Why teach Heisenberg to archaeologists?

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The archaeological department at the University of Bradford is the only one in Britain to be called a 'Department of Archaeological Sciences'. Its Professor — whose own background was in physics and then chemistry before archaeology — explores the relationship of archaeology to the sciences in a contribution adapted from his talk given at Harvard University on 'Science and archaeology'.

At the beginning of the academic year, one of the many pleasures of being Head is to welcome new students to the Department. In my introductory remarks, I like to challenge the new undergraduates to name a science which has no relevance to archaeology. One can easily go through the scientific alphabet, from astronomy to zoology, and find many obvious applications. Alternatively, it is possible to work through all the Departments of a university and find an archaeological context for at least some of their work. Certain Departments, of course, provide more of a challenge than others — Environmental Sciences, for example, is obviously closely related, whereas one has to invoke Icarus or Leonardo da Vinci to encompass Aeronautical Engineering!

Another measure of the breadth of the modern discipline of archaeology is to look through one's own reference collection of journal offprints, and work out how many different journals are consulted in the course of research. My own collection, of some 2500 items, encompasses contributions from more than 350 journals, ranging from *Acta Praehistorica et Archaeologica* and *Advances in Agronomy* through to *Yearbook of Physical Anthropology* and *Zeitschrift für Rechtsmedizin*. Some, such as *Nature* or ANTIQUITY, are frequent companions — others may only be sought once in a lifetime. This is not to be boastful — indeed, many of my colleagues see it as a 'lack of focus' in research design — but it does show how dispersed and varied the information of relevance to archaeology can be.

The serious point to be made from these observations is that the modern discipline of archaeology has recourse to support from an extremely wide range of scientific, engineering and humanities subjects. This poses an enormous problem in particular for those departments which attempt to teach archaeology as a science-based subject — where does one begin (or, perhaps more importantly, end!)? The recent trend in the UK for otherwise 'traditional' departments of archaeology to advertise for an 'archaeological scientist' (discipline usually unspecified) to join the staff, and then to lay claims to being a 'science-based department' (a status which may carry certain financial rewards), would be amusing if it were not a serious indictment of the state of academic archaeology in the UK. Who would take seriously the claims of, say, a history department which appointed an archaeologist (discipline unspecified), and then claimed competence in the broadest areas of archaeology? It is gratifying to see the increasing appreciation of the role of science in some sectors of archaeology, but it has to be accepted that there is a difference between a commitment (which is costly) and tokenism.

In fact, the academic discipline of archaeology apparently has the qualities of a chameleon — it can take on almost any appearance, depending on the 'academic colour' of an individual's background. The extremes can be, and often are, caricatured. On the one hand, archaeology can be approached as a 'pure arts' subject — for example, looking at stylistic and decorative trends in pottery, metalwork, or art, and sometimes where appropriate integrating this approach with the writings of the classical authors. This particular view sometimes tends to downplay the technological aspects associated with human development, despite the possibility that stylis-

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tic development may be the result of some new technological capability. This caricature is often taken to represent the 'traditional' approach in the UK, and is usually the one which the general public associates with archaeology. Another caricature is that of the social anthropological archaeologist, who reminds us that archaeology is about people, not things, and that no 'experiment' can tell us what was in the minds of our predecessors. At the limit, some 'post-processualists' tell us that all interpretations of the past are equally valid, and that we are all simply 'telling stories'. At yet another extreme, archaeology, classified by many as one of the historical sciences (Embree 1987), can be seen simply as one particular aspect of quaternary geology — that which considers the mutual influence of human development and the 'natural' environment. The raw material for all archaeological research usually comes from excavation or fieldwork, and this creates a natural affinity between archaeology, geology and environmental sciences. This approach usually underplays (or more often ignores completely) the importance of social behaviour in human society. This particular caricature sometimes portrays a second-rate scientist seeking a less challenging arena in which to work. There are, of course, many other positions in between, and it must always be remembered that, unlike almost any other academic discipline, there is no clear consensus even within archaeology about the nature of the discipline itself.

