Archaeology

SAMPLER

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Archaeological Sciences

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Archaeological sciences and *archaeological science* are generic terms commonly used to refer to the many subdisciplines that involve the application of science, technology, engineering and mathematical methods in archaeology. Most frequently defined by their methods rather than by specific aims or study areas, archaeological sciences cover the engagement of a wide range of disciplines such as physics, chemistry, biology, genetics, computing, or medicine to the study of both organic and inorganic archaeological remains, as well as associated sediments or contextual information such as their date or spatial location.

Most archaeological sciences generate primary data about aspects of the composition and microstructure of archaeological samples and reference materials, which in turn allow inferences about subsistence (e.g. through bone isotopes that inform about diet (see DIET AND CARBON ISOTOPES and DIET AND NITROGEN ISOTOPES)), or organic residue analyses in cooking pots (see ORGANIC RESIDUE ANALYSIS), health (e.g., identifying paleopathology (see PALEOPATHOLOGY)), environment (e.g., through pollen identification (see PALYNOLOGY) or zooarchaeological analysis (see ZOOARCHAEOLOGY)), technology (e.g., through metallographic analyses (see METALLOGRAPHY) or ceramic petrography (see PETROGRAPHY AND CERAMICS)), trade (e.g., through geochemical provenance studies (see CHERT, SILEX, AND OBSIDIAN SOURCING)), migration (e.g. through ancient DNA (see DNA: NEXT GENERATION SEQUENCING and DNA: MITOCHONDRIAL)), and other aspects of past lifeways. In addition, archaeological sciences are useful in the identification and survey of archaeological sites (e.g., in remote sensing (see AIRBORNE REMOTE SENSING)), conservation, documentation, and heritage management. Computing and mathematics are sciences often used for the processing and analysis of primary data (see STATISTICS IN ARCHAEOLOGY), as well as to develop predictive models (see PREDICTIVE MODELING).

It is important to differentiate between *archaeological science* on the one hand, and *scientific archaeology* on the other. Advocates of scientific archaeology predicate the conviction that archaeology should model its methods of inquiry and inference upon those of the natural sciences, irrespective of whether the strategies employed to generate the data are borrowed from advanced science and technology or not. For example, scientific archaeologists often try to falsify hypotheses using archaeological evidence, and apply theories from evolutionary biology to generalize about past cultural behavior. Conversely, archaeological science refers to the development and application in archaeology of techniques and concepts drawn from the natural sciences and engineering, without exclusive reference to any theoretical persuasion. As such, an archaeological project may be framed in postpositivist and relativist theory, and hence negate the possibility of offering any objective facts or generalizations about the past, but still incorporate data obtained with scientific instruments.

Archaeometry (see ARCHAEOMETRY) is often used as a synonym of archaeological science, although the former term tends to be restricted to the study of sites and inorganic materials rather than biogenic materials. Another relevant term is *heritage science*, which is defined as encompassing "all technological and scientific work that can benefit the heritage sector, whether through improved management decisions, enhanced understanding of significance and cultural value, or increased public engagement" (Williams et al. 2013, 7). Even though some claim that archaeological science is a subdiscipline within heritage science, in practice both fields can share methods but tend to be very different in their aims, scope, and study objects: While archaeological sciences are mostly concerned with making inferences and answering questions about past societies, heritage science tends to be more concerned with the preservation, management, and public

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use of individual heritage items in the present. There are, however, many synergies and overlaps among all of these fields, and sometimes the term employed by a particular researcher or team may respond more to academic traditions or branding than to real distinctions.

Natural scientists applied scientific reasoning to infer the relative ages of some archaeological sites from the late-seventeenth century, some 200 years before the emergence of archaeology as a discipline. By the early twentieth century, pioneer geoarchaeologists, dendrochronologists, zooarchaeologists, and archaeological palynologists sought close cooperation with archaeologists, often doing joint fieldwork with them. Numerous scientists also contributed occasional studies of archaeological materials such as ceramics or metals, though many of these were published as unintegrated appendices. By the 1960s, laboratory-based chemical, provenance, and dating studies were widespread in Europe and America, partly thanks to a renewed optimism about the potential of science in archaeology, and to concerted efforts to ring-fence and fund archaeological science projects (Killick and Young 1997). However, inflated expectations and problems of cross-disciplinary communication led to some frustration and failed efforts, with scientific data often devoid of archaeological interpretation or significance, and not incorporated in core archaeological narratives. The problem was often blamed on the reluctance of scientists to engage with archaeological concerns, although many archaeologists were also guilty of failing to learn about the potentials and problems of science and technology so that they could make more informed requests (Olin 1982). These disagreements led to a backlash against what was perceived by some as an intromission of scientists in archaeology. The retreat was fueled by a growing influence of postmodern relativistic theories in the archaeology of the 1980s and 1990s, which seemed incompatible with the claimed objectivity of science (De Atley and Bishop 1991; Jones 2002). Since 2000, archaeology and science have been increasingly integrated, and the majority of the most significant research topics and findings in archaeology have input from the sciences in both their conception and implementation. This is in large part due to the growing institutionalization of training in archaeological science, with university degrees that are explicitly concerned with both archaeology and science, and which typically involve staff from different backgrounds and/or departments. As a result of this process, there is a generation of graduates with interdisciplinary training that are ideally suited to facilitate synergies (Martinón-Torres and Killick 2015; Pollard and Bray 2007).

While some archaeologists still see the sciences as a subservient partner whose only role is to produce data, interdisciplinary archaeological scientists have made countless contributions to archaeological research agendas, theories, and models, often driving major developments in the discipline. For example, a surge of research on ancient models of trade and exchange in the 1980s was encouraged by the availability of geochemical provenance studies, which allowed linking artifacts to their source. Discussion of diffusionism versus independent development of multiple phenomena was initially stimulated by developments in dating techniques and, more recently, by high-resolution characterization of technological traditions that can inform about modes of knowledge transmission. Comparative approaches to plant and animal domestication, their pace and cultural significance are led by better sampling strategies, improved microscopy and, increasingly, DNA and statistical reanalysis of legacy radiocarbon dates. It is generally accepted that human evolution can only be understood by drawing on theories and data from science-based anthropology and biology. Core archaeological subjects of clear relevance in the contemporary world, such as agency and identity, are best informed by the combination of genetic, geographic, and cultural data enabled by the archaeological sciences (Martinón-Torres and Killick 2015).

This picture is applicable, to different extents, to the academic and institutional environment in the United Kingdom and United States, in addition to some universities and research centers in Belgium, France, Germany, Italy, Scandinavia, Spain, Israel, South Africa, China and Japan (Killick 2008). In these contexts, attempting to demarcate archaeological science as a branch separate from mainstream archaeology is becoming increasingly irrelevant, since very few would deny that archaeology, like any other academic discipline, only realizes its full potential when empowered by science. However, the growth of archaeological science is geographically uneven, with many developing countries lagging behind because of difficulties in access to instrumental facilities and relevant training. As such, the development of balanced international partnerships has been identified as one of the major challenges for archaeological sciences in the medium term (Killick 2015). Another major hindrance for the development of archaeological science in some countries has been the reluctance by some governments to allow invasive sampling of heritage objects and/or the export of samples to countries with suitable laboratories. Even though portable and noninvasive analytical techniques have made major strides to overcome these problems, some fundamental techniques still require samples. Most archaeologists favor negotiated decisions that consider the uniqueness of the objects and their heritage value but also the enhanced information and public interest obtained through scientific analyses.

The interdisciplinary collaboration between natural sciences and archaeology has also led to an increased acceptance of the protocols of science as benchmarks for the quality of archaeological research, particularly as regards rigorous data acquisition, reproducibility, and curation that may facilitate validation and reanalysis. The impact of archaeological theories and inferences in the sciences has been more limited, however, and this is another area with great potential for future developments: While archaeology has contributed to reformulations in ecology, including key input to current discussion of the Anthropocene and the management of climate change, scientists are yet to take significant notice of archaeological lessons in other crucial arenas. These arenas include, among others, a time-deep understanding of the contexts that trigger creativity and innovation, the development of productive and socially responsible forms of public engagement, and the use of flexible research frameworks that take advantage of science but accept more methods than the deductive-nomological prescription.

