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Archaeology, Archaeological Science, and Microarchaeology

The archaeological record is mainly composed of materials related to past human behavior. Some of these are visible to the naked eye – the so-called macroscopic record – and some require instruments, such as microscopes or spectrometers, to be seen and characterized. This is the so-called microscopic record, and the study of this record is referred to here as *microarchaeology*.

The macroscopic record is composed of strata, buildings, graves, floors, and so on, as well as artifacts such as pottery, bones, stone, and metal tools. The microscopic record is composed of the materials of which the macroscopic artifacts are made, as well as the sedimentary matrix in which the artifacts are buried. Thus the investigation of the archaeological record as a whole involves the integration of both the macroscopic and microscopic records. It incorporates activities that span the humanities, social sciences, and natural sciences, with the former two disciplines being focused mainly on the macroscopic record and the latter discipline being focused mainly on the microscopic record. Herein lies a problem: the different parts of the archaeological record are studied by investigators with diverse backgrounds and approaches. Often lacking is an integration of these different worlds.

In this book, the focus is on the archaeological information that can be extracted from the microscopic record and, in particular, from the materials commonly found in most archaeological sites such as ceramics, bones, rocks, ash, and sediments. The process starts in the field, where problems are identified, preliminary analyses are carried out, and samples are collected for further analysis. It then proceeds to the laboratory and finally returns to the field to better understand the results in terms of their archaeological contexts. Even though the idea is simple and certainly not new, in practice, it is by no means straightforward to integrate information from different subdisciplines, collected by different investigators using different methods. One requirement is that the archaeological contexts under study be well defined and understood by all involved. Another essential requirement is that the quality of all forms of data be evaluated so that the weight given to high-quality data is much more than the weight given to low-quality data. When independent lines of evidence point to the same conclusions, then the real benefit of integrating all the data is obtained, and the conclusions reached are well grounded. These concepts are not unique to archaeology, but are common to all scientific approaches to solving problems.

The term *scientific* conjures up different concepts in different archaeologists' minds, as it does in different scientists' minds. A definition of *science* I like is from a plaque I photographed in a small museum in Udaipur, India (Figure 1.1). The reference to "verified terms" encapsulates the essence of science, and the "bubbling with excitement" characterizes the way it should be. Of course, there are more formal definitions, such as the following: "the ultimate goal of any science is construction of an axiomatized theory such that observed regularities can be derived from a few basic laws as premises" (Watson et al., 1984, p. 14). It helps, however, to keep things simple. Following ideas popularized by Richard Feynman (1998), an appropriate definition of science in the context of archaeology is the extent to which the uncertainty of a given observation can be assessed. Reading texts can be scientific if the information is evaluated, based, for example, on assessing the reliability of the sources and obtaining independent lines of information. Field archaeology is scientific if the observations are recorded in a manner such that the site structure can be later reconstructed, and for this to occur, the stratigraphy has to be well substantiated based on different lines of evidence, and so on. A radiocarbon date is the product of a scientific process not only if the accuracy and precision of the date are reported, but also if the uncertainty involved in determining the context from which the sample was taken and an assessment of the sample purity are reported prior to analysis (Chapter 10).

Science does not, of course, confine itself to the dry facts, and the word *truth* is never used in so-called polite scientific circles as this implies that there is no uncertainty, and such a condition never exists. Almost every scientific article has a results section, in which the new data are presented together with an assessment of the degree of uncertainty, and if this also includes numbers, the measurement error (uncertainty) is reported. The results section is followed by a discussion section, in which the implications of the data are interpreted and thoughts about the broader implications are presented. The same format should be appropriate for most archaeological studies and is often used. The main difference I discern between many archaeological studies and studies in other fields of the natural sciences relates to the manner in which the uncertainty of the observations is addressed (or ignored) and the extent to which the archaeological community is willing to, or expects authors to, speculate – often more than in most natural sciences.

