Institution: University of Bristol

Unit of Assessment: Chemistry UoA 8

Title of case study:
CH6: Molecular and Isotope 'Fingerprinting' to Enhance Food Quality Assurance, Forensic Approaches and Wider Public Interest in Chemistry through Archaeology

1. Summary of the impact (indicative maximum 100 words)

Evershed and his research group in The School of Chemistry, University of Bristol, have pioneered a suite of novel molecular and stable isotope analytical chemical techniques for provenancing amorphous organic residues in archaeology, particularly for the elucidation of ancient diet and the origins of agriculture. Their on-going research continuously achieves impact worldwide at all levels. Impact has been actively enhanced via the involvement of Evershed and his entire team in hundreds of public engagement activities (art/science exhibitions and festivals, personal presentations, media interviews/articles/documentaries), school and college educational outreach activities (teacher/student conferences, items/articles in the educational literature and contributions to educational films/documentaries). Critically, their 'fingerprinting' methods have found application in detecting food fraud in the vegetable oil trade, protecting the human population worldwide from consuming impure corn oil for ca. 15 years to the present day. Most poignantly, when called upon, their methods were pivotal in solving a murder case for the Metropolitan Police.

2. Underpinning research (indicative maximum 500 words)

Evershed joined the School of Chemistry as Lecturer in 1993, was promoted to a personal Chair of Biogeochemistry in 2000, and elected Fellow of the Royal Society in 2010. He is one of the pioneers of the use of cutting-edge chromatographic and mass spectrometric approaches for interrogation, at the *molecular level*, of organic residues preserved in archaeological materials. His group's discoveries have provided unequivocal evidence for the widespread occurrence of biomolecules of both original and modified structures in a variety of amorphous organic archaeological deposits, human, plant and animal remains, sediments and artefacts. Critically, his team were the first to recognise in the 1990s the hitherto untapped potential of the compound-specific stable carbon isotope ratio technique to archaeological science. These approaches have been widely adopted by not only archaeologists but researchers in a wide variety of other fields. Notably, **Evershed** and a PhD student (**Woodbury**) working with the food industry (primarily Rossell, Leatherhead Food Research Association, LFRA) provided one of the first examples of the use of these methodologies to detect food fraud; most importantly they developed and applied a highly robust method (e.g. (**3)** and references therein) which has been adopted as the standard method (INTERNATIONAL CODEX) for detecting commercial vegetable oil adulteration to the present day. Recognising the wider utility of their approach, and when called upon, they applied the technique (with **Bull** and **Berstan**, Bristol) with the Metropolitan Police to secure a murder conviction (**6**).

The Bristol group led by **Evershed** has continued to develop the archaeological applications of these techniques very extensively, to show how molecular and isotopic information contained in such residues can answer fundamental questions concerning early agriculture and ancient diet, specifically concerning man's relationships with the domesticated animals. The following high profile studies underpin the impact of this research. A landmark paper appeared in *Science* in 1998 (**1**) and led to a series of papers culminating in a report in *Nature* (**2**) of the earliest *chemically–based* direct proof of milk use, from the oldest pottery in Europe and the Near East, dating to nearly 9,000 years ago. This had major ramifications for our understanding of the production and processing of this key staple by early pastoralists, who overcame the health impacts of lactose intolerance by processing milk to resduce the lactose content of the dairy products they consumed. This is further emphasised in two recent high profile papers in *Nature* which demonstrated the first evidence for dairying in Saharan Africa (**4**)[†] and for cheese-making in northern Europe (**5**)[†], both around 7,500 years ago. These studies are exemplars of the chemical and stable isotope

'fingerprinting' concept which links environmental and metabolic isotope signals to specific lipid structures, and underpins the wider application of these approaches in the food quality assurance and forensic fields. These far reaching applications have stimulated worldwide public and academic interest and provide the basis for the diverse impacts listed in Section 4.

†These two articles have been viewed nearly 30,000 times on the journal website since their publication

3. References to the research (indicative maximum of six references)

Publications

(1) Direct demonstration of milk as an element of archaeological economies, S. N. Dudd and R. P. Evershed, *Science* 1998, **282**, 1478-148, DOI: 10.1126/science.282.5393.1478.*

(2) Earliest date for milk use in the Near East and southeastern Europe linked to cattle herding, R. P. Evershed, S. Payne, A. G. Sherratt, M. S. Copley, J. Coolidge, D. Urem-Kotsu, K. Kotsakis, M. Özdoğan, A. Özdoğan, O. Nieuwenhuyse, P. M. M. G. Akkermans, D. Bailey, R.-R. Andeescu, S. Campbell, S. Farid, I. Hodder, N. Yalman, M. Özbaraşan, E. Bicakci, Y. Garfinkel, T. Levy and M. M. Burton, *Nature* 2008, **455**, 528-531, DOI: 10.1038/nature07180.

