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BIOAVAILABLE STRONTIUM FOR ARCHAEOLOGICAL STUDIES IN MODERN MANHATTAN, NEW YORK

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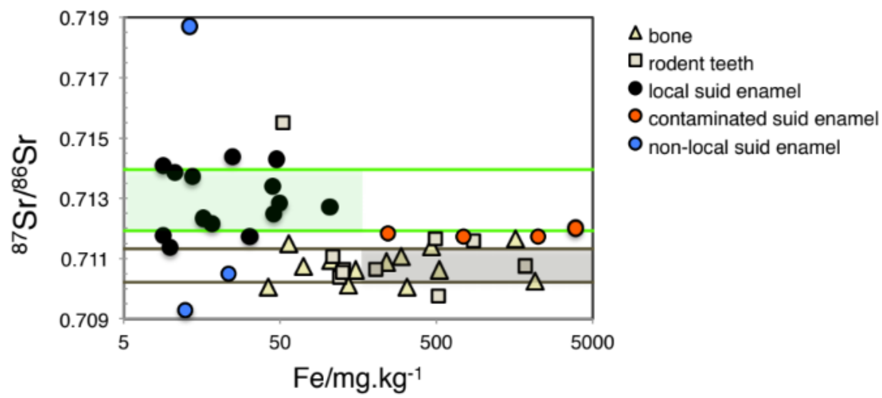
In 2006, 200 burials were unearthed during construction in lower Manhattan. These 200 people had been buried within four vaults in Spring Street Cemetery beneath the city between the years 1820 and 1846. During this time, the Manhattan area was urbanizing and African Americans were travelling north on the Underground Railroad. Abolitionist ministers at Spring Street Presbyterian Church welcomed these migrants, resulting in a diverse population within the neighborhood of the cemetery. The study of those buried in the Spring Street Cemetery is intriguing to researchers across disciplines studying population migration and provenance.

Many migration studies compare the strontium (Sr) isotopic ratio $^{87}Sr/^{86}Sr$ in skeletal remains with that of bioavailable Sr from the local surroundings to determine if the individuals originated from that specific geographic area (Maurer, Schweissing & Grupe, Frei & Price, Montgomery, Knudsen). The type and age of a particular bedrock determines the abundances of Sr isotopes, lending the rock a specific $^{87}Sr/^{86}Sr$ ratio. This allows us to generate an isotopic map of expected $^{87}Sr/^{86}Sr$ values from Earth's bedrocks (Bentley). Manhattan's bedrock, the late Devonian Manhattan Schist (Lupulescu) has not been well characterized for $^{87}Sr/^{86}Sr$. For the related Fordham gneiss, formed during the same Neo-Acadian Orogeny event and underlaying the Manhattan schist, $^{87}Sr/^{86}Sr$ has been determined with values in the range of 0.762 to 0.796 (Long and Kulp). As bedrock weathers and contributes to soil development, the $^{87}Sr/^{86}Sr$ ratio is preserved by plants which take it up from the soil, and is then retained up through the trophic levels in herbivores and the carnivores that eat them (Hamilton). Dietary Sr substitutes for calcium (Ca) in bone tissue as bone gradually replaces its cells over time, a dynamic process that remodels its chemical composition in about ten years (Price & Gestsdottir). Because of this regeneration, the Sr signature of bone reflects the more recent locality of the individual. However, Sr is incorporated into human tooth enamel during early development and is not remodeled over the lifespan, yielding an $^{87}Sr/^{86}Sr$ ratio that reflects where the individual was raised during this developmental period (Hamilton, Schweissing & Grupe).