The rise (or, as some would say, the re-emergence) of scientific archaeology in the 1960s has resulted in a sometimes heated debate in the UK and elsewhere about the relationship between the natural sciences and archaeology. The chasm which is now perceived to exist is encapsulated in the opening statement of the book review by Dunnell (1993) which is destined to become widely quoted, so I have no hesitation in repeating it here: 'Many, if not most, archaeologists regard archaeometry as a sometimes interesting, largely irrelevant, and definitely optional endeavor'. I would like to spend some time analysing this view from my own perspective, but from the outset I have to say that regrettably I accept that this is a true statement, although obviously there is much more to be said.

The main forum for such debate in the UK has been the annual meeting of the Theoretical Archaeology Group (TAG), which has over recent years organised a number of sessions critical of the rise of 'scientism' in archaeology. One of the most coherent critics has been Julian Thomas (perhaps not surprisingly, since he holds a B.Tech. in Archaeological Sciences). He makes a number of points about the current applications of science to archaeology (e.g. in Thomas 1991) with which I can only agree wholeheartedly. For example —

> one can only conclude that archaeological scientists display a shocking lack of awareness of the philosophy of science.

Sadly true, but how many other scientists are also unaware of the philosophy of science, but whose lack of knowledge goes unchallenged because they are 'mainstream' ? Yet more:

> For archaeological science is not a science as it would be recognised in the natural sciences. Rather, it is an assemblage of techniques lacking a coherent epistemology adequate to the tasks to which it might be expected to aspire.

How true! A friend of mine — a geochemist, and one of the two best scientists I have ever known — was always amazed that all most archaeological scientists ever seemed to do was 'analyse things' (Thomas' 'accretional theory of knowledge'). Some geochemists were also like that, he said, 'but it's not what grown-ups do' (the full impact can only be obtained by the application of a strong Australian accent!). As Thomas has said, most archaeological scientists demonstrate a 'naive empiricism' — an observation which has been made in various forms by many of the more critical archaeological scientists over the last few years (e.g. De Atley & Bishop 1991), but one which has yet to influence decisively the apparent direction of scientific endeavour in archaeology.

In order to prevent harmony breaking out, let me state my position as clearly as I can. I do believe that significant elements of what has masqueraded as science within archaeology over the past 30 years has lacked the true (but largely undefinable) characteristics of scientific research. The post-processualist jibe of 'scientism' as opposed to 'scientific' certainly has some justification. But wait — the angels are not entirely on the side of post-processualists! There seems to be a view which almost amounts to arrogance in certain quarters which assumes that the only valid use of archaeological data is archaeology

— the reconstruction of past human society from its material remains. This is simply not true. Archaeological data is like any other scientific data — once it is published (and certain areas of archaeological science have a shocking record for publication of basic data), it is public-domain information, and may be used for any purpose. Does anyone believe, for example, that radiocarbon dating would have been so heavily supported and developed if archaeology was the only beneficiary? Late Quaternary geologists of one sort or another are by far the biggest users of radiocarbon dating in the UK, and it is doubtful if any radiocarbon laboratory could survive if it had to rely on archaeologists as sole customers. Moreover, would the high-precision calibration curves for radiocarbon dating be so advanced if the information they provide on changes in ^{14}C flux were not of interest to atmospheric physicists, astronomers, etc.? I believe strongly in the concept of a community of scientists interested in the geologically recent past (archaeologists, palaeoenvironmentalists, climatologists, palaeobiologists etc.), all of whom have a valid interest in, and a right of access to, archaeological data. In fact, I believe that the potential of this pooled data has yet to be exploited to its full extent by archaeologists. This observation was made briefly by Martin Aitken over 10 years ago as a self-confessed 'heretical note' in his contribution to the round table debate on *Future directions in archaeometry* (Aitken 1982), which he entitled 'Archaeometry does not only serve archaeology'. Unfortunately it still seems to be the case that the potential benefits of the exploitation of archaeological data for other purposes are not yet fully appreciated.

