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INTRODUCTION TO ENVIRONMENTAL ARCHAEOLOGY

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Introduction to Environmental Archaeology

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Preface

Introduction to Environmental Archaeology is based on a set of lecture notes from an introductory course on environmental archaeology given in English to students in Central Europe. Each chapter represents one week of lecture. This 'book' falls between a textbook and lecture notes and is definitely not intended to replace standard reference texts on Environmental Archaeology, some of which are used as required and recommended reading and others of which are listed at the end of the book. Nor is it intended to be a stand-alone text. Rather it serves as a set of 'class notes' for students who presumably have attended the lectures and read the assigned readings. It should supplement the required and recommended literature, and provide illustrations and examples from in-class teaching materials.

Environmental archaeology is the study of human-environmental interactions and the science of reconstructing past environments and the relationships between past societies and the environments they lived in. The relationship between humans and the environment is an ongoing concern for politicians, environmental activists, scientists, the public, and people who make their living from the earth. Are humans over-using the earth's resources, or damaging the environment to the point of global catastrophe? One of the strengths of archaeology is the ability to study how humans have transformed the environment, and how environments have in turn altered human culture, over thousands of years. The course that this book supports introduces the concepts and methods used in environmental archaeology, giving students an informed understanding of the paleoenvironment as a context for archaeological research. In addition, it addresses the integration of environmental data with archaeological and anthropological questions.

The course covers the basic topics in environmental archaeology with extensive readings from textbooks and digital encyclopedias, as well as case studies from scientific journals, which should supply comprehensive coverage of the methods and concepts. These readings are provided to course participants, but should also be accessible to most students through university libraries or open access. The final weeks of the course typically include class discussions about climate change, human ecodynamics, societal collapse, and cultural and ecological resilience, among other topics. Some suggested readings are provided in the selected bibliography, but there are no lecture notes for these. The course itself is constantly updated to reflect current understandings of environmental change and human-environment interactions, as well as methodological improvements or innovations. Therefore, this text must be taken as reflecting the state of knowledge in 2020 when it was last taught. Errors, omissions, and decisions to include or omit subjects, methods, or other books belong to the author.

Part 1. Introduction and Overview

Chapter 1. Introduction and overview of Environmental Archaeology

In this book, you will be introduced to the aims and objectives of Environmental Archaeology, as it is understood by the author and with particular emphasis on the prehistory of North America and Central & Southeast Europe. If you read the preface, then you know that this text is intended to supplement an introductory course in Environmental Archaeology. An outline to the rest of the course will introduce the different kinds of environments, human cultures, and theoretical approaches for reconstructing past environments and human-environmental interactions.

What is Archaeology?

This book, and its author, approach archaeology as the study of the human past through material remains, from human origins to the present day. Archaeologists analyze the interactions between people, artifacts, and the environment (including all living and non-living entities), in all times and places, to gain a broad and systematic understanding of human culture. In addition, archaeologists are interested in the organization, operation, and evolution of human societies.

In Central Europe, archaeology is a historical science and forms its own discipline within universities and research institutes. Generally, archaeology has been divided into prehistory, classics, and historical archaeology. The question raised by this classification is whether prehistorians aren't doing archaeology (prehistorical archaeology). How does one get to the evidence of pre-history, if not via archaeology? In some other traditions, particularly in North America, archaeology is part of anthropology, as a larger social science tradition. Anthropology is the "science of man", the study of humans, human behavior, and human societies in the past and present. Anthropology in Central Europe usually means biological anthropology; cultural anthropology is referred to as ethnology. In the Americanist tradition, Anthropology includes cultural and biological anthropology, linguistics, and archaeology. Classical archaeology is typically found in departments of classics.

These disciplinary and education traditions raise an interesting question. Is archaeology a science, history, or humanity? The North American tradition places archaeology as a Social Science, between the natural sciences and the humanities, focusing on society and human interactions. The benefit of this approach is the bringing of natural science methods and data together with social and humanistic questions. Bringing these very different approaches together creates an inter-disciplinary discipline, which can be as difficult as it sounds. Is archaeology "trans-disciplinary"? Do we transcend disciplines? So far, at least, this author says no, we have not. This is in large part due to disciplinary boundaries within university faculties, funding bodies, and museums, most of which require that teaching, research, and even display be done within one discipline or a cluster of similar disciplines.

Anthropological archaeologists use scientific methods to understand social phenomena and provide a holistic account of humans and human nature. Scientific epistemology is essential for research in archaeology, and particularly for Environmental Archaeology. At the same time, attention to social and historical questions is essential for interpretation in Environmental Archaeology. Environmental archaeologists use scientific methods to understand social and natural and provide a holistic account of human-environmental interactions.

Environmental archaeology

What is environmental archaeology?

Environmental archaeology is here considered as an interdisciplinary methodology for the study of past human relationships with the natural world and the study of interactions between people and their physical environment. Included in this is the reconstruction of past environments, landscapes, and the human ecosystem. As such, it includes botany, zoology, and geology in archaeo forms. It also includes using these subfields to study specific aspects of the environment, such as climate, vegetation, the microbiome, and geomorphology.

The premise of environmental archaeology is that humans interact with the environment in all of their daily activities. Human activities cause environmental changes that can be identified and analyzed. Environmental archaeology attempts to reconstruct the total environment of a past society, and to understand human impact on, and changes to, that environment. In addition, some environmental archaeologists contribute to understanding human cultural and biological adaptations to environmental change.

Environmental Archaeology

- is "directed toward understanding the ecology of human communities"
- "interprets human behavior set in an environmental framework that includes broad social, spatial, temporal, physical, and biotic parameters"
- "emphasizes systemic relationships among peoples and their environments"

- includes both cultural and non-cultural environments
- is cross-disciplinary – many specialized fields of research contribute to Environmental Archaeology (palaeoclimatology, geology, paleobotany, zoology, human biology, soil science
(quotes from Dincauze 2000 and Reitz et al. 2008)

What is the environment?

The environment encompasses all the physical and biological elements and relationships that impinge upon a living being (Dincauze 2000: 3). It is the complex of physical, chemical, and biological factors that act upon an organism or an ecological community and ultimately determine its form and survival.

Natural vs. Cultural Environment
The total environment includes human (social/cultural), non-human biological, and physical aspects. Physical environment: non-biological elements of the total environment created or modified by natural forces (abiotic).

- Biological environment: those elements of the total environment consisting of living organisms (biotic).
- Cultural environment: those elements of the total environment created or modified by human culture (anthropogenic).
- Built Environment: similar to the cultural environment; the human-made space and structures in which people live and work (e.g. buildings, parks, pollution).

These are frequently grouped into two opposing groups: nature vs. culture. In this book, we reject this opposition and instead accept that nature and culture are inseparable. Human societies and ecosystems are interacting and interwoven complex systems that co-evolve when changes in one system result in selective pressure to the other (Fitzhugh et al. 2019; Gunderson & Holling 2002; Van der Leeuw & Redman 2002). Such approaches are referred to as human ecodynamics, socio-natural systems, and socio-ecological systems, among others.

Ecosystem

An Ecosystem is a community of living organisms (biotic) and its nonliving components of the physical environment (abiotic; e.g. air, water, and mineral soil), interacting as a system. The human ecosystem is "the environmental matrix and of its potential spatial, economic, and social interactions with the human subsistence-settlement system" (Butzer 1982: 12). This transcends the traditional preoccupation with artifacts and with sites in isolation and focuses on the interdependence of cultural and environmental variables.

Definitions

Ecofact: any organic (floral, faunal) or inorganic (mineral) material found at an archaeological site.

Paleoenvironment: the ancient environment, which can be reconstructed using techniques such as archaeozoology, palynology, and geoarchaeology. Often, reconstruction is achieved by analyzing proxies and correlates.

Proxies: preserved physical characteristics of the environment that can take the place of direct measurements. Proxy data comes from natural records of climate variability such as tree rings, ice cores, fossil pollen, ocean sediments, and corals, as well as from archaeological and historical data.

Correlates: interrelated things where one implies the other, suggest a causal relationship between two things. In archaeology, remains that suggest a related behavior.

An ecofact is any organic (floral, faunal) or inorganic (mineral) material found at an archaeological site. In some cases, mineral components are called geofacts. Such material has not necessarily been technologically altered but is associated with human cultural activities. Shell carried from the ocean, seeds, pollen, animal bone, insects, fish bones, molluscs, rocks, sediments, and soils can all qualify as ecofacts. Are these not artifacts? If people moved soil and built a mound, the soil becomes sediment and has been changed by human action (anthropogenically altered), as well as being of cultural relevance (soil as material culture, Salisbury 2012; 2016). The concept of 'ecofact' relies on a narrow view of artifacts as things made by people. Despite this, it is widely used in environmental archaeology. In any case, artifacts, ecofacts, and geofacts are archaeological materials with relevance to human beings, cultures, and societies.

Context

"Environment as context for human actions" (Dincauze 2000: xvii). Context has several meanings within evidence-based archaeology.

- Context: the spatial and chronological position and relationships of artifacts, ecofacts, features ... anything.

- Contextual Archaeology: the study of archaeological phenomena as part of the human ecosystem (Butzer 1982).
- "a four-dimensional, spatial-temporal matrix that comprises both a cultural and non-cultural environment" (Butzer 1980: 418).
- Systemic context: the past living society; artifacts and features as they functioned in the system that produced or used them (Schiffer 1972).
- Archaeological context: what we study today; the remains of the systemic context (Schiffer 1972).

Fields of specialization

Environmental archaeology is commonly divided into three broad sub-fields:

- Archaeobotany: the study of plant remains.
- Zooarchaeology: the study of faunal remains; the study of the relationships between humans and animals over time.
- Geoarchaeology: the study of geological processes and their relationship to the archaeological record.

Other related fields include:

- Environmental Isotopes
- Chronology
- Climatology

Each of the subfields and related fields is the subject of a chapter in this text. They are briefly summarized here as an aid to understanding the larger discipline, or sub-discipline. It is also worth noting that Geoarchaeology is not always and everywhere seen as a subfield of environmental archaeology. On the contrary, and following Karl Butzer (1982), some aspects of environmental archaeology can be seen as subfields of Geoarchaeology. This is particularly true when proxies for environmental reconstruction are recovered from sediments using geoarchaeological methods.

Archaeobotany is the study of botanical (plant) remains, including seeds, pollen, phytoliths, charcoal, and wood from archaeological contexts. It includes not only the plants that people used (domesticated or wild) but all plants in the environment. The major subsections of archaeobotany include

- Macrobotanicals (macroscopic plant fragments, such as seeds)
- Palynology (pollen and spores)

- Phytoliths (microscope silicate remains of plant cells)
- Diatoms
- Anthracology (wood charcoal)

Zooarchaeology, or archaeozoology, is the study of faunal (animal) remains, including bones, shells, insects, and fossils from archaeological contexts. It includes the identification of species and analysis to reconstruct the environment, human diet, domestication, and the importance of animals in past economies. The major subdivisions of zooarchaeology include

- Animal bones
- Malacology (molluscs)
- Microfauna (ostracods, foraminifera)
- Entemology (insects)

Geoarchaeology is the study of geological material, including soils, rocks, and artifacts from archaeological contexts using methods and concepts from geology, physical geography, and other Earth sciences. Subdivisions of geoarchaeology are many; major ones discussed in this text include

- Solid geology (rocks)
- Sedimentology
- Soil chemistry
- Micromorphology

Geoarchaeological field methods are important to the interpretations of all methods and data in environmental archaeology, and arguably in archaeology more generally. These include

- The systematic description of cross-sections and profiles to reconstruct stratigraphic events, stratigraphic variations, and formation processes inside and outside of the archaeological site.
- Off-site locations where lithostratigraphic and pedological evidence can be collected,
- studies site surroundings, and
- sampling for later sedimentological, soil chemical and micromorphological analysis and dating.

In the lab, geoarchaeologists conduct sedimentary grain size analysis, soil chemistry (organic matter, phosphate, trace elements, bulk density, magnetic susceptibility), and soil micromorphology (thin-section analysis). For example, anthropogenic phosphates (soil P) are used to locate sites, identify vertical and horizontal site boundaries, and interpret archaeological deposits. Phosphates

- are present in each plant and animal cell,
- deposited with urine, excrement, bone, and other organic material,
- tend to accumulate quickly,
- have low solubility and mobility, and
- fix quickly within the soil profile and can remain in place for millennia.

Geomorphology, in archaeology, is a subfield of geoarchaeology focusing on the origin, evolution, form, and distribution of landforms (topographic and bathymetric) created by physical, chemical, or biological processes. These processes include

- Erosion
- Colluviation
- Deflation
- Lake floor

Stable isotopes in archaeological materials and archaeological contexts are studied to reconstruct environmental conditions, pollution, diet, and mobility. Commonly used stable isotopes include

- Strontium
- Oxygen
- Carbon
- Nitrogen

However, several other stable isotopes also contribute to archaeological investigations, including sulfur, lead, and hydrogen.

Chronology is a related subfield of environmental archaeology. Chronology involves the study of material from archaeological contexts to determine the chronological age or the seasonality of human activities. Several of the methods derive from geology or geochemistry and can be considered as geoarchaeological. These include

- Radiometric isotopes (14C, K/Ar, U/Th, fission track)
- Trapped charge (Luminescence; OSL, TL, ESR)
- Incremental (tree rings, varves, tephra)
- Calibrated relative chronology (Archaeomagnetism, OCR, amino acid racemization, obsidian hydration, fluoride absorption)

Dendrochronology is another chronological method. Related more to archaeobotany, dendrochronology is part of dendroarchaeology, which provides data for chronology, resource use, and environmental reconstruction. Dendrochronology is the chronological analysis of wood from the past, regardless of its current physical context, and is commonly called tree-ring dating. Dendroarchaeology also includes the study of vegetation remains, buildings, wells, artifacts, furniture, art, musical instruments, and any other wood from archaeological contexts. Wood species identification contributes to reconstructing what plants were available to people, and what plants people used.

Archaeo-climatology is the study of changes in climate in relation to human activity over human timescales. In addition to historical records, the application of palaeoclimatology or historical climatology to specifically archaeological periods and questions involves the analysis of

- lake and marine sediments
- tree rings
- ice cores
- speleothems
- macro-fossils (molluscs)
- micro-fossils (pollen, ostracods, diatoms)
- alkenone

Sampling

Each theme and method will present sampling strategies, challenges, and potential biases or contamination issues for each set of methods and proxies. However, the most common sampling method for environmental samples is coring, followed by bulk sampling from excavations, sampling for thin-section, and samples for chronology.

- Coring
    - palynology
    - isotopes
    - chronology
    - malacology
    - microfauna
    - sedimentology
- Bulk sampling
    - flotation
    - soil chemistry
    - micro-charcoal

    - chronology
- Micromorphology
- Dating
    - OSL
    - 14C
    - U-series

Inference, critical thinking, and scientific writing

To do environmental archaeology we must write scientifically, and we have to remove our personal biases – as much as possible – and focus on what the facts are. We must read and think critically. Sometimes what the facts appear to be is not reality, but we must try. Here is one example. Davos, climate change, and environmental policy. Hundreds of world leaders flying with their entourages in private jets to Davos are bad for the environment, even if they talk about fixing the environment. To be critical is to ask why the one climate recommendation is that other people fly less often.

Inference and Critical Reading

An "inference" is a determination arrived at by reasoning. Inference to best explanation (Lipton 2000) is to infer from the available evidence to the hypothesis that, if correct, would best explain that evidence. We infer, for example, from changes in pollen, changes in sedimentation rates, and the presence of a Neolithic settlement, that Neolithic farmers caused a change in the trophic status of the lake where they lived (eutrophication).

Most people are not natural 'critical thinkers', because humans evolved to be estimators (not calculators). We evolved to survive lions and poisonous mushrooms, not to debate whether lions also need to eat, or what positive role poisonous mushrooms might have in a properly functioning ecosystem. Therefore, we need to practice critical thinking and critical reading, and learn to be self-critical (e.g. Gibbon 2013).

To read and think critically is to

- understand the logical connections between ideas
- identify, construct and evaluate arguments
- detect inconsistencies and common mistakes (logical fallacies) in reasoning
- identify the relevance and importance of ideas
- recognize bias
- reflect on the justification of our own beliefs and values

In Environmental Archaeology, we need to ask, do the methods fit the questions? Do the conclusions follow from the data? Do I know what the author's agenda or philosophical paradigm is?

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Chapter 2. People and the environment

Readings

- Dincauze 2000 Chapter 1 Environmental archaeology and human ecology (or Reitz & Shackley 2012 Chapter 1; Reitz et al. 2008 Chapter 1)
- Dincauze 2000 Chapter 2 Concepts for environmental reconstruction
- Dincauze 2000 Chapter 3 Mechanisms of Environmental Change

As archaeologists, we rely on the material remains of human activity to answer questions about people in the past. Typically, archaeologists study ***artifacts***, or items that were made and used by humans, as well as ***sites***, or concentrations of artifacts. In environmental archaeology, we study ***ecofacts***, which we have defined as any organic (floral, faunal) or inorganic (mineral) material found at an archaeological site. These have not necessarily been technologically altered, but have cultural relevance. When they have been physically altered by people, these could be considered artifacts. In any case, we are all confronted with the same problems of inference.

A primary emphasis of this course is the relationship between natural systems and human society, and how humans have impacted and been impacted by natural systems at varying scales. This concept requires considering various ways of making a living; that is, different cultural types, and how these cultures interact with various kinds of environments, i.e. different biomes. All human groups have had an impact on the environment: the domestication of plants and animals, the controlled use of fire, the pollution of air and water, and the use of field systems are only some of the ways that people have changed the world around them. It is clear that modification of the immediate environment is fundamental to human culture.

Different kinds of cultures

In this chapter, cultures are categorized by their ways of “making a living”. This focuses not on their ideological or political organization, but on the ways that people supply themselves with food, and to a lesser degree with shelter, clothing, and basic raw materials. Many cultures do not fit neatly into a single category. Rather, they employ several strategies. For example, Neolithic villagers in the eastern Carpathian Basin grew crops, hunted, fished, collected wild fruits, and kept domesticated animals. They are categorized as farmers because they lived and kept animals in sedentary villages, and emphasized domesticated plants in their diet. The categories of making a living include

- Hunter-forager
- Cultivator (horticulturalists)
- Farmer (agriculturalists)
- Herder (pastoralists)
- Urban dweller

As a brief example, people of the Adena culture lived in Ohio, Pennsylvania and western NY c. 800 BC to AD 100 (Early Woodland period in North America). The Adena were early mound builders, constructing burial mounds and large zoomorphic earthworks such as Serpent Mound. They cultivated local wild plants, such as pumpkin, squash, sunflower, sumpweed, goosefoot, knotweed, maygrass, little barley, and tobacco. Most of these are weedy plants with many small, starchy (pseudo-cereal) and oily seeds (Mueller 2018). These plants are called cultigens. Most were never completely domesticated – sunflowers and pumpkins/squash are exceptions – but they were collected and maintained by people. A convincing argument has been made that if women were the primary gatherers of seeds and other plant foods, then they also were responsible for early cultivation of pseudo-cereals and other cultigens (Watson & Kennedy 1991).

Sometimes, aspects of subsistence are complicated by semi-domestication, or strategies that might lead to domestication. One example of this are the Huron, or Wendat, an Iroquoian-speaking people from what is now southern Ontario. In prehistory and early history, they were farmers, growing maize, beans, and squash (kurbis). Most of their protein came from deer. They also used deerskins for clothes, shoes, blankets, and bags, among other things (Trigger 1987). They had domesticated dogs. Did they domesticate deer? If not, why not? They certainly managed deer herds. White-tailed deer are difficult to domesticate because they typically live in family groups rather than large herds. However, they are not difficult to keep around. By feeding them with maize and getting them more or less accustomed to people, they can be herded into enclosures and killed *en masse*.

Major environmental transformation: Glacial and interglacial periods

Major cultural transformations

- Neolithic revolution
- Urban revolution
- Industrial revolution
- Digital revolution

Different kinds of environments

- Temperate plains and woodlands
- Mountains/alpine
- Deserts
- Rivers and Wetlands
- Tropical forests
- Cities / urban
- Coasts and islands

Temperate plains and woodlands include forest-steppe ecosystems with high biomass and high to moderate biodiversity. Soils in these systems are fertile with rich nutrients and minerals. Seasonal changes in temperature and rainfall are common and more or less predictable. Groups living in such systems include the aforementioned Wendat people and Adena culture, as well as Kyrgz nomads on the Eurasian steppes.

Mountains, or Alpine ecosystems, contain varied biomes that are distributed irregularly. People and animals can move relatively rapidly between biomes. Soils are likewise varied but generally thin on slopes and upper ecozones, and thicker on footslopes and valleys. Steep slopes increase the danger of erosion, landslides, and avalanches. A common use of these areas is for transhumant pastoralism, with seasonal mobility of herds between biomes. For example, transhumant shepherds in the Alps move seasonally between valleys and upland pastures. Agriculture is also possible in these areas, often using terrace farming, such as in the Andes (Guillet et al. 1987).

Desert ecosystems receive less than 10 inches of rain and evaporate more than 10 inches of rain per year. They have low biomass, low biodiversity, and low bio-density. Soils are generally sandy or stony with low fertility. Preservation of ecofacts is generally good. Landforms include mountains, sedimentary plains, and exposed bedrock. Making a living in deserts generally requires seasonal mobility around different resources, for example as displayed by the San of the Kalahari Desert (Yellen 1976). However, large, permanent settlements are possible with the use of irrigation farming and extensive trade. The classic examples of this include Chaco Canyon and Casa Grande in the North American Greater Southwest (Fagan 2005).

The arctic is a particularly difficult ecosystem, comparable in some respects to deserts, yet people do make a living in the arctic. Vegetation is dominated by tundra with permafrost with limited drainage and little to no soil development. Biomass, diversity, and density are uniformly low. The landscape consists of high mountains, sedimentary plains, exposed bedrock, and lowlands, and includes the frozen sea ice. Large seasonal differences in amount of sunlight and a very short growing season precludes agriculture; people living in the arctic are hunter-gatherers (Dugmore et al. 2012), such as Thule hunters in prehistoric eastern arctic of North America.

Freshwater biomes include rivers, wetlands, and lakes. Wetlands are the most biologically diverse ecosystem. Wetlands are defined by plant species – an area that is wet enough for long enough to support a majority of plants that are adapted to wet conditions. These include

- marshes
- swamps
- bogs
- fens

Wetlands generally have good preservation of environmental data; for example Must Farm, a Bronze Age site in fens near Cambridge, UK (Knight et al. 2019). Wetlands provide a wealth of resources, including fish, water birds, bird and turtle eggs, turtles, molluscs, and reeds, among others. Wetland agriculture can be as simple as farming the margins or constructing raised fields (Janusek & Kolata 2004). Lakes and ponds are subject to changes in trophic status that can be caused by human activity and can become wetlands over time through eutrophication. Living on lakes and rivers, as well as around them, often include pile dwellings, such as the Prehistoric Pile Dwellings around the Alps on the UNESCO World Heritage list.

Tropical forests have high rainfall, temperature, sunlight, and flooding, with generally two seasons – wet and dry. These ecosystems have high biomass, high biodiversity, and low bio-density. This means that resources are scattered across relatively large areas. As with most other ecosystems, tropical forests can support both hunter-foragers and farmers. In Mesoamerica, for example, people in the past and present use swidden agriculture (slash-and-burn) and raised fields (Dunning et al. 1998; Fig. 2.1).

Fig. 2.1. Boat on canal within chinampas, c. 1912 (photo by Karl Weule, Leitfaden der Voelkerkunde, Leipzig 1912; public domain)

Coasts and islands form a highly varied set of ecosystems. Even in a contained region, such as the circum-Caribbean, islands take on many different sizes, elevations, and micro-regions. People living in these systems tend to rely heavily on marine resources. Archaeological and environmental evidence is preserved in shell middens in many areas of the world. Other data is often found underwater, via sediment coring, LiDAR, and artifacts found in beach sand brought up from off-shore. These settings are in danger of loss through erosion, human recreation, and changing sea levels.

Urban environments, or cities, require a surrounding resource base for food, usually farmers and herders. Many cities have low biomass (except for people) and low biodiversity. An exception to this general rule is the prehistoric Maya, who practiced low-density agrarian urbanism (Isendahl 2014). Environmental proxies are often preserved under pavements or other construction layers.

Interpretation - from data to explanation

Environmental archaeology works, and contributes to many different archaeological problems, because people are always interacting with the environment, and these interactions leave measurable records, or ***proxies***, and because we know something about ***taphonomy*** and ***formation processes***.

Definitions

Proxies: preserved physical characteristics of the environment that can stand in for direct measurements.

- natural records such as tree rings, ice cores, fossils, pollen, molluscs, ocean sediments, and corals
- archaeological and historical data

Taphonomy: any physical, chemical, or biological environmental process that affects an organism after death.

Formation processes: the processes that occur before, during, and after deposition; i.e., all process that contribute to the archaeological context, or archaeological record.

Soil Archive: record of past human and natural activity
Example: Ecse-halom, a Late Copper Age kurgan eastern Hungary (Bede et al. 2015) with a record of the natural geochemistry, soil types, and vegetation c. 3300-2500 BC. |

Soil Memory: how well soil retains traces of chemical and physical transformations. In many settings, chemical and physical elements in the soil are less prone to post-depositional movement (unless the soil itself moves)

- Fine grained alkaline or acidic soils have good soil memory
- e.g. loess and loess-derived soils (chernozem, braunerde)

Analogy: applying observed behavior to non-observed behavior; provides clues, ***not*** explanations (no direct analogies!).

- Based on the assumption that if two things are similar in some respects, then they should be similar in other respects.
- ethnographic or historical information is used to form hypotheses about archaeological cultures

Adaptive Cycle: a conceptual model that helps humans understand the structure and processes of complex system dynamics over time. It consists of four “phases” wherein the system structures, collapses, and reorganizes itself.

Aside from palaeoenvironmental reconstructions and identification of resources, environmental archaeologists contribute to a body of scholarship and interpretation about humans and the environment. Human-environmental interactions, as a general term, covers several concepts that are superficially similar but with distinctive epistemological and meta-theoretical attributes.

- Human ecodynamics
- Human adaptation to environmental conditions
  - biological and cultural coevolution
  - collapse of civilizations
- Ecological adaptations to human habitation
  - Adaptive cycles; panarchy (Fig. 2.2)
  - resilience and sustainability

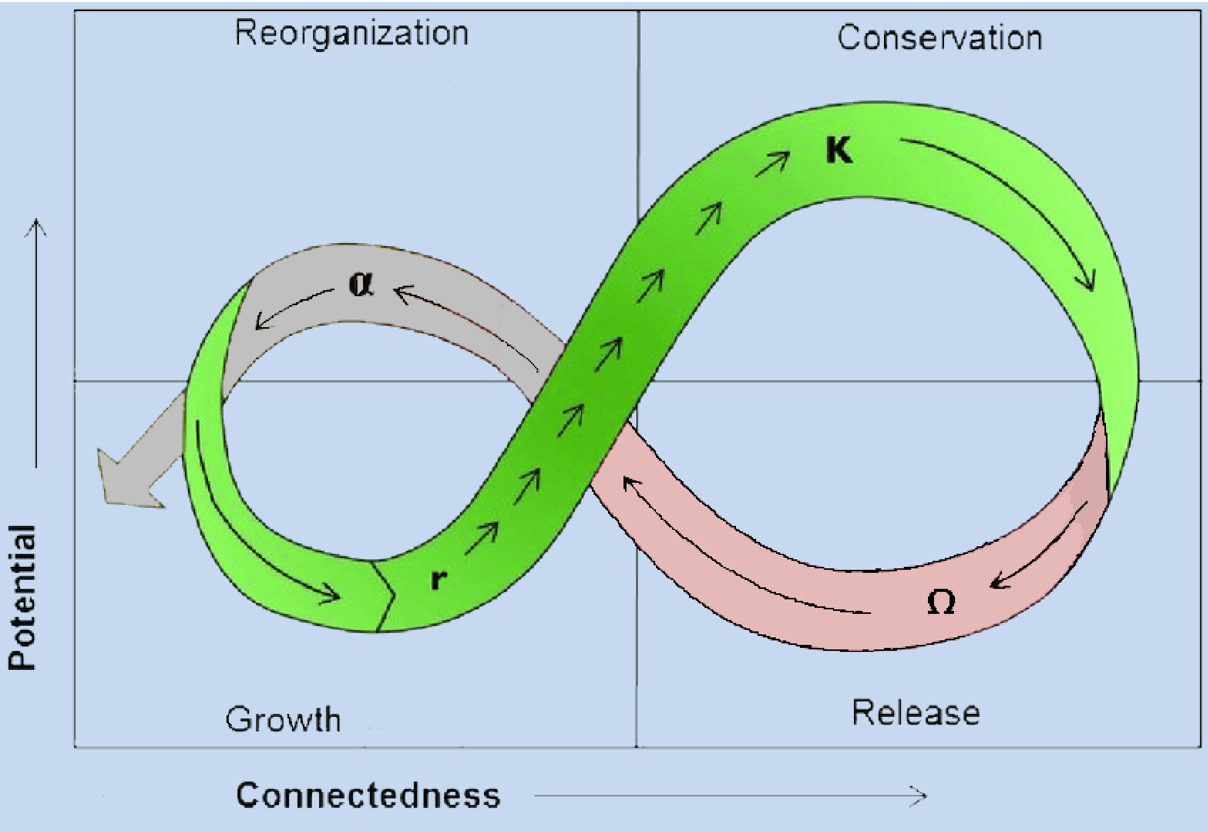

Fig. 2.2. The adaptive cycle, following Gunderson & Holling 2002.

Human-Environmental Interactions

Human-environmental interactions are the processes by which the human social system and the rest of an ecosystem act and react to each other. These human-environmental interactions are diachronic and studying them requires a multi-disciplinary approach.

- Diachronic: change over time
- Multi-disciplinary: combining several usually separate fields of science or kinds of expertise

Several approaches to human-environmental interactions are used in archaeology, including Cultural Ecology, Historical Ecology, Human Behavioral Ecology (HBE), Settlement Ecology, Human Ecodynamics, and Cultural Niche Construction. Most of these conceptual frameworks are transdisciplinary, in that they are used by archaeologists, anthropologists, geographers, and others.

The human social system, or the ***type of society***, strongly influences peoples' behaviour, their attitudes towards nature, and their impact on ecosystems. Important characteristics of human social systems are a society's way of making a living, population size, social organization, ideology (social values), technology, education, and knowledge.

Cultural Ecology is the study of human biological and/or cultural adaptations to social and physical environments and the ways in which culture is used by people to adapt to their environment. The natural environment is thought of as a major contributor to social organization and other human institutions, and similarities or differences in culture are interpreted in relation to the environment (Blute 2008). Although this sounds very environmentally deterministic, cultural ecology was defined more than 50 years ago as "the study of the role of culture as a dynamic component of any ecosystem" (Frake 1962: 53).

Historical ecology focuses on historical patterns of interactions between human society and the environment over long periods of time (centuries or many generations). Two key aspects of historical ecology differ from cultural ecology or human ecodynamics. These differences are (1) a focus on qualitative types of human cultural interconnectedness with natural environments, and (2) the effect of anthropogenic disturbances on the landscape (Balée 2006), rather than on co-evolution of ecosystems.

Human Behavioral Ecology (HBE) examines human cultural and behavioral diversity from an explicitly evolutionary perspective. In this, it differs greatly from historical ecology. The main assumptions of HBE are that genes may influence behavioral tendencies, that people adapt – either biologically or culturally – to environmental pressures, and that people and societies succeed by making rational choices (Winterhalder & Smith 2000).

Settlement Ecology is the study of settlement strategies as part of a complex system of relationships between settlement, population size, subsistence (way of making a living), transportation, and socio-political organization (Kellett & Jones 2017). Unlike the other approaches described here, settlement ecology is exclusive to archaeology. Cause and effect relationships on settlement locations and associated change.

Human Ecodynamics address the dynamics of human-modified ecosystems set within a long-term perspective (diachronic) and viewed as a non-linear dynamical system. Core concepts include coevolution as a never-ending process of mutual adjustment and change between human social systems and the environment, including processes of stability, resilience, and change (Fitzhugh et al. 2019). Human society and the ecosystem are "coupled" in dynamic ways. Terms used for essentially the same conceptual approach include socio-ecological systems and socio-natural systems. Human ecosystems, or socio-natural systems, are complex systems wherein all processes are feedback loops. Complex systems are those having attributes such as being non-linear, emergent, uncertain, multi-scalar, and self-organizing.

Cultural Niche Construction (CNC) is a branch of Niche Construction Theory that addresses the "passive-resource-consumer" flaw of optimization strategies (e.g., Rational Actor Theory, Optimal Choice Theory) by recognizing the active role of foragers in modifying their environments. As the ultimate ecosystem engineers, human societies have been actively modifying a wide range of environments in ways that enhance their resource base for ca. 40,000 years, and one of the most powerful evolutionary forces on earth today (Smith 2011). However, while humans are certainly niche constructors, a good argument can be made that archaeologists should not need a new term or sub-discipline to discuss these facts (Spengler 2021).

Resilience, Sustainability, and Collapse

Resilience refers to the ability of a system to recover from disturbances and to tolerate or adapt to cultural or environmental change. Resilience theory emphasizes the inevitability of both stability and transformation. Neither stability nor transformation is assumed to be the norm; systems are seen as moving between the two in what has been termed an adaptive cycle. Subsequent iterations of the cycle can repeat previous patterns or generate new patterns. Transformation can be revolutionary, leading to fundamentally new configurations, possibilities, and dynamics. Change is neither continuous and gradual nor consistently chaotic; rather, it is episodic with periods of slow accumulation of "natural capital," punctuated by sudden releases and reorganization (Redman 2005). Resilience, as a concept, developed in environmental sciences but is also applied to culture.

Collapse is the sudden, major loss of an established level of socio-political complexity. Typically, this is seen archaeologically as a drastic decrease in human population size, loss of cultural knowledge or social memory, migration away from central places (cities), and/or fragmentation of the political order over a considerable area, for an extended time (Butzer 2012). This must be considered in light of scale, or the size of the society in which it occurs. Simple societies can lose an established level of complexity just as state-level societies. Sedentary horticulturalists may become mobile foragers as easily as empires can dissolve into village agriculturalists (Tainter 1988: 4-5).

Sustainability refers to actions that can be done by people continuously or for long periods of time with little or no adverse impact.

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Part 2. Methods

** Refer to Reitz et al. 2008 for additional case studies for each method or topic.*

Chapter 3. Sampling for Environmental Archaeology

Analyses of paleoenvironmental remains from archaeological excavations and landscapes provide a range of insights into past societies and environments. Therefore, sampling strategies and protocols are an essential part of environmental archaeology and paleoenvironmental reconstructions. This chapter introduces the basics of sampling design for environmental archaeology.

Readings

- Huntley 2018 Sampling in Environmental Studies
- Reitz & Shackley 2012 Ch. 3 Research Design & Field Methods
- Orton 2000 *Sampling in Archaeology* (skim – look for interesting sections)

Environmental data, or proxies, are present in all archaeological contexts. These data can inform about a wide range of topics, from environmental change to prehistoric cultures and historic land use. Sampling for the study of such material should therefore be a part of every archaeological project. Since these proxies and data take many different forms and are influenced by many different factors, a sampling strategy must be developed for each archaeological project and each research question.

Sampling aims to recover a reasonable representation of the remains present in a context.

A good sampling strategy should include:

- asking the right questions (why?);
- which types of samples to take (what?);
- methods for sampling (how?);
- what to consider when taking samples;
- how to store samples.

Sampling strategies

Excavators tend to use judgment, or so-called strategic sampling, wherein samples are taken from deposits expected to be productive. On the one hand, there is no argument that this is practical and provides supporting evidence for interpreting archaeological deposits. On the other hand, strategic sampling alone will not provide new information about otherwise unrecognized contexts. For example, areas devoid of macroscopic features and artifacts are not necessarily empty. Many classes of material are not visible to the naked eye, for example, fish bones, small seeds, or changes in magnetic susceptibility. Appearances can also be deceptive; black deposits might or might not contain charred material. Therefore, it is essential to collect samples from all types of deposits (Fig. 3.1).

The environmental material recoverable from a site will depend on the geology and depositional environment of that site, as well as on the nature of the cultural system that produced the deposits and various post-depositional formation processes (see Chapter 4). For example, sand is a poor sediment for retaining chemical enrichment, and bone does not preserve well in acidic soils. Dry fill, such as in pits and ditches, can be sampled for charred plant remains, while samples for plant and invertebrate remains can be taken from waterlogged deposits, such as in wetlands. Phytoliths and charcoal can be expected in nearly every context. These factors must also be considered when planning the environmental sampling strategy. Some prior knowledge of geology and environmental conditions will improve the sampling strategy.

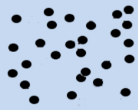
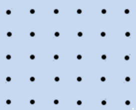
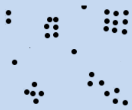
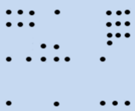
Method		Advantages	Disadvantages
Random		• statistically robust (no intentional bias) • stratified sampling is scalable	• can (randomly) miss areas of interest; • complicated to implement
Grid		• practical in field • easily scalable • uniform coverage • good statistics	• might miss higher resolution detail • generates a lot of data
Strategic		• can support other proxies from samples • can be done on-the-fly	• biased (stats unsound) • might only confirm prior assumptions
Strategic grids		• target interest • compromise between detail and statistical robustness • easy to cover background & features	• can generate interpolation problems (worst case = undetected) • emphasizes researcher bias

Fig. 3.1. Sampling strategies.

3 Qs: why sample, what to sample, and how to sample.

Why sample?

- To answer a research question?
- To save a representative part of the sediment archive?

To

- Reconstruct local environment
- Identify functional use of space and/or archaeological contexts
- Identify agricultural or other subsistence activity
  - e.g., food preparation and consumption
- Identify the use of plants or other environmental resources for purposes other than food
- Chronology
- Contribute to social and cultural questions: ideology, ritual, *inter alia*

What to sample:

Every context (systematic): every layer, feature, surface; every stratigraphic unit.

- Positive – preserves data from destroyed contexts; provides the chance to ask new questions or reanalyze samples in the future.
- Negative – costly in terms of time, money, and other resources; requires lots of storage.

Targeted contexts: sample only contexts that will answer an existing question.

- Positive – easy to justify based on a research project; less expensive in terms of time and money.
- Negative – highly subjective, inflexible, and leads to data loss; permanent destruction of the archive.

How to sample:

- What types of context to sample? (all of them!),
- What is the density of sampling?
- What is the sample size?

Environmental remains are not necessarily homogenously distributed through a given deposit. The best way to collect a representative sample from a context is to take the sample from several different areas within the context (random sampling). A single sample of equivalent size from a single area in a context will be less representative of the context as a whole. How much to sample is context-dependent. That is, it depends on research questions, project resources, and time.

Random sampling assures that every possible subset of the population which has the desired sample size is given the same probability of selection. Gridded sampling is systematic and scalable. Strategic sampling, which is judgment-based, can be randomized at different levels (e.g. house foundation & area around). Other variations exist. For example, strategic sampling can be employed at any stage of fieldwork.

Bulk Samples should be taken from discrete stratigraphic units. Thick deposits can be subdivided into spits and sampled to check for vertical variability. These can be large or small, depending on intended analytical tests. Large samples are collected in quantities of liters from individual excavation units or from vertical sections.

- 10-20 liters in temperate or tropical environments;
- 1-2 liters in waterlogged (anoxic; wetland) or arid (desert) environments;
- 1-2 liters for molluscs.
- These samples are typically used for flotation (Archaeobotany, Zooarchaeology);
- can be sub-sampled for soil chemistry and particle size analysis.

Small samples are collected in quantities of grams from individual excavation units or vertical sections.

- 10-50 grams for ostracods,
- 100-500 g for geoarchaeological analyses,
- 10-20 mm^3 for pollen and spores (archaeobotany),
- 100-500 g separate small samples collected for organic biogeoarchaeology (aDNA, biomarkers).
- Separate small bulk samples are collected for Geoarchaeology (inorganic chemistry, particle size analysis, bulk density analysis), and Archaeobotany (pollen, phytoliths).

Fig. 3.2. Author taking a thin-section sample in the field

Monolith Samples are collected from clean vertical sections as monoliths in tins, Kubiena boxes, or similar containers. These can subsequently be sub-sampled for pollen, spores, diatoms, etc., as well as being used for micromorphological thin sections.

Samples should be taken at a size appropriate for the recovered material and analyses (Fig. 3.2). The tins must be clearly marked top, bottom, north, and exposed side. Photographic, geolocational, and written documentation for geological or environmental samples is essential.

Cores and Core Sampling

Coring is the examination of stratigraphy and sediments using mechanical devices drilled into the stratigraphy from above. These involve borehole surveys, stratigraphic mapping, and sample collection. Sampling intervals again depend on research questions and cost. Samples are extracted from locations such as lakes, peat bogs, paleochannels, and woodland hollows using specialized coring equipment such as drilling rigs, vibration corers, percussion corers, and hand augers. Typical cores are 100 mm diameter and 1 m long. Other coring equipment includes agricultural soil samplers (e.g. Oakfield samplers), gouge augers, and Russian corers, among others.

Core tubes fitted with core liners made of PCV, CAB (cellulose acetate butyrate), or polycarbonate enable entire 1 m long sections to be transported to a laboratory and analyzed in a clean and secure setting. Cold storage of cores lessens the likelihood of decomposition, germination of seeds, and microbial activity. Core splitters enable rapid splitting of most core liner widths. The split cores are then available for subsampling and in situ measurements.

- Multi-Sensor Core Logger: Bartington MS, spectrophotometer, digital camera
- ITRAX - High-resolution XRF analysis of sediment cores

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Chapter 4. Formation processes

Soils and sediments are an archive of past human activity. Over time, many processes influence what kinds of remains are available to be sampled and analyzed, and in what form they are available. A range of 'natural' processes and anthropogenic activities directly affect archaeological contexts, thus changing the available remains. This chapter defines and discusses the challenges posed by cultural and non-cultural formation processes.

Readings

- Goldberg & Macphail 2008 Formation Processes, or Schiffer 1983 Towards the Identification of Formation Processes (the Original, but not as up-to-date)
- Reitz & Shackley 2012 Ch. 2 Processes by which Archaeological Sites Form
- Heilen-Schiffer-Reid 2008 Landscape Formation Processes

Case studies

- Banerjea et al 2015 Micromorphology activity areas and site formation processes
- Friesem et al. 2016 Site Formation Processes & Hunter-Gatherer use of space in a Tropical Environment
- Karkanas et al 2010 Palaeoenvironment & Formation Processes Neolithic Greece

Formation Processes

Site formation processes provide a framework for understanding the formation of artifacts, deposits, and sites (Schiffer 1983, 1987). These are the processes that occur before, during, and after occupation. That is, all processes – natural and cultural, individual and combined – that affected the formation and development of the archaeological record; that contribute to the archaeological context. These include

- natural sedimentation,
- cultural deposition and modification (of everything: artifacts, soils, features, inter alia),
- soil formation (pedogenesis),
- bioturbation.

Formation processes are influenced by time, climate, the topography of the site, and type/complexity of the systemic context (hunter-foragers, farmers, pastoralists, urban industrial, etc.). These have been subdivided into cultural and natural, or non-cultural, processes. Natural formation processes refer to natural or environmental events which govern the burial and survival of the archaeological record. These include taphonomic processes that might alter remains after they are deposited at a site. Cultural formation processes include the deliberate or accidental activities of humans.

Natural Transformation Processes (N-Transforms) are natural events involving physical, chemical, and biological (non-human) processes that affect the context of the material remains. Examples include the accumulation of sand and soil, land movement by rain and water, plant and animal interference, and natural disasters and phenomena such as landslides and volcanic eruptions. These are now referred to ***Noncultural Formation Processes***; sometimes ***Environmental Formation Processes.***

Cultural Transformation Processes (C-Transforms) are products of all human activity, intentional or otherwise, that create the patterns of artifacts and features. Examples include farming, tool making, building, etc. Human interaction follows a cycle of acquisition, manufacturing, use, and disposal. These are sometimes called ***Anthropogenic Formation Processes.***

Non-cultural formation processes

Unlike C-Transforms, N-Transforms are continuously ongoing and depend heavily on climate and location. This also plays a role in regards to what is preserved in the archaeological record. Inorganic materials have a better chance of surviving regardless of what transformation process occurs, whereas organic substances degrade much faster and are more sensitive to N-Transforms.

- Physical
- Biological
- Chemical

Physical processes

Physical processes are natural forces that change and shape deposits using the energy and elements of the earth. These include mass movements, erosion, deposition, soil formation, and the impact of thermal forces (heat and cold) on rocks and sediments.

- Mass movement is when materials move downslope, mostly under the influence of gravity, though water may contribute to the transport. Mass movement may be slow, such as creep or subsidence, or it may be fast, such as landslides and rock falls.

- Pedoturbation is the disturbance and mixing of the soil or sedimentary matrix. Pedogenesis is the ongoing natural process of soil genesis and modification by incorporation of organic elements. Soils constantly form and reform on exposed natural sediments, on human-made deposits, or on previously formed soils. Changes in color, texture, composition, and structure indicated pedogenesis (e.g., Roman and medieval urban dark earth).
- Cryoturbation refers to freeze/thaw activity that moves artifacts up and down, mixes sediments, and creates involutions (deformation).
- Argilliturbation is vertic mixing of sediments due to shrink/swell processes as clay-rich soils go through wet-dry cycles. Moisture causes clay minerals to swell, and drying causes them to shrink. When clay-rich soils or sediments shrink a lot, cracks open in the land surface. These vertical cracks can be very deep, and materials can fall down profile. This is referred to as vertic mixing.
- Site burial is a very rare phenomenon. When burial of a site by natural forces does occur, the results can be very spectacular, and leave exceptional remains. Examples include the Roman site Pompeii, and the Maya site Joya de Ceren in El Salvador (covered by ash deposits about 595 AD). More commonly, high- or low-energy water lakes, rivers, or streams disturb and/or bury archaeological sites in less rapid and less spectacular ways.

Fluvial processes: Water erosion

- Sheet erosion: uniform removal of top soil in a thin layer from the field. This is the least obvious process, although repeated sheet erosion can become substantial over time.
- Rill erosion: results from poor water infiltration into the soil. When a poorly structured soil cannot absorb all the rainfall, the runoff creates small, well-defined stream channels, called rills. Rills are generated when water running across the ground surface is concentrated in natural depressions. and channelization begins.
- Gully erosion: unchecked rills result in increased channelization and sharp down cutting, and soil particles are transported through larger channels. Gullies typically carry water for short periods of time during rainfall or snowmelt, and are dry during the dry season.
- Stream-bank erosion: the process in which rushing streams and rivers wear away their banks. This can create larger valleys, or can result in lateral stream movement, with erosion on the high-energy side and aggradation (deposition) on the low-energy side.

- Landslides: the movement of rock, earth, or debris down a slope, generally caused by the combination of energy (rainfall, volcano) and factors generating slope instability (geologic, morphologic, or anthropogenic).

Natural sedimentation involve sedimentation processes that would take place whether or not humans were active in a region. Human activity might increase the speed, scale, or frequency of sedimentation, but sedimentation would take place regardless. The most common types of natural sedimentation are

- Fluvial, through the action of water. Landforms include colluvial (slopewash) deposits, alluvial fans, and overbank deposits on floodplains.
- Eolian, through wind action. Examples include loess plains and sand dunes.
- Biogenic, caused by animals, particularly bird or bat droppings.
- Chemical sedimentation involves the precipitation of elements in solution through a soil or sediment profile, and the aggregation of these. Examples include ferrous or magnesium nodules, $CaCO_3$ nodules in loess (loess babies), and speleothems.

Eolian processes: Wind erosion

- Deflation: removal of sediments causing the collapse of sequences and the mixing of archaeological materials and components.
- Suspension: most spectacular method of transporting soil particles is by suspension. Dust particles of fine sand (less than 0.1 mm dia) are moved parallel to the ground surface and upward (c. 5-15 % of total movement by wind).
- Saltation: particles in the range 0.1-0.5 mm diameter are lifted by the wind, then fall back to the ground, so they move in a hopping or bouncing fashion. These particles cause abrasion of the soil surface and as they hit other particles they break into smaller particles, a process called attrition (c. 50-70% of the total movement).
- Surface creep: rolling and sliding of larger particles (more than 0.5 mm dia) along the surface (c. 5-25% of total movement).

Chemical processes

Chemical processes cause the breakdown or decomposition of stone, metal, ceramic, and organic materials (such as bone, shell, and wood). Chemical modifications also factor into site preservation. These include cementation of deposits by carbonate from groundwater, or iron precipitation/dissolution or diagenetic destruction of bone and organic materials, and the creation of secondary materials such as phosphates and carbonates.

- Oxidation/Reduction: involve the oxygen exchanges that take place between water and inorganic materials. Oxidation of iron (Fe) and subsequent reduction of oxygen.
- Carbonation: formation of carbonate minerals in soils.
- Humification: decomposition of labile, plant-derived carbon.
- Chemical precipitation and sedimentation: e.g., speleothems.

Biological processes

Biological processes include bioturbation (or biopedoturbation) and biological sedimentation. Bioturbation is the mixing of soil and sediment by living organisms (plants, animals, insects). One famous example is the movement of gravestones or the Stonehenge menhirs by worm action, as described by Charles Darwin (1881). Floralturbation is bioturbation by plants, for example when plant roots extend through several cultural deposits, pushing material from one deposit down into deeper deposits. Another example is tree-throw, when a tree falls and its roots pull materials from cultural deposits to the surface, removing them from their archaeological context. Faunalturbation is bioturbation by animals. The Classic example is animal burrows, which can mix materials from several deposits and introduce surface materials into buried deposits. A krotovina is an animal burrow that has been filled with organic or mineral material from another soil horizon. Bioturbation is particularly difficult to account for, as shown by several experimental studies. For example, pocket gophers can repopulate the artifacts in a 1x2 meter pit backfilled by clean sand in the space of 7 years. Biological sedimentation is primarily formed by bird and bat guano, but any thick deposits of animal dung can form localized biological sediments.

Taphonomy is the study of the processes of how plant, animal, human, and material (artifact) remains accumulate and are differentially preserved within archaeological sites. These include the processes that disturb and damage bones before, during, and after burial (burial, decay, preservation). The scientific understanding of taphonomic processes in the archaeological record relies on the combination of reference cases, geological constants, natural principles from the physical and biological sciences, forensic anthropology, experiments, and ethnoarchaeology and ethno-geoarchaeology.

Cultural Formation processes

Cultural transforms

- Anthropogenic processes are far more complicated than natural ones because they consist of a potentially infinite variety of activities.
- People build up (walls, plazas, kilns), dig down (trenches, wells, privies), set fires, plow and manure fields, and, worst of all (from an archaeological point of view) clean up after themselves.
- Procurement
- Manufacture
- Use
- Maintenance (cleaning; secondary refuse)
- Discard
- Loss
- Abandonment
- Burial (ritual, mortuary)

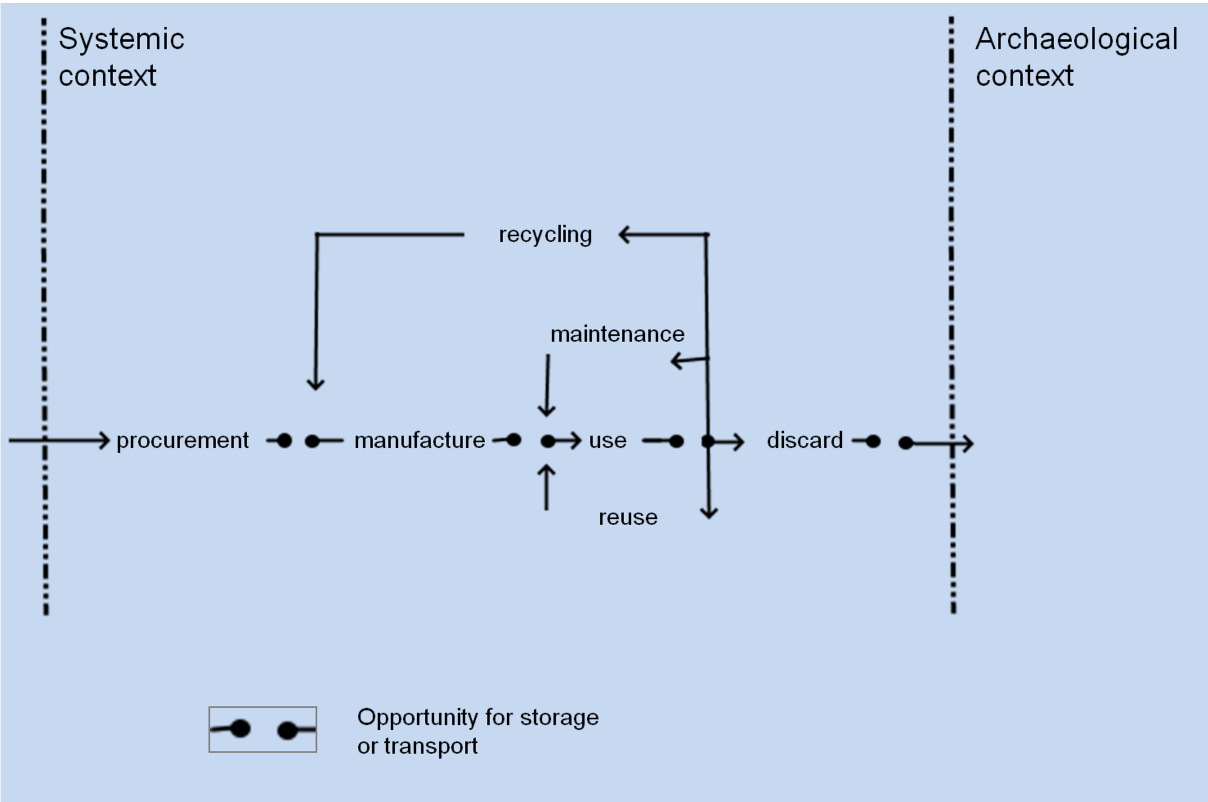

Fig. 4.1. A flow model for viewing the life cycle of durable elements (after Schiffer 1972: 158, Fig. 1).

For maintenance, an important general rule is the McKellar principle (McKellar 1983). This states that when an activity area is cleaned, small items (micro-refuse) are likely to be left behind as residual primary refuse.

- Reincorporation
- Collecting
- Scavenging

Reclamation: from the archaeological context into a new systemic context

- Plowing / earthmoving
- Trampling
- Looting

Disturbance: transformation of materials within the archaeological context

Context in archaeology

The matrix relevant to interpreting an artifact or feature is called a context. In ascending order of generality, the context may be a layer, a feature, a trench, a structure, a zone, or a site. Single events or actions that leave discrete, detectable traces in the archaeological sequence or stratigraphy. These are formed within the systemic context through anthropogenic and non-anthropogenic formation processes.

Deposits in archaeology

An archaeological deposit is what encloses the archaeological finds and, as a result, the finds constitute an inseparable part of the deposit (Karkanas & Goldberg 2019: 11). This is the material that is excavated in order to 'reveal' the archaeology of a site. Deposits are three-dimensional units that are distinguished in the field on the basis of the observable changes in some physical properties (Schiffer 1983, 1987); an aggregate of sedimentary particles.

Depositional contexts

Schiffer (1987) defined several depositional contexts. De facto refuse is in situ; artifacts deposited in their original use location, through loss or sudden abandonment, e.g. Pompeii. Primary refuse is material discarded where it was used, such as a flint core deliberately left at a flint knapping location. Secondary refuse is more common. These materials were "cleaned up" and discarded in a different location, such as flint debris in a rubbish dump. Tertiary deposits represent re-deposition of secondary contexts, such as the use of rubbish dump materials to infill a ditch or building. Understanding these is crucial to the recording of artifacts, because measurements are meaningless without context and a correct interpretation of depositional circumstances.

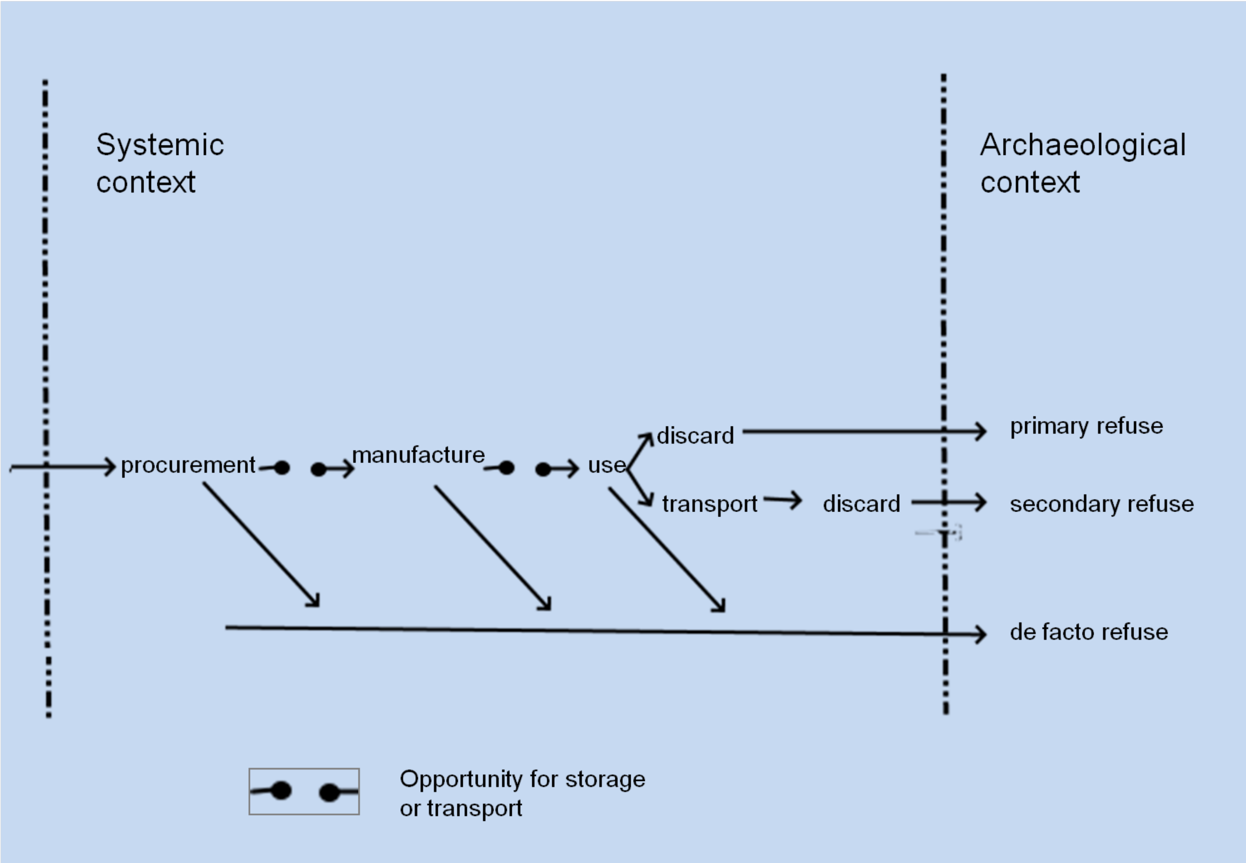

Fig. 4.2. Simplified flow model for explicating the differences between primary, secondary, and de facto refuse, after Schiffer 1972: 162, Fig. 3.

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Chapter 5. Archaeobotany

This chapter focuses on archaeobotany, palynology, and anthracology. Plants are not the only sources of food for people and animals, but also provide clothing, rope, building material for houses, heating, lighting, furniture, vessels, medicines, poisons, as well as providing shelter for wild animals, helping to prevent soil and water loss, and much more. Unfortunately, they rarely leave traces, but as part of economic and social systems of land-use, traces of specific tasks may indicate where missing evidence for plants can be found. In the lecture, we will examine how to use the remains of plants, in various forms (seeds, pollen, phytoliths, diatoms, etc) to reconstruct past environments and the vegetable portion of past economies.

Readings

- Hastorf 2008 Paleoethnobotany
- Crawford 2008 Macroremains
- Jones 2008 Pollen Analysis
- Reitz & Shackley 2012 Microbotanical Remains (or Dincauze 2000 Part VI)

Case studies

- Astudillo 2018 Soil phytoliths as indicators of initial human impact
- Cordova et al 2011 environmental change inferred from phytoliths and other soil proxies
- Heiss & Oeggl 2008 Anthracology LBA-EIA Tirol
- Kasper 2009 Spatiality of Food ECA Bikeri
- Tinner et al 2009 Holocene environmental and climatic changes at Gorgo Basso Sicilia

Much information about the past environment can be gained through macro- and micro-botanical remains. Microbotanical remains are plant remains that can only be seen through a microscope. Palynology, the study of ancient pollen grains, can give archaeologists some idea of fluctuation in vegetation types over time. Phytoliths, the particles of silica from the cells of plants that survive after the plant has decomposed, can be used to recover similar information. Phytoliths often survive in sediments where pollen will not be preserved, but are more difficult to interpret to the species level. Macrobotanical remains, those that can be seen by the human eye (such as seeds, wood, and charcoal), provide information about what plants grew near sites and which were consumed by humans.

Archaeobotany

Archaeobotany is the study of botanical (plant) remains, including seeds, pollen, phytoliths, charcoal, and wood from archaeological contexts. This includes not only the plants that people used (domesticated or wild), but all plants in the environment. Analyses of the following materials are included:

- macrobotanicals
- palynology (pollen)
- anthracology (wood charcoal)
- phytoliths
- starch grains
- biomarkers
- plant impressions, representations, text references

Paleoethnobotany is the study of relationships between humans and plants in the past. Archaeobotany and paleoethnobotany are often treated as synonymous because the concepts are similar, but the focus of research is subtly different. Ethnobotany is the study of interactions between recent or living cultures and plants. Paleobotany is the study of ancient plants, usually before modern humans. Both research foci analyze micro and macro remains.

- e.g., Gremillion 1997 People, Plants, and Landscapes: Studies in Paleoethnobotany

Strands of research, or research directions, in environmental archaeology include:

- environment (paleoenvironmental reconstruction)
- subsistence
- economy (other than subsistence)
- religion and medicine

Environmental reconstruction – which plants lived in and around human settlements and which plant resources were available to people – is perhaps the most common understanding of what environmental archaeologists do. The importance of such research extends to climate and environmental change, biodiversity, ecosystem resilience, and human impacts on the environment.

Subsistence refers to how people make a living. For environmental archaeology, this includes what food people ate, how they got it, and how and where they stored, processed and used it. Basic strategies have always been collecting food (hunter-fisher-foragers), producing food (agriculturalists and pastoralists), or some combination of these. In complex, urban societies, some people collect and produce food and then exchange it for other products.

Non-subsistence economy is an important research area, despite it not being the first thing we imagine when we think about environmental archaeology. Plant materials that people traded or exchanged, or used for fuel or as construction material are all essential aspects of historic and prehistoric life. For example, thatch traditionally used for making roofs is still grown and harvested today for cultural heritage management. Perfumes, dyes, and cosmetics were important for everyday use and exchange or markets.

Religion and Medicine: plants were used as medicine, for rituals, or accorded some mystical properties. For example, the Iroquois share a myth that describes how tobacco and other important plants came from the Iroquoian Sky World (in Snow 1994).

- Yonomami green snuff (yopo; Charles & Steyermark 1976)
- Indian Hemp (*Apocynum cannabinum*) – Dogbane, rheumatism root; poisonous plant used to treat coughs, asthma, fever, dysentery, and used as a sedative.
- dandelion, lavender, and many other herbs

Practice of archaeobotany

- Data collection: field and lab work
- Data analysis: systematic description of species
- Interpretation: theories regarding the origins of domestication, human impact on vegetation, human and plant coevolution

Data collection

- Field: collecting cores, soil samples
    - Bulk soil sampling
        - several liters in volume for flotation samples
        - a few grams for pollen, phytolith, and other microscopic material
    - Core sampling
- Laboratory
    - Flotation: charred plant remains are usually recovered by flotation. Soil samples are slowly added to agitated water
        - *light fraction* - less dense organic material, such as charred seeds, grains and charcoal, tend to float to the top

        - heavy fraction - soil, sand, and other heavy material sink to the bottom
    - remains are dried and stored for analysis
- Core splitting; subsampling

Data analysis

Macroremains are remains that can be observed, and sometimes analyzed, macroscopically (e.g., charcoal, most seeds). Identification is often carried out under a binocular microscope, using morphological features such as shape and surface features in the case of seeds, or microanatomy in the case of wood or charcoal. Specimens are compared to reference collections and published keys and atlases.

Microremains can only be seen microscopically, or are small enough to require magnification for positive identification (e.g. seeds of most berries). Analyses are carried out using high-powered microscopes with comparison to reference collections and published keys and atlases.

Macrobotanicals

Macro-botanicals are plant macro-remains such as seeds, nut shells, fruits, chaff, buds (leaf or flower), rinds, tubers, bulbs, wood, and stems. These are usually carbonized (charcoal, burnt seeds, kurbis rind), which dramatically improves preservation, or are recovered from very wet (bogs) or dry (deserts) contexts.

Charred plant remains are usually recovered by flotation, using a machine that gently bubbles water up through the soil/sediment sample, which is held on a wire mesh screen. Dense materials, such as ceramic fragments, micro-debitage and other stone, bone fragments, metal droplets, sand, and other relatively heavy materials, remain on the screen to be collected as the heavy fraction. Materials such as charcoal, seeds, carbonized plant fragments, fish bones, and other lighter remains are called the light fraction. These float up on the water and pour off into a fine-mesh sieve.

Macrobotanical analysis is conducted by weighing and sorting the light fraction, sometimes with the aid of sieves. Selected remains are then examined using compound and dissecting microscopes, often capable of polarizing light, and often with digital cameras attached. Magnification typically ranges between 10x and 50x. Results are quantified using ubiquity, percent frequency, density, comparison ratios, and diversity indices. Comparisons with reference collections and published atlases and databases are an essential component of identification (Fig. 5.1). Collections openly available through the internet have changed to accuracy, accessibility, and comparability of archaeobotanical analyses (e.g. http://www.paleobot.org/).

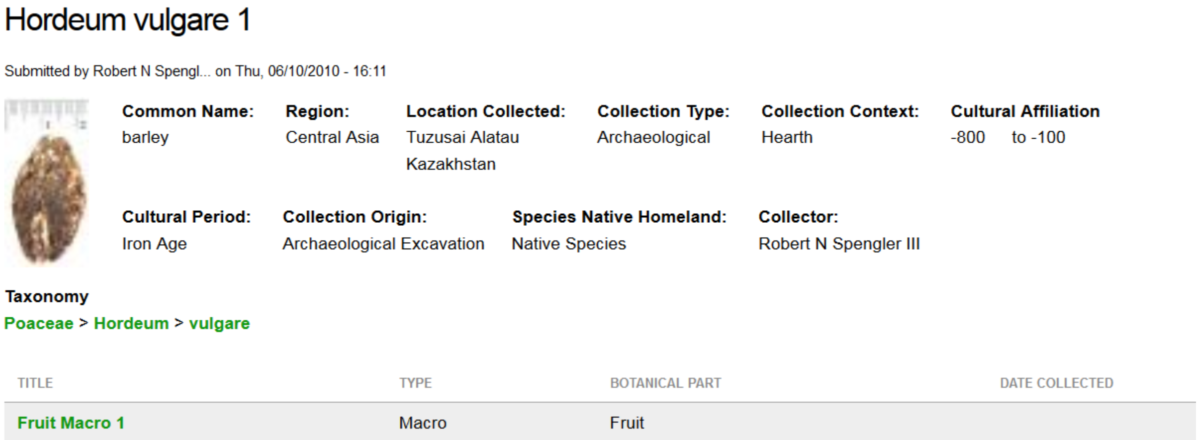

Fig. 5.1. Hordeum vulgare (barley), from http://www.paleobot.org/node/122, data uploaded by Robert N. Spengler III.

Palynology

Pollen analysis, or palynology, is the analysis of grain of pollen and spores from cores, monoliths, or volumetric piston sampling. Pollen can also be recovered from human and animal coprolites, complementing information on general vegetation with details about animal grazing or foddering and human diet (Hunt et al., 2001). Pollen is chemically extracted from very small subsamples of soils and sediments (e.g. a few cubic centimeters). Strong acids dissolve the mineral component, leaving the organic component (pollen, spores, charcoal). For example, the removal of carbonates with hydrochloric acid and the removal of silicates with hydrofluoric acid. Other alkaline and acid bath treatments remove other unwanted organics and remaining minerals.

Samples can then be examined using binocular dissecting microscopes with plain and cross-polarizing light, often with digital cameras attached. Magnification typically ranges from 400x – 1250x. As with macrobotanicals, pollen is identified using reference collections and published atlases, databases and other resources. One example is Pollen Online at UCL (http://www.ucl.ac.uk/archaeology/about/facilities/ archaeobotany/index). Good practice requires that a precise amount of an exotic 'tracer' pollen grain or spore be added to the sample during extraction. This provides a way to quantify pollen abundance via the ratio of ancient pollen to a known volume of tracer pollen. Quantification is by a standardized count of several hundred identifiable pollen grains and displayed as ***pollen diagrams*** (Fig. 5.2).

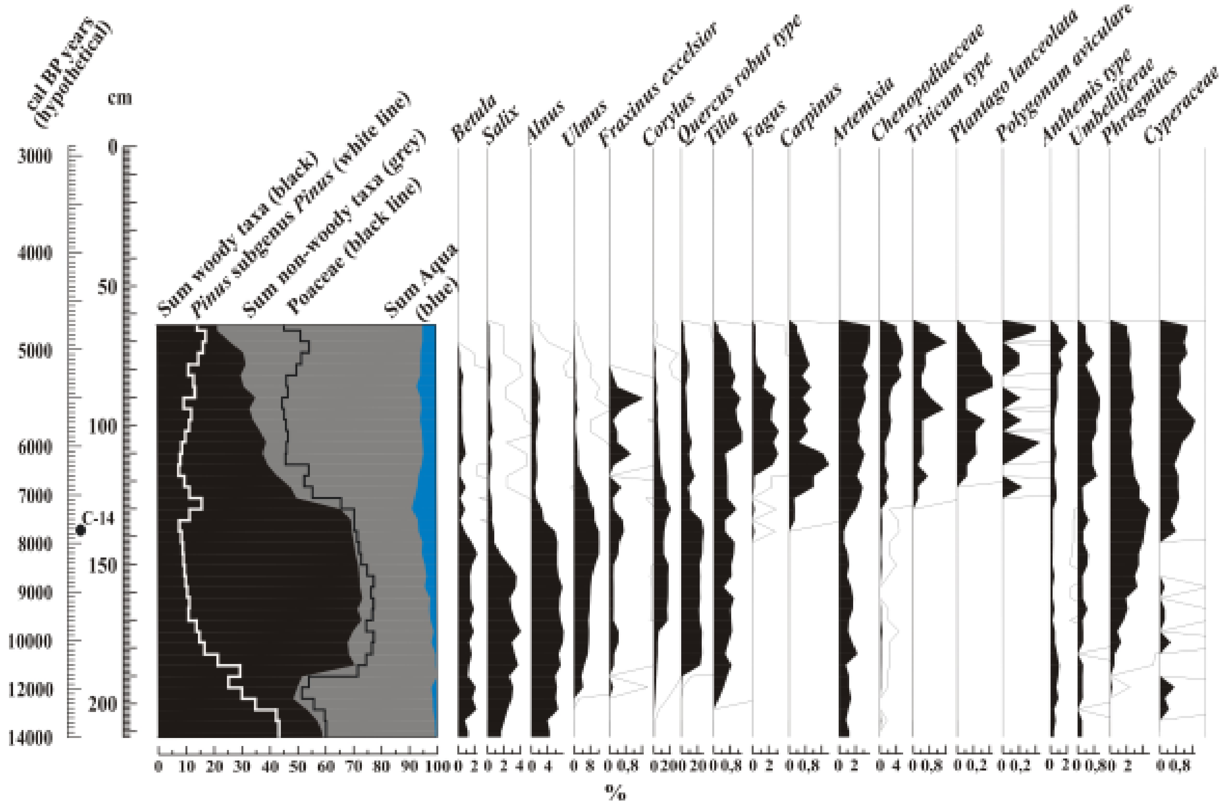

Fig. 5.2. Pollen diagram for a soil monolith taken in a paleochannel near the Neolithic settlement site of Csárdaszállás 8, Békés County, Hungary (Salisbury et al. 2013: Fig. 4).

Anthracology

Anthracology, often called charcoal analysis, is particularly useful for determining which wood was selected for fuel or construction, and differences between wood used for kinds of fires or construction. Anthracology involves the identification of species from wood and carbonized wood from archaeological sites. Charcoal persists in the archaeological record because it does not decompose biologically – it is largely unaffected by organisms such as bacteria, fungi, insects, and other invertebrates, and provides a record of vegetation, available resources, which resources people used, and environmental change. In deserts or other arid environments, charcoal may be the only source of paleoenvironmental data.

Charcoal is generally recovered from flotation sample light fractions, or from sediment samples through disaggregation. Charcoal assemblages are cleaned in hydrofluoric acid, and then carbonates removed with dilute hydrochloric acid. The anatomical structure of the carbonized wood forms the basis for identification. Anatomical features of the wood remain intact during pyrolysis (burning) and the carbonization process. These features can be seen using incident light microscopy at magnifications between 100x and 1000x for three planes of view - cross-sectional, radial, and tangential sections (Fig. 5.3). Acceptable analysis requires a minimum of 100 fragments per stratigraphic unit, and optimally 300-400 fragments per and comparison with wood atlases and reference collections (e.g. https://insidewood.lib.ncsu.edu/search; Wheeler 2011).

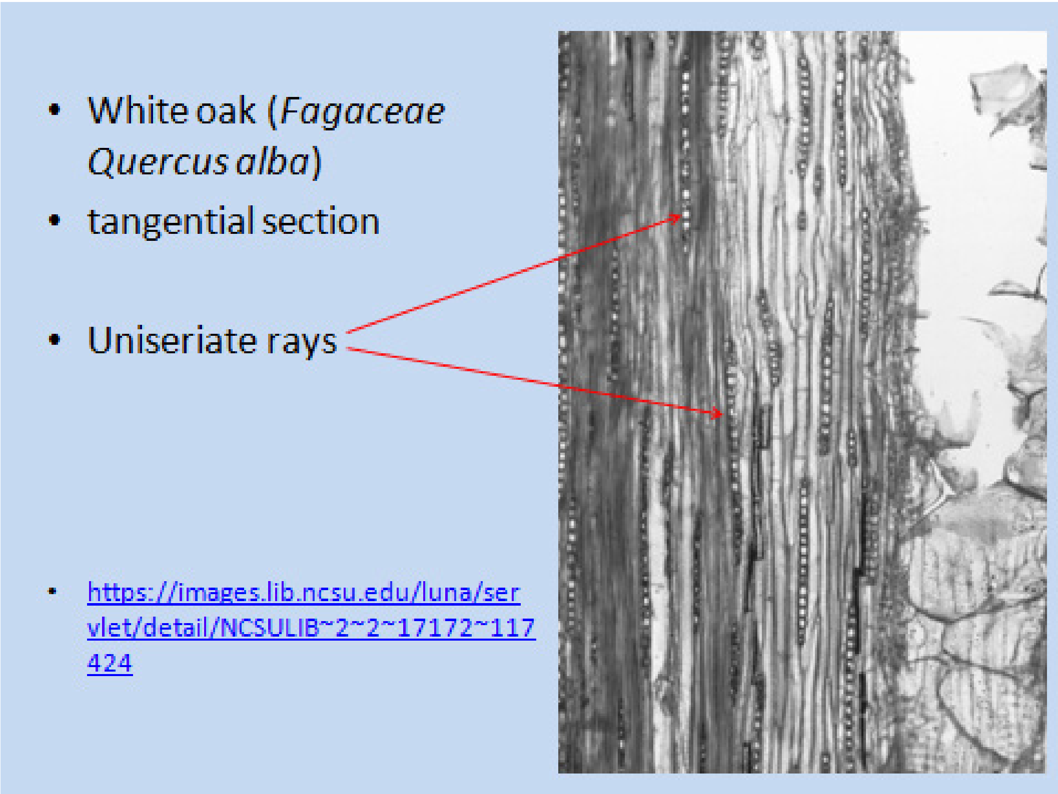

Fig. 5.3. Tangential section of White Oak (Quercus alba), from InsideWood. 2004-onwards. Published on the Internet. http://insidewood.lib.ncsu.edu/search [6.12.2021]

Phytoliths

Phytoliths are plant cells or intercellular voids in plant tissue that have accumulated minerals (usually silica, sometimes calcium or opal). The minerals harden and form a 'skeleton'. Phytoliths are inorganic and therefore persist in the archaeological record in most environments. They are particularly useful in tropical regions, where other types of plant remains are typically not well preserved. These microfossils are relatively easy to recover and have good preservation, but they are tiny, no larger than a single plant cell, so between 10 and 70 microns.

Phytolith production is dependent on environmental conditions. Some plant families produce either no phytoliths at all or amorphous or redundant phytolith types that are not taxonomically distinct. Therefore, some species will be over or underrepresented in the archaeological record. For example, amaranthus (which includes archaeologically relevant food sources such as goosefoot or Chenopodium) does not produce phytoliths. Furthermore, different parts of a single plant may produce different phytoliths, while different species of plants can produce the same kind of phytolith. These factors make identification challenging.

There are several archaeological and environmental sources for phytolith recovery, including dental calculus (build-up on teeth), grinding stones, scrapers, cooking or storage vessels, floor surfaces, and sediments. Physical or chemical separation of phytoliths from the soil matrix is done by some combination of disaggregation, removal of organic materials (combustion or acid digestion), and a chemical flotation to separate the phytoliths from the mineral component. Phytoliths from surfaces in the Neolithic village of Makri in northern Greece indicate that the settlement was inhabited all year long and engaged in cereal farming and pastoralism, as well as helping identify areas for crop processing (Tsartsidou et al., 2009). Phytoliths can also be recovered from artifacts, for example indicating that a grinding stone was used primarily for cereals or tubers. Samples are mounted on microscopes slides for analysis and examined using binocular dissecting microscopes with plain and cross-polarizing light, often with digital cameras attached, at a magnification of 400x. Scanning Electron Microscopy (SEM) may also allow for a more detailed study of phytoliths. As with other ecofacts, identification includes comparison to reference collections (e.g. https://www.homepages.ucl.ac.uk/~tcrndfu/phytoliths.html).

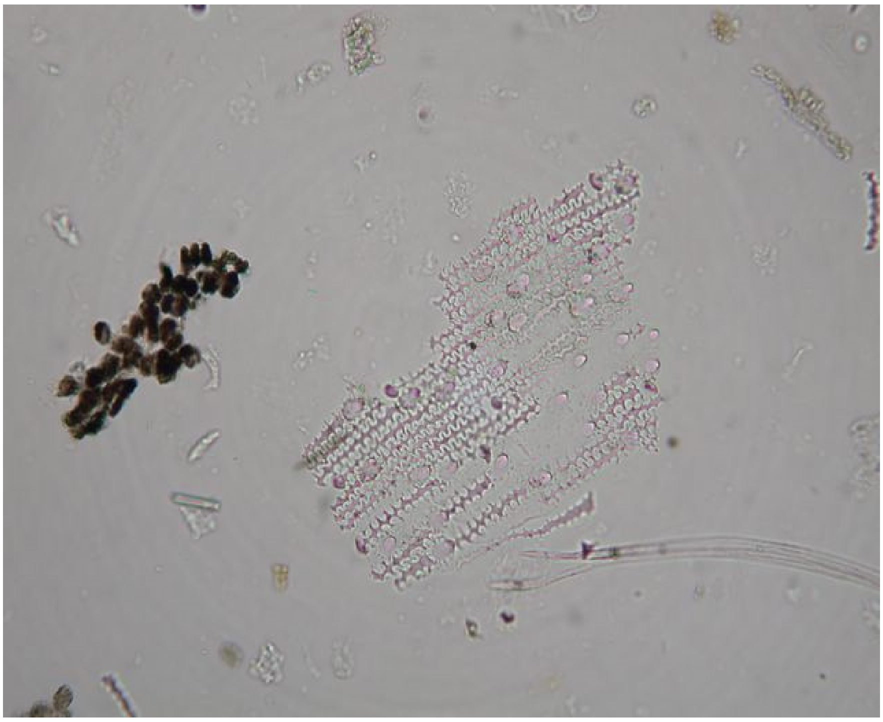

Fig. 5.4. Phytoliths of Hordeum vulgare (barley, 2-row type), from Old World Reference Phytoliths version 1.3.

Starch Grains

Starch is the common form of carbohydrate and is located in most plant tissues, especially in tubers, grains, and other starchy vegetables. Starch grains have been recovered from stone tools, ceramic sherds, organic materials, dental calculus, and sediment. Starch granules are mounted onto a slide, using a variety of mounting media including water, glycerol, and glycerine jelly, among others. The grains are then identified using polarized light microscopy and reference collections. Heat, water absorption, and other formation processes may affect the structure of the grains.

Analysis of starch grains is based on size, shape, and the presence of

- hilum (core of the grain)
- lamellae (layering)
- birefringence
- extinction cross

In terms of size, potato starch is c. 15-100 µm, Maize starch c. 5-25 µm, and rice starch c. 3-8 µm.

Starch grain analysis is not as widespread or well-developed as other methods, but online databases are being developed (e.g. http://clarissacagnato.weebly.com/starch-grain-database.html; Cagnato et al. 2021).

Biomolecules

Biomolecular studies in archaeobotany are increasing in frequency and accuracy, as they are elsewhere in archaeology. Residue analysis uses the separation and identification (via gas chromatography and mass spectrometry) of biomarkers associated with plants. For example, leaf wax lipids produce chemical signatures specific to different plants. These compounds can be extracted from sediments after thousands of years and used to reconstruct plant communities and species changes, such as from forests to grasslands or lacustrine to terrestrial (Schatz et al., 2011).

Plant impressions

Other sources of information about plants come from plant impressions in other artifacts, such as in ceramic sherds and clay. For example, impressions in clay daub from house walls help identify seasonality of construction and species and the size of plants used for prehistoric houses (Seltzer & Peacock 2011).

Epigraphic and Iconographic Sources

Artistic and literary representations of plants are also useful. Roman authors wrote books focusing specifically on agricultural practices, for example *Res Rustica* by Varro. A mural in the Red Temple at Cacaxtla, Mexico depicts cocoa and maize plants. The ears of maize were replaced with human heads.

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Chapter 6. Archaeozoology

Animals, both wild and domestic, are well-known as sources of human food, transportation, clothing, tools, and labor. However, animals also serve as proxies for environmental conditions, produce changes in the archaeological record, and their presence or absence are strongly influenced by human behavior. The analysis of vertebrates and invertebrates (mammals, beetles, snails, and ostracods preserved in the paleoenvironmental record) help us to reconstruct past environments and living conditions in and around archaeological sites and understand how people lived and worked in the past.

Readings

- Reitz 2008 Archaeozoology
- Reitz & Shackley 2012 Vertebrates
- Elias 2008 Insect Analysis
- Çakirlar 2014 Molluscs

Case studies

- Bartosiewicz 2005 Plain talk: animals, environment and culture
- Buckland et al 2018 Caught in a trap- landscape climate insects Roman well
- Dincauze 2000 How do we read these bones?
- Gulyas & Sümegi 2012 Gorsza tell malacology

Animals can have many roles in human society. They may be important sources of food and other raw materials, and they frequently have a place in peoples' ideologies. Animal remains supply interesting clues about past climatic conditions. The remains of large animals found at archaeological sites, known as macrofauna, mainly help us build a picture of past human diet. Microfauna, such as rodents, molluscs, and insects, are better indicators of environmental conditions than larger species, as they are more sensitive and adapt more quickly to climate change. The importance of these lines of investigation, together with the abundance of faunal remains on many sites, means that analyses of animal bone are now routinely undertaken as part of the post-excavation process.

Archaeozoology

Zooarchaeology is the study of faunal (animal) remains, including bones, shells, insects, and fossils from archaeological contexts. This includes the identification of species and analysis to reconstruct the environment, human diet, domestication, and the importance of animals in past economies, through

- Animal bone
- Malacology
- Entomology (insects)

Do we "identify the bones, add up the numbers, write the report" (Grayson 1984: xix)? In fact, there are several zooarchaeological approaches using animal bones. For environmental archaeology, zooarchaeