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What is Biomolecular Archaeology?

A curiosity about our past is one of the things that makes us human. Over the last century **archaeology** has developed into a sophisticated discipline that interprets the past through examination of the physical remains of human life, those remains often but not exclusively recovered by excavation of archaeological sites. Science has always played an important role in archaeology, increasingly so since the 1950s when techniques invented by nuclear physicists for measuring the decay of radioactive atoms were first used by scientific archaeologists to date artifacts. Biological methods have become equally important. Knowledge of human anatomy and pathology enables **osteoarchaeologists** to use skeletal features to identify the sex of a person, to work out an approximate age at the time of death, and to determine if the person had been suffering from diseases such as tuberculosis or anemia. **Archaeobotanists** are similarly adept at studying seeds and other plant remains, and from these identifying the types of plants that were grown and consumed by people in the past. By combining information from different kinds of analysis, we can address broader issues such as the development of agriculture in particular parts of the world, and how agriculture and the concomitant changes such as increases in population density affected human diet and health.

Since 1985 the way in which biological remains have been studied by scientific archaeologists has undergone a remarkable revolution. Osteology, archaeobotany, and other approaches that involve examination of the physical structure of remains are still vitally important, but they have been supplemented with techniques in which the biomolecular content of the artifact is analyzed. This is called **biomolecular archaeology** and the first thing we must do is understand what this term means.

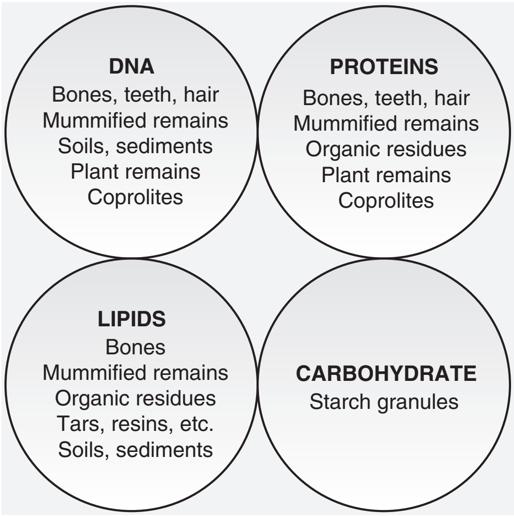

Figure 1.1 The four types of ancient biomolecule studied in biomolecular archaeology, with the main types of archaeological material from which each one can be obtained.

1.1 The Scope of Biomolecular Archaeology

The biomolecules studied by biomolecular archaeologists are the large organic compounds found in living organisms and sometimes present, usually in a partly degraded state, in the remains of those organisms after their death (Figure 1.1).

There are four categories of these **macromolecules**:

- **Nucleic acids** (Chapter 2), of which there are two types, **deoxyribonucleic acid** (**DNA**) and **ribonucleic acid** (**RNA**). Three features of DNA make this molecule valuable in biomolecular archaeology. First, in the cell, DNA acts a store of biological information, which means that DNA can be used to identify at least some of the biological characteristics of an archaeological specimen, such as the sex of a human skeleton (Chapter 10). Second, the DNA of different species can be distinguished, enabling DNA from a pathogen such as *Mycobacterium tuberculosis* to be detected in human bones (Chapter 15). Third, DNA is a record of ancestry, and so can be used to deduce if two human skeletons could be related (Chapter 11), and to map the evolutionary relationships between domesticated animals and their wild progenitors (Chapter 13). RNA molecules are copies of parts of the cell's DNA, and could, theoretically, be used in a similar way to DNA, but RNA has not been extensively studied in biomolecular archaeology. This is because RNA molecules are relatively unstable, and it has been assumed (perhaps incorrectly) that RNA is rarely present in human, animal or plant remains (Section 7.3).
- **Proteins** (Chapter 3) play structural and functional roles in living organisms. Structural proteins, such as collagen and osteocalcin, which are found in all vertebrate bones, are relatively stable and can often be identified in preserved material. Other proteins, usually ones that are less stable, have more limited distributions. Casein, for example, is found only in milk, and can therefore be used as a **marker** for the presence of milk residues in cooking or storage vessels. By showing that certain vessels once contained milk products, the development of dairying in prehistory can be followed (Section 12.3). The blood protein, hemoglobin, has a slightly different structure in different species, and with modern material these differences can be used to identify the origin of a bloodstain. One of the most controversial areas of biomolecular archaeology concerns the analysis of possible blood residues on stone tools to identify the species that were butchered using those implements (Section 9.2).
- **Lipids** (Chapter 4) are a diverse group of macromolecules, the major biochemical classes being fatty acids and their derivatives (which include substances commonly referred to as fats and oils), waxes, steroids, and terpenes. These compounds have various biological functions, both structural (some fatty acids are important components of cell membranes) and functional (some lipids are hormones). Lipids are so hugely diverse that many are species specific – they are found only in a single or small group of species and so can be used as

markers for those species. Analysis of lipids in organic residues from cooking vessels can therefore identify the type of vegetable or meat that was being prepared, and similar studies with storage vessels can show if they were used to hold, for example, a particular type of oil (Section 12.2). Identification of the terpenes in the adhesives used to attach flint arrow heads to wooden shafts can reveal which trees were exploited as sources of tar and pitch, taking biomolecular archaeology into the area of prehistoric technology (Chapter 14).

