The Environmental Dynamics of Human Evolution

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Evidence of the accumulation of human qualities
TIME | EVOLUTIONARY CHANGE
--- | ---
100 ka to present | Increased cultural diversity & technological innovation
by 250 ka | Enhanced symbolic behavior
by 250 ka | Complex spatial mapping & resource exchange
by 800 - 400 ka | Controlling fire & building shelters
by 800 - 200 ka | Most rapid increase in relative brain size
by 1.7 Ma | Initial advances in stone technology
by 2.0 – 1.5 Ma | Pronounced elongation of the legs
by 2.0 Ma | Extensive carrying of stones & food
by 2.6 Ma | Simple stone flaking
by 4 – 3 Ma | Increased range of foods eaten
by ~6 – 2 Ma | Bipedal walking & tree climbing

\( ka = \text{thousands of years ago} \)

\( Ma = \text{millions of years ago} \)
Today
1 Million years ago
2 Million years ago
3 Million years ago
4 Million years ago
5 Million years ago
6 Million years ago
Past

- **Paranthropus group**
- **Homo group**
- **Australopithecus group**
- **Ardipithecus group**

You are here.
Olorgesailie, S. Kenya Rift
How did early humans adjust to environmental change over the past 1 million years?
Overview of the talk

1. Background to why environmental variability provides the critical context for human evolution

2. Alternating phases of high/low climate variability: A new framework for tropical/subtropical African climate

3. Can adaptability evolve?

4. African climate variability linked to the origin of Homo sapiens
Potential evolutionary responses to environmental change

Onset & spread of novel behaviors & ecological interactions

Morphological change, speciation, extinction
Olorgesailie: Rift Valley, southern Kenya
Savanna Hypothesis of Human Evolution

- Bipedal walking
- Tool making
- Expanded diet
- Use of fire and new tools
- Hunting
- Larger brain
- Complex social life
- Language
- Use of fire and new tools
- Hunting
- Expanded diet
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Savanna grassland
Olorgesailie
~ 670,000 to 633,000 yrs ago
Hillside = Slice of Time
(Example: 1.00 – 0.99 million years ago)

- Deep Lake
- Volcanic Ash
- Drought
- Wet grassland
- Dry grassland soil
Since 3 million years ago, glacial fluctuations

Beginning ~ 6 million years ago, warm-cold climate fluctuation became more dramatic.

During the strongest fluctuations, the genus *Homo* evolved.

Oxygen isotope data for marine benthic foraminifera over the last 10 million years.
Sapropels:
5-million-year record of tropical African moisture & aridity
The Three Ways Earth's Orbit Changes

Eccentricity

Precession

Tilt
Tropical African climate is strongly influenced by variation in solar insolation. The main variation is due to the interaction of orbital precession (19,000 & 23,000-year cycles) and eccentricity (100,000 & 413,000-year cycles).

The interaction alternating phases of high & low climate variability in tropical Africa.
Adaptation to ‘the environment’?
Adaptation to environmental dynamics

Tropical African Climate Variability
Sapropel data (Nile flooding & aridity)

Strong aridity
Spectral reflectance
High moisture
Tropical African Climate Variability
Sapropel data (Nile flooding & aridity)

Million Years Ago

Strong aridity

Spectral reflectance

High moisture

P. deMenocal aridity phases
M. Trauth 200-kyr wet phases (deep lakes)
ENVIRONMENT

THE FATE OF SPECIES

Present

Past

Warm Moist → Cold Dry

Become Extinct

Move

Become Versatile

Following habitat change

Adaptive versatility
Conceptual model of variability selection

Potts, 1996, Science
Variability selection:

A process by which particular combinations of genes are favored (increased in the gene pool) due to instability in the survival conditions over time.

The resulting adaptations enlarge the options available to the organism (i.e., the ways in which a species uses its surroundings).

Adaptation to novelty and to change itself.
Environmental variability occurs at all time scales:

micro-seconds $\rightarrow$ daily $\rightarrow$ seasonal $\rightarrow$ interannual $\rightarrow$

decadal $\rightarrow$ millennial $\rightarrow$ orbital time scales

The ability to adapt to this variability ($\Delta$ variance, tempo, predictability) may be found at diverse biological levels:

- Genominal organization & variation - cells -
- tissue & organ systems - physiology - individual behavior -
- group behavioral ecology - lineage history
One path to adaptability: alleles at different loci are expressed (or suppressed) in different environments.

Schmitt et al., 2010, *Science*

Gene regulation is critical.

(Yes, also in the lineage of *H. sapiens.* )
Adaptation to Environmental Variability: Adventures in Experimental Evolution

**C. elegans** (nematodes worms):
Lab populations that encountered temperature extremes at irregular intervals (160 generations) → better adapted to novel temperatures

Chiu et al., 2006, AAPA abstracts

**B. calyciflorus** (rotifers):
When exposed to highly variable & novel environments, rotifers evolved a capacity for sexual reproduction. The capacity for asexual reproduction was retained (and was elicited in homogenous environments).