SEE ALSO: Heritage Ethics; Philosophy of Science; Scientific Practice

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Bioarchaeology

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Today, the field of bioarchaeology is generally understood to encompass a broad range of methodologies that extract biological and cultural information from archaeological human skeletal remains. Although the term was first applied in the broader context of any biological data recovered from archaeological sites, such as paleobotanical remains (see PALEOETHNOBOTANY), faunal remains (see ZOOARCHAEOLOGY), and other indicators of paleoenvironment (Clark 1972), this usage has given way to a narrower focus on human skeletons and mortuary contexts as a source of data. The term "bioarchaeology" was first applied to human remains in this sense by Buikstra (1977). Thereafter, the field emphasized the bridging of biological and cultural data obtained from human remains, especially as applied in a populational perspective. Thereby, bioarchaeology was distinguished from the traditional descriptive osteological report typically published as an appendix to an archaeological site report and from "osteobiography" (Saul 1972) that emphasized individual life histories. This new discipline was situated in the more evolutionary context of population biology that laid the framework for the "New Physical Anthropology" (Washburn 1951) and was also allied with the growth of processual archaeology. Thus, one can consider bioarchaeology to be an endeavor that bridges between physical (biological) anthropology and archaeology.

Despite focusing on human remains as a source of biological data, bioarchaeology emphasizes the cultural context of human remains and archaeological theory building as sources of research hypotheses. Hence, bioarchaeological research designs of the later twentieth century, and, in particular, North America and the United Kingdom, emphasized the use of skeletal data to address cultural questions about major demographic transitions, such as the adoption of agriculture (Cohen and Armelagos 1984), the arrival of Europeans in the Americas (Larsen and Milner 1994), and the emergence of social complexity (Steckel and Rose 2002). The new millennium has seen a return to questions of individual life histories and biocultural aspects of identity, and has embraced studies of paleomobility and population genetics.

Osteology and paleodemography

Bioarchaeology is rooted in the study of the human skeleton, called osteology (see OSTEOLOGY), and begins with the excavation of human remains in archaeological sites (see BURIAL EXCAVATION and COMMINGLED HUMAN REMAINS) and an attempt to understand the mortuary or funerary context (see MORTUARY ANALYSIS) in which they were encountered. In addition to evaluating the depositional history of the remains, human osteologists attempt to identify the age at death and skeletal sex of the remains they examine.

For remains that are not skeletally mature, age is typically estimated by reference to dental development (see ESTIMATING SUBADULT AGE: DENTAL DEVELOPMENT AND ERUPTION), growth of limb bones (see ESTIMATING SUBADULT AGE: DIAPHYSEAL LENGTH), or maturation of epiphyses (see ESTIMATING SUBADULT AGE: EPIPHYSEAL UNION). Ongoing research in human skeletal biology and growth and development has led to a variety of new methods and standards for such age assessment in recent years. For remains of adults, the age-related deterioration of the skeleton occurs more variably; however, research continues to refine methods to assess age using the cranial sutures, pubic symphyses (see ESTIMATING ADULT AGE: PUBIC MORPHOLOGY), and auricular surfaces of the ilium (see ESTIMATING ADULT AGE: AURICULAR SURFACE MORPHOLOGY), among other features. Recent publications emphasize Bayesian statistical treatment of skeletal age characteristics to obtain probabilistic estimates of age at death (see ESTIMATING ADULT AGE: TRANSITION ANALYSIS).

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Identification of sex from skeletal remains is usually limited to adult skeletons or those nearing skeletal maturity. Dimorphic features of the cranium and pelvis (see ESTIMATING SKELETAL SEX: CRANIAL AND PELVIC MORPHOLOGY) are most useful for sexing adult skeletons, although metric dimensions of the postcranial skeleton (see ESTIMATING SKELETAL SEX: METRICS) are also useful if appropriate population-specific reference data are available. Although some skeletal features may be dimorphic in children, considerable interpopulation variation and conflicting study results lead most workers to shy away from making such assessments. However, sex assessment using ancient DNA is quite promising (Faerman et al. 1998) (see CHROMOSOMAL DNA).