If this is true, then what does it mean for those scientists who have chosen to commit themselves to the study of archaeological material? What should 'grown ups' do? My personal view is very clear. There is a responsibility to ensure that scientific work carried out in the name of archaeology is of the same quality as would be expected from any other scientific endeavour. This means that it must be peer-reviewed at all stages, not only by appropriate archaeologists for its archaeological relevance, but also by scientists active in the mainstream parent scientific disciplines. A brief example. We believe that presently accepted measurements of the solid solubility limit of arsenic in copper in the copper–arsenic binary system is wrong at the low temperature end, which is of importance for the technological interpretation of the composition of archaeological Cu–As alloys. It is not in our opinion good enough to report our findings to an archaeological science journal, where the refereeing rigour in respect of the metallurgical evidence may be called into question. Our evidence must be opened to the full investigation of the metallurgical literature, for our own peace of mind. Only if we can convince the referees of these journals that our views are correct is it then satisfactory to publish an interpretation of the archaeological implications in the archaeological literature. This is in no way intended to decry the metallurgical skills of professional archaeometallurgists — it is simply to recognize the small size of the pool. The same is true of many or most other areas of archaeological science. The best way of ensuring that the science is valid is to publish in the scientific literature, as well as in the archaeological literature. The goals of the research may well be principally of interest to archaeologists, but the science must stand on its own. The relatively low standing of archaeological science in some quarters of the scientific community almost certainly stems from this apparent unwillingness to open up the research to full scientific scrutiny.

My views are not as negative as they might seem. There is an enormous amount of scientific work going on in the name of archaeology which is of the highest quality, but there are some 'presentational' problems. The term 'archaeometry' is one which I do not personally like — it can have the connotation of simply being 'scientific measurements applied to archaeology', which, to use a mathematical phrase, is 'necessary but not sufficient' (although unfortunately it does often adequately describe the character of the work). This concern was more eloquently expressed by Cyril Stanley Smith (1982), when he pointed out the danger of over-emphasizing the '-metry' at the expense of the 'archaeo'. I prefer the phrase 'archaeological science', but I accept that it is tautological, and as far as possible I prefer to talk simply about 'archaeology'. Accumulating data in a routine fashion is often part of the scientific process, but too often it is used as a substitute for thought about a problem. It usually signifies a poor (or missing) research design. If the data do not contribute to an answer to the key question 'how would I know if my theory was wrong?', then it is either the wrong data or the wrong theory! It is interesting to ruminate on

the emphasis which has been accorded in the past to data collection in archaeology itself. It has often been said that the excavation of an archaeological site is an unrepeatable experiment, and that the excavator therefore has a duty to record everything regardless of current research priorities. This philosophy is particularly prevalent when the prime motive for excavation is rescue as a result of development pressure. In my view this has resulted in unreadable excavation reports which are nothing more than catalogues, and, worse still, this paradigm has been accepted uncritically by some 'archaeometrists' — the assumption that accumulating analytical evidence is a meaningful end in itself. It may simply be an excuse for not having the confidence to define one's own thoughts about priorities! I also question the concept of the uniqueness of most archaeological sites when taken in the wider context, but that is not a matter for discussion here.

A very important presentational problem is the structure of the conferences devoted to 'archaeometry'. They have been much criticized for being too techniques- or materials-orientated, with little emphasis placed on the archaeological problem (if any) being addressed. This is clearly the root cause of the problem encapsulated by Dunnell (1993) — 'why archaeologists don't care about archaeometry'. They do not see it as relevant, because it is not presented in a relevant manner and rarely is it open to criticism from an archaeological viewpoint. Invariably, conference delegates bemoan the fact that no 'big player archaeologists' have attended the conference to hear their earth-shattering discoveries. Why? — because the structure of the meeting is often completely without archaeological logic! The solution is obvious — re-structure some (if not all) of the conference into archaeologically-relevant themes, and invite appropriate specialists to review various aspects of cultural or theoretical archaeology relevant to the theme! It must be remembered, however, that archaeological data has relevance to other sciences apart from archaeology, and participants must be prepared to contemplate themes such as human-climate interactions, or the evolutionary biology of the horse. I can testify from personal experience that scrutiny by archaeologists can often lead to moments of great humility. On one occasion, I gave an extremely eloquent and concise account of the value of using stable isotope studies in bone to determine the terrestrial/marine balance of diet in Neolithic Britain, when one robust character stood up and said that it didn't need a mass spectrometer to tell that marine food had been important at a certain site — the ground was knee-deep in limpet shells! Scope, perhaps, for further erudite discussion about food webs, nutritional value etc., but point taken. Archaeological scientists often seem to spend a lot of time and money to demonstrate the obvious! In my more cynical moments, I have often felt tempted to ask at a conference how much a piece of research cost — especially one which produces a result of great import to nobody but the author. Dangerous thoughts!