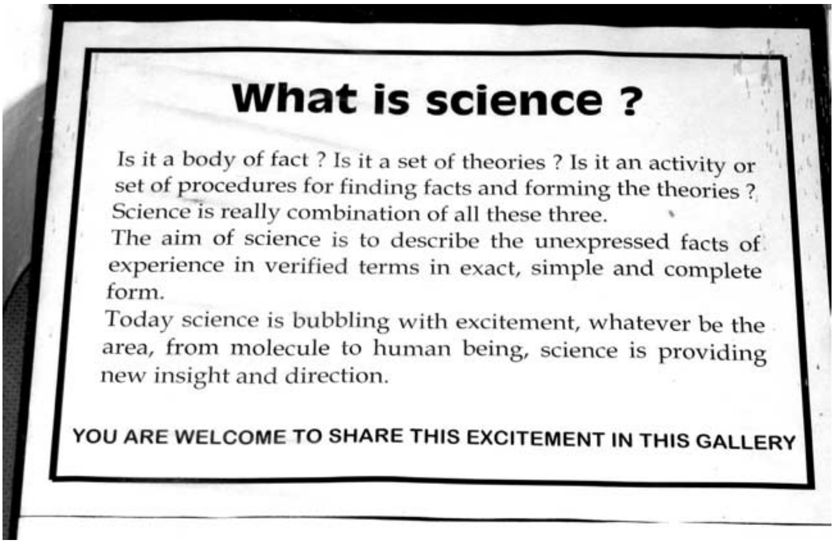

Figure 1.1 A photograph of a plaque in a two-room science museum in Udaipur, Rajasthan, India.

This difference falls into the realm of tradition and is not inherent to the subject itself, and probably also reflects the fact that almost all archaeologists are trained in the humanities or social sciences, and not the natural sciences.

The practice of archaeology is indeed scientific. Archaeological studies in which the observations are carefully made and supported in different ways, and are then interpreted in terms of other well-established observations that are consistent with or not consistent with the new observations, are good science. Many of the ideas expressed in this chapter are also described by Weiner (2008).

ARCHAEOLOGY IS A DIFFICULT SCIENCE

E. O. Wilson (1998), in his book titled *Consilience*, wrote, "Everyone knows that the social sciences are hypercomplex. They are inherently far more difficult than physics and chemistry, and as a result they, not physics and chemistry, should be called the hard sciences. They just seem easier because we can talk with other human beings but not with photons, gluons, and sulfide radicals" (p. 183). Archaeology is even more difficult than the social sciences as humans from the past can only "speak" through the material remains that are excavated.

The recognition that, among all the historic natural sciences, archaeology is probably the most difficult field is a first essential step in figuring out how best to approach and at least partially solve some of these very challenging problems. Furthermore, recognizing the difficulty brings with it a lowering of expectations as to what problems can be solved at a given time, and an appreciation for archaeological studies that succeed in firmly putting well-substantiated observations into the pool of common knowledge. This lowering of expectations might well make archaeology more boring as excessive speculation will be looked down upon, but on the other hand, it will encourage the best in archaeological research.

HISTORICAL PERSPECTIVE

In the book titled *A History of Archaeological Thought*, Trigger (1989) identifies the beginnings of scientific archaeology with the work of the Danish scholar Christian Jürgensen Thomsen (1788–1865). Thomsen knew that in general, artifacts of stone were produced before those of bronze, and bronze artifacts were produced before iron artifacts. The problem that Thomsen solved was finding a systematic way to identify stone artifacts produced in the Bronze Age, or bronze artifacts produced in the Iron Age, and so on. He did this by paying attention not only to the material of which the artifact was made, but also to shapes and decorations (seriation), and he paid particular attention to assemblages of artifacts excavated in closed contexts. In this way, he could arrange the artifacts into chronological sequences. The method is, of course, predictive and can be reproduced by anyone using the same criteria on different materials – all characteristics of a sound scientific approach.

Another Dane who contributed most significantly to the beginnings of archaeology was Jens J. A. Worsaae (1821–1885). He followed in the footsteps of Thomsen (they both worked in what is now the National Museum of Denmark in Copenhagen) and tested Thomsen's approach by associating the stratigraphy of archaeological sites to the assemblages found in different layers. Trigger (1989) also notes the complementary contribution of Scandinavian Sven Nilsson (1787–1883), who had studied under the famous French paleontologist Cuvier. He introduced the use of ethnographic specimens to shed light on the functional use of artifacts excavated from archaeological contexts.

The development of Scandinavian archaeology in the scientific tradition, according to Trigger, was not based on the model developed earlier by paleontologists and geologists for arranging fossils into a relative chronology, but rather, was inspired by social-evolutionary theories of the Enlightenment. Denmark was, in fact, one of the first countries to adopt these ideas, which were developed in France. The Scandinavian approach to archaeology spread to other small countries in Europe (Scotland and Switzerland, in particular) but did not immediately impact those studying the archaeological record in Britain and France, who, for the most part, adopted the paleontological approach to studying human fossils and associated artifacts. This approach is also, of course, based on the scientific method.

Thus the foundations of modern archaeology from the very beginning are well entrenched in the scientific method: the Scandinavian approach that developed out of the field of history, the French and British approaches that developed from the field of paleontology, and

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the use of ethnographic models that later came to be associated with the field of anthropology. The focus was, and still is, on understanding past cultures based on preserved material remains.

