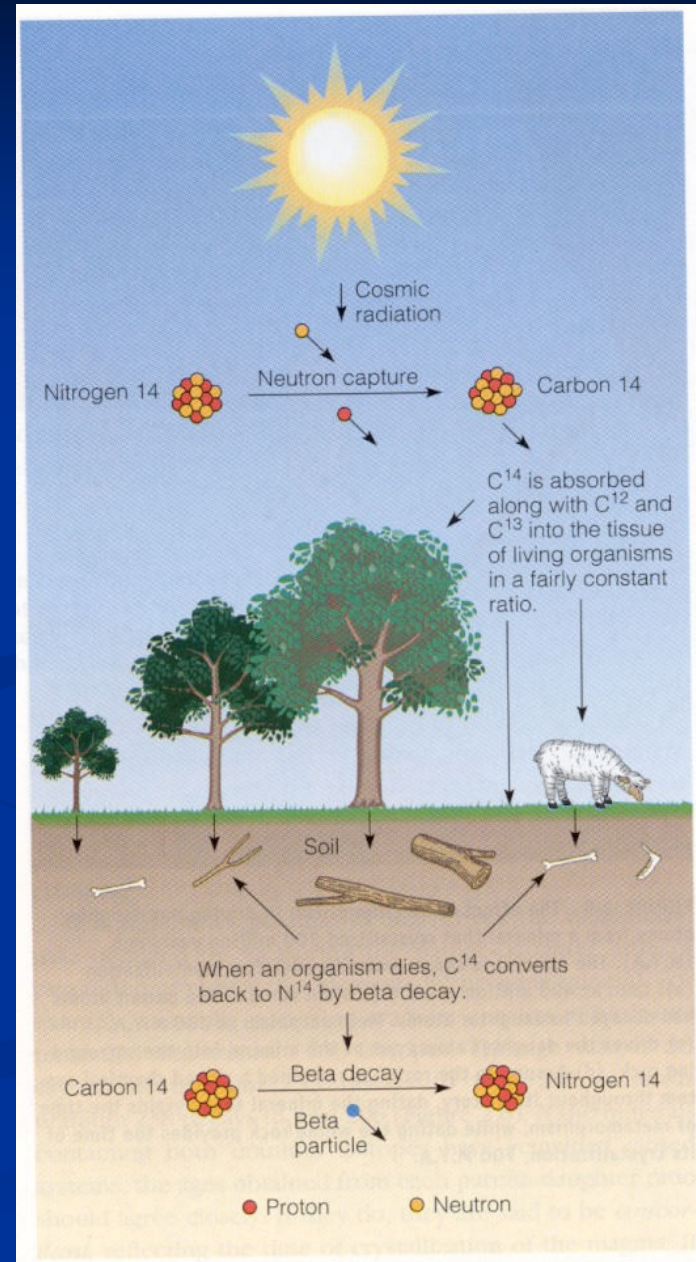
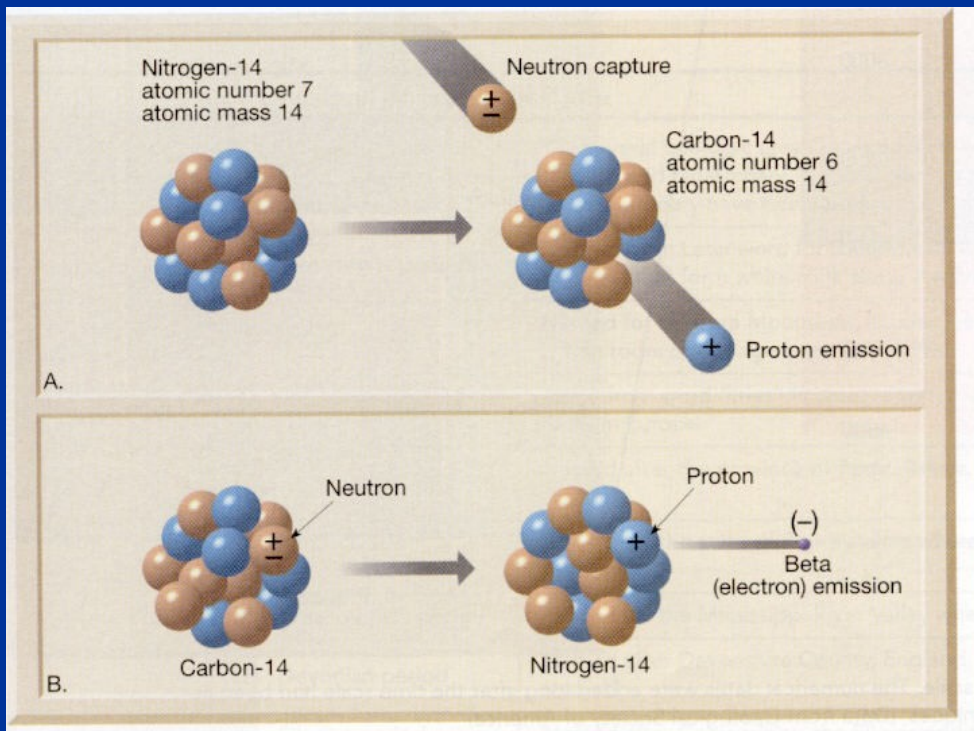
pravidelně se opakující proces, doba trvání jednoho cyklu

jednotky: rok a násobky ka (ky), Ma (My), Ga (Gy),



# Metoda radiouhlíku

- Organická hmota, poločas rozpadu 5700 let, použití: holocén, svrchní pleistocén
- $N_{14} \rightarrow C_{14}$ ,
- fixace  $C_{14}$  do organické hmoty
- $C_{14} \rightarrow N_{14}$





# Metoda štěpných stop (fission track)

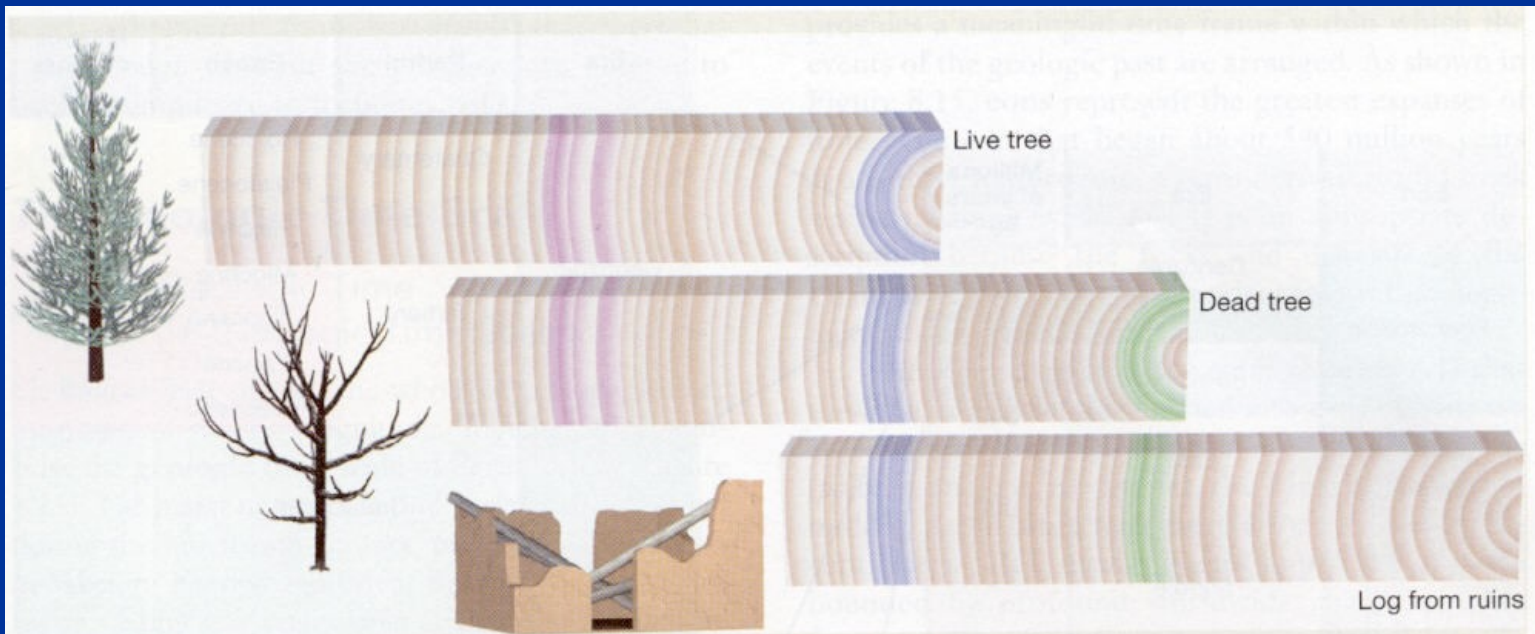
- Stopy po částicích emitovaných z jader na mikroskopickém naleštěném povrchu
- Počet stop / jednotka plochy = dceřinné izotopy
- Umělé dokončení štěpné reakce v reaktoru
- Počet stop / jednotka plochy = mateřské + dceřinné izotopy
- Poměr dceřinných / mateřských izotopů (poločas rozpadu) = stáří



FIGURE 2.10 Each fission track (about  $16 \mu\text{m}$  in length) in this apatite crystal is the result of the radioactive decay of a uranium atom. The crystal, which has been etched with hydrofluoric acid to make the fission tracks visible, comes from one of the dikes at Shiprock, New Mexico, and has a calculated age of 27 million years.

# Dendrochronologie

- **Proces: růst letokruhů dřeva**
- **Doba cyklu: 1 rok (sezónní přírůstek)**
- **Použití: do – 5 000 let**



◆ **Figure 8.E** Cross dating is a basic principle in dendrochronology. Here it was used to date an archaeological site by correlating tree-ring patterns for wood from trees of three different ages. First, a tree-ring chronology for the area is established using cores extracted from living trees. This chronology is extended further back in time by matching overlapping patterns from older, dead trees. Finally, cores taken from beams inside the ruin are dated using the chronology established from the other two sites.

# Chronologie varvitũ

Lakes can produce annual layers.

Usually occur in glacial lakes or those that freeze over in winter.

Coarser sediments are deposited in summer.

Winter-summer layers are called **COUPLETS**.

Couplets in lakes are known as **VARVES**.

Count the **couplets** back from the sediment surface to determine numerical age.