So, to turn at last to the title, why teach Heisenberg to archaeologists? It is a shorthand, of course, for the simple question, Why do archaeologists need to know the fundamental principles of science? The answer, if my arguments are correct, should by now be obvious. Archaeology, if not regarded as a science in its own right, has recourse to a very wide range of other scientific disciplines. In order to ensure that the scientific work carried out in the name of archaeology is of acceptable quality, it must be peer-reviewed by scientists from the parent disciplines, and therefore the practitioners must be competent in the parent disciplines. Hence, they need to know the fundamentals of scientific principles, and therefore may have cause to make the acquaintance of Heisenberg.

I will give a brief example to illustrate the point (Pollard forthcoming). An often-expressed view in the archaeological literature is that the nature of the 'burial environment' of a bone (or, indeed, any buried object) can in some way be reconstructed in the laboratory after excavation providing a sample is taken of the sediment containing the bone. This is naïve to the point of being ludicrous. A chemical analysis of the sediment for an element such as strontium will give little indication of the level of strontium in the groundwater moving through the sediment and the bone, even if the analysis is relevant in terms of assessing the 'available' strontium rather than the total strontium in the deposit — a point already made by Williams (1988). Control of the uptake of elements from sediment into groundwater is far more subtle than this, and depends not only on the prevailing aqueous environment (temperature, pH, Eh) but also on the mineralogical form of the element, and the concentra-

tion (more accurately, activity) of other dissolved species. In most natural dilute groundwaters, for example, the pH is entirely controlled by the $CaCO_3$–H_2O–CO_2 equilibria (Garrels & Christ 1965: 75). In soil solutions, phosphate solubility is often controlled by the aluminium content (activity) of the soil (Lindsay 1979: 169). The concentration of trace elements such as strontium in groundwaters will therefore almost certainly be controlled by the activity of other species — in this case, probably calcium and magnesium. Some of these issues have been discussed in the archaeological literature by Pate and co-workers in an excellent series of papers (Pate & Hutton 1988; Pate *et al.* 1989; 1991), but unfortunately the implications so far appear to have been generally overlooked.

There is, of course, a very good reason for this. Field measurements of the important parameters such as pH, Eh, dissolved CO_2 levels, and the various trace element concentrations are fiendishly difficult to perform without unbalancing the system, even if all of the relevant parameters could be identified in advance. Not only that, it is well established that an important factor affecting the chemical properties of groundwater is not simply the dissolved trace element or cationic concentrations, but the form which the element is in — the speciation. The situation rapidly becomes so complex that it becomes impossible to deal effectively with real systems. It is at this stage that geochemists turn to computer modelling of such systems in order to provide further understanding of how they might behave. Computer models of the chemistry of dilute aqueous solutions have been in existence since the mid-1960s, and are now commercially available and documented (e.g., Bassett & Melchior 1989). This type of calculation can be used to predict the stability fields for a large number of minerals over the range of naturally encountered conditions of pH and Eh. Although widely used in geochemistry, little use has been made of these programs in archaeology, with the exception of the work done by Thomas and colleagues in Cardiff in order to understand the corrosion behaviour of copper in the burial environment (Thomas 1990). There must be a pressing need to use this approach to study other systems of archaeological interest (including bone).