- **Carbohydrates** (Chapter 5) are important structural and storage compounds in living organisms, and include starch and cellulose in plants, and glycogen in animals. Of the four types of macromolecule, carbohydrates are the least studied by biomolecular archaeologists because, although they are stable over long periods, it is difficult to obtain useful information from them. One exception is the examination of starch grains in archaeological deposits, which can indicate the types of plants that were present at a particular site (Section 13.3).

In studying these four types of macromolecule, biomolecular archaeologists use a variety of methods and analytical techniques, as will be described in Chapters 2–5. Most of these techniques are applicable to just a single type of macromolecule, but one method has greater breadth and is of such general importance that it is often looked on as a distinct area of biomolecular archaeology. This is **stable isotope analysis**, in which ratios of different isotopes of certain elements (primarily carbon and nitrogen) are analyzed in proteins and lipids (Chapter 6). The natural ratios of these elements are constant, but variations can be introduced by biological and environmental processes. These variations can be exploited in studies of diet, as the stable isotope ratios present in bone proteins, or in hair, reflect the types of organism consumed by that individual (Section 12.2). A diet rich in marine resources can be distinguished from, for example, a diet largely made up of terrestrial animal protein, and the presence of maize in the diet can also be detected because this plant has a different isotope ratio to many other cereals and vegetables. In a particularly clever application of the technique, stable isotope analysis has been used to identify lipids derived from dairy products (Section 12.3).

1.2 Ancient and Modern Biomolecules

It will already be clear that research in biomolecular archaeology largely involves the analysis of the compounds that are preserved in archaeological remains. We call these **ancient biomolecules** and archaeologists are not the only scientists interested in their study. Forensic scientists are increasingly using information from preserved biomolecules, especially **ancient DNA**, in samples such as hair, bloodstains, and other bodily fluids collected at crime scenes years or decades ago in order to solve what are popularly called "cold cases." Zoologists also use ancient DNA from animal fossils to study extinct species such as mammoths and moas, and to follow changes in genetic diversity over time in populations of animals such as bison, whose numbers have been affected by climate change and human predation. DNA is rarely preserved for more than a few tens of thousands of years, but other biomolecules are present in much older materials. Proteins have been extracted from dinosaur bones and lipids and carbohydrates from the remains of plants and insects in sediments that are tens of millions of years in age.

The breadth of ancient biomolecules research is important because it means that biomolecular archaeologists have scientific colleagues who have very different interests but who use the same techniques and face the same challenges in planning and interpreting their experiments. Over the years there has been a large amount of cross-fertilization of ideas between researchers working with ancient biomolecules in different disciplines, and this has contributed greatly to the development of biomolecular archaeology. Indeed many biomolecular archaeologists also study ancient biomolecules in non-archaeological material, hence making direct contributions to forensic science, zoology, or paleontology, and the boundaries between the these disciplines and biomolecular archaeology often become blurred.

Although most research in biomolecular archaeology involves the study of ancient biomolecules, this is not exclusively the case. Studies of one biomolecule – DNA – in living organisms can contribute greatly to our understanding of certain archaeological issues. This is because DNA contains a record of the ancestry of individuals and the past evolution of populations and species. We can therefore study the relationships between different human populations by typing DNA taken from living representatives of those populations and using techniques from **molecular phylogenetics** and **population genetics** to analyze the data. This approach, sometimes called **archaeogenetics**, has been particularly informative in understanding the timing and trajectories followed by the migrations of modern humans out of Africa into Asia, Europe, Australasia, and the New World (Chapter 16). Using similar approaches with DNA from living crop plants and domestic animals, information is being obtained on the origins and spread of agriculture (Chapter 13). These studies overlap with evolutionary biology and crop and animal genetics, broadening still further the range of researchers who can be looked on as the scientific partners of biomolecular archaeologists.

1.3 The Challenges of Biomolecular Archaeology

All scientists work at the frontiers of their discipline – that is one of the characteristics of research – and all disciplines provide challenges that must be met and overcome if research is to progress. Biomolecular archaeology is no different, the challenges coming in two guises: technical and intellectual.