# Chronologie varvitů

## Stokesův zákon

$$u = \frac{1}{18} \frac{\rho_p - \rho_f}{\mu} g D^2$$

$u$  = rychlost usazování

$\rho_p$  = hustota pevné částice

$\rho_f$  = hustota kapaliny

$g$  = gravitační zrychlení

$D$  = průměr částice

$\mu$  = kinematičká viskozita



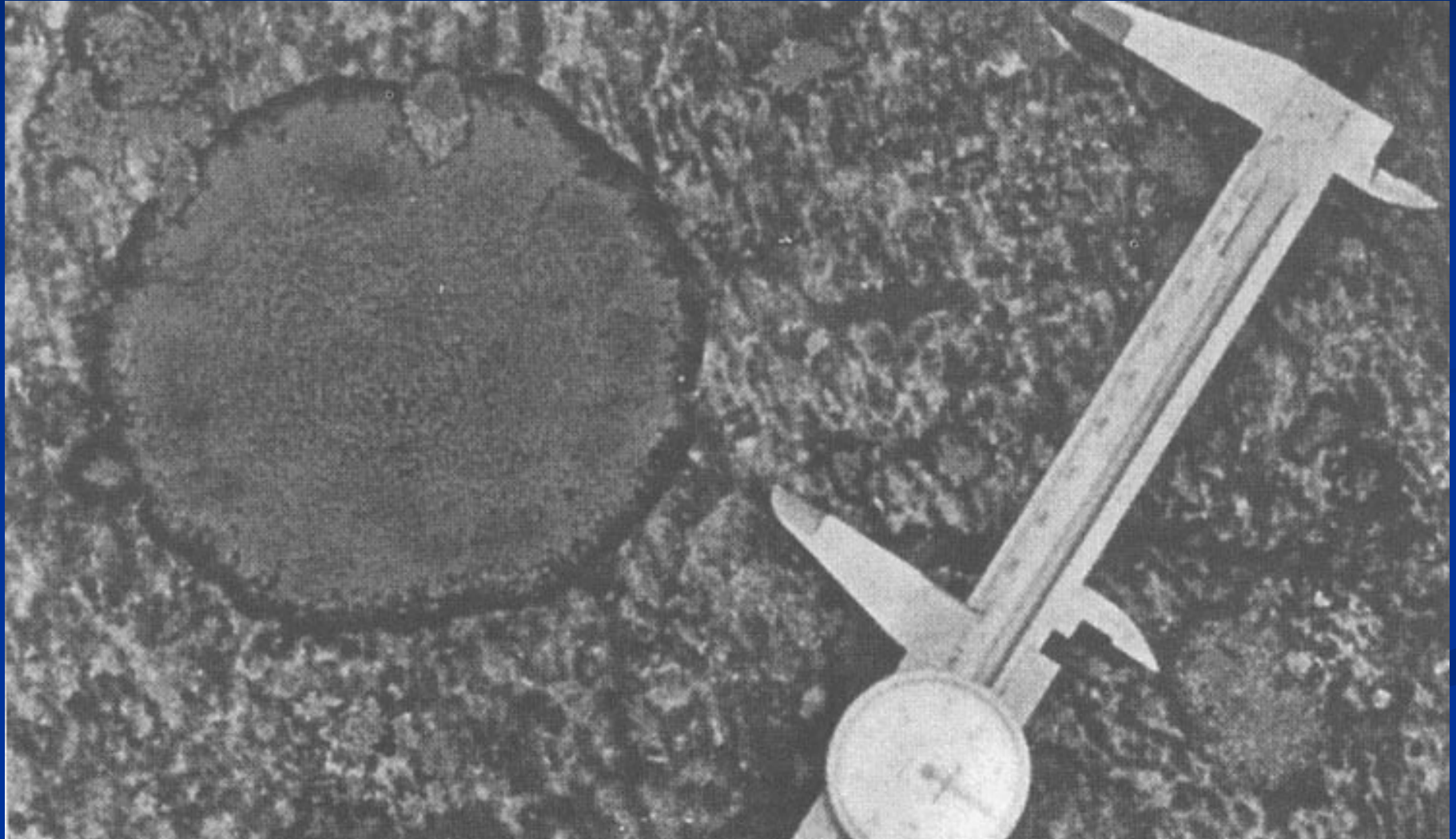


# Lichenometrie

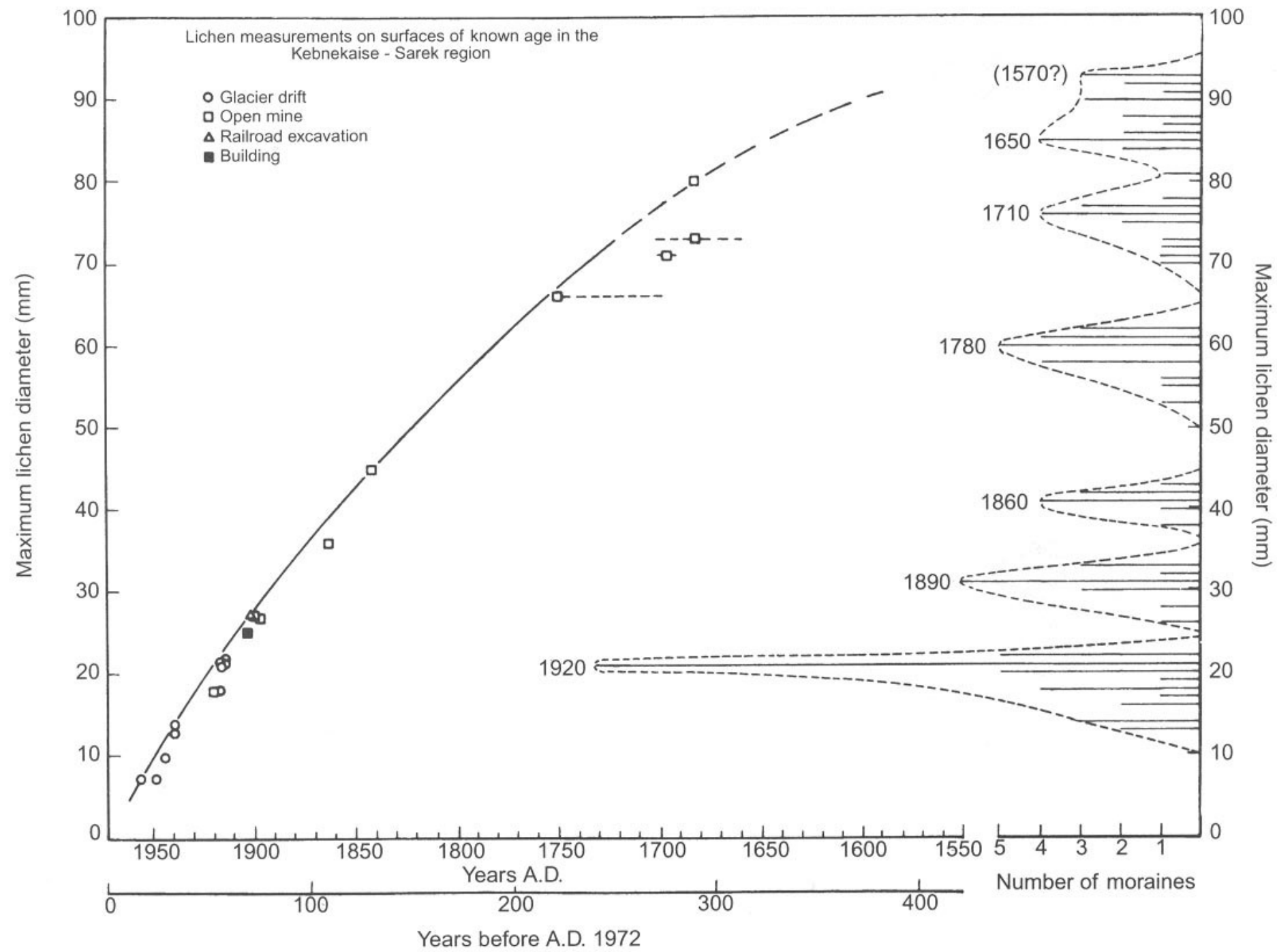
- \* Lichen (lišejníky) are a **symbiotic** relationship between **algae and fungi**
- \* Assumes **constant growth rate of lichen** so that the **largest diameter lichen will be the oldest**
- \* Most used to date glacial deposits in tundra environments
- \* Also used to date lake-level, sea-level, glacial outwash, trim-lines, rockfalls, talus stabilization, former extent of permanent snow cover



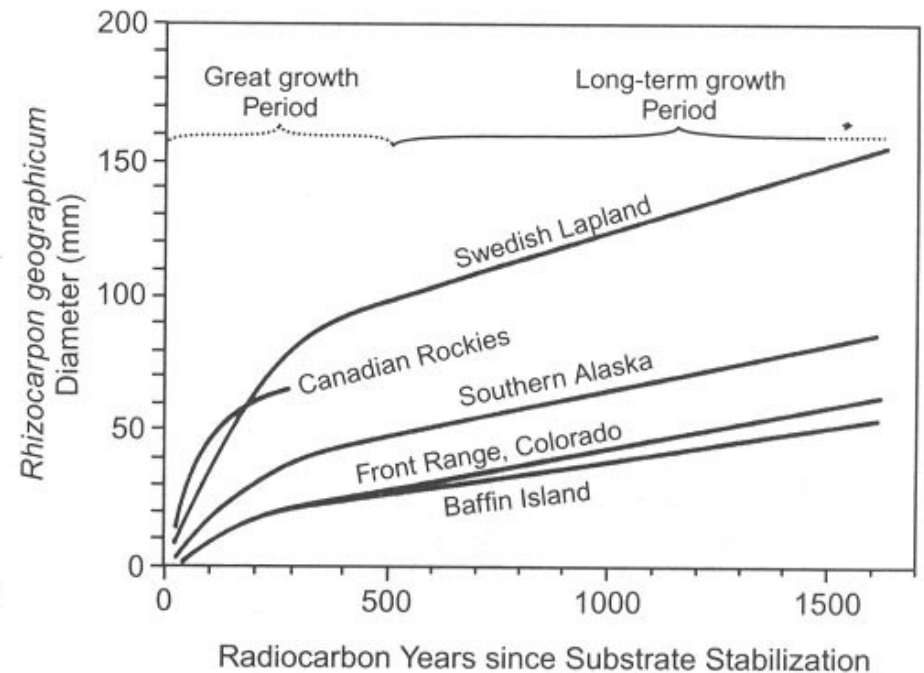
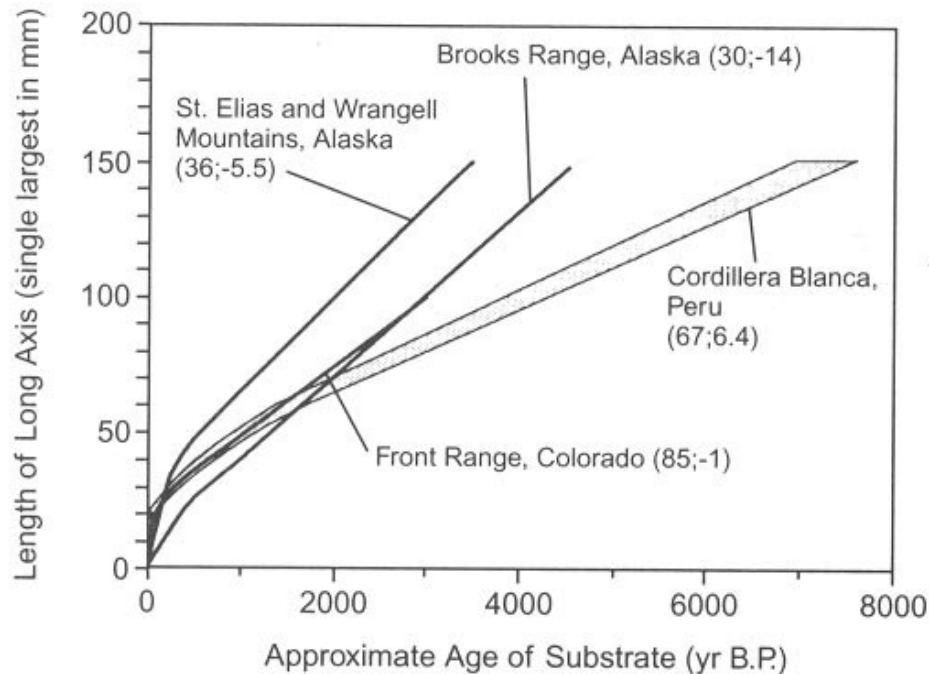
*Rhizocarpon geographicum*, Norsko







