3.6. Food and Diet Analysis

Important aspect in archaeology is migration and trade; isotope analysis of human remains such as bone and teeth delivers important information on diet & origin.

Isotope distribution in teeth and bone reflects characteristic isotope ratios (C, N, O, Sr) in food and water from local habitat. Teeth mineralize at early age, maintaining the isotopic signature from early age in teeth enamel. Dentin and bones adopt every twenty years. Comparison of teeth and bone isotope ratios indicates changes if a person has drastically changed its habitat.
Depth analysis in teeth

Drilling and sequential isotope ratio analysis reveals fine structure, possibly due to migration habits.

tooth enamel is formed in early childhood ⇒ origin dentin & bone changes with time ⇒ death
World wide $^{18}O/^{16}O$ distribution
Fractionation

Natural chemical or physical processes can fractionate the carbon, nitrogen, or oxygen isotopes during the up-take and alter the $^{13}$C/$^{12}$C, $^{15}$N/$^{14}$N, and $^{18}$O/$^{16}$O isotopic ratios. This requires correction.

e.g. photosynthesis enriches lighter isotopes → carbon in plant has relatively higher $^{12}$C/$^{13}$C ratio than atmosphere.

$^{18}$O/$^{16}$O ratio fractionates by weight, the ratio decreases with altitude and with distance to coast due to weight difference in isotopes.

Fractionation is expressed in terms of $\delta^{13}$C which is a measure (in parts of a thousand ppm) of the deviation of the isotopic ratio $^{13}$C/$^{12}$C from a standard material (PDB belemnitella americana). Typical $\delta^{13}$C vary between +2ppm to -27ppm and need to be determined for the material to be dated. Additional fractionation may occur during the chemical preparation of the sample.
Fractionation effects

Fractionation term $\delta^{13}C$ is defined from $^{13}C/^{12}C$ isotopic ratios for the sample (sm) and the standard (st) as:

$$\delta^{13}C \equiv 1000 \cdot \left( \frac{\frac{^{13}C}{^{12}C}_{sm} - \frac{^{13}C}{^{12}C}_{st}}{\frac{^{13}C}{^{12}C}_{st}} \right) = 1000 \cdot \left( \frac{\frac{^{13}C}{^{12}C}_{sm}}{\frac{^{13}C}{^{12}C}_{st}} - 1 \right)$$

A negative value $\delta^{13}C$ means that the sample is isotopically lighter than the standard probe. The standard is the fossil belemnite from the Pee Dee formation in South Carolina, PDB, $(^{13}C/^{12}C)_{PDB} = 0.0112372$. A positive value means that the sample is enriched in the heavier isotope components.
The $\delta^{13}C$ Map

Global mean value = -23.23
Excursion: fractionation and eating habits and its impact on human isotope ratios

There are two different processes of photochemical assimilation of CO₂ in plants (photosynthesis cycles). This leads to different carbon fractionation values $\delta^{13}C$ in plants and the associated food chains ranging from $\delta^{13}C = -26.5\%$ (C₃) to $\delta^{13}C = -12.5\%$ (C₄).

C₃ plants dominate the northern cooler regions of Europe and North America. The habitat of C₄ plants are the warmer regions in South- and Central America, Africa, and Australia.
Fractionation in food chain processes

bicarbonate in ocean water and in ground

CO₂ in air

plants

bones of plant-eaters

bones of meat-eaters

human bones

plant eater or animals

PDB-Standard

enrichment in δ¹³C in bone collage

pure C₄ eaters

pure C₃ eaters

N. Van der Merve, American Scientist 70 (1982) 596
North American Values

North American plants are predominantly C3 plants \(\implies\) fractionation values of \(\delta^{13}C = -21.4\) are observed in bone collages of plant and meat eating animals.

If additional C\(_4\) plants - like corn – are consumed than will the \(\delta^{13}C\) value increase accordingly. e.g. \(\approx10\%\) corn \(\implies\delta^{13}C \approx -20\ \%\). Pure maize diet will result in \(\delta^{13}C \approx -10\ \%\).

Is sea food consumed, drastic changes occur since the ocean food chain is characterized by different fractionation processes leading to \(\delta^{13}C \approx -18\ \%\).
Ancient eating habits

The fractionation analysis of bone material with parallel $^{14}C$ dating can help to identify changing eating habits.

Example: increase of corn consumption ($C_4$ plant) by population due to the corn migration into North America. The values result from bone analysis of human skeletons. At 1500 AD: $\sim 75\%$ corn consumption.

Sea food chains

bicarbonate in ocean water and in ground

CO₂ in air

plankton similar C₃ (-17.8)

mammals
fish, crabs, and coastal fauna

C₃ (-18.7)

land fauna
animal meat
birds, fresh water fish

bone material of coastal residents

ocean proteins

nutrition

100% from sea

bone material of inland residents
C₃ consumer

100% from land (C₃)

-17.8

(+5)

-13.8

(+5)

-7

0

δ¹³C(PDB) in %
Observations

Analysis of skeletons of early population of coastal British Columbia:
$\delta^{13}C = -13.4 \pm 0.9\text{%}$ $\Rightarrow \approx 100\%$ seafood based nutrition.