Having said all this, it is also naïve to expect that a purely geochemical approach to the question of the detailed interaction of buried bone with groundwaters will solve all the problems associated with excavated bone. In the early stages of burial the organic component will exert a massive influence, which may not be easily accounted for by simple experimentation. Indeed, the primary mechanism of alteration at this stage will probably not be chemical but microbiological. The chemical modelling advocated here can also only be part of the solution, in that the physics of the groundwater–bone system must also be considered, especially for an understanding of the flow of water through the bone. This aspect of hydrological modelling is being tackled by other workers (e.g. Hedges forthcoming), and will eventually need merging with the geochemical factors. Although the way ahead is undoubtedly convoluted, at least I believe we now have some idea of where we should be going — that is to strive to raise the level of understanding in this particular aspect of archaeological chemistry to the same level of scientific clarity as is demonstrated in other biogeochemical disciplines, in order to ensure that archaeological interpretations may be based on meaningful rather than spurious observations.

I hope I have demonstrated that archaeological science is a discipline which needs to emerge from the old diffusionist paradigm. The problems thrown up in the course of research can be unique to archaeology, and may bear little relation to the research carried out in the parent scientific disciplines of metallurgy or microbiology, or any of the other sciences which now bear upon archaeology. Serious scientific work in archaeology needs serious scientific knowledge in order to make progress beyond the trivial level of applying analytical techniques developed in other disciplines to archaeological material. Hence the modern archaeological scientist needs a thorough scientific background in a range of relevant disciplines. That is why we teach the Heisenberg Uncertainty Principle to archaeologists — not only because it appears to set a limit on what we can know, but also because, when combined with a good archaeological education, it will make them better archaeological scientists. We cannot expect to have it both ways — if archaeology is, at least in certain aspects, a science, then it has to act like a science, which includes a commitment to the publication of all basic data and a willingness to open up to full scientific scrutiny. If it isn't prepared to do so, then it can make no claims to be treated as a science.

Nothing I have said here of course is particularly new. To some extent it is reassuring to realize that archaeological science is not the only interdisciplinary area with an identity problem. Forensic science suffers similarly — for example, Sensabaugh (1986) states that

Forensic science may be defined broadly as the application of science to the analysis and interpretation of physical evidence in criminal and civil litigation. Because just about any object or event in the natural or man-made universe may be evidence at one time or another, forensic science draws on a diversity of scientific disciplines from astronomy to zoology. Forensic science is, however, more than a collection of fragments borrowed from the various basic disciplines. The field has a unique body of concerns that are not addressed by other disciplines, and it is this body of concerns that gives the field an identity of its own. These concerns also provide the subject matter for research having a specific forensic science focus.

Replace 'forensic' with 'archaeological', and 'criminal and civil litigation' with 'archaeology', and this quotation is a neat encapsulation of my arguments in this paper.

I will end by quoting from an article published over 50 years ago by V. Gordon Childe in *Nature*, entitled 'Archaeology as a science' (Childe 1943):

The antithesis between history and science as central disciplines in 'education for citizenship' can be resolved by making history more archaeological and recognizing that archaeology is a science.

What archaeology reveals is precisely 'the progress of mankind — of art, science and industry' from the painted caves of the mammoth-hunters not only to the early cities of Sumer and Crete but also right down to Manhattan and Magnitogorsk. Flint axes and rotary querns, the history of which is provided by archaeology alone, are just as much embodiments of science as the cyclotron.

On the other hand, the methods of archaeology — accurate and dispassionate observation, systematic comparison and classification, the continual reference of explanatory generalizations to the concrete data derived from observation — are truly scientific.

Hence a lesson in archaeology, even if it consists only in the comparison and classification of rusty bolts and broken tobacco-pipes from a town rubbish pit, could be at once a lesson in science and a lesson in history.

The corollaries would be, on one hand a more generous treatment of archaeology by the State and local authorities, on the other a fuller recognition of the subject' s scientific status by universities and institutions.

Fifty years on, these words are still highly relevant!

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