(3) Purity assessments of major vegetable oils based on $\delta^{13}C$ values of individual fatty acids, S. E. Woodbury, J. B. Rossell and R. P. Evershed, *Journal of the American Oil Chemists Society*, 1998, 75, 371-379. DOI: 10.1021/ac00111a029.*

(4) First dairying in the green Sahara in the 5th millennium BC. J. Dunne, R. P. Evershed, M. Salque, L. Cramp, S. Bruni, K. Ryan, S. Biagetti and S. di Lernia. *Nature* 2012, **486**, 390-394. DOI: 10.1038/nature 11186.

(5) Earliest evidence for cheese making in the sixth millennium bc in northern Europe M. Salque, P. I. Bogucki, J. Pyzel, I. Sobkowiak-Tabaka, R. Grygiel, M. Szmyt and R. P. Evershed, *Nature*, 2013, **493**, 522-525. DOI:10.1038/nature11698.

(6) Identification of a disinterred grave by molecular and stable isotope analysis, I. D. Bull, R. Berstan, A. Vaas and R. P. Evershed, *Science & Justice*, 2009, **49**, 142-149, DOI: 10.1016/j.scijus.2009.01.016.*

Grants

- Analysis of organic residues in Iron Age/Roman pottery from Stanwick (RAP). (**PI**) English Heritage 1993-1995. £19k.
- Experimental approaches to the study of organic residues in archaeological ceramics. (**PI**) SERC 1992-1995. £71k.
- Detecting vegetable oil adulteration using irm-GC/MS. (**PI**) Leatherhead Food Research Association 1994-1997. £30k.
- New criteria for the identification of animal fats from prehistoric pottery. (**PI**) NERC 1995-1998. £123k.
- Was dairying an important element of animal husbandry in prehistoric Britain? (**PI** with Straker and Payne) NERC/English Heritage. 1998-2001. £207k.
- The emergence of dairying in early farming practices of the Fertile Crescent (**PI** with Sherratt and Payne) Leverhulme Trust. 2002-2005. £161k.
- Horse specialisation and pastoralism in the prehistoric Eurasian Steppe [co-**PI** with Outram(Exeter)] NERC 2005-2009. £256k.

4. Details of the impact (indicative maximum 750 words)

Chemical archaeology

Evershed began to combine chemistry and archaeology to capture public interest and stimulate chemistry education in the 1990s and has continued to evolve this to the present day via the full range of mechanisms. The combination regularly attracts students not normally inspired to study chemistry:

School and college educational outreach

- Presentations to schools by **Evershed** and his team have a profound impact on students and teachers, with the latter recognising the value of conveying the ideas of chemistry through case studies drawn from ancient human societies from across the world (**a**). Formalisation of this is evidenced by inclusion of Evershed's work on the chemistry of food residues in ancient pottery in the Nuffield GCSE Chemistry textbook. First published in 2006, this text is used by most OCR GCSE Science (TFCS) students [estimated by OUP to be ca. 75% of those students, >20,000 students p.a., based on market share (**b**)].
- **Evershed's** work has contributed to more than 20 documentaries broadcast worldwide most recently: *The Making of the Fittest: Got Lactase? The Co-evolution of Genes and Culture* by HHMI (**c**). On the 1st October, since posting in March 2013 the film had 43,429 stream attempts and 21,483 downloads.
- Members of his team (**Cramp** and **Salque** as PhD students and **Gill** as PDRA) authored educational articles in the RSC's journal *Catalyst* circulation 10,000 (**d**).

Public outreach events

- **Evershed** and his team have promoted the wider interest in chemistry through archaeology via >50 community events, public outreach activities and presentations to local interest groups throughout the UK, e.g. 'Set7', 'Chemistry Alive', 'Scientific Power to the People', ChemSix, 1996, University of Bath Millennium lecture Series (2 invitations), University of Bristol Centenary celebrations and Open Days, Discover 2010, Oxford May Music Festival 2011, and the Bristol Festival of Nature 2011-2013. A highlight of this activity was the group's participation in the 2009 Royal Society Summer Science Exhibition (RSSSE) (**e,f**) attended by >5000 school/college students, members of the public of all ages and backgrounds, and academics/educators of all types (school teachers to FRS).
- Developed in 2009 *'The Palaeodetective'* display as an outreach tool. Central to the display is a computer game played on touch-screens, enabling users to learn about ancient worlds through 'cases' drawn from the group's work. The game is designed for any age and appeals to many interests. The exhibit originally created for RSSSE 2009 has been re-used over a dozen times, including at Festivals and University Open Days, and is available to teachers online (**e**). This game has now been played by thousands of children and adults.
- **Dunne** from **Evershed's** group represented the University of Bristol in the 2013 'Soapbox Science Event', promoting women in science, presenting an informal interactive street talk "*Milking it*" at the South Bank, based on her archaeological chemistry research (**g**).