# Růstové křivky lišejníku





# Výsledky lichenometrického datování

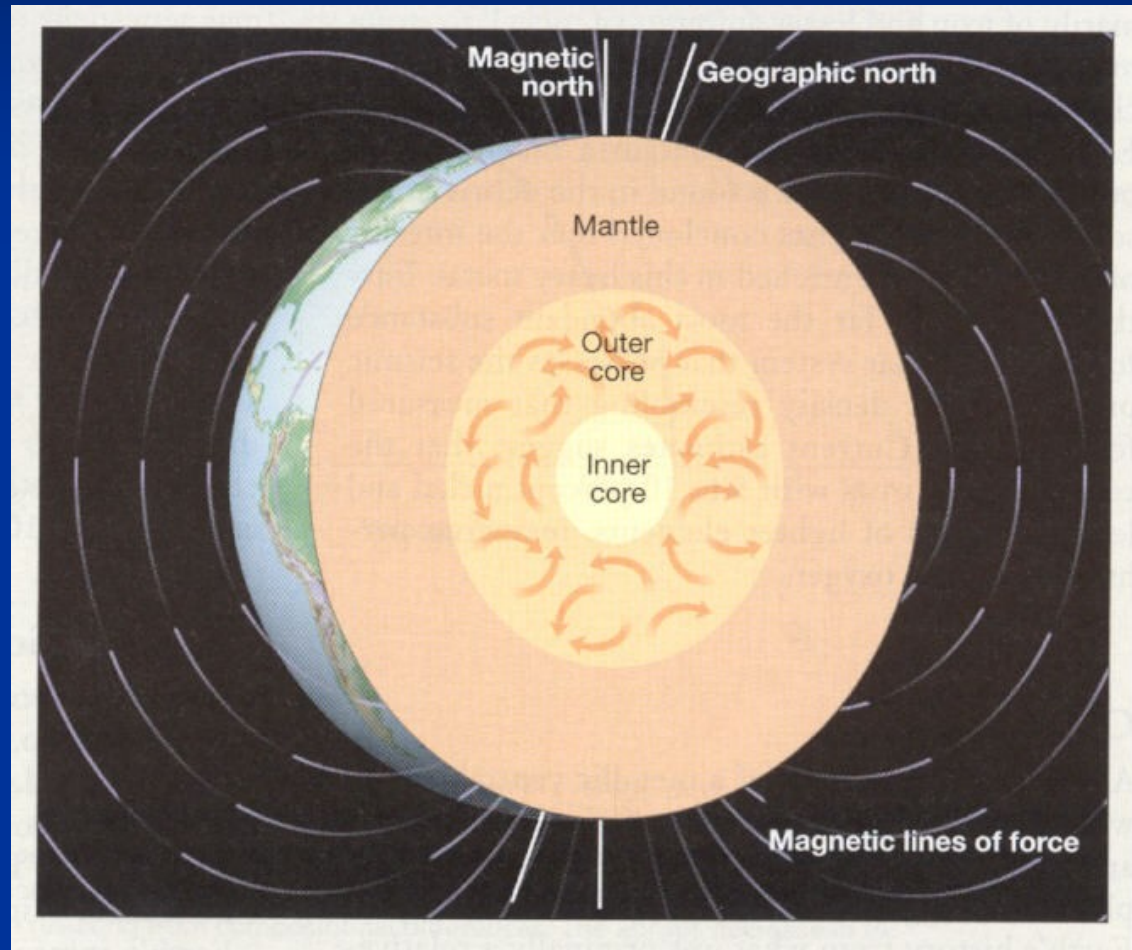
Druh	Průměr	Stáří	Lokalita
<i>Alectoria minuscula</i>	160mm	500-600 yrs	Baffin Island
<i>Rhizocarpon geographicum</i>	280mm	9,500 +/-1500 yrs	Baffin Island
<i>Rhizocarpon alpicola</i>	480mm	9,000 yrs	Swedish Lapland

# Problémy lichenometrie

- \* Growth rate differs by genera
- \* Variable growth rate (fastest when the lichen is young)
- \* Growth dependent on **substrate type** (surface texture and chemical composition)
- \* Slower growth rates occur with low **temperatures**, short growing seasons, and low **precipitation**
- \* Must be calibrated regionally
- \* Must locate **the largest lichen on the surface**
- \* **Irregular growth of older lichen**

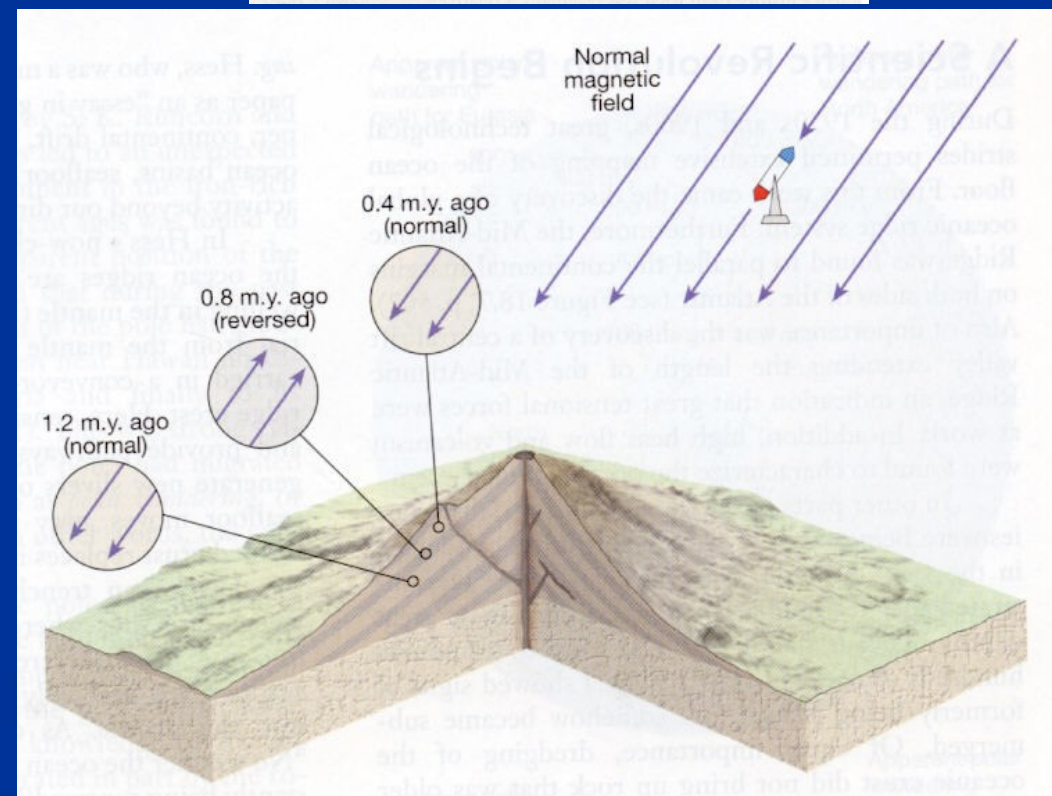
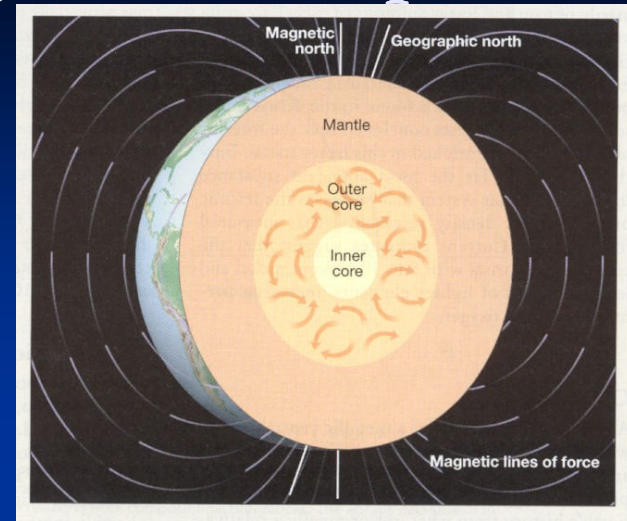
# Paleomagnetismus: Magnetické pole Země

- silné magnetické pole, jaké neznáme z žádné jiné planety ve sluneční soustavě
- magnetický dipól, jehož póly se nacházejí poblíž geografických pólů (pólů rotace)
- Magnetické siločáry, podle kterých se orientuje střílka kompasu.
- Inklinace : odchylka od horizontály
- Deklinace: odchylka od pólu rotace



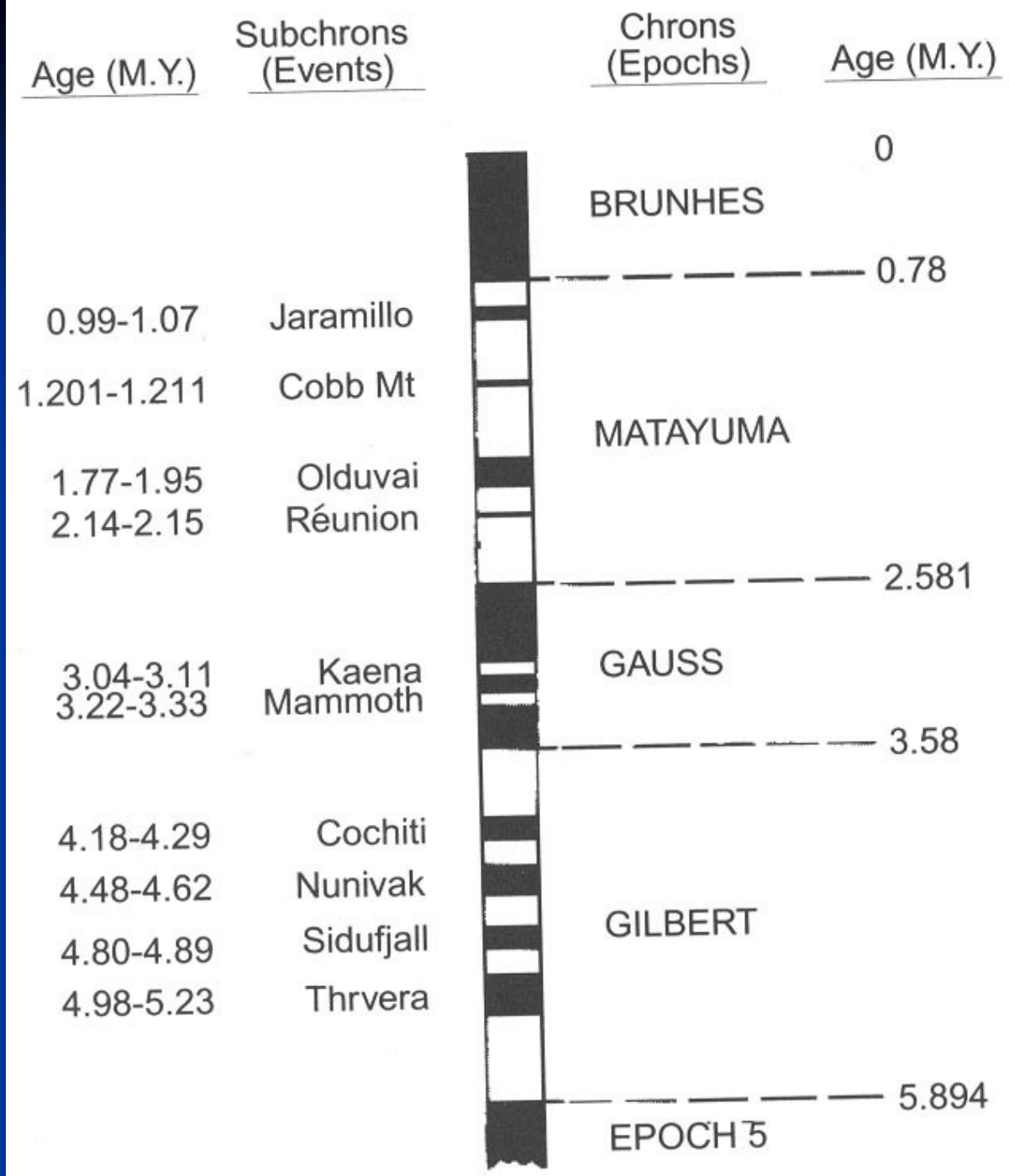
# Změny orientace magnetického pole

- Celá řada hornin je samovolně magnetizovatelná - feromagnetické minerály se orientují souhlasně se siločarami zemského magnetického pole a vytvářejí tak vlastní magnetická pole.
- Měřením zbytkových magnetických polí změny magnetického pole Země.
- Změny – intenzita, deklinace, přepólování, probíhá synchronně na celé Zemi
- období **normální magnetické polarity** (severní magnetický pól u severního pólu rotace)
- Období **reverzní magnetické polarity** (severní magnetický pól poblíž jižního pólu rotace).
- Poslední přepólování : 790 000 let, kdy se změnila polarita z reverzní na normální (dnešní).