The chemical analysis of ancient artifacts started in the 18th century. Many famous chemists analyzed such artifacts. A fascinating description of these early studies is given in the first chapter of Pollard and Heron (2008). Many of the studies carried out in the 19th century also addressed archaeological problems such as provenience and dating. One of the first attempts to date artifacts was based on the fluoride contents of bones (Middleton, 1844). It was not uncommon to ask a chemist to analyze samples from an excavation to resolve a specific problem. This was done, for example, to determine whether certain black-colored samples from Zhoukoudian, China, were composed of charred material to better understand the use of fire (Black, 1931; Oakley, 1970). A better-known example is the work of the chemist Oakley, who, together with the anthropologist J. S. Weiner, exposed the Piltdown forgery based on chemical analyses of fossil bone (Weiner, 1955). For the first half of the 20th century, these studies appear to have made little impact on the overall nature of the research carried out in the field of archaeology.

This situation changed dramatically, however, with the development, by Libby et al. (1949), of the absolute dating technique using radiocarbon. This not only enabled an independent check of the relative chronologies that, to this day, serve as the foundation for much of archaeological research, but also provided the first absolute chronology. The importance of radiocarbon dating in archaeology is now hardly disputed, although the manner in which it is applied is often scientifically compromised (with dates that do not fit preconceived ideas finding their way into lists of unpublished data filed in drawers; Chapter 10). Since the advent of radiocarbon dating, a plethora of other analytical techniques, in addition to dating techniques, have been applied to solving archaeological problems. The result is that today, an excavation can be investigated based not only on what can be seen with the naked eye (the macroscopic record), but also using all the information that can be extracted using microscopes and various other analytical tools (the microscopic record). The integration of the macroarchaeological record with the microarchaeological record (microarchaeology) results in a better understanding of the entire archaeological record.

ARCHAEOLOGICAL SCIENCE

If all archaeology is inherently scientific, and has been since the early 19th century, then clearly, referring to a subfield of archaeology as "archaeological science" makes no sense. Even though conceptually, there is no such subfield, when archaeologists refer to "archaeological science" and/or "archaeometry," they do have something specific in mind. This something is encapsulated in the types of papers that are published in the two journals that bear these names. These papers, for the most part, involve analyses of materials from archaeological sites, with, of course, their archaeological contexts and the implications of the results for the broader picture – as in all scientific studies.

Irrespective of the illogicality of calling a subfield "archaeological science," even though the whole field is itself based on the scientific method, the facts on the ground are that with the majority of archaeologists being trained in the humanities, their access to the microscopic record is often not direct, but via a so-called archaeological scientist, and vice versa. This situation has been exasperated by the tendency of some archaeologists to emphasize aspects of archaeology that are more meaningful or significant, and do not, as Hodder (1999, p. 14) so aptly stated, say something about the past that is "true."

THE MICROSCOPIC RECORD

The archaeological record, even under fairly favorable conditions, preserves little of the complexity and diversity of a site during occupation (Chapter 3). Even robust architecture does not withstand the ravages of time well. Many materials, particularly of plant origin, are hardly ever preserved, and what is preserved is often altered to some extent. Reconstructing human behavior is thus a major challenge. This situation is often exacerbated by the manner in which excavations were, and often still are, carried out. Kathleen M. Kenyon (1960) pointed out, in the context of her archaeological projects in the Near East, that excavation has "big potential prizes – temples, palaces and royal archives – and also a large and cheap labour force available, and therefore minutiae of archaeological observation were ignored" (p. 14). In the almost 50 years since she published this statement, excavation practices have improved enormously, and so have the possibilities of learning more from the "minutiae" of the microscopic record.

The microscopic record has a huge amount of "space" below the submillimeter scale that is not visible to the naked eye. The physicist Richard Feynman gave a prophetic lecture in 1959, titled "There's Plenty of Room at the Bottom," in which he explained the implications of the fact that between the millimeter scale and the scale of atoms, there are seven orders of magnitude. The example he gave was that if you magnify the head of a pin 25,000 times, the area of the pin is so large that the entire *Encyclopedia Britannica* can be written on it. From the point of view of archaeology, this large "space" potentially contains much embedded information that can be used to better understand the record.

