Climate Changes in the Mediterranean During the Development of Northern Hemispheric Glaciation

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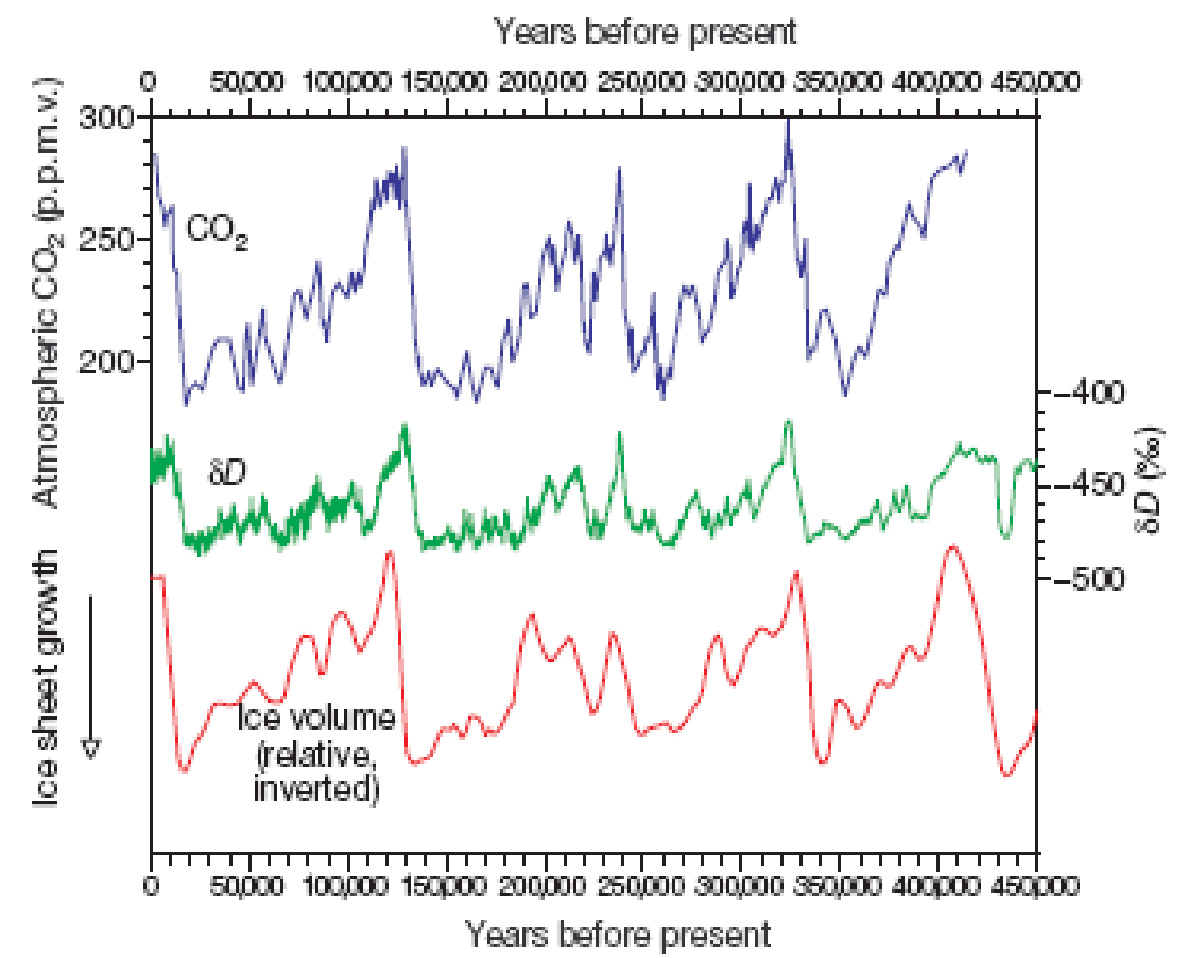
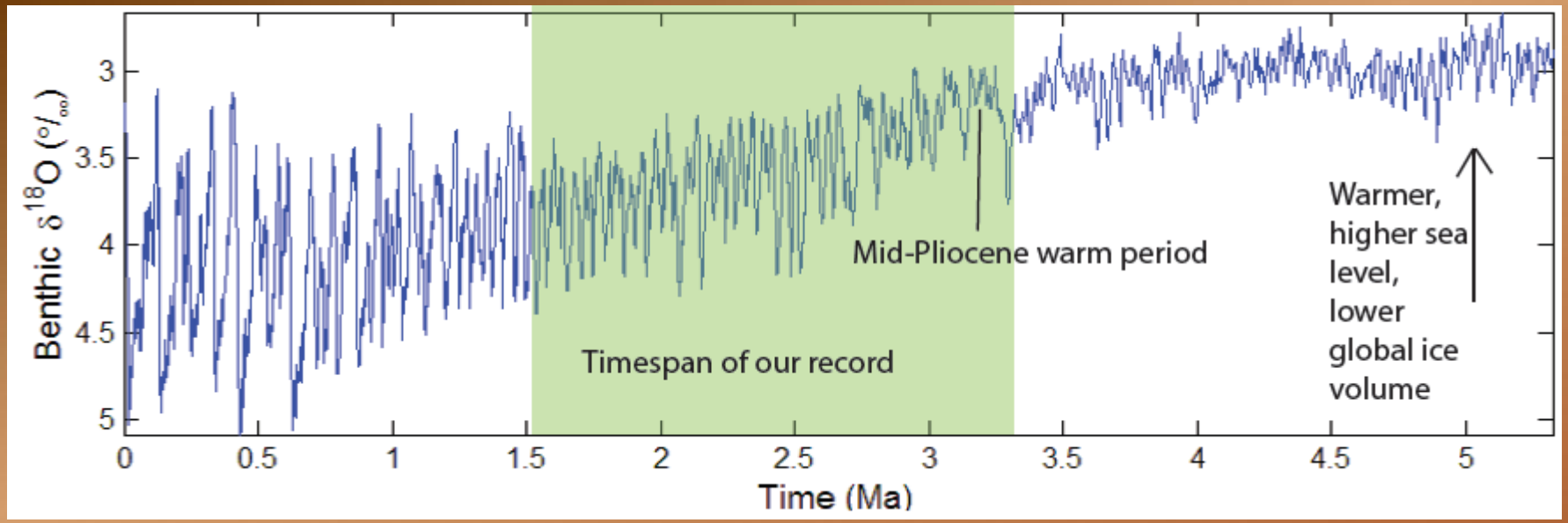