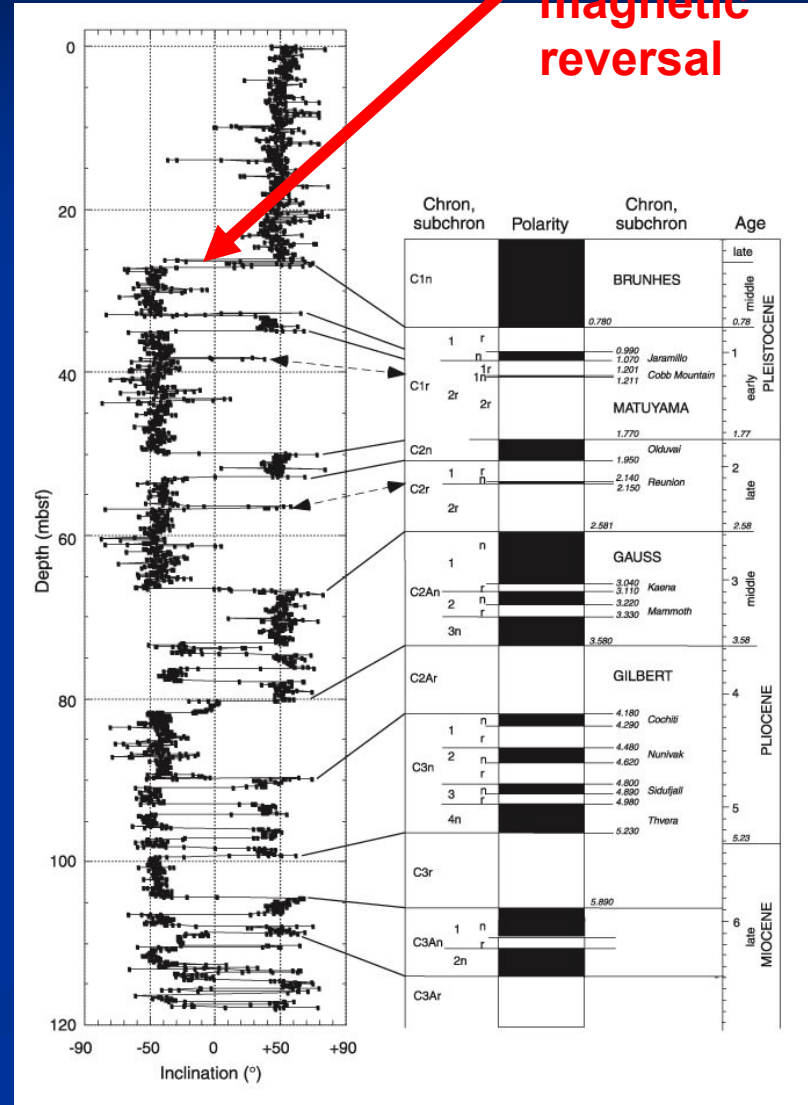
# Magneto- stratigrafické epochy



# Chronology

- A simple age model can be obtained by assuming a constant accumulation rate.
- Reversals in Earth's magnetic field can be used for benchmarks.
- Magnetic reversals have been radiometrically dated.

**Brunhes-Matuyama magnetic reversal**



# Magnetizace hornin

- ❄ Termoremanentní magnetizace (TRM)
  - ❄ Currie Point – Below which the igneous rock's magnetic record is fixed
  - ❄ Effective on lava flows and baked clays at archaeological sites
- ❄ Remanentní magnetizace detritických zrn (DRM)
  - ❄ Magnetic particles become aligned with the ambient magnetic field as they settle through the water column
- ❄ Postdepoziční magnetizace
  - ❄ Based on the water content for some sediments, they may take on their magnetic characteristic after deposition
- ❄ Chemická remanentní magnetizace (CRM)
  - ❄ Post-Depositional magnetization due to chemical changes in magnetic minerals

# Problémy paleomagnetismu

- ❄ DRM is not instantaneous
- ❄ Sediments are subject to **bioturbation** (especially effecting post-depositional DRM)
- ❄ **Overtured sediment** may give false excursions
- ❄ Post-Depositional magnetic changes due to **chemical recrystallization**



# Metody datování na základě chemických změn

- ❄ Analýza aminokyselin organické hmoty
- ❄ Stupeň zvětrávání minerálů a hornin
- ❄ Chemická alterace vulkanických skel

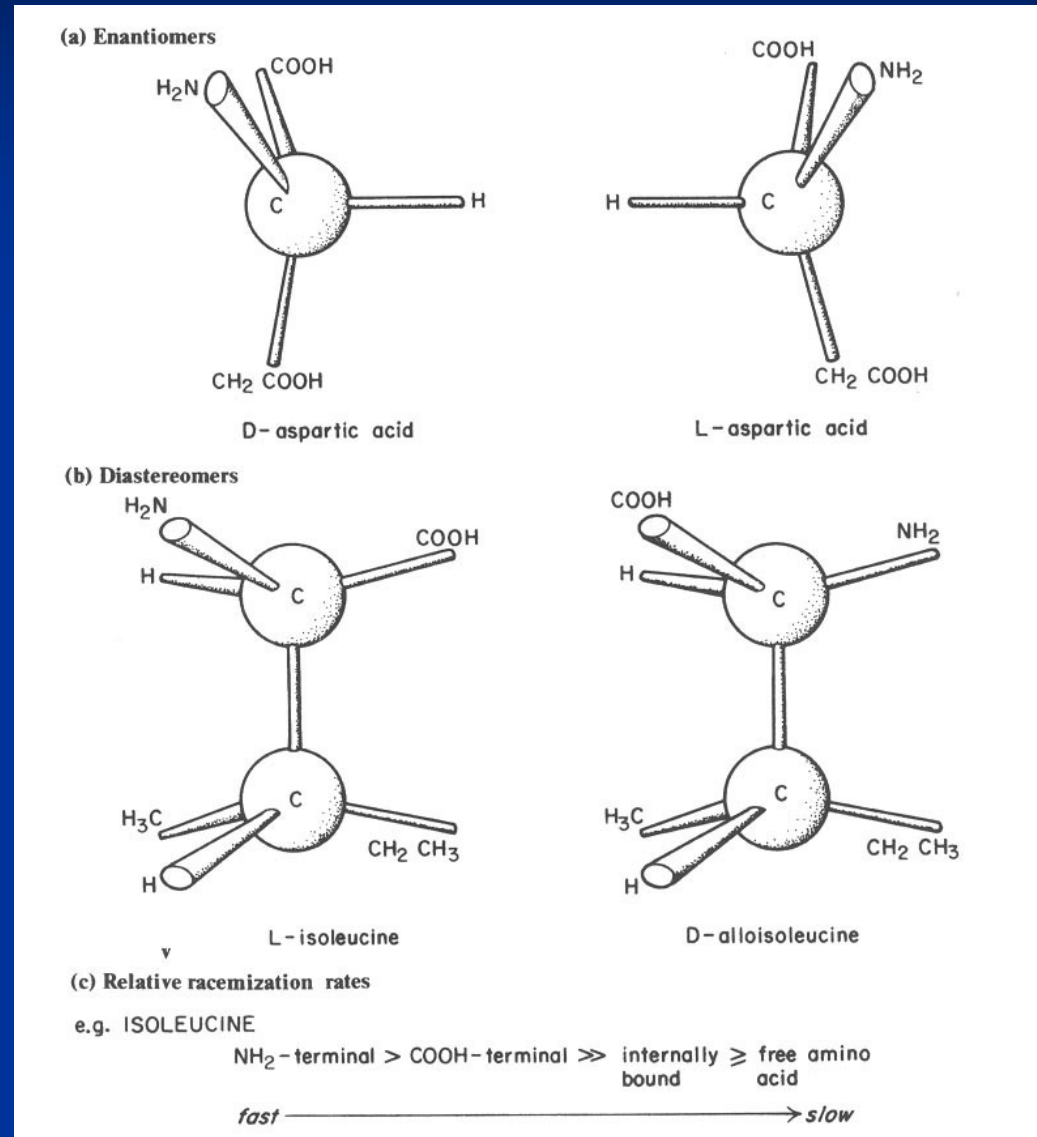
# Datování na základě aminokyselin

- ❄ All living organisms contain amino acids
- ❄ Living organisms have levo (left rotating) formation
- ❄ Amino acid formation is dextro (right rotating) after an organism dies
- ❄ D/L ratios can give the age of a sample
- ❄ Can date samples from a few thousand years old to a few million years old

