

Mobility of populations in the transition from Muslim world to Portuguese Kingdom in the Algarve, south Portugal, 11th-13th centuries

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6.3. Mobility modelling

6.3.1. Database update

The Sr isotope database by Bataille et al. (2020) was amended with newly generated ($n = 36$) and published data using plants from Portugal, Spain and Tunisia (see Supplementary Material 2). Published data came from Díaz-del-Río et al. (2022) ($n = 98$), James et al. (2022) ($n = 173$), Nikita et al. (2023) ($n = 34$) and Frank et al. (2022) ($n = 24$). The animal database was implemented with data from 85 animals from the Iberian Peninsula, compiled by Díaz-del-Río et al. (2022). Only wild fauna was extracted from this compilation consisting of *Cervus elaphus* (deer), *Erinaceus europaeus* (hedgehog), snail (*Helix aspera*, *Helix sp.*, *Otala lactea*), Lagarto (reptile), *Lepus sp.* (hare), *Rodentia sp.* (rodents) and *Vulpes vulpes* (fox). 29 samples from Tunisia (Nikita et al., 2023) were also included. Finally, strontium isotope data of 9 European rock and 566 agricultural soil samples (ApN and ApS) were removed from the database of Bataille et al. (2020) to include only soil leachates but exclude anthropogenic contaminants affecting the Sr isotope values of agricultural soils. The soil database was then amended with 24 samples from Spain (Frank et al., 2022).

6.3.2. Mapping Sr isotope signatures of Europe and Portugal

The above-mentioned updated database was used to update the bioavailable Sr isoscapes published by Bataille et al. (2020). Geospatial modelling of Sr isotopes was completed using the machine learning approach (an R script) of Bataille et al. (2018, 2020). Three sets of data were trained: 1) a combination of Sr isotope values from plants, soils and fauna from western Europe; 2) plant data of Europe; and 3) plant data of Portugal. These datasets were trained together with 23 geological, environmental, climatic and anthropogenic predictors (Supplementary Material 3) in the form of georeferenced rasters. At each projected sample location, raster values were extracted. VSURF (Genuer et al., 2019) was then applied to select the most important predictors, which were then used to train the random forest (RF) models (*Caret* package, Kuhn, 2008) with the full datasets and a 10-fold repeated cross-validation with 5 repetitions. The Root Mean Squared Error (RMSE) and R^2 informed about the accuracy of the models, while variables were sorted according to their importance in the model construction. Predictions from the RF models were saved as rasters. The latter were used for mapping provenance probability (see below). This also required, for each raster, the calculation of the spatial uncertainty of predicted Sr isotope values for each raster, based on the mean absolute residual value between predicted and measured $^{87}\text{Sr}/^{86}\text{Sr}$, as a function of predicted $^{87}\text{Sr}/^{86}\text{Sr}$ values (Bataille et al., 2020).

REFERENCES

- Bataille, C. P., Crowley, B. E., Wooller, M. J., & Bowen, G. J. (2020). Advances in global bioavailable strontium isoscapes. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 555, 109849. <https://doi.org/https://doi.org/10.1016/j.palaeo.2020.109849>
- Bataille, C. P., von Holstein, I. C. C., Laffoon, J. E., Willmes, M., Liu, X.-M., & Davies, G. R. (2018). A bioavailable strontium isoscape for Western Europe: A machine learning approach. *PLOS ONE*, 13(5), e0197386-. <https://doi.org/10.1371/journal.pone.0197386>
- Díaz-del-Río, P., Uriarte, A., Becerra, P., Pérez-Villa, A., Vicent, J. M., & Díaz-Zorita, M. (2022). Paleomobility in Iberia: 12 years of strontium isotope research. *Journal of Archaeological Science: Reports*, 46, 103653. <https://doi.org/https://doi.org/10.1016/j.jasrep.2022.103653>
- Frank, A. B., Frei, R., Kristiansen, K., & Frei, K. M. (2022). A multi-proxy, bioavailable strontium isotope baseline for southern Almería, Spain: Using modern environmental samples to constrain the isotopic range of bioavailable strontium. *Applied Geochemistry*, 144, 105405. <https://doi.org/https://doi.org/10.1016/j.apgeochem.2022.105405>
- Genuer, R., Poggi, J., & Tuleau-Malot, C. (2019). VSURF: Variable Selection Using Random Forests.R package version 1.1.0.
- James, H. F., Adams, S., Willmes, M., Mathison, K., Ulrichsen, A., Wood, R., Valera, A. C., Frieman, C. J., & Grün, R. (2022). A large-scale environmental strontium isotope baseline map of Portugal for archaeological and paleoecological provenance studies. *Journal of Archaeological Science*, 142, 105595. <https://doi.org/https://doi.org/10.1016/j.jas.2022.105595>
- Kuhn, M. (2008). Building Predictive Models in R Using the caret Package. *Journal of Statistical Software*, 28(5), 1–26. <https://doi.org/10.18637/jss.v028.i05>
- Nikita, E., Alexander, M., Cox, S., Radini, A., Le Roux, P., Chaouali, M., & Fenwick, C. (2023). Isotopic evidence for human mobility in late antique Bulla Regia (Tunisia). *Journal of Archaeological Science: Reports*, 47, 103816. <https://doi.org/https://doi.org/10.1016/j.jasrep.2022.103816>