Age and sex assignments form the basic data used in paleodemography (see PALEODEMOGRAPHY), especially life table (see LIFE TABLE ANALYSIS) and hazards analyses (see PALEODEMOGRAPHY AND HAZARDS ANALYSIS). Together with archaeological indicators of population growth and decline, paleodemography gives considerable insight into the population dynamics of past societies through time, and the consequences of human adaptation to environmental contexts.

Biodistance

Human remains provide the possibility of understanding the evolutionary relationships between ancient societies and peoples. Such "biodistance" studies (see BIOLOGICAL DISTANCE) attempt to measure the extent of biological separation, and conversely the shared ancestry and intermixture among ancient skeletal remains across both geographic and chronological space. Until the last few decades, such work emphasized the size and shape of the cranium (see CRANIOMETRY) and teeth (see DENTAL METRICS) as well as morphological traits of the skeleton and dentition (see DISCRETE TRAITS). Both approaches have helped flesh out population dynamics in prehistoric North America and Europe. Recent advances in the recovery, authentication, and interpretation of genetic material from ancient skeletons (see GENETICS: ANCIENT) and teeth have begun to provide more detailed understanding of human diversity than was possible from early studies of mitochondrial DNA alone (see DNA: NEXT GENERATION SEQUENCING). New methods for sequencing DNA, called "next generation sequencing" (see DNA: MITOCHONDRIAL), now permit rapid sequencing of many fragments of DNA from a single sample, which ultimately allows reconstruction of partial genomes (see GENOMICS: ANCIENT) and more detailed biodistance analysis of ancient remains.

Paleomobility

Geochemical approaches to document population movement are an important new complement to paleodemographic and biodistance research. Ratios of the stable isotopes of strontium ($^{87}Sr/^{86}Sr$) (see MOBILITY AND STRONTIUM ISOTOPES) and lead ($^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$) (see MOBILITY AND LEAD ISOTOPES) are incorporated into bone mineral in proportion to their abundance in foods. Since these ratios reflect the geological origins of soils on which plant foods have grown, they preserve a geological signal in the bone or tooth mineral. Similarly, stable oxygen isotopes reflect the geographic and climatological origin of water imbibed, and are an important complement to the above methods. The stable isotope ratios of oxygen ($\delta^{18}O$) (see MOBILITY AND OXYGEN ISOTOPES) provide an important additional source of paleomobility data, but are affected by nursing and cultural practices, so are somewhat more challenging to interpret than the heavy Sr and Pb isotopes.

Paleodietary reconstruction

Direct measures of food consumption through chemical analyses of human remains have flourished since the 1980s. An early focus on the relative concentrations of the alkaline earth elements (strontium, barium, and calcium) in bone mineral (see DIET AND TRACE ELEMENTS) has given way to measurement of stable isotope ratios in bone collagen and tooth and bone mineral. Elemental analysis has been put aside largely due to concerns about both the effects of diagenesis (elemental exchange with the burial environment (see DIAGENESIS OF BONE)) on alkaline earth ratios and uncertainty about interpretation of observed patterning. Diagenesis can also be a problem for isotope ratios; however, isotope signatures are somewhat more straightforward to interpret. Stable carbon isotope ratios ($\delta^{13}C$) (see DIET AND CARBON ISOTOPES) in bone collagen and skeletal mineral reflect the intake of foods with disparate content of the two stable isotopes of carbon, ^{13}C and ^{12}C. Such $\delta^{13}C$ ratios vary among plants due to enzymes used in varied photosynthetic pathways. This approach has been especially helpful in the Americas where maize (*Zea mays*) stands out as nearly the only major ancient cultigen with a distinctive $\delta^{13}C$ ratio. Stable nitrogen isotope ratios ($\delta^{15}N$) of animal tissues are enriched in ^{15}N compared to the proteins consumed, and therefore measure sources of dietary protein (see DIET AND NITROGEN ISOTOPES). A newer addition to the isotopic toolkit, the stable isotopic ratios of sulfur in bone collagen ($\delta^{34}S$), is useful to isolate proteins from aquatic sources in the diet (see DIET AND SULFUR ISOTOPES). Together, these methods have enabled a much more precise understanding of food intake by individual participants of the past, and of ancient paleoecology.