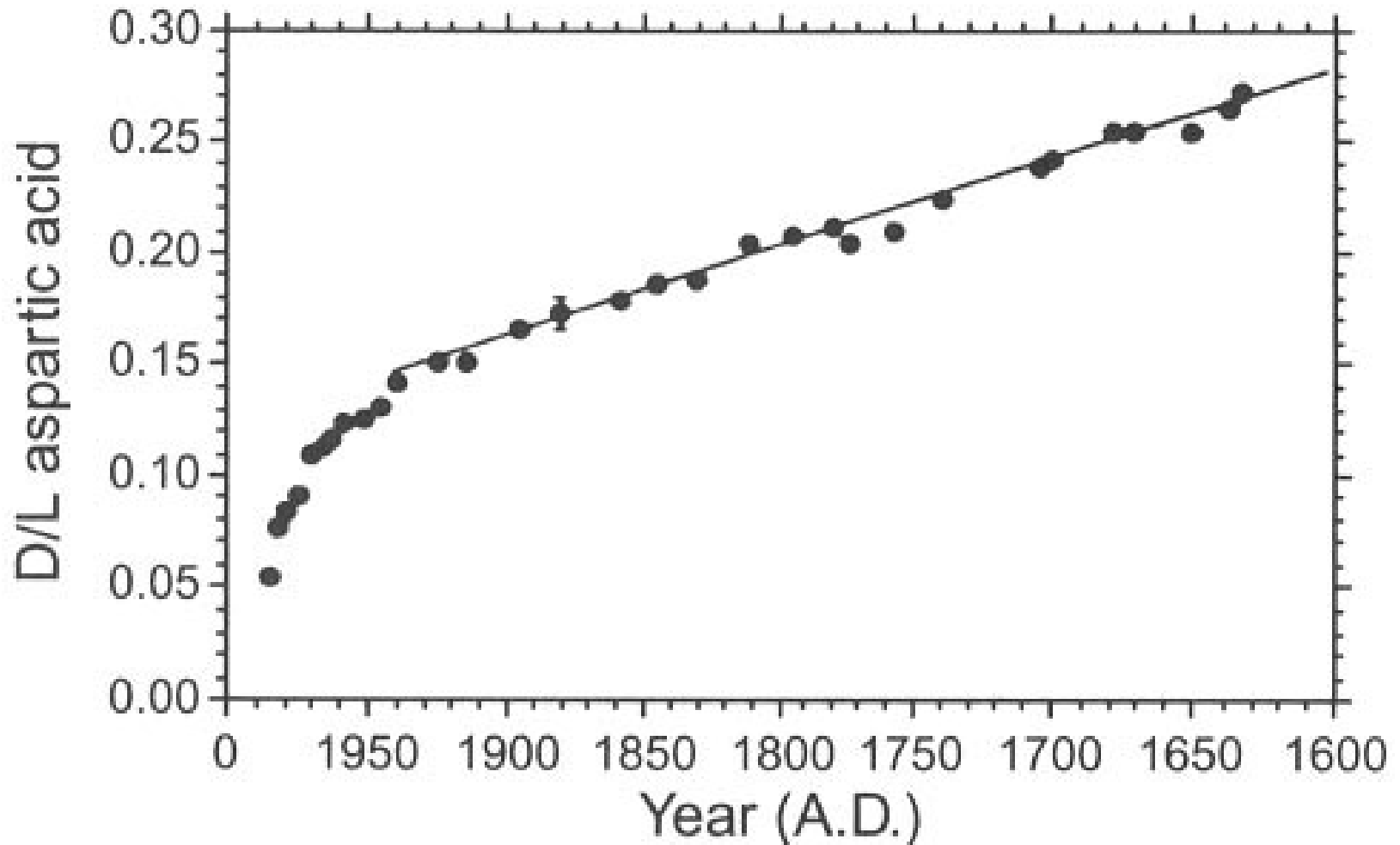
# L- a D-aminokyseliny

kyselina D-asparágová  
kyselina L-asparágová

L-izoleucin  
D-izoleucin



# kyselina L- a D-asparágová



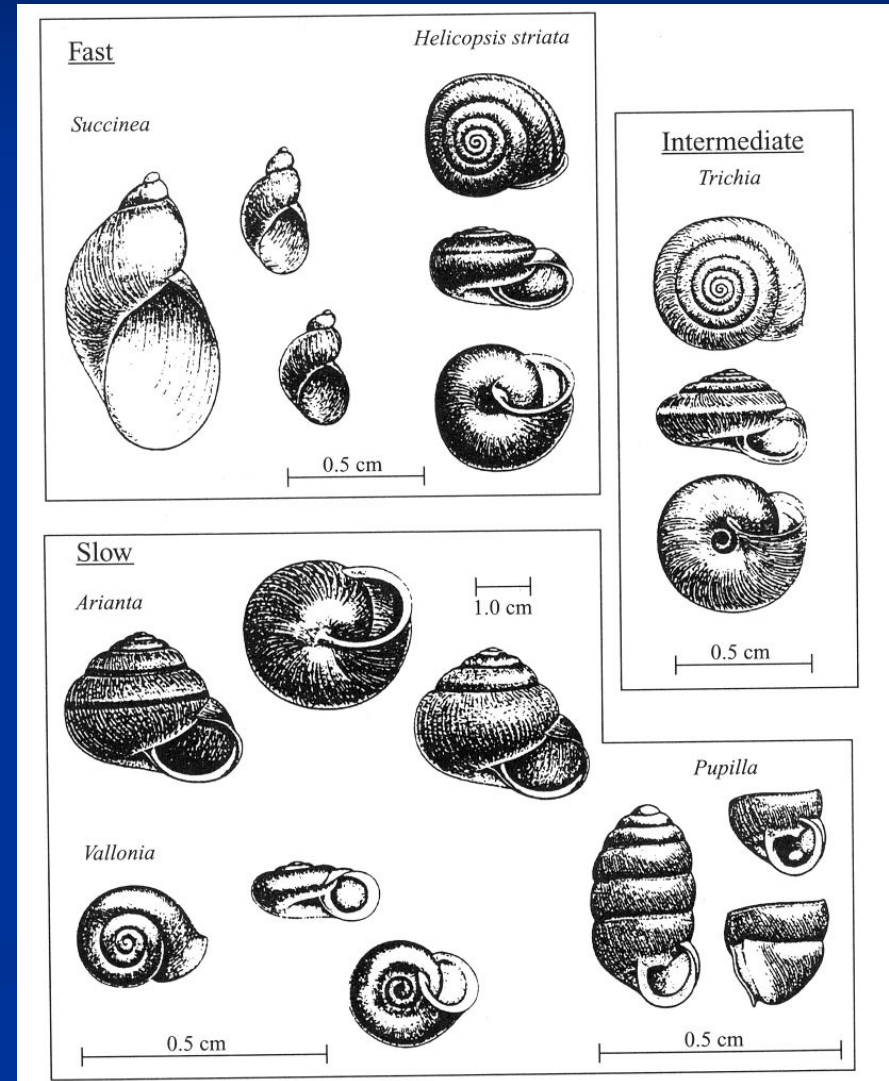


# Podmínky datování na základě aminokyselin

- ❄ First studies in 1968 (Hare and Mitterer 1968)
- ❄ Can be conducted on small samples <2mg in mollusks or foraminifera
- ❄ Can also be conducted of wood, speleothems, and corals

# Problémy datování na základě aminokyselin

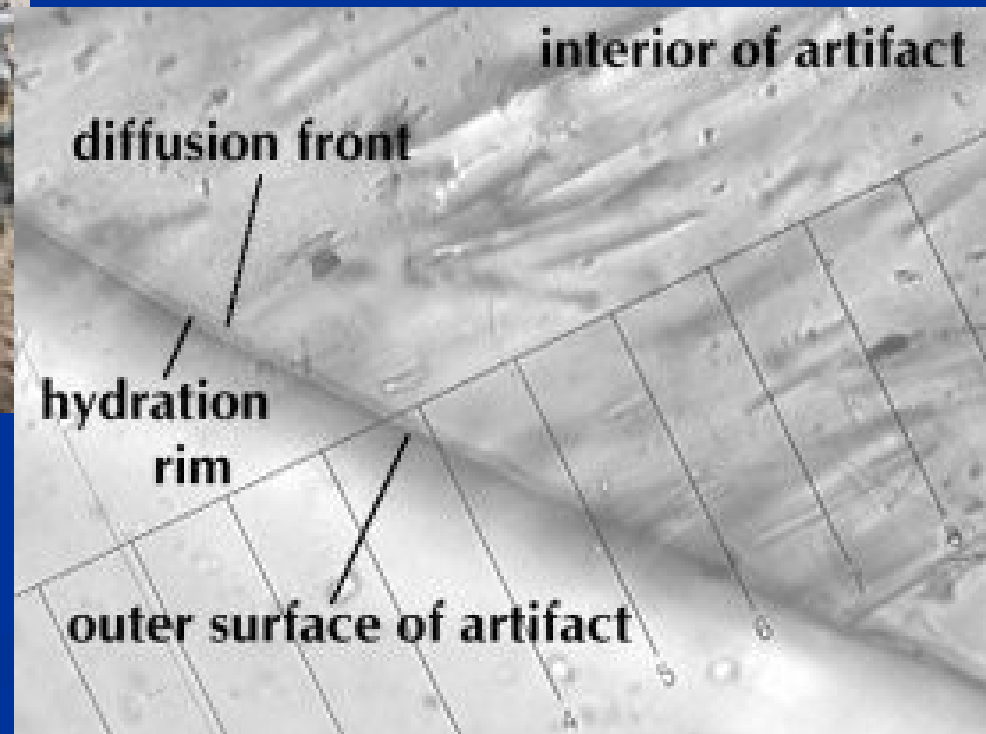
- ❄ Must be **calibrated** to provide absolute dates
- ❄ Very **sensitive to temperature** history
  - ❄ An uncertainty of  $\pm 2$  C is equivalent to an age uncertainty of  $\pm 50\%$
- ❄ Can also be affected by contamination and leaching
- ❄ Rates **vary from one genus to another**



# Hydratace obsidiánu

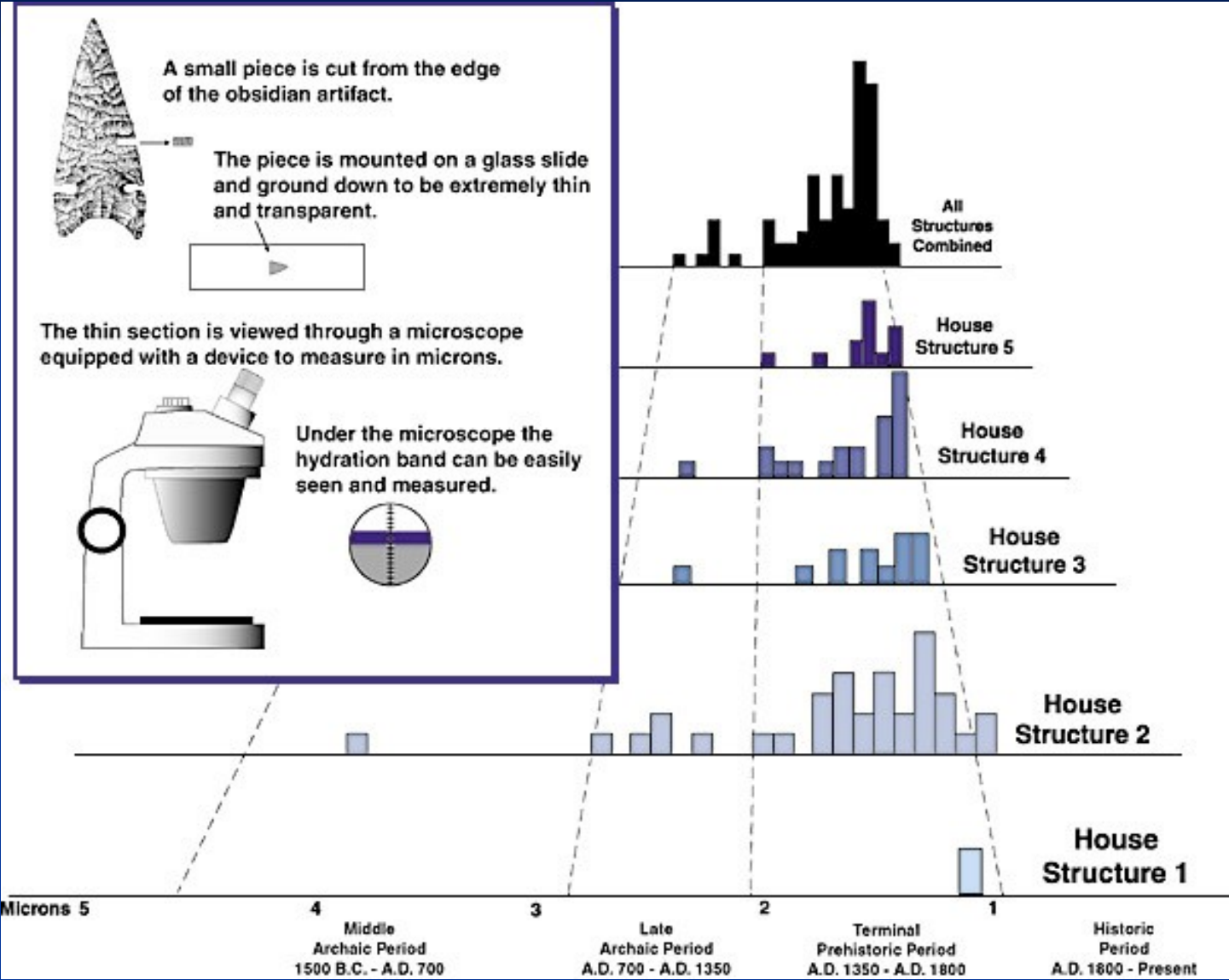
- \* Fresh surfaces of obsidian will react with water from the atmosphere or soil to create a hydration rind
- \* The **thickness of the hydration rind** can be measured and used to tell the age of the sample
- \* Mainly used in **archaeology** can also date glacial or volcanic events

# Hydratace obsidiánu





Obsidian hydration profiles from Crooks Canyon in Northern California. The large number of readings between 0.8 and 1.5 microns indicate occupation at the very end of the Terminal Prehistoric Period, as well as during the Historic Period.