Record of $[CO_2]_{atm}$, deuterium isotopes, and ice sheet growth of the past 450 kyr from the Vostok ice core in Antarctica. *Source: Sigman et al 2000.*

- Greenhouse gas and climate fluctuations in the geological past offer insight into modern climate change
- Glaciation and atmospheric CO_2 are closely linked
- Due to anthropogenic climate change, modern $[CO_2]_{atm}$ is ~380 ppm and climbing, far beyond the $[CO_2]_{atm}$ range of the most recent (late Pleistocene) glacial cycles of ~180-280 ppm



Benthic oxygen isotope ($\delta^{18}O$) record, reflecting high-latitude ocean temperatures, global ice volume, and sea level. *Source: Lisiecki 2005.*

- Mid-Pliocene warm period ~3 Mya was the last time Earth was warmer than today: 3°C warmer, ~30% higher $[CO_2]_{atm}$, 10-20 m higher sea levels, emerging but small Northern Hemispheric ice coverage

- Over the past 3 Myr, glaciation in the Northern Hemisphere intensified and climate fluctuated in glacial cycles paced by variations in Earth's orbit around the sun (obliquity and eccentricity)

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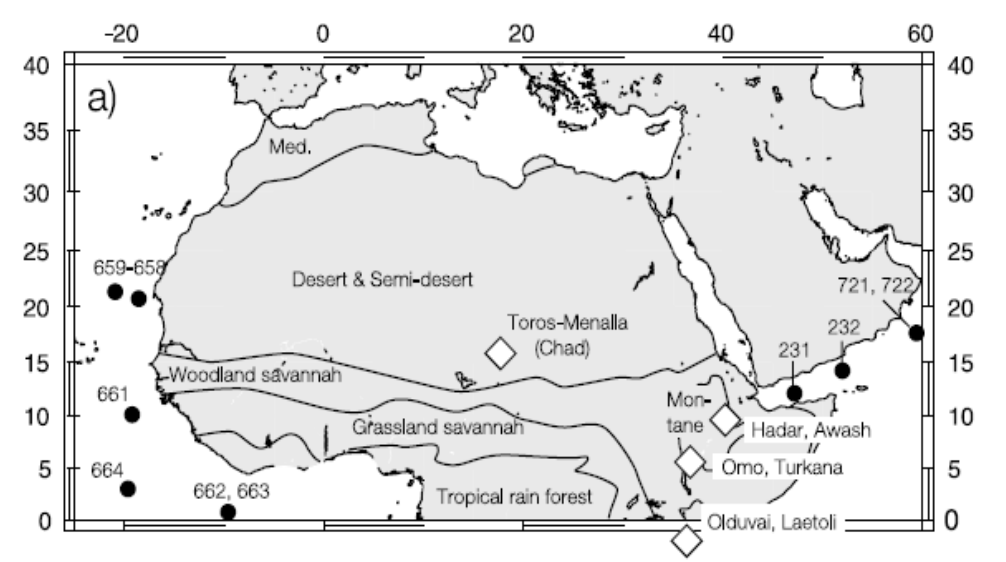
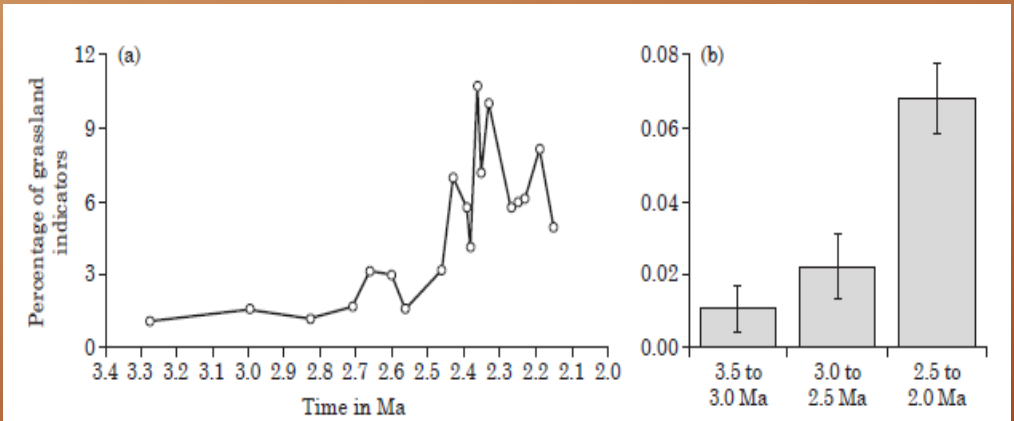
Pollen records displaying climate control on Mediterranean vegetational ecology. Left: succession of vegetation species during a glacial cycle. Right: temperate tree pollen percentage (middle) compared to $\delta^{18}O$ (bottom) and high-latitude solar insolation (top). *Source: Tzedakis 2007.*