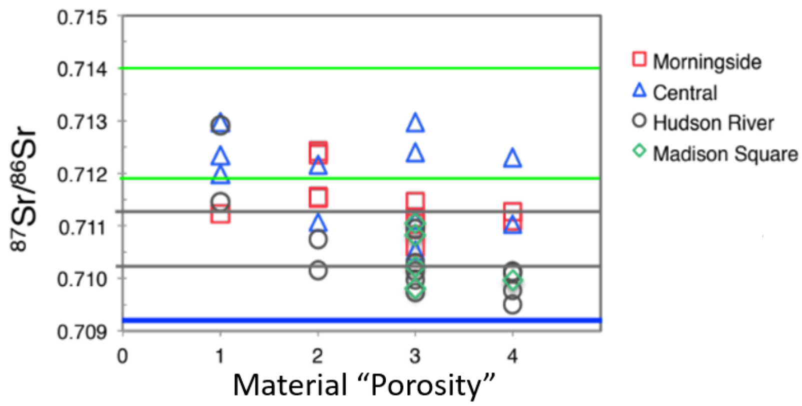
This figure shows $^{87}Sr/^{86}Sr$ for 19th century hydroxyapatite samples from Manhattan as a function of their iron (Fe) concentrations. Low-iron suid enamel samples are indicated by the green box, while high-iron bone and rodent teeth are highlighted by the grey box. This figure establishes low-iron suid enamel samples as the uncontaminated 19th century Manhattan $^{87}Sr/^{86}Sr$ baseline. Suid samples with low Fe concentration but deviant Sr ratios, indicative of a non-local individual, are marked in blue. Suid enamel with high Fe concentrations, marked in red, are considered to be contaminated and fall just below one sigma range (demarcated by green horizontal lines) for uncontaminated local samples. High-iron bone and rodent teeth represent contaminated hydroxyapatite (demarcated by grey horizontal lines).



Fe ions are among the trace elements incorporated in teeth and bones during burial, and is not often considered to be a constituent of the hydroxyapatite crystalline structure, but rather a common contaminant in archaeological samples (Bauminger). The contamination in New York tends towards lower values of $^{87}Sr/^{86}Sr$, and as indicated by the figure, Fe is indeed an effective indicator of contamination and is visibly correlated with Sr concentration in the sampled suid enamel. In other words, the more Fe present in the hydroxyapatite, the lower the $^{87}Sr/^{86}Sr$ value will be. Particularly, highly-porous (high surface area) bones and dentine-rich rodent teeth represent the most contaminated samples. Archaeologically "clean" suid samples with low Fe concentrations can then be used to define an uncontaminated baseline $^{87}Sr/^{86}Sr$ ratio for Manhattan. We estimate the range of $^{87}Sr/^{86}Sr$ in 19th century Manhattan to be 0.713 ± 0.001 (2 σ).

In rural environments, vegetation and local fauna with small foraging ranges, like rodents, are typically free from anthropogenic contamination and are the best indicators of local bioavailable Sr (Maurer). This makes them useful determinants of confidence limits for differentiating migrants and natives. If the $^{87}Sr/^{86}Sr$ value in the enamel of an individual falls within the range found for vegetation and rodent teeth, then that individual likely lived in the area during the enamel development. If not, the individual is unlikely to be native to the area and bears the $^{87}Sr/^{86}Sr$ of a different geographical location. However, since modern Manhattan is a complex urban environment, it is unclear whether the modern bioavailable $^{87}Sr/^{86}Sr$ agrees with that of the time of the individual's burial. Vegetation is useful to this end, as it serves as an accurate proxy for local bioavailable Sr (Maurer). We have thus utilized archaeological suid enamel and modern vegetation to establish the Manhattan baseline over time.

Thirty-eight vegetation samples were gathered from Manhattan's Central, Hudson River, Morningside, and Madison Square Parks. They consisted mainly of tree branch segments, leaves, pine cones, and large seeds. These samples were categorized and prepared for testing by first removing the shells from the nuts and seeds as well as the bark from the sticks and twigs, which were archived as separate samples. The samples were then rinsed with ultraclean water under ultrasound to remove dust and other contaminants. A microwave-digestion process then produced a clear solution devoid of organic carbon from the sample material, which was then tested for trace element concentrations with quadrupole inductively-coupled plasma mass spectrometry (QICPMS). Sr was afterwards purified using automated chromatography and the $^{87}Sr/^{86}Sr$ ratio measured using a multicollector ICPMS (MC-ICPMS).