# Problémy hydratace obsidiánu

- \* Must be **regionally calibrated** to provide absolute dates
- \* **Dependent upon temperature**
- \* **Varies with sample composition**
- \* **Not very precise**

# SED: Surface Exposure Dating (datování expozice povrchu)

## COSMOGENIC ISOTOPES.

isotopes produced on the surface of newly exposed rocks by bombardment of **cosmic rays**.

**COSMIC RAYS** are high velocity neutrons.

Penetrate rocks to a depth of 2-3 m. Go right thru you.  
Cosmic rays produce new “cosmogenic” radioactive isotopes.

Si, Mg, Al, Fe → converted to  $^{10}\text{Be}$ ,

K, Ca, Cl → converted to  $^{36}\text{Cl}$ ,

$t_{1/2} = 300\,000$  let

$t_{1/2} = 1,5 \cdot 10^6$  let

Once formed they begin to decay.

# SED

- **Surface exposure dating** is a collection of geochronological techniques for estimating the length of time that a rock has been exposed to the Earth's atmosphere. Surface exposure dating is used to date glacial advances and retreats, erosion history, lava flows, meteorite impacts, rock slides, fault scarps, and other geological events. It is most useful for rocks which have been exposed for between 10 and 30,000,000 years.
- The Earth is constantly bombarded with cosmic rays, high energy charged particles comprising mostly protons and alpha particles. They couple strongly with matter, and are absorbed within the first meter of exposed material. When one of these particles strikes an atom in the atmosphere or a rock on the surface of the Earth, it can dislodge one or more protons or neutrons from that atom, producing a different element or a different isotope of the original element. These new elements and isotopes are called cosmogenic nuclides, and the process is termed cosmic ray spallation. By measuring the concentration of these cosmogenic nuclides in a rock sample, and accounting for the flux of the cosmic rays and the half-life of the nuclide, it is possible to estimate how long the sample has been exposed to the cosmic rays.



# SED

- The two most frequently measured cosmogenic nuclides are  $^{10}\text{Be}$  and  $^{26}\text{Al}$ . These nuclides are particularly useful to geologists because they are produced when cosmic rays strike  $^{16}\text{O}$  and  $^{28}\text{Si}$ , respectively. The parent isotopes are the most abundant of these elements, and are common in crustal material, whereas the radioactive daughter nuclei are not commonly produced by other processes. As  $^{16}\text{O}$  is also common in the atmosphere, the contribution to the  $^{10}\text{Be}$  concentration from material deposited rather than created *in situ* must be taken into account.

# SED: Surface Exposure Dating (datování expozice povrchu)

**Použití:**

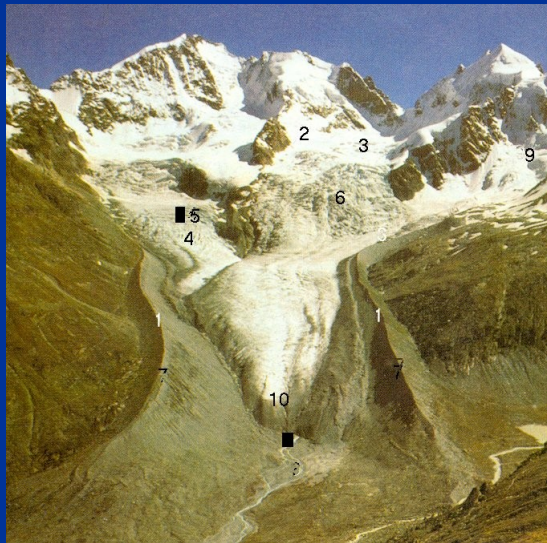
**Kontinentální sedimenty  
dlouhodobě odkryté na povrchu**



**Alluvial fan**



**Moraine**



# OSL Optically stimulated luminescence

- **Conditions and accuracy**
- Ages can be determined typically from 300 to 100,000 years BP, and can be reliable when suitable methods are used and proper checks are done. Ages can be obtained outside this range, but they should be regarded with caution. The accuracy obtainable under optimum circumstances is about 5%.
- The optical dating method relies on the assumption that the mineral grains were sufficiently exposed to sunlight before they were buried. This is usually, but not always, the case with Eolian deposits, such as sand dunes and loess, and some water-laid deposits.
- All sediments and soils contain trace amounts of radioactive isotopes including uranium, thorium, rubidium and potassium. These slowly decay over time and the ionizing radiation they produce is absorbed by other constituents of the soil sediments such as quartz and feldspar. The resulting radiation damage within these minerals remains as structurally unstable *electron traps* within the mineral grains. Stimulating samples using either blue, green or infrared light causes a luminescence signal to be emitted as the stored unstable electron energy is released, the intensity of which varies depending on the amount of radiation absorbed during burial. The radiation damage accumulates at a rate over time determined by the amount of radioactive elements in the sample. Exposure to sunlight resets the luminescence signal and so the time period since the soil was buried can be calculated.

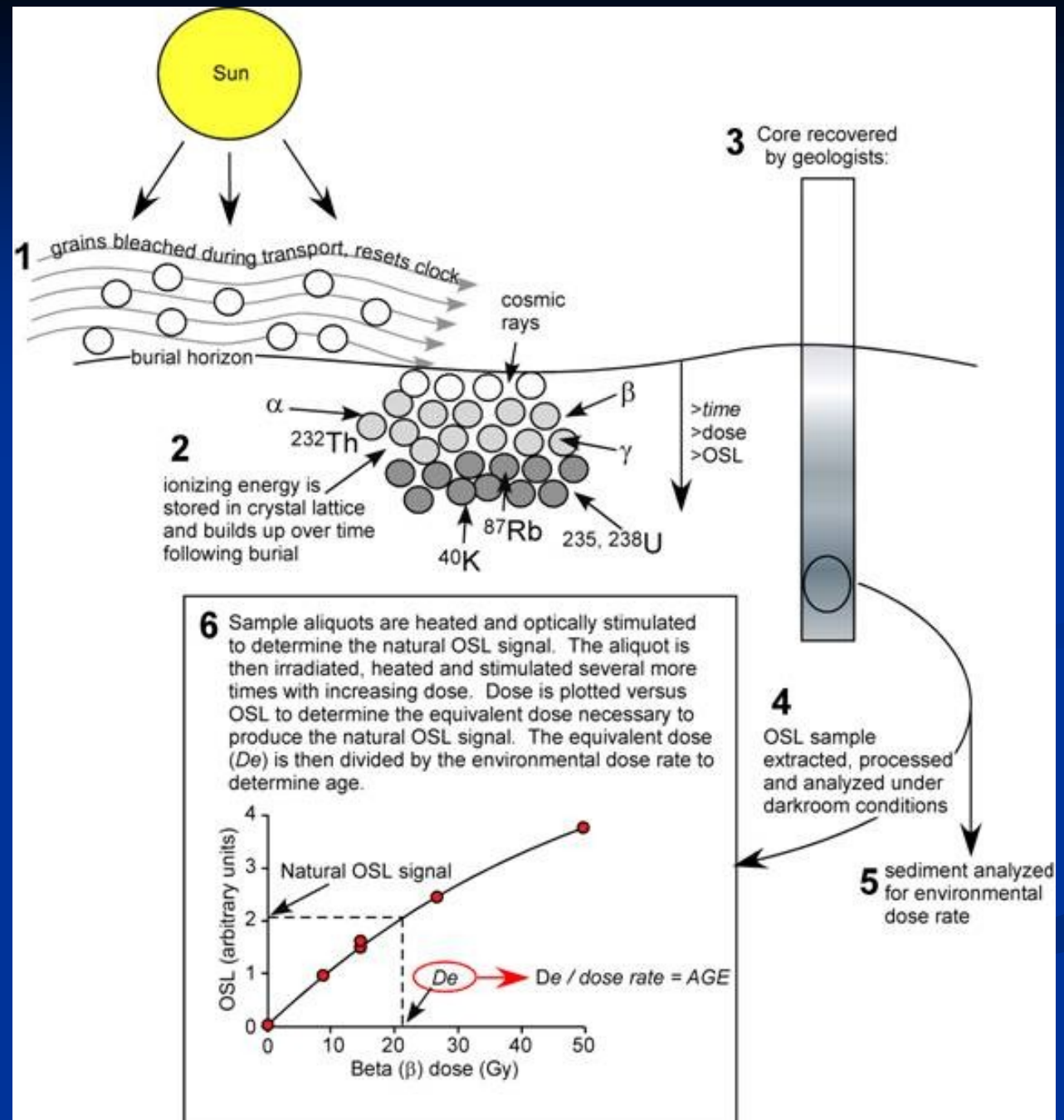
# OSL

## ■ Physics

- Optical dating is one of several techniques in which an age is calculated as follows:  $(\text{age}) = (\text{total absorbed radiation dose}) / (\text{radiation dose rate})$ . The radiation dose rate is calculated from measurements of the radioactive elements (K, U, Th and Rb) within the sample and its surroundings and the radiation dose rate from cosmic rays. The dose rate is usually in the range 0.5 - 5 grays/1000 years. The total absorbed radiation dose is determined by exciting specific minerals (usually quartz or feldspar) extracted from the sample with light and measuring the light emitted as a result. The photons of the emitted light must have higher energies than the excitation photons in order to avoid measurement of ordinary photoluminescence. A sample in which the mineral grains have all been exposed to at least a few seconds of daylight can be said to be of zero age; when excited it will not emit any such photons. The older the sample is, the more light it emits.