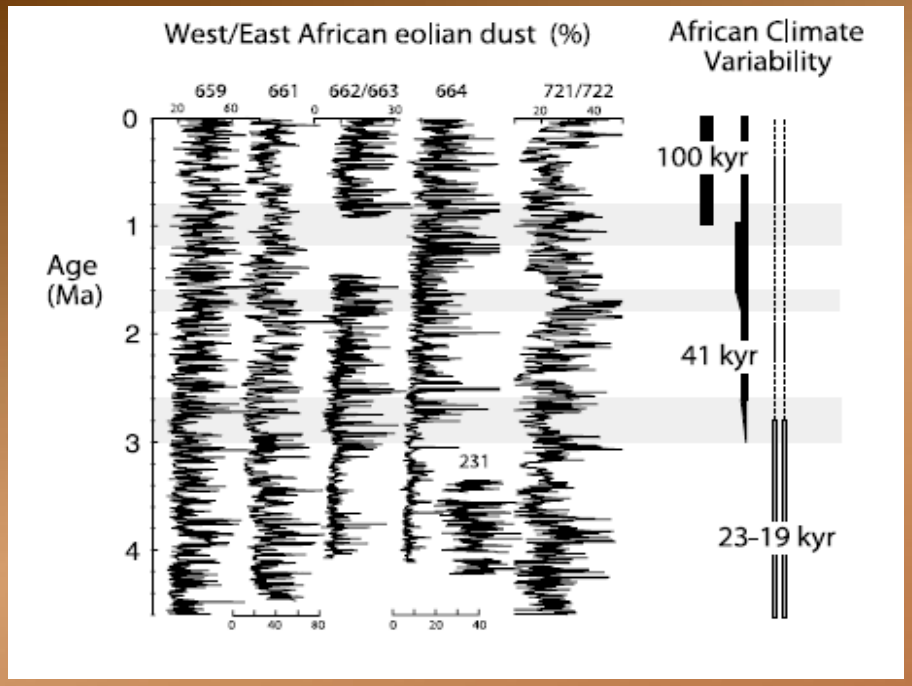


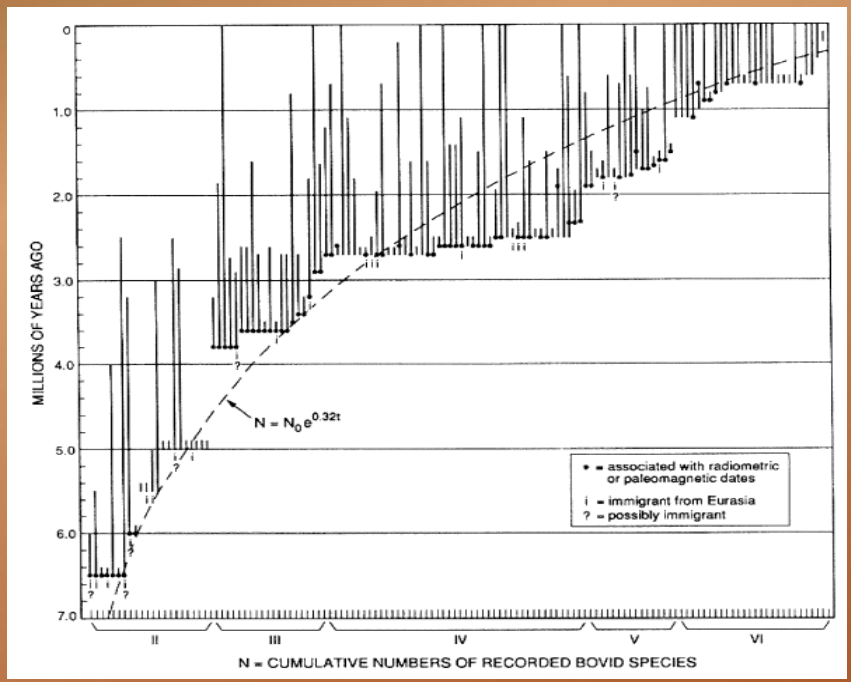
Modern biome distribution of North Africa. *Source: deMenocal 2004.*



Percentage of grassland-adapted taxa (left) and arid-adapted species in mammalian fossil record in Ethiopia. *Source: Bobe 2002.*