Analysis of skeletons of early population of Ottawa region:
$\delta^{13}C = -19.6 \pm 0.9\text{%}$ $\Rightarrow \approx 100\%$ C$_3$ originated nutrition.

Analysis of skeletons of early population of central British Columbia:
$\delta^{13}C = -15.4 \pm 0.3\text{%}$ $\Rightarrow \approx 65\%$ seafood (salmon) & $\approx 35\%$ C$_3$ originated nutrition.
Viking Food

Change of living habits, from farming to seafaring, changes diet!
The Norsemen and Vikings

drastic change of nutrition

Immigration of Indo-Europeans?

Viking migrations!
Checking on Yax K’uk Mo

5th century AD the City of Copan in southern Yucatan converted from a small village to a center of Mayan culture within only decades through installation of Yax K’uk Mo as local ruler (coronation 9. 5. 426 AD).

Origin of Yax K’uk Mo is unknown! Speculation is that he was installed by Teotihuacán (Central Mexico) to extend its political influence south.

Main indicator “Goggles”
Strontium Sr isotope ratio in upper incisor

Ratio $^{87}\text{Sr}/^{86}\text{Sr}$ is an important indicator for tooth analysis.

Strontium Sr behaves chemically similar to Calcium Ca in tooth enamel (formed during the early childhood). Sr can replace Ca by food intake. Isotopic ratio reflects origin.

$^{87}\text{Sr}/^{86}\text{Sr} = 0.7084$

Origin of $^{87}\text{Sr}/^{86}\text{Sr}$

Stable Strontium Sr isotopes:

$^{84}\text{Sr} \ (0.56\%)$, $^{86}\text{Sr} \ (9.86\%)$, $^{87}\text{Sr} \ (6.94\%)$, $^{88}\text{Sr} \ (82.58\%)$

$^{87}\text{Ru}$

$T_{1/2} = 4.7 \times 10^{10} \text{ y}$

$^{87}\text{Sr}$

$^{86,87}\text{Sr}$ are stable isotopes, $^{87}\text{Sr}/^{86}\text{Sr} = 0.704$

Stable $^{87}\text{Sr}$ is enriched by decay of $^{87}\text{Rb}$.
An environment with high Rb content therefore causes high $^{87}\text{Sr}/^{86}\text{Sr}$ ratio!
Abundance of non-radioactive $^{86}\text{Sr}$ in mineral is constant. $^{87}\text{Sr}$ is stable but continuously produced by decay of the radioactive $^{87}\text{Rb}$ ($T_{1/2}=48.8$ Gy). Continental rock is rich in $^{87}\text{Rb}$, limestone contains little $^{87}\text{Rb}$.

Radiogenic Infusion

Rubidium Rb isotopes: $^{85}\text{Rb}$ (72.16%), $^{87}\text{Rb}$ (27.84%)

Limestone Chemistry: the typical Rb/Sr ratio is $\approx 0.05$

$$\left[ \begin{array}{c} \text{Rb} \\
\text{Sr} \end{array} \right] = \left[ \begin{array}{c} ^{87}\text{Rb} \\
0.2784 \\
^{86}\text{Sr} \\
0.0986 \end{array} \right] = 0.05 \quad \Rightarrow \quad \left[ \begin{array}{c} ^{87}\text{Rb} \\
^{86}\text{Sr} \end{array} \right] = 0.05 \cdot \frac{0.2784}{0.0986} = 0.141$$

Can the decay of $^{87}\text{Rb}$ increase the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio from $\approx 0.705$ to $\approx 0.708$, assuming that the Yucatan Peninsula was formed during the early tertiary period $\approx 1$ billion years ago?

$$\left[ \begin{array}{c} ^{87}\text{Sr} \\
^{86}\text{Sr} \end{array} \right] (t = 100\text{My}) = \left[ \begin{array}{c} ^{87}\text{Sr} \\
^{86}\text{Sr} \end{array} \right] + \left[ ^{87}\text{Rb}(t = 0) \cdot (1 - e^{-\lambda^{(87}\text{Rb}) 10^8 \text{y}}) \right] \left[ \begin{array}{c} ^{86}\text{Sr} \end{array} \right]$$

$$\lambda^{(87}\text{Rb}) = \frac{\ln 2}{47 \cdot 10^9 \text{a}} = 1.47 \cdot 10^{-11} \text{y}^{-1}$$

$$\left[ \begin{array}{c} ^{87}\text{Sr} \\
^{86}\text{Sr} \end{array} \right] (t = 10^9 \text{y}) = 0.705 + \left[ ^{87}\text{Rb}(t = 0) \cdot (1 - e^{-1.47 \cdot 10^{-11} \cdot 10^9 \text{y}}) \right] \left[ \begin{array}{c} ^{86}\text{Sr} \end{array} \right] = 0.705 + 0.141 \cdot (1 - 0.9854) = 0.707$$
Yucatan peninsula formed by Ca/Rb containing Marine sediments $\Rightarrow$ $^{87}$Sr enrichment declining south.

Central Mexico is volcanic origin low Ca/Rb content
The analysis of strontium in the teeth of the skeleton indicates that the individual spent his early years near Tikal in the Petén Basin region and then at some point between Tikal and Copán, and the $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic signature does not match with a Teotihuacan origin.