Infant feeding and childhood growth

Paleodietary research that compares carbon and nitrogen isotope signals in skeletons of differing ages at death has shed light on the diets of infants and children and developed into the study of breastfeeding and weaning in the past. This approach has been extended to include the use of oxygen isotopes (see INFANT FEEDING) in dental tissues, which form in infancy and childhood, allowing researchers to track water intake, nursing, and dietary changes during childhood within an individual.

The consequences of infant feeding and nutritional practices on health through the lifespan have been a longstanding interest in bioarchaeology (see INFANT FEEDING). Infant health has been studied both by examining the remains of infants and though the study of dental enamel hypoplasias, which are defects formed in tooth enamel due to growth arrest during childhood (see DENTAL DEVELOPMENT). Completed skeletal stature (see STATURE ESTIMATION) provides a long-term index of growth achievement. Together, these approaches shed light on the processes of morbidity and mortality that form the basis of demographic change in ancient and modern societies.

Paleopathology

Evidence of ill health during life is often recorded in the skeleton; however, it is important to underscore that most morbid conditions leave little mark on the skeleton (see PALEOPATHOLOGY). Although some conditions, such as certain bone cancers (see CANCER) and congenital conditions, leave distinctive skeletal features (see CONGENITAL CONDITIONS), most nutritional (see ANEMIA and MALNUTRITION) and metabolic (see METABOLIC DISEASE) conditions leave much less obvious signs in the skeleton and most infectious conditions (see INFECTIOUS DISEASE) cause nonspecific bony reactions. Careful differential diagnosis (see DIFFERENTIAL DIAGNOSIS) of skeletal anomalies is necessary to identify the health challenges affecting past communities. In the unusual case where soft tissues are preserved through mummification, imaging studies may aid diagnosis (see IMAGING IN HUMAN REMAINS), and parasites may also be preserved in or on the body (see PARASITOLOGY). Dental caries, abscesses, and calculus deposits can provide indications about oral health (see ORAL HEALTH) and dietary practices.

Behavior

Paleopathology may also shed light on past physical activity and behavior. For instance, bones fracture in characteristic ways depending on the stresses they are placed under (see TRAUMA), and their occurrence is unequal among archaeological skeletal populations. Similarly, bony joints degenerate with age and repetitive motion (see DEGENERATIVE JOINT DISEASE). Together with study of muscle attachment sites that remodel when placed under functional pressures (see MUSCULOSKELETAL STRESS MARKERS), bone architecture and cross-sectional geometry (see CROSS-SECTIONAL GEOMETRY) reflect behavior and activity to a degree, and may shed light on differing lifeways at the population or subpopulation level.

There has also been considerable interest in cultural modifications of the human skeleton since the earliest archaeological work, and intentional cranial shaping (see CRANIAL SHAPING) and esthetic decoration of the teeth (see DENTAL DECORATION) continue to be frequent subjects of bioarchaeological work. Recently, these have been key components of archaeological theory building that emphasizes exploration of ancient ideas of embodiment (see EMBODIMENT) and the symbolic role of the body in cultural discourses of the past.

Ethics

Bioarchaeology too must grapple with ethical questions concerning how the study of human remains intersects with culturally appropriate treatment of the deceased, often requiring considerable efforts at collaboration and negotiation with descendant communities. Often, repatriation of remains may be required after study, a compromise that makes clear the need for detailed and standardized data recording of osteological, chemical, and genetic data such that these would be available for future comparative study.

SEE ALSO: Bodies and Embodiment; Coprolites; Embalming; Heritage and Human Rights; Human Growth and Development; Human Lives and Deaths; Human Skeletal Geochemistry; Sampling Theory; Sequencing DNA; Three-Dimensional (3D) Facial Reconstruction; Zooarchaeology and Ancient DNA; Zooarchaeology and Human Trade and Migration; Zooarchaeology and Stable Isotopes

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