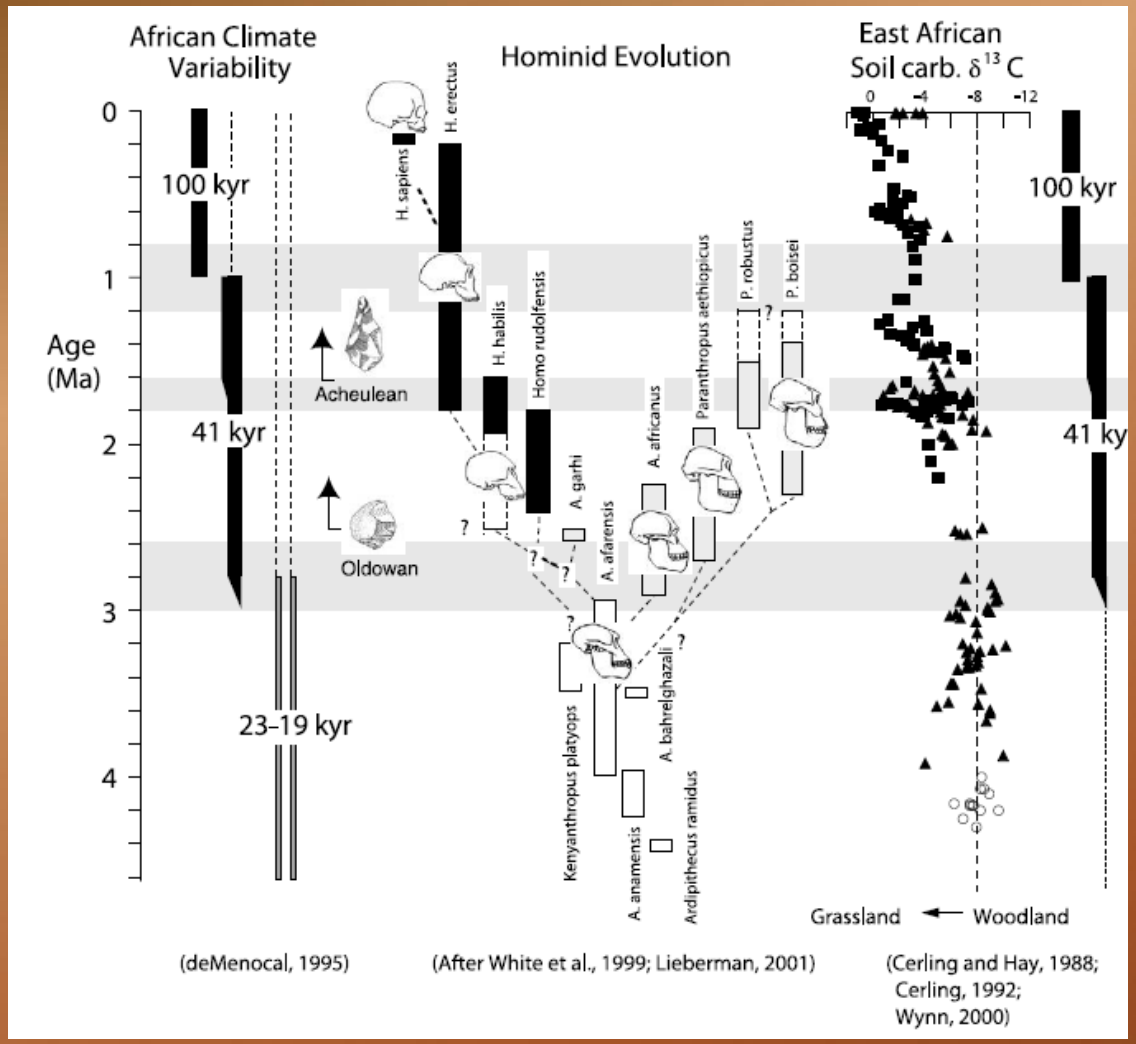
- The distribution of biomes is governed by climatic variations in precipitation and temperature patterns
- Cold North Atlantic SST's during glaciations cause cooler and drier conditions in North Africa
- Intensification of Northern Hemispheric Glaciation caused expansions of deserts and grasslands, contractions of woodlands
- **Habitat selection hypothesis**: climate-forced shifts in habitat distributions led to the evolution of arid-, grassland-adapted species and extinction of humid,-woodland- adapted species





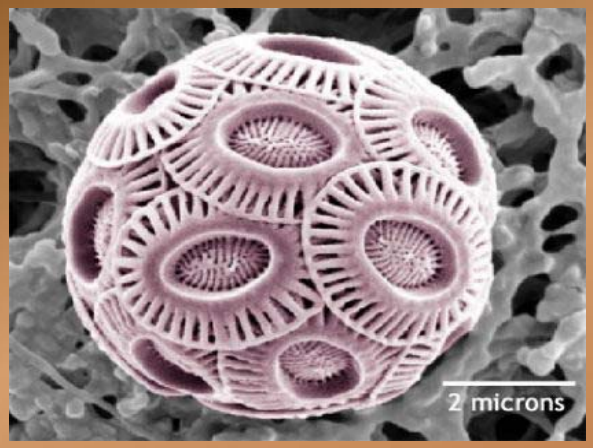
Left: African eolian dust record, reflecting cycles of precipitation and aridity. Right: evolutionary history of North African bovid (antelope) species. *Source: deMenocal 2004.*

- **Variability selection hypothesis**: Speciation and extinction events clustered at times of changes in the variability and pacing of aridity patterns: ~2.7 Mya, ~1.8 Mya, and ~0.9 Mya
- The change in aridity pattern and species turnover pulse at ~2.7 Mya corresponds to the initiation of Northern Hemispheric Glaciation
- What caused the increase in variability at ~1.8 Mya, at the Pliocene-Pleistocene boundary?



Evolutionary history of hominids, and East African soil carbonate carbon isotopes reflecting the relative abundance of woodland versus grassland. *Source: deMenocal 2004.*

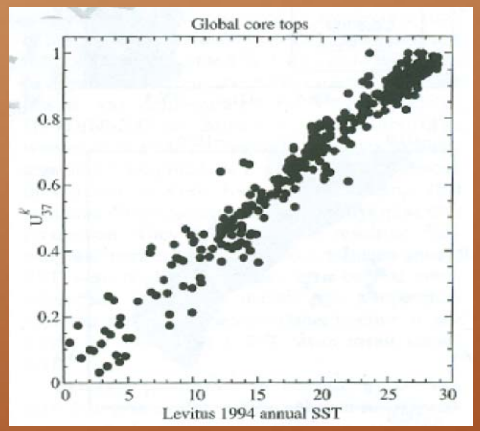
Alkenone Paleotemperature Method



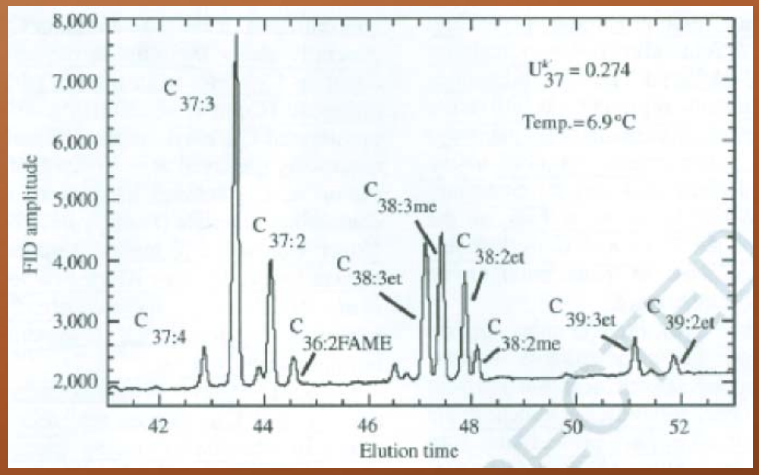
The haptophyte algae *Emiliana huxleyi*.