Millions of Years Ago

Allele Frequencies

Millions of Years Ago

v = 0.00008

M. Grove, JHE 2011
### HIGH & LOW CLIMATE VARIABILITY

<table>
<thead>
<tr>
<th>Variability</th>
<th>Mean eccentricity</th>
<th>Interval (Ma)</th>
<th>Duration (kyr)</th>
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<tr>
<td>H14*</td>
<td>0.0384</td>
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Low: $\varepsilon \leq 0.0144$

* Higher or lower variability confirmed by dust flux variance
Eolian dust standard deviation
\[ r = 0.785, \quad p < 0.001 \]

Sapropel standard deviation
\[ r = 0.517, \quad p < 0.001 \]
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Stages of prolonged high climate variability

Hominin species lineages

Milestones in hominin evolution

Time: millions of years ago

H2

FADs: MSA, LSA, H. sapiens, dispersal

H9

Homo

Paranthropus

H14

FADs: Acheulean, Homo dispersal

H17

FADs: Homo, P. boisei

H18

FADs: Oldoway, Paranthropus

H19

LAD: A. afarensis

Australopithecus

H30

FAD: Australopithecus

H31
Oldowan Technology – the oldest known technology: a response to environmental instability (i.e., an increase in adaptability)

1. Stone flaking $\rightarrow$ increased the range of accessible foods.

2. Stone + food transport $\rightarrow$ buffered changes in the spatial locations & abundances of food items.

3. Access to meat/fat $\rightarrow$ helped offset habitat & resource instability.
Kanjera South, western Kenya: ~2.0 million years old

- The first tool kit: hammerstones, flakes, & cores
- Carrying stones up to 12 km
- A change to a diet rich in meat & tubers
Oldest spread of *Homo* to Eurasia
1.9 to 1.7 million years ago
Adaptability: The ability of an organism ...

... to endure change in the environment.

... to thrive in novel environments.

... to spread to new habitats.

... to respond in new ways to the surroundings.
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<th>EVOLUTIONARY CHANGE</th>
<th>ADAPTIVE BENEFITS</th>
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<td>100 ka to present</td>
<td>Increased cultural diversity &amp; technological innovation</td>
<td>Expanded range of adaptive options</td>
</tr>
<tr>
<td>by 250 ka</td>
<td>Enhanced symbolic behavior</td>
<td>Greater capacity to imagine, plan, &amp; communicate novel ideas</td>
</tr>
<tr>
<td>by 800 - 400 ka</td>
<td>Complex spatial mapping &amp; resource exchange</td>
<td>Enlarged store of information about the ecological &amp; social surroundings</td>
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<td>800 - 200 ka</td>
<td>Controlling fire &amp; building shelters</td>
<td>Food sharing at home bases: enhanced social memory &amp; buffering of uncertainty</td>
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<td>by 1.7 Ma</td>
<td>Initial advances in stone technology</td>
<td>Expanded memory &amp; processing of data about the surroundings</td>
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<td>Pronounced elongation of the legs</td>
<td>Increased ability to use &amp; modify the environment</td>
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<td>by 2.0 Ma</td>
<td>Extensive carrying of stones &amp; food</td>
<td>Enhanced mobility &amp; dispersal capability</td>
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<td>by 2.6 Ma</td>
<td>Simple stone flaking</td>
<td>Improved ability to adjust to changes in food availability &amp; spatial distribution</td>
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<tr>
<td>by 4 – 3 Ma</td>
<td>Increased diversity in tooth microwear</td>
<td>Expanded ability to process new foods, like meat, marrow, &amp; underground plants</td>
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<td>~6 – 2 Ma</td>
<td>Bipedal walking &amp; tree climbing</td>
<td>Improved access to diverse foods</td>
</tr>
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<td></td>
<td></td>
<td>Versatile movement in wooded &amp; open environments</td>
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1.7 million - 500,000 years ago
Acheulean handaxes

By 320,000 years ago
Middle Stone Age innovations

Extinct Species ➔ Modern Species

Projectile points
Pigments
Olorgesailie: 2 groups of sediment

320,000 to 50,000 years ago

1.2 million to 500,000 years ago
Olorgesailie: southern Kenya Rift Valley

Drill core: 500 kyr high-resolution climate record
Olorgesailie Drilling Project
216m sediments ~ the past 500 kyr
Olorgesailie Drilling Project

Kay Behrensmeyer

René Dommain
Bernie Owen

Lake diatoms
Olorgesailie Drilling Project

Peter deMenocal, Stephen Rucina, Alan Deino
Lake (dry & wet seasons)

Volcanic ash

Lake (dry & wet seasons)

Land
Magnetic susceptibility & Gamma radiation analysis
Core 1A: 120 - 166m
Goal: Investigate the environmental conditions associated with the emergence of *Homo sapiens*:

500,000 – 300,000 yrs ago: Transition from handaxe technology to innovative Middle Stone Age behaviors, including new tool kits & pigments (Olorgesailie)

500,000 – 300,000: Emergence of the modern African large mammal biota (Olorgesailie, Lainyamok)

By ~200,000 yrs ago: First appearance of *H. sapiens* (Fossils: Omo Kibish  Genomics: E. Africa)

100,000 – 60,000 yrs ago: Low population size (genetic bottleneck?), followed by expansion & dispersal
Behavioral Innovations of the Later Pleistocene in Africa

- Increasing innovation
- Wider social networks (trade)
- Complex symbolic activity
- Expressions of the human imagination

Greater capacity to adjust to novelty

(From: McBrearty & Brooks, 2000)
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