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1 Resolving archaeological populations with strontium mixing diagrams

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Strontium isotope analysis of tooth enamel is a useful provenancing technique to investigate the childhood origins and residential mobility of ancient people[1-3]. Enamel is a highly mineralised, acellular, biogenic apatite that is particularly resistant to post-mortem contamination and thus preserves the integrity of lifetime signatures [4-6]. The ^{87}Sr/^{86}Sr value of enamel is thus derived from food and water ingested when the tissue was mineralising, that is, in early childhood. Food and water have ^{87}Sr/^{86}Sr values that reflect their geographical origin because strontium weathers from the host rock into groundwater, river water and overlying soils and is ultimately transferred with negligible fractionation into plants and animals. This provides the mechanism to establish whether a person or animal has an isotope ratio consistent with locally grown food or locally sourced water, and if this is not the case, to conclude that they either imported substantial resources from elsewhere (perhaps more likely in modern populations) or that they had moved from a different geological province at some time after the tooth had mineralised.

Our current model for strontium isotope uptake from the geosphere is that a community living on and sourcing their food from a single, homogeneous rock unit will nevertheless exhibit a range of ^{87}Sr/^{86}Sr values that fall between two end-members: the local rock and $\sim$0.7092 [5,7]. Rainwater (which has seawater of ^{87}Sr/^{86}Sr = 0.7092 as its source) can be ingested in variable quantities through food and drink. Consequently, a sedentary, fairly self-sufficient population will not define a normally distributed range of $^{87}Sr/^{86}Sr$ values *around* the local rock value but a range offset above or below the rock value[7]. The magnitude of the range will depend on how different the local rock strontium is from 0.7092: i.e. a population from a region of 0.715 rocks will, through personal choice, cultural practice and resource availability, have the opportunity to obtain an enamel $^{87}Sr/^{86}Sr$ value between 0.7092 and 0.715 that is a weighted average of all inputs. Alternatively, a population living on Cretaceous Chalk ($^{87}Sr/^{86}Sr \sim 0.707$) will only have the opportunity to fall within the range 0.707 – 0.7092 and will, therefore, define a much smaller spread of values.

The model becomes increasingly problematical in regions of complex geology and heterogeneous rocks such as granites and sandstones, where the strontium released through weathering may not be representative of the whole rock value but will be dominated by unradiogenic strontium derived from the easily weathered and strontium-rich feldspar component [8]. Drinking water sources (such as rivers, deep aquifers and springs) that are not derived directly from rain may also have $^{87}Sr/^{86}Sr$ values quite different from seawater if strontium has been dissolved from the host rocks. In addition, populations vary considerably in their food procurement strategies, level of sedentism and cultural practices and this suggests we are unlikely to find populations who have a simple strontium ratio derived from only two dominant sources.

Given this opportunity for overlapping ranges in many populations, it has proved difficult in previous UK studies to resolve the strontium isotope ranges of two different populations [7,8]. However, two of our recent case studies suggest that simple mixing systems with only two end-members *do* occur in archaeological populations and, despite overlapping strontium isotope *ranges*, it is possible to separate two populations based on the *structure* within the data set. We present the results of two studies: from the Western Isles of Scotland spanning the time of Viking colonisation of the islands[1]; and from a study of Neolithic and Early Bronze Age populations from the Yorkshire Wolds, NE England. What the structural differences found in the data sets at both locations might tell us about the people, their geographical origins and food procurement strategies at each location will be discussed. Moreover, given the assertions in the literature that skeletal strontium concentrations do not reflect in any linear way the amount of strontium *ingested*[9,10], we discuss why and how archaeological populations may define a clear two-way mixing line and what underlying factors may be ultimately controlling an individual's strontium uptake.

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