- *Emiliana huxleyi* and other haptophyte algae produce alkenones in various unsaturation forms, depending on growth temperature

- The U_k^{37} index is calculated using the ratio of tri-unsaturated (37:3) to di-unsaturated (37:2) alkenones and used to estimated sea-surface temperature

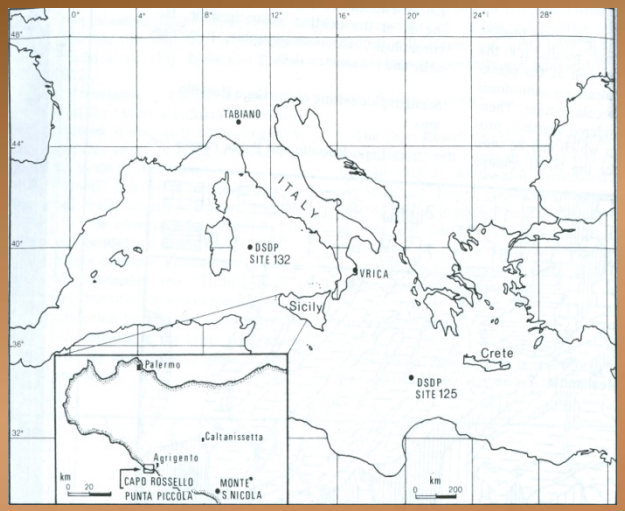


Correlation between Uk37 index and sea-surface temperature. Source: Herbert 2003.

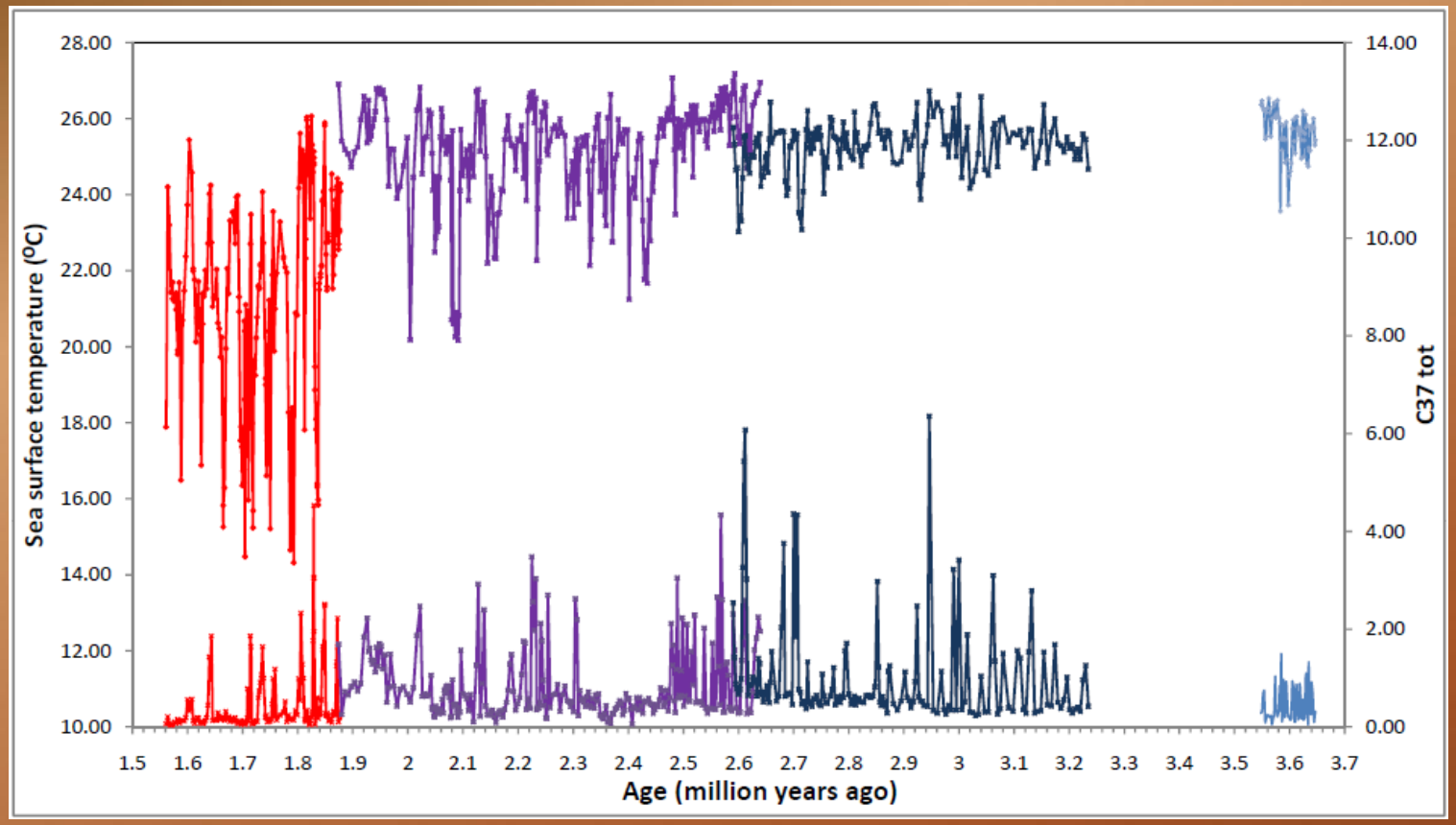


The 37:3 and 37:2 alkenone unsaturation forms in a gas chromatogram.