To better appreciate the size of the "space" available in the microscopic record, consider the following. If you stand in front of a section in an archaeological excavation and focus only on a mollusk shell easily visible to the naked eye, and you start zooming in on the shell structure

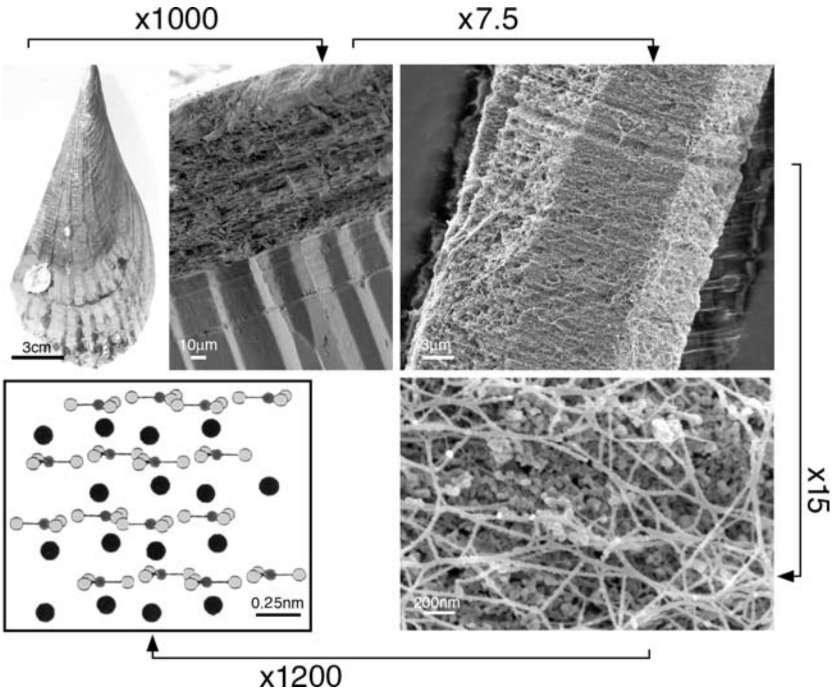

Figure 1.2 Zooming in to the microstructure of a mollusk shell, starting in the left-hand upper corner. The shell has to be magnified about 135 million times to see the atoms.

(Figure 1.2), you will easily see, at a magnification of 1,000 times, the layered structure: for example, prisms on the outer side and pearly nacre on the inner side. At a magnification of around 7,500 times, you will see the surface structure of one prism. If you slightly etch the prism surface and examine it at a magnification of around 110,000 times, you will see that it is composed of protein spheres attached to chitin fibers. We would still need to zoom in another 1,200 times to see the atoms themselves. There are seven orders of magnitude in scale between the visible shell and the atoms. There really is a lot of room at the bottom (Feynman, 1998)!

What can be learned about an archaeological section by turning up the magnification? In the case of the mollusk shell, you can find out whether the original shell components are still preserved (at low magnifications). At higher magnifications, you learn that some of the organic macromolecules are occluded inside the mineral phase. These occluded molecules are known to be relatively well preserved (Collins et al., 1991), and together with the preserved mineral phase, they could therefore be used to study the paleoenvironment in which the mollusk lived, the temperature of the water, and the season of death (Chapter 8). Much of this work is done using stable isotopes, namely, analyses at atomic resolution (Chapter 2).

One of the main purposes of this book is to provide access to the microscopic world of the archaeological record and, by so doing, make it easier for the archaeologist to extract the embedded information and thus obtain a better understanding of the archaeological record under investigation.

TOOL KIT FOR DECIPHERING THE MICROSCOPIC ARCHAEOLOGICAL RECORD

An integral part of the training of an archaeologist is to acquire a set of skills that makes it possible to extract information about past human behavior from an excavation in an orderly and systematic manner. This requires excavation skills; the ability to define loci, strata, and so on; and the ability to identify the major classes of materials that are often encountered: pottery, bones, charcoal, and so on. The archaeologist is also trained to differentiate between records that are mixed and/or altered, as opposed to those that are in primary, so-called sealed contexts. In essence, archaeological training can be described as providing the student a "tool kit" for reliably extracting and interpreting information from the archaeological record. This training is, for the most part, confined to the macroscopic record. The training should apply just as much to the microscopic record; however, deciphering the microscopic record is complicated by the fact that instruments are needed to reveal it. The modes of operation of these instruments need to be understood, as do the results they provide. The results also need to be understood in terms of their strengths and weaknesses (uncertainty) and, of course, in relation to the whole archaeological record.

I therefore advocate that the tools that should be in the "tool kit" of modern archaeologists not be confined to those useful for deciphering only the macroscopic record, but also the microscopic record. It is hoped that this book will provide an accessible framework for archaeologists to learn more about the tools available for deciphering the microscopic record.