Media interactions and engagement

- **Evershed's** research has generated over 10 press releases, he has given over 50 interviews to print and radio media and contributed to 12 documentaries.
- **Evershed's** media engagement has resulted in vast coverage of his research in the national and international media, including, for example, over 100 newspaper and magazine publications and nearly two dozen national and international interviews.
- Typing *"Evershed ancient dairying"* into Google gives >100,000 hits referring extensively to his group's work in a diversity of sources from across the world.

In this respect his work continually reinforces the importance of chemistry in understanding the origins of humankind.

Detection of vegetable oil fraud

In 1996 **Evershed** collaborated with the Leatherhead Food Research Association (representing a consortium of food producers comprising FOSFA, International, Unilever Research, Bedford, UK, and Nestec Ltd., Lausanne, Switzerland). The Bristol-based PhD student (**Woodbury**) developed a new method for detecting the adulteration of corn oil which was incorporated into the CODEX Standard for Named Vegetable Oils (CODEX-STAN 210-1999) (**h**). The CODEX was published in 1999, but remains the UK (and international) standard for detecting vegetable oil adulteration, thereby protecting consumers' economic and health interests through the REF period. **Evershed's** methodologies predate the recent horse meat debacle, emphasising the need for the use of sophisticated analytical methods to ensure the quality of the food we consume. Although such

frauds are rarely injurious to human health they raise moral concerns, however, the famous "Spanish Toxic Oil Syndrome" resulted in 600 deaths, emphasising the need for constant vigilance.

Murder case

Approached by the Metropolitan Police, **Evershed**'s team rapidly reconfigured their methodologies to provide unequivocal evidence that led to an immediate confession and subsequent murder conviction (**i**). The methods employed were published (**6**) with the agreement of the Metropolitan Police in 2009 to provide an exemplar for others to follow. The case rested on the substantial stable isotope database built on **Evershed**'s archaeological chemical research, bolstered by further samples provided by the "*Body Farm*", made famous by Patricia Cornwall's novel of the same name.

5. Sources to corroborate the impact (indicative maximum of 10 references)

(a) Example of educational outreach impact arising from Evershed and his team's archaeological chemistry research embedded in the School of Chemistry's ChemLabs wider outreach activity coordinated by Tim Harrison, Bristol ChemLabS School Teacher Fellow.

(b) Email letter from Barry Stone, Senior Editor, Education Division, Oxford University Press confirming the widespread use of the TWENTY FIRST CENTURY SCIENCE textbook by GCSE students.

(c) Dated pdf of webpage screen shot including link (http://www.hhmi.org/biointeractive/making-fittest-got-lactase-co-evolution-genes-and-culture) to an educational film produced by John Rubin for the Howard Hughes Medical Institute (HHMI) that arose directly from the research and features Evershed and colleagues discussing the relationship between his archaeological chemistry findings the evolution of lactase persistence.

(d) Pdfs of 2 educational articles in *Catalyst* arising from research generated through outreach and engagement activities.

(e) Examples of public engagement activity arising from Evershed and his team's archaeological chemistry research, and the web link to the *Palaeodetective* educational game played by thousands of visitors to exhibitions and festivals attended by his team and now available on-line.

(f) Pdf of leaflet distributed during 2009 Royal Society Summer Science Exhibition showing the central role played by archaeological chemistry research in this event.

(g) Pdf of link to blog in *The Independent* arising from 2013 Soapbox Science event highlighting the importance of women in science.

(h) CODEX Standard for Named Vegetable Oils (CODEX-STAN 210-1999). Only three peer reviewed journal papers are cited (page 11) in the CODEX and all are the work of Evershed's group in collaboration with LHFRA on the authentication of vegetable oils using fatty acids in conjunction with stable carbon isotope analyses. Copy of report to LHFRA RESEARCH REPORT No. 755 by Evershed's PhD student Woodbury is available on request.

(i) Pdf of letter from DCI Ephgrave, The Metropolitan Police, London, confirming our role in providing evidence to secure the murder conviction; they are also cited on page 143 of Bull et al. (2009).