This figure displays $^{87}Sr/^{86}Sr$ for the sampled vegetation. Samples were divided into four categories: (1) woody tissues, (2) bark and sticks (diameter greater than 6mm), (3) twigs (diameter less than 3 mm), and (4) leaves. The grey lines show the $^{87}Sr/^{86}Sr$ cutoff for contamination (0.71132) established by the upper-bound grey line of the first figure. The mean and standard deviation $^{87}Sr/^{86}Sr$ for plant tissue above the contamination cutoff is 0.71220 ± 0.00016 (1SD, N=14). The blue line demarcates the $^{87}Sr/^{86}Sr$ value for marine Sr (0.70921).

The data indicates that woody materials are significantly more radiogenic than those of leaves, suggesting that porous materials were more easily contaminated. This is corroborated by the contamination of the bone and rodent tooth samples, which are of more porous structure than suid enamel. This contamination is likely due to Sr-rich marine aerosols (indicated by the blue line) since the bone and rodent teeth, which are known to be contaminated, also tend towards the lower marine $^{87}Sr/^{86}Sr$ value. The similarity of the vegetation to the uncontaminated suid data evidences that modern vegetation is comparable with archaeological uncontaminated enamel. This essentially serves as a proof of concept; even in a complex urban environment like Manhattan, we have evidence that vegetation may be an excellent proxy for the uncontaminated baseline Sr signature.

Though the vegetation samples offer a cohesive reference for comparison with the Sr levels of individuals of Spring Street Cemetery, we must further understand how to distinguish between contamination and clean vegetation samples for a more detailed picture of Manhattan's bioavailable Sr. The species of our vegetation samples were unknown, and thus we cannot determine root depth or nutrient acquisition of specific plants, which may affect their Sr uptake. Soil studies of the sampled parks may help us answer this question. However, despite these ambiguities, in measuring Sr in modern vegetation samples and comparing them with archaeological pig and rodent samples, we are able to determine how closely modern samples of urbanized Manhattan agree with those from a time when the residents of Spring Street lived. Our results suggest that vegetation is a promising material with which to measure bioavailable Sr and map how Sr isotopes may or may not change in an urban environment over time.

Though vegetation allows us to effectively compare modern and archaeological bioavailable Sr levels, for Manhattan and other similar environments, there may be more to the story. We must also consider that, in comparison to other studies utilizing this isotopic method, Manhattan may have more complex anthropogenic contamination than that of a rural environment. Studies in Iceland (Price & Gestsdottir), Bavaria (Schweissing & Grupe), and the

Isle of Lewis in Scotland (Montgomery) were relatively isolated from the process of urbanization. However, Manhattan presents a new set of problems for us to navigate. Even at the time of the burials, the Manhattan area was a bustling port. The influx of imported goods and the effects of industrial technologies add nuances which lie outside the current scope of this study. It may be additionally beneficial to study the dietary differences of humans and pigs, and whether imported goods had an effect on Sr uptake from the human diet. For example, according to Cindy R. Lobel, Spring Street Market, which operated between 1800 and 1829, would be where many Spring Street residents would have gotten their food. They would have been able to procure local fruits, vegetables, and locally-sourced seafood, in addition to meat raised in New York's hinterlands: New Jersey, Westchester, and Dutchess Counties, and as far as New England (Lobel). Thus, a full picture of the dietary Sr influencing the residents of the Spring Street area depends heavily on food sourcing and the Sr isotopic ratios of the production regions. Further understanding requires the integration of diverse fields of study, from the history of Manhattan's urbanization to human and animal diets.

Overall, despite Manhattan's inherent isotopic complexity as an urban port city, we are able to use this method of $^{87}Sr/^{86}Sr$ isotopic comparison to determine the bioavailable Sr signature in 1800s Manhattan using modern vegetation samples. This link between the past and the future through isotopic analysis allows us to compare modern and archaeological samples to analyze bioavailable Sr over time. Furthermore, the application of this isotopic method to an environment like New York could yield a tool for studying other questions of provenance in complex urban environments.

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