Kenyon (1960) referred to the "big potential prizes" of an archaeological excavation as temples, palaces, and royal archives. Archaeologists of the next generation may well include in their list of big potential prizes materials so well preserved that they contain, for example, archives rich in genetic material, or a material that can provide a radiocarbon or dendrochronological date with an error of less than ±20 years, or a sherd that can reveal the recipes of past cooks based on preserved molecules within its pores. To find these "molecular treasures," archaeologists will need good insight into both the macroscopic and microscopic records of the sites they investigate.

THE IMPORTANCE OF INTEGRATING MICROARCHAEOLOGY WITH MACROARCHAEOLOGY

Faced with the reality that archaeological problems are difficult to resolve with a reasonable degree of certainty, it is clear that it makes sense to exploit every possible means for solving these problems. This interdisciplinary approach to the archaeological record has been an integral part of modern archaeology from the 19th century. It, too, has its roots in Denmark, with the work of Worsaae (Trigger, 1989, p. 82), who used all the diverse materials available for interpreting the archaeological remains of shell middens close to the present Danish coastline. Worsaae headed a team that included a biologist and a geologist. They reconstructed the paleoenvironment, the season of occupation, the presence of domesticated dogs, and the distribution of hearths. They also conducted experiments by feeding bones to dogs to understand the preponderance of the midshafts of long bones (Trigger, 1989).

The inherent problem with integrating the macroscopic and microscopic records is that more often than not, the archaeologists studying the macroscopic record are not also involved in studying the microscopic record, and vice versa. There are two communities of archaeologists, which usually meet not at scientific meetings where results are discussed, but briefly in the field, where the so-called archaeological scientists visit for a few days to obtain samples. There is a widening communication gap, especially as the analytical techniques used by the archaeological scientists become more diverse and sophisticated, making it even more difficult for archaeologists trained in the humanities to critically evaluate the quality of the data provided and the degree of uncertainty of the conclusions. The archaeological scientists do not usually spend enough time at the excavation to really appreciate the subtle problems related to defining the uncertainty of context and the stratigraphic problems that are the basis for any interpretation of the data, whether they are from the macroscopic or the microscopic record.

The ideal solution to this problem

Ideally, the basic training of all archaeologists should include both natural sciences and archaeology so that the graduate of such a program is at home intellectually in both disciplines. These new-generation archaeologists, like many archaeologists today, can and should also have their own specialties such as lithics, ceramics, bones, micromorphology, and so on. The difference will be that they will be able to pursue the questions they ask seamlessly, from the macroscopic to the microscopic record and back, taking full advantage of their knowledge of the natural sciences and archaeology. Thus, for example, a specialist in ceramics may not only document the typology, ornamentation, and so on, but may also examine the ultrastructure of the ceramic using a scanning electron microscope and use X-ray diffraction to identify the possible presence of minerals formed at high temperatures to better understand production conditions. The latter studies will be based on an understanding of the kinetics and thermodynamics of phase transformations and other factors. An archaeozoologist may not only classify the bones, reconstruct the number of individuals represented, and so on, but may also analyze the bones to reconstruct migration pathways using strontium isotopes or reconstruct ancient diets using stable isotope analyses of collagen, if, indeed, the collagen is well preserved. The basis for these studies is an understanding of bone structure, mineral and bone organic matrix formation, and the stabilities of these materials over time.

The reality

The above scenario is indeed the ideal solution. Perhaps the more realistic solution is that this integrated training will allow all archaeologists to communicate at a meaningful level, irrespective of whether the data being analyzed are derived from the macroscopic or the microscopic records. It will allow some to work in both arenas. At the very least, it should allow all archaeologists to have the basic knowledge to know, for example, not only that a flint tool can be used for provenience studies or for determining whether the raw material was derived from the surface or below the ground, but also the principles of the application and, most important, the conditions necessary to evaluate the uncertainty of the data obtained. This involves a subtle understanding of preservation conditions, archaeological context, local geology, and so on. In other words, all archaeologists should be able to ask the right questions and should be able to understand and evaluate the uncertainty of the results. One of the major objectives of this book is to facilitate this process by making the information needed to access the microscopic archaeological record more accessible.

ON-SITE LABORATORY

The place where this integrative approach to archaeology begins is on-site, not only for understanding and documenting the macroscopic record, but also, at least in part, the microscopic record. The iterative process of asking a question, gathering data, and then, in light of the new data, reformulating the question is at the heart of the scientific method of excavation. This can be done most effectively when some analytical capability is available in the form of an on-site laboratory (Figure 1.3). For more details on the concept and practicalities of operating on-site laboratories, see Chapter 11.

THE CONCEPT OF THIS BOOK

The overall aim of this book is to provide both the conceptual framework and the knowledge necessary for extracting as much information