Tracing the country of origin of cocaine is now feasible through automated, routine analysis of both stable isotopes and trace alkaloids, opening up strategic options for identifying source regions and trafficking routes. We have shown how ecological and isotopic-fractionation principles used to predict isotopic-ratio patterns associated with plants from different ecosystems can also be applied to determine the distribution of an illegal drug, as well as to identify new coca-producing regions as they develop.

James R. Ehleringer*, John F. Casale†, Michael J. Lott*, Valerie L. Ford†

**Stable Isotope Ratio Facility for Environmental Research, Department of Biology, University of Utah, 257 S 1400 E, Salt Lake City, Utah 84112-0840, USA*

e-mail: ehleringer@biology.utah.edu

†*Special Testing and Research Laboratory, Drug Enforcement Administration, US Department of Justice, 7704 Old Springhouse Road, McLean, Virginia 22102-3494, USA*

1. Moore, J. M. & Casale, J. F. *Forensic Sci. Rev.* **10,** 13–46 (1998).
2. Moore, J. M. & Casale, J. F. *J. Chromatogr. A* **674,** 165–205 (1994).
3. Wassenaar, L. I. & Hobson, K. A. *Proc. Natl Acad. Sci. USA* **95,** 15436–15439 (1998).
4. Giulani, G. *et al. Science* **287,** 631–633 (2000).
5. Farquhar, G. D., Ehleringer, J. R. & Hubick, K. T. *Annu. Rev. Plant Physiol. Mol. Biol.* **40,** 503–537 (1989).
6. Ehleringer, J. R., Hall, A. E. & Farquhar, G. D. (eds) *Stable Isotopes and Plant Carbon/Water Relations* (Academic, San Diego, 1993).
7. Roden, J. S., Lin, G. & Ehleringer, J. R. *Geochim. Cosmochim. Acta* **64,** 21–35 (2000).
8. Martinelli, L. A. *et al. Biogeochemistry* **46,** 45–65 (1999).
9. Moore, J. M., Casale, J. F., Klein, R. F., Cooper, D. A. & Lydon, J. *J. Chromatogr. A* **659,** 163–175 (1994).
10. Moore, J. M., Casale, J. F. & Cooper, D. A. *J. Chromatogr. A* **756,** 193–201 (1996).
11. Ehleringer, J. R., Cooper, D. A., Lott, M. J. & Cook, C. S. *Forensic Sci. Intl* **106,** 27–35 (1999).

Archaeology

Detecting milk proteins in ancient pots

Deciding whether to farm cattle for milk or beef was just as complex in the past as it is today. Compared with meat production, dairying is a high-input, high-output, high-risk operation indicative of an intensive, sophisticated economy, but this practice is notoriously difficult to demonstrate in the archaeological record[1]. Here we provide evidence for the presence of milk proteins preserved in prehistoric vessels, which to our knowledge have not been detected before. This finding resolves the controversy that has surrounded dairying on the Scottish Atlantic coast during the Iron Age[2–5] and indicates that farming by the early inhabitants of this harsh, marginal environment was surprisingly well developed.

The analysis of sorbed lipid residues in prehistoric ceramics has provided a powerful new indicator of how vessels were used[6–8]. Although proteins are more diagnostic of specific foodstuffs than lipids, they are difficult to extract from archaeological ceramics[9]. We have developed an immunological detection method, the digestion-and-capture immunoassay (DACIA)[10], which overcomes this difficulty by dissolving the ceramic then capturing the liberated proteins for immunodetection.

We obtained sherds from nine coarseware cooking vessels, dated to the middle of the first millennium BC, from the fill of an Early Iron Age house at Cladh Hallan, South Uist, in the Outer Hebrides, and analysed them by DACIA. Extracts were tested using a monoclonal antibody raised against heat-degraded and dephosphorylated bovine α-casein (about 1.4% w/v milk), which was specific for bovine milk.

Immunological analysis of archaeological materials has been criticized for the lack of negative controls[11], so we included an extensive array of reference samples (Fig. 1). Seven of nine of the interior sections of sherds recovered from Cladh Hallan tested positive for casein and the amounts were comparable to those found on experimentally buried milk sherds (Fig. 1). DACIA analysis failed to detect the presence of bovine α-casein in the associated sediment or exterior surfaces of the samples.

The large number of neonatal cattle remains found at this site (42% of individuals) has been attributed to the deliberate culling of young calves in order to preserve fodder in an adverse environment[2,3] or to sustain a high-input dairying economy[4,5]. The presence of bovine α-casein on a substantial number of sherds (Fig. 1) lends support to the latter interpretation. Our successful characterization of protein residues after 2,500 years demonstrates the potential of DACIA as a high-resolution technique for determining how archaeological ceramics were used.