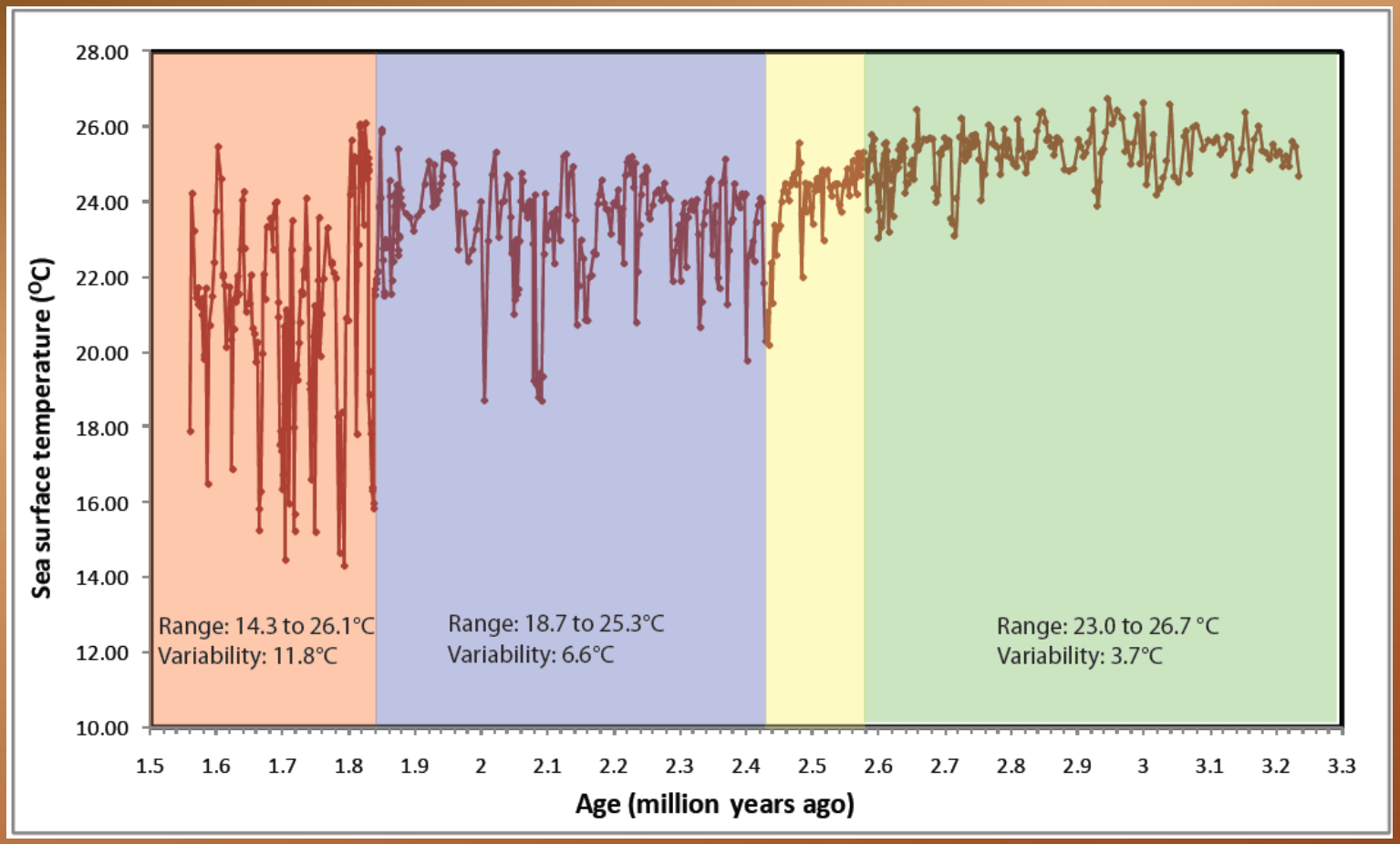
Outcrop sites and field sampling



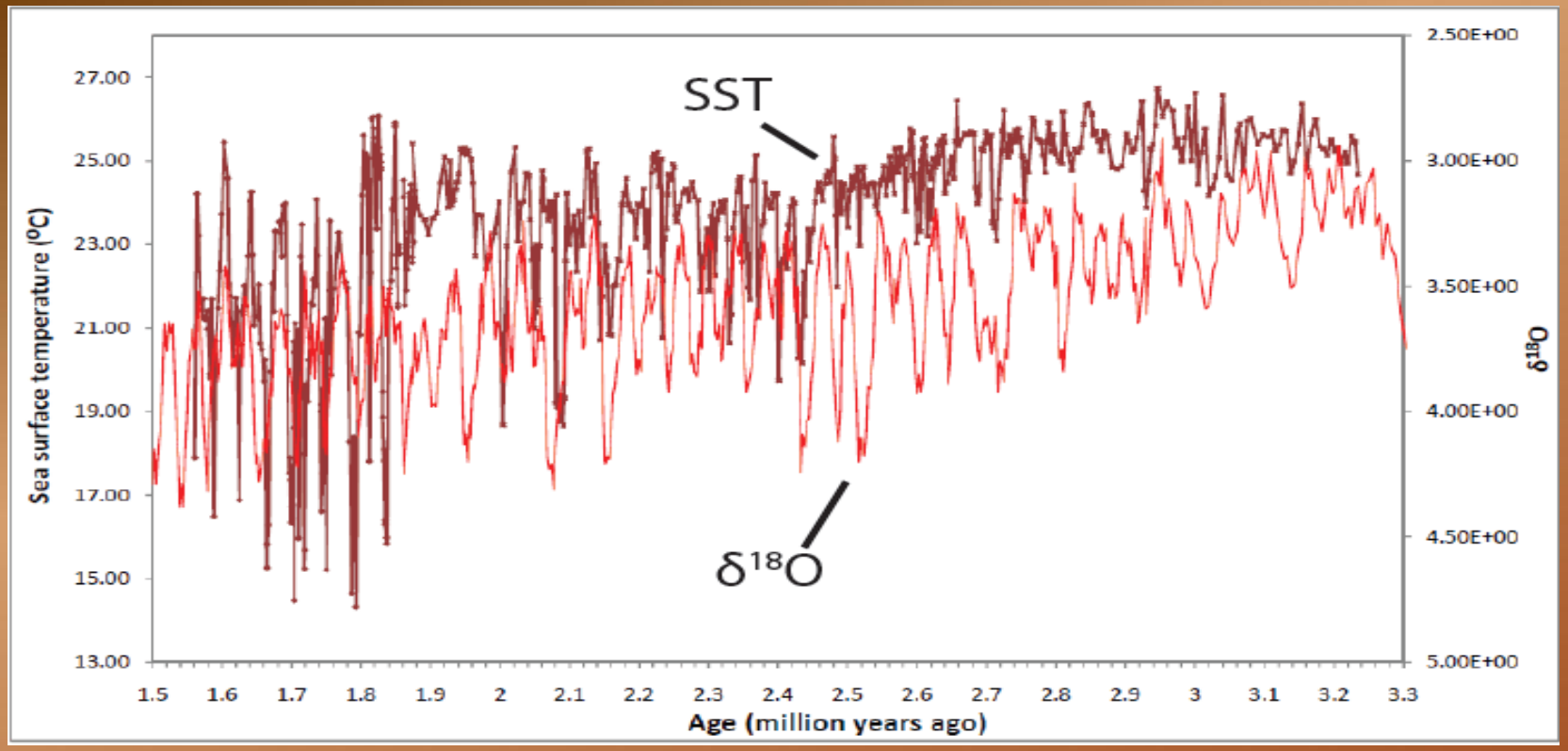
- The Mediterranean: an area influenced by surrounding continental climates
- San Nicola and Punta Piccola, two outcrops of lithified, uplifted Mediterranean Sea sediments, spanning the late Pliocene
- Connecting to an early Pleistocene record from Vrica, in southern Italy (Cleaveland 2009)
- First attempt to derive alkenones from lithified sediments



The SST (top) and C_{37}-total (bottom) records from Vrica (red) (Cleaveland 2009), San Nicola (purple), Punta Piccola Monte Narbonne section (dark blue), and Punta Piccola Trubi section (light blue).



- Two distinct transitions: ~2.5 Mya and ~1.8 Mya