# OSL DATING



# Dolní Věstonice

## OSL dating

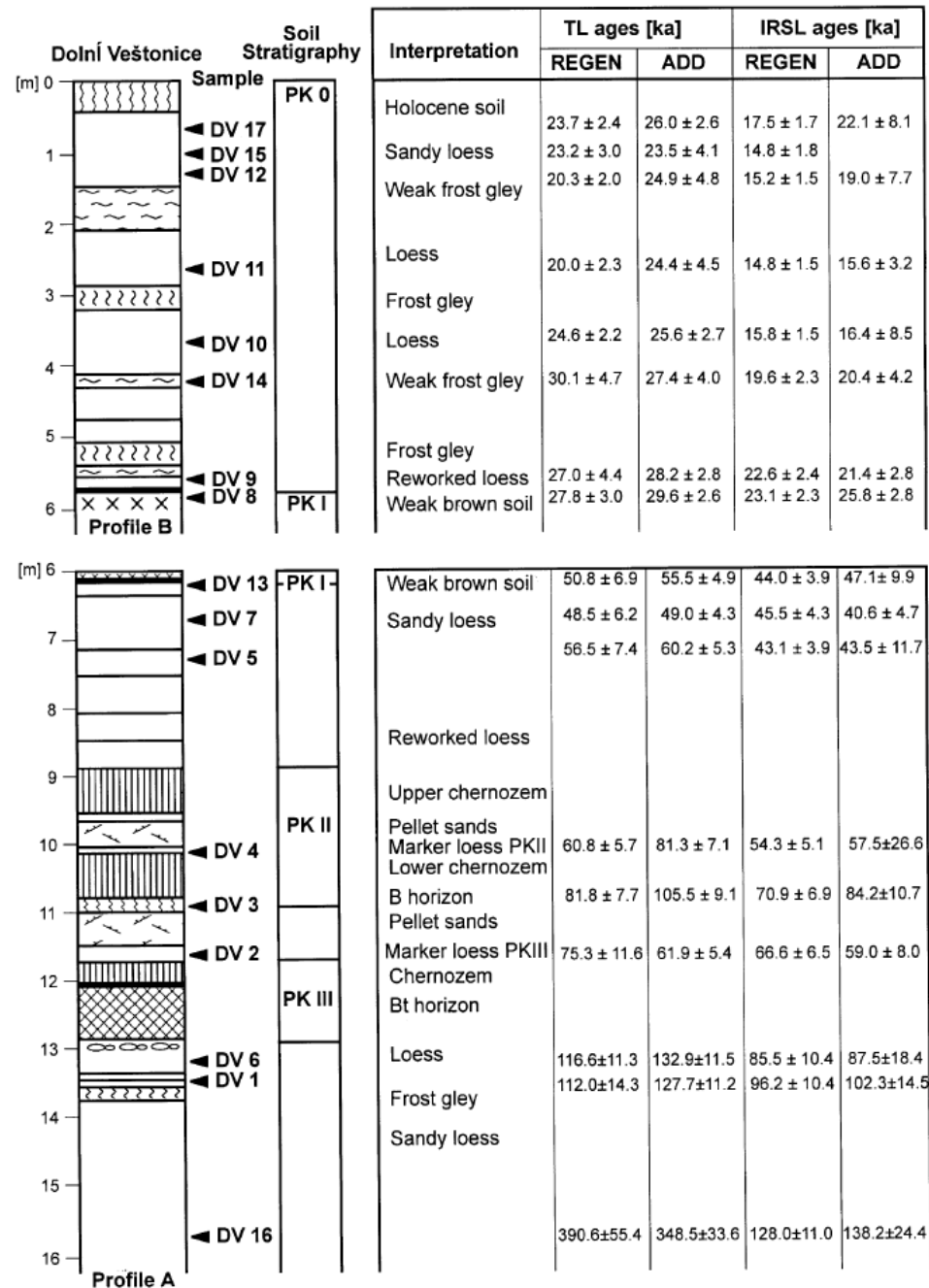


Fig. 5. Loess stratigraphy and luminescence dating results for the section at Dolní Věstonice. REGEN: regeneration method; ADD: additive dose method.

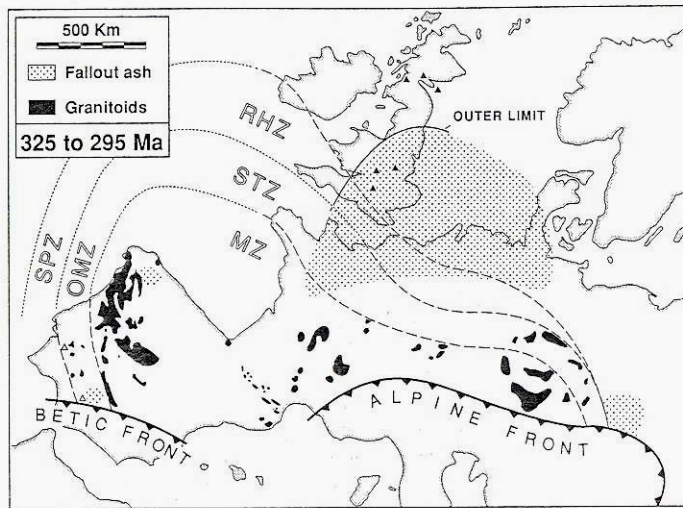
# Age equivalence methods: Tephrochronologie

- ❄ Airborne pyroclastic material ejected during a volcanic eruption
- ❄ Form **isochronous stratigraphic markers**
- ❄ Must be dated by  $^{40}\text{K}/^{40}\text{Ar}$  or fission-track dating
- ❄ Can be used in for bounding dates

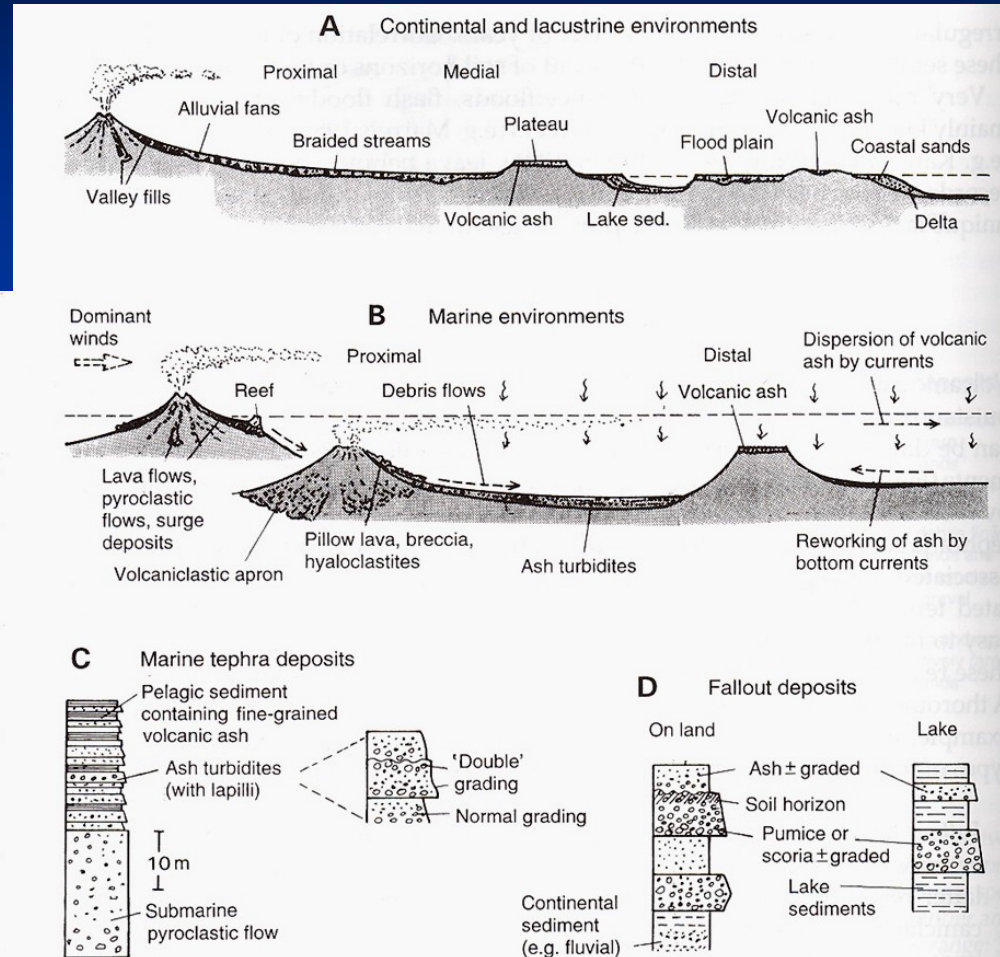
# Depoziční události v kontinentálním prostředí: Tefrostratigrafie

400

Chapter 2 Event Stratification



**Fig. 6.** Areal distribution of Lower Carboniferous fallout ash layers (bentonite or “tonstein” layers) in front of the main areas of granite intrusions in Europe. *Open triangles* (felsic) and *closed triangles* (mafic) indicate occurrences of volcanic rocks. *SPZ* South Portuguese zone; *OMZ* Ossa Morena zone; *RHZ* Rhenohercynian zone; *STZ* Saxothuringian zone; *MZ* Moldanubian zone. (After Francis 1988)



**Figure 6.11** Various tephra events in (A) continental and (B) marine environments. C. Compound section of marine tephra deposits reflecting the transition from maximum to waning stages of submarine eruption. D. Repeated fallout deposits on land surface and in lake. [Modified from: Einsele (1992)]