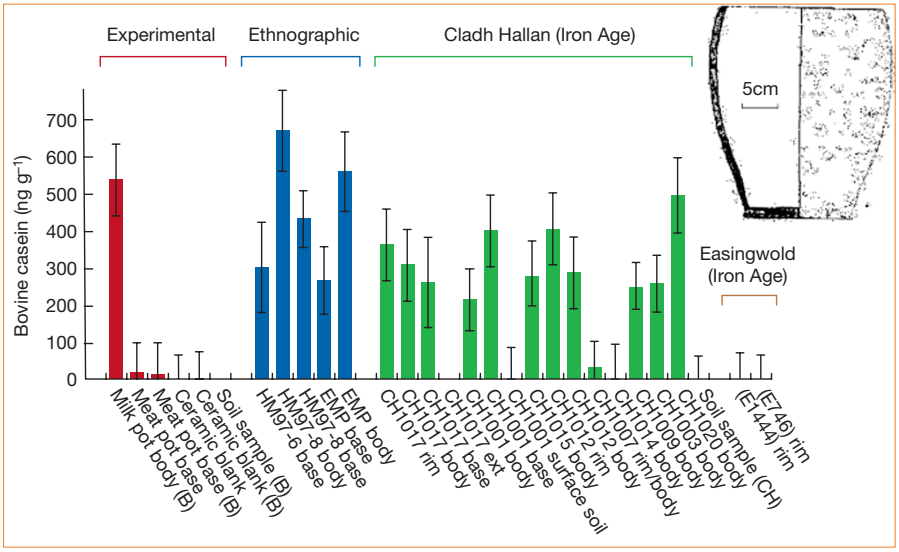

Figure 1 Amounts of bovine α-casein present in samples of pottery and soil, as determined by duplicate assay using digestion-and-capture immunoassay with a monoclonal antibody raised against this protein. Error bars, one standard deviation. The assay is specific only for cows' milk and is able to detect as little as 100 ng protein per g of ceramic (0.1 p.p.m.). Experimental coarseware pots (ceramic 'blank') were used to boil either milk (milk pot) or beef (meat pot) repeatedly and were buried for 1 year in upland soil. Ethnographic pots were obtained from Pakistan (HM) and India (EMP); each had been recently used to prepare dairy products. Cladh Hallan (CH) vessels (inset) were collected from a single site (fill of house 112, South Uist, Outer Hebrides). Domestic cooking pots from Easingwold, North Yorkshire (E), contained large amounts of well-preserved animal fats.

Oliver Craig*, Jacqui Mulville†, Mike Parker Pearson‡, Robert Sokol§, Keith Gelsthorpe§, Rebecca Stacey‖, Matthew Collins*

**Fossil Fuels and Environmental Geochemistry, NRG, Drummond Building, University of Newcastle-upon-Tyne, Newcastle-upon-Tyne NE1 7RU, UK*

e-mail: o.e.craig@ncl.ac.uk

†*English Heritage, Oxford University Museum, Parks Road, Oxford OX1 3PW, UK*

‡*Department of Archaeology and Prehistory, University of Sheffield, Northgate House, West Street, Sheffield S1 4ET, UK*

§*Regional Blood Transfusion Centre, Longley Lane, Sheffield S5 7JN, UK*

‖*Department of Archaeological Science, University of Bradford, Bradford BD7 1DP, UK*

1. Halstead, P. *Anthropozoologica* **27,** 3–20 (1998).
2. McCormick, F. in *Life on the Edge: Human Settlement and Marginality* (eds Mills, C. M. & Coles, G.) 49–53 (Oxbow, Oxford, 1998).
3. Gilmour, S. & Cook, M. *Antiquity* **72,** 327–337 (1998).
4. Parker-Pearson, M., Sharples, N. & Mulville, J. *Antiquity* **70,** 57–67 (1996).
5. Parker-Pearson, M., Sharples, N. & Mulville, J. *Antiquity* **73,** 149–152 (1999).
6. Rottländer, R. C. A. in *Proc. 24th Int. Symp. Archaeometry* 403–405 (Smithsonian Institution, Washington DC, 1986).
7. Evershed, R. P. *World Archaeol.* **25,** 74–93 (1993).
8. Dudd, S. N. & Evershed, R. P. *Science* **282,** 1478–1481 (1998).
9. Evershed, R. P. & Tuross, N. *J. Archaeol. Sci.* **23,** 429–436 (1996).
10. Craig, O. E. & Collins, M. J. *J. Immunol. Meth.* **236,** 89–97 (2000).
11. Tuross, N., Barnes, I. & Potts, R. *J. Archaeol. Sci.* **23,** 289–296 (1996).