- Increases in the amplitude of SST cycles
- The ~1.8 Mya transition (Plio-Pleistocene boundary) not observed in other paleoclimate records



Comparing the Mediterranean SST record (dark maroon) with the global benthic $\delta^{18}O$ record (red; Lisiecki 2005)

- Coherence between Mediterranean SST and $\delta^{18}O$ after the ~2.5 Mya transition
- Suggesting the climate influence of high-latitude glaciation on the Mediterranean
- $\delta^{18}O$ record does not display an increase in amplitude at ~1.8 Mya

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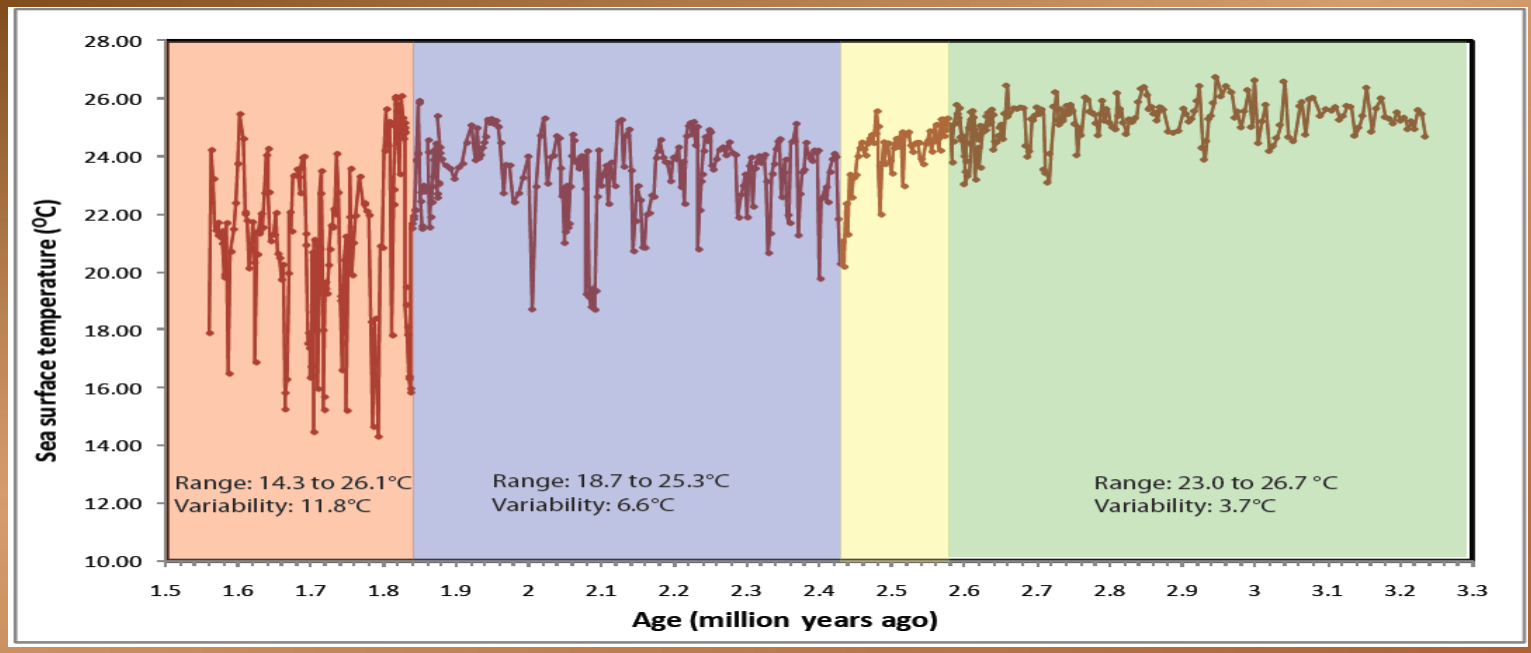
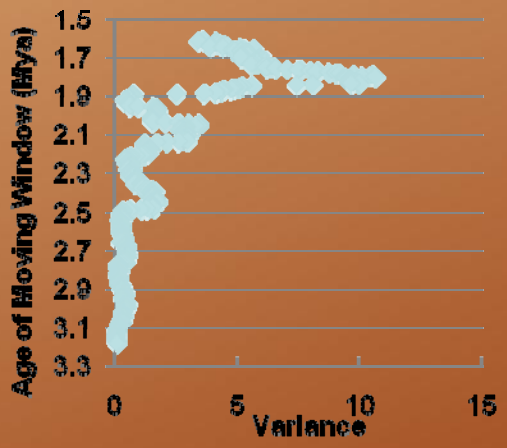
Spectral analysis of the Mediterranean SST record