# Tefrostratigrafie

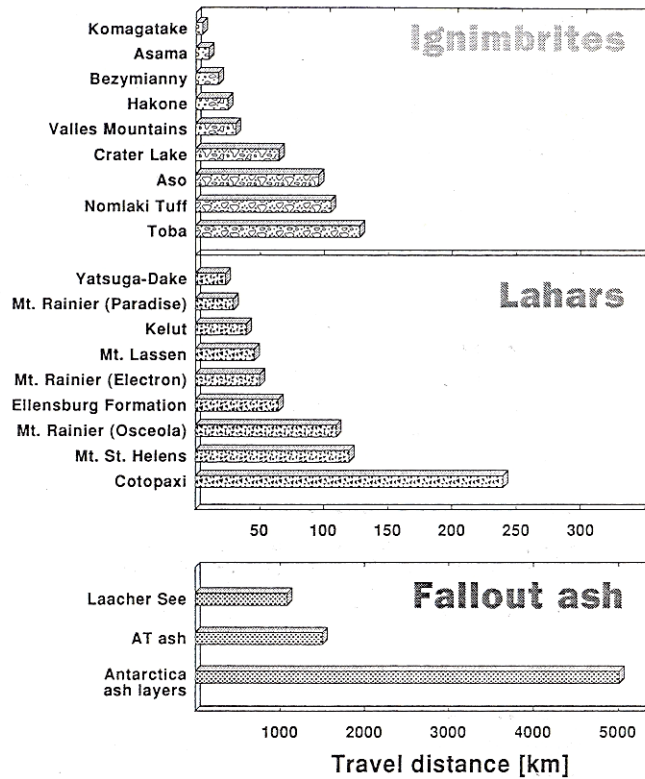
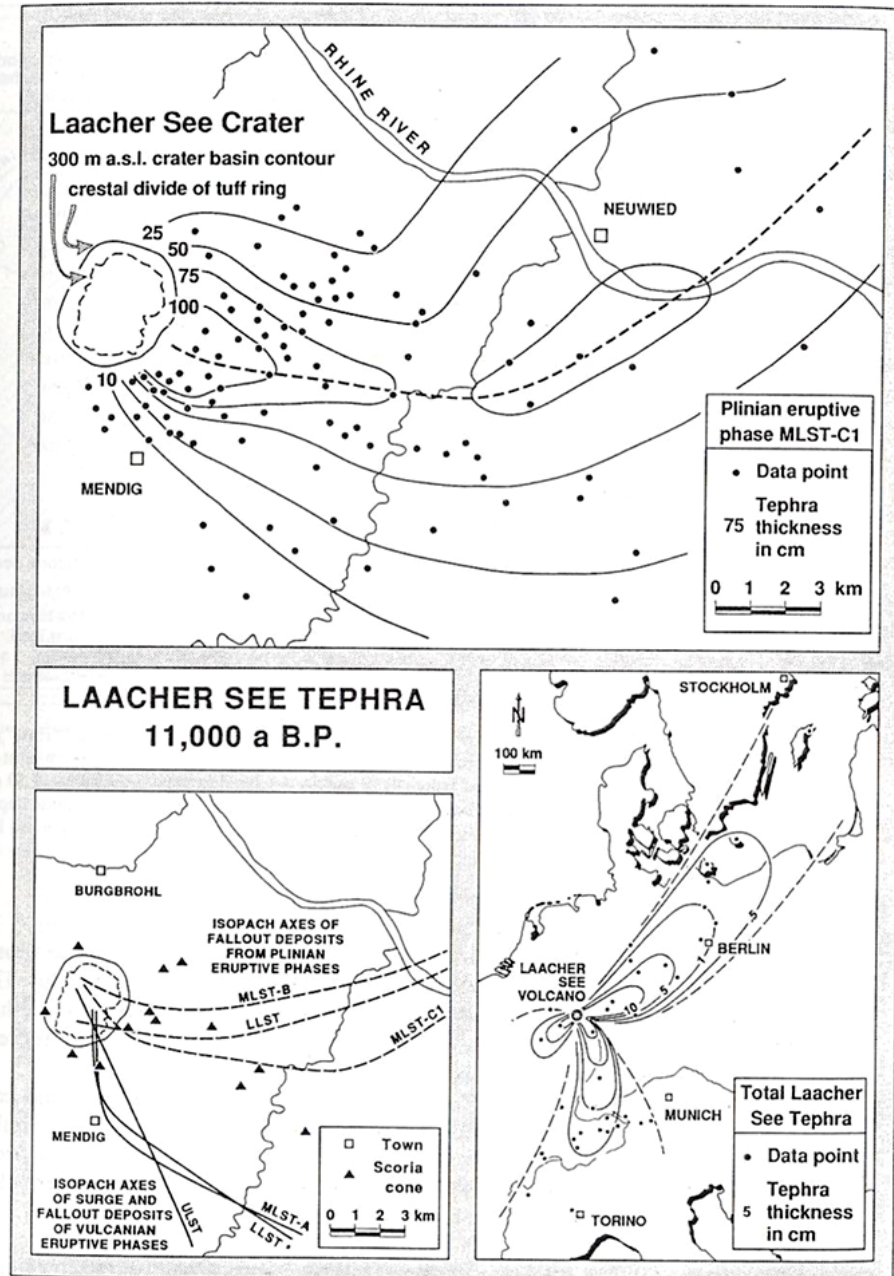
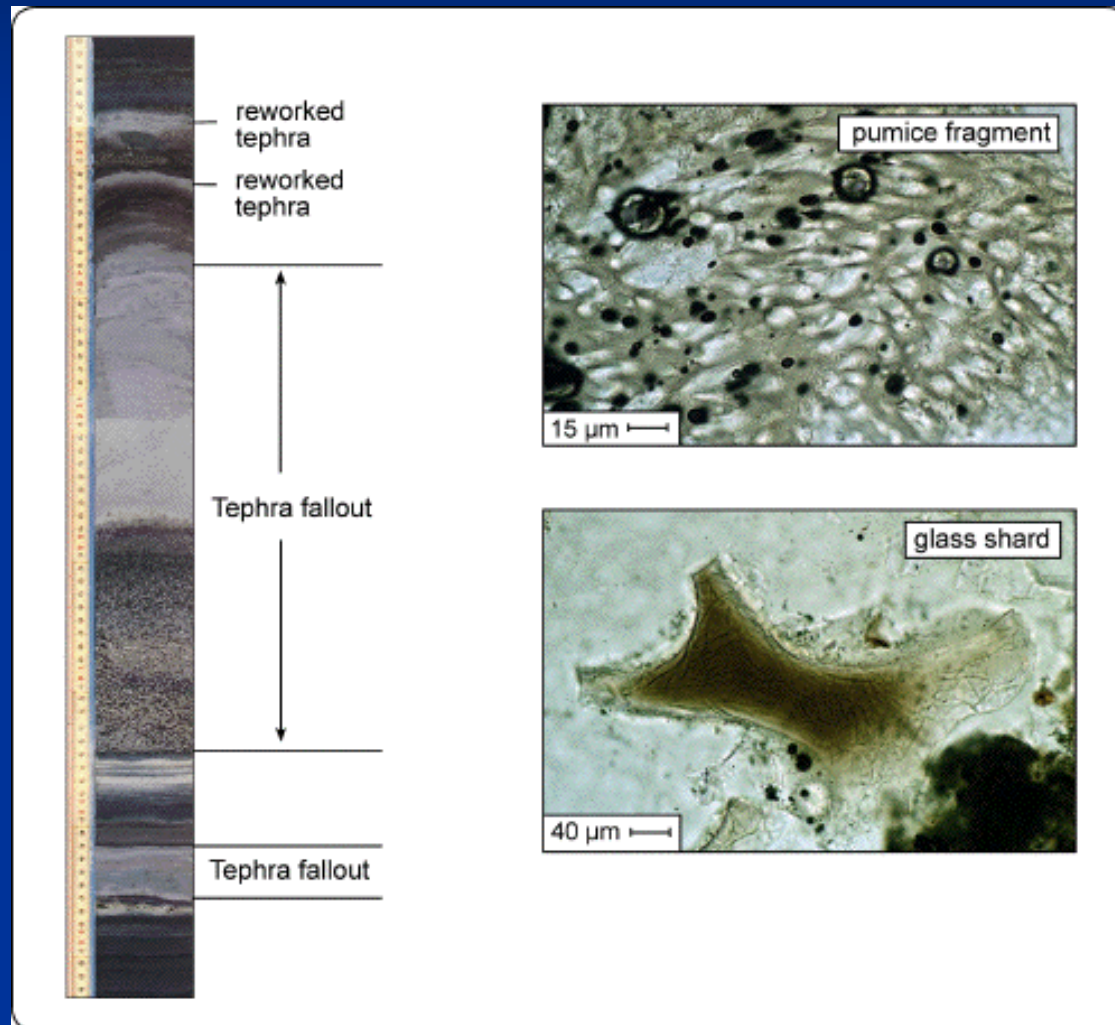


Fig. 8. Typical transport distances of ignimbrites and lahars, and traceable extent of Plinian fallout ash layers. Various sources compiled in Schmincke (1988) and Fisher and Schmincke (1984, 1990). Cotopaxi and St. Helens lahar data may include lahar run-out hyper-concentrated stream deposits as well. (Fallout data from Machida 1981, Kyle and Seward 1984, and van den Bogaard and Schmincke 1985)

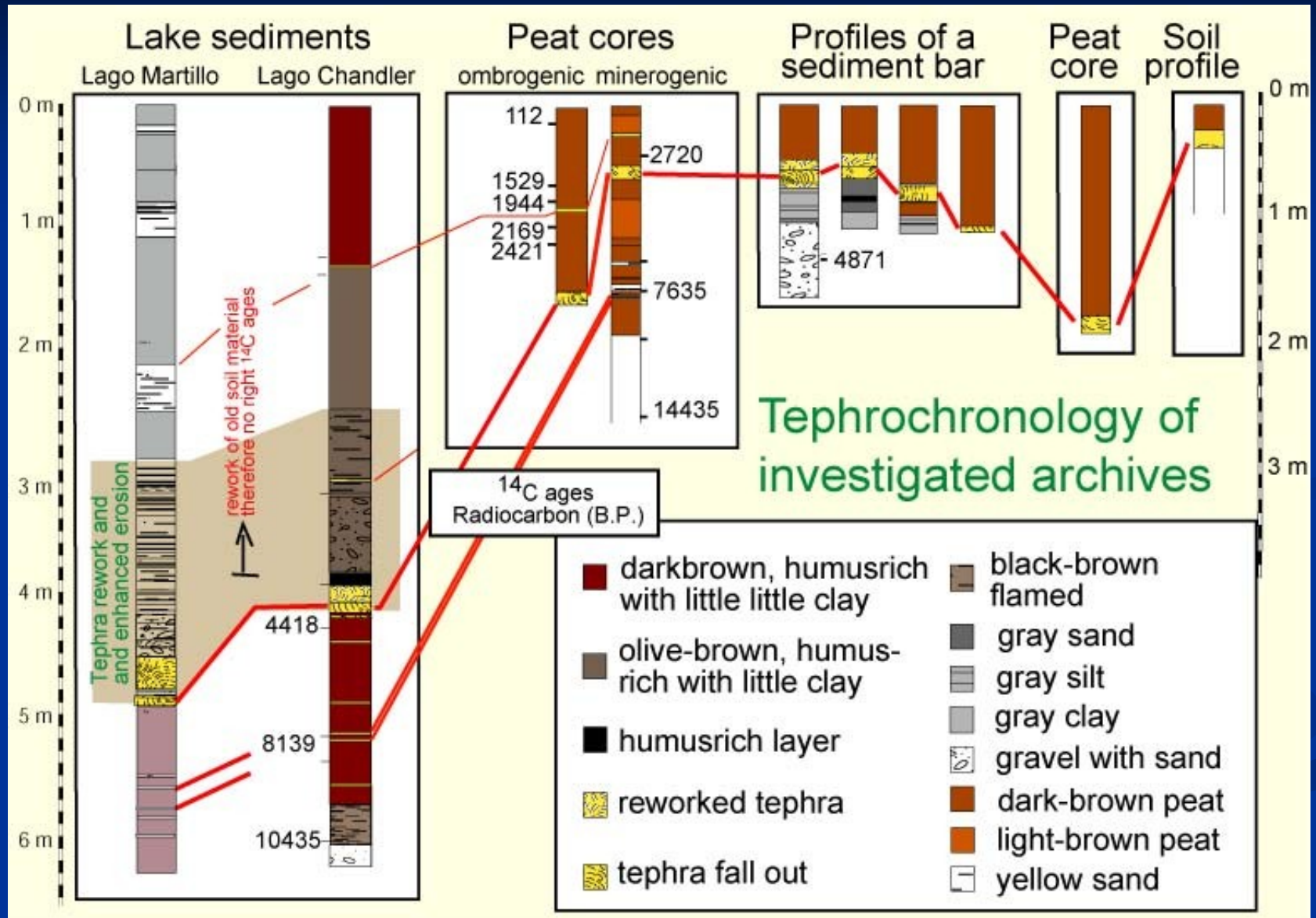


# Tephrochronologie

- ❄ Petrographic and chemical studies can identify unique tephra signatures which can then be used in a tephrochronology



# Tephrochronologie



# Zvětrávání a pedogeneze

## ■ **Relative dating**

- One control upon the degree of weathering of a rock surface or the degree of soil development in the time over which those processes may have operated.
- All other things being equal (!), a more highly weathered surface or a more well developed soil will be older than a surface less weathered or a less mature soil.
- Degree of rock surface weathering commonly be measured in the field by use of a **Schmidt hammer**.
- Thickness of the **weathering rind** on a rock surface or boulder can also be used.
- Degree of **rock varnish** development provides another alternative in some environmental situations. Chemical composition of the varnish 'matures' with time.