The technical challenges are posed by the degradation of ancient biomolecules and by contamination of specimens with modern biomolecules. All biomolecules begin to decay when the organism that contains them dies. Some, especially the nucleic acids, are relatively unstable and may completely degrade within a few years. Others, such as carbohydrates, are more stable and their decay products might still be detectable tens of millions of years after death (Chapter 8). These are not precise comparisons, because the environmental conditions, in particular the temperature and water content, greatly affect the rate at which a biomolecule decays, but the outcome is always the same. Almost every biomolecular archaeology project requires analysis of very small quantities of biomolecules that have undergone a greater or lesser degree of chemical degradation. The small quantities of ancient biomolecules present in archaeological specimens mean that detection techniques have to be pushed to their very limits, and often this affects the amount of information that can be obtained by biomolecular analysis of a specimen. Frequently, results are frustratingly incomplete, sometimes tempting the unwary researcher to make speculations that are not entirely warranted by their data, a problem that seems particularly prevalent in some areas of ancient DNA research.

The changes in chemical structure that occur during **diagenesis** can also confuse the detection processes, so that precise identification of an ancient biomolecule becomes difficult. For example, a process specific for the detection of human hemoglobin in modern bloodstains, when applied to archaeological material, might also give positive results with the partially degraded hemoglobins from other animals. Because of these problems, studies of biomolecular degradation form an essential adjunct to biomolecular archaeology, as it is only by understanding the decay processes for particular biomolecules that misidentifications can be avoided.

The small quantities of ancient biomolecules present in even the best preserved archaeological specimens leads to the second major technical problem, the possibility that modern contaminating molecules swamp the detection process, again leading to erroneous results. This issue is most clearly recognized in ancient DNA studies, because the exquisite sensitivity of the **polymerase chain reaction** (**PCR**), the primary detection method for DNA (Section 2.5), enables samples containing just a few hundred ancient DNA molecules to be examined. Similar or greater numbers of modern DNA molecules are present in human sweat, droplets expelled from the mouth and nose by sneezing, and in aerosols derived from previous PCR experiments that adhere to the clothes and skin of laboratory workers. Ancient and modern human DNA are very difficult to tell apart, and it is very easy to mistakenly assign to an archaeological specimen the genetic attributes of one or a mixture of the people who have handled the specimen. The problem is so acute that ancient DNA researchers carry out their experiments in ultraclean laboratories, wearing overalls that cover their entire body and face, a regime more commonly associated with research on deadly virus pathogens. The aim is not, however, to prevent escape of a pathogen from the test tube, but to prevent entry into the test tube of modern DNA from the researcher. Such practices are possible within the confines of a modern laboratory, but less feasible in the field, so it is almost inevitable that human bones become contaminated with DNA from the excavators who first uncover them. Solving these conundrums has greatly exercised not only ancient DNA researchers but all biomolecular archaeologists, as we will see in Chapter 9.

In addition to these technical issues, biomolecular archaeology poses a major intellectual challenge. Biomolecular archaeology is an interdisciplinary subject, and biomolecular research is of no value if it is not carried out within an archaeological context. This may seem obvious, but frequently projects that reach high standards as far as the biomolecular aspect is concerned fail to interest archaeologists because the results are not relevant to the issues that are important in archaeology. The problem arises because, until recently, very few biomolecular scientists possessed anything more than a rudimentary understanding of archaeology, and few archaeologists had a strong training in the biomolecular sciences. Successful biomolecular archaeology therefore requires collaboration between archaeologists and biomolecular scientists, and meaningful collaboration is often difficult to achieve. It is easy to assemble a "team," but much less easy to reach the mutual intellectual understanding that is required for interdisciplinary research to flourish. It is difficult to become an expert in both biomolecular research and archaeology – both are complex subjects with their own languages and ways of thinking – but such dual expertise has to be the goal of anyone who wishes to become a biomolecular archaeologist. The aim of this book is to help you achieve that goal.

Further Reading

Brothwell, D.R. & Pollard, A.M. (eds.) (2001) *Handbook of Archaeological Sciences*. Wiley, Chichester. [Covers all areas of archaeological science.]

Cox, M. & Nelson, D.L. (2008) *Lehninger Principles of Biochemistry*, 4th edn. Palgrave Macmillan, New York. [One of the best student textbooks in biochemistry.]

Jones, M.K. (2003) *The Molecule Hunt: Archaeology and the Search for Ancient DNA*. Arcade, New York. [A popular account of the early days of biomolecular archaeology.]

Renfrew, C. & Bahn, P. (2008) *Archaeology: Theories, Methods and Practice*, 5th edn. Thames and Hudson, London. [One of the best student textbooks in archaeology.]