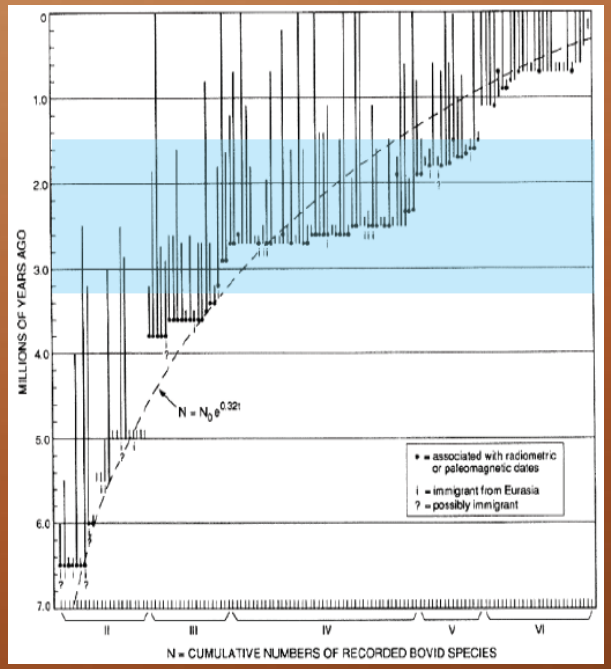
- Precession's 23 kyr periodicity most consistent before ~2.5 Mya – suggesting dominance of local solar insolation

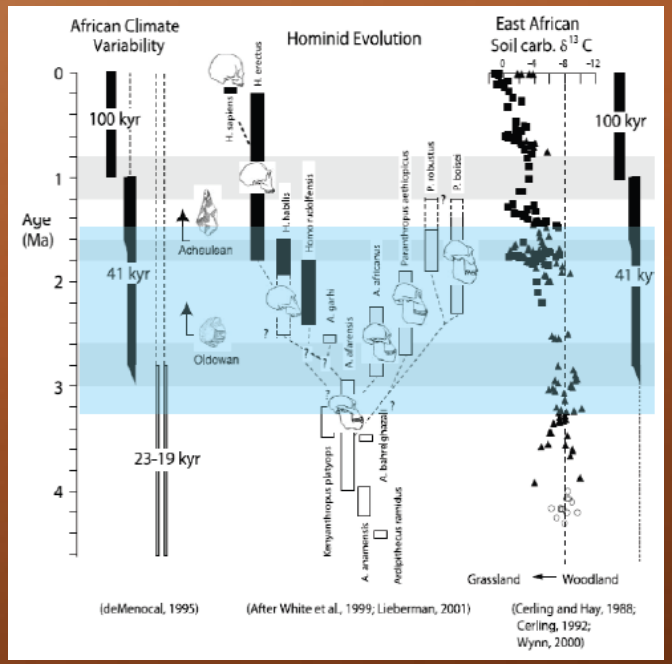
- Obliquity's 41 kyr band strengthens after ~2.5 Mya and develops into the strongest spectral power of the dataset at ~1.8 Mya

- Obliquity has little direct influence on solar insolation on Mediterranean's 35^{O}N latitude, but controls high-latitude glaciation


Sea surface temperature (°C)
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
1.5 1.6 1.7 1.8 1.9 2 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3 3.1 3.2 3.3
Age (million years ago)
Range: 14.3 to 26.1°C
Variability: 11.8°C
Range: 18.7 to 25.3°C
Variability: 6.6°C
Range: 23.0 to 26.7 °C
Variability: 3.7°C


Age of Moving Window (Mya)
1.5
1.7
1.9
2.1
2.3
2.5
2.7
2.9
3.1
3.3
0
5
10
15
Variance


MILLIONS OF YEARS AGO
N = N0 e 0.321t
* = associated with radiometric or paleomagnetic dates
I = immigrant from Eurasia
? = possibly immigrant
II
III
IV
V
VI
N = CUMULATIVE NUMBERS OF RECORDED BOVID SPECIES


African Climate Variability
Hominid Evolution
East African Soil carb. δ13C
Age (Ma)
100 kyr
41 kyr
23–19 kyr
Acheulean
Oldowan
H. sapiens
H. erectus
H. habilis
Homo rudolfensis
A. africanus
A. garhi
A. afarensis
Paranthropus aethiopicus
P. robustus
P. boisei
Kenyanthropus platyops
A. anamensis
A. bahrelghazali
Ardipithecus ramidus
Grassland
Woodland
(deMenocal, 1995)
(After White et al., 1999; Lieberman, 2001)
(Cerling and Hay, 1988; Cerling, 1992; Wynn, 2000)

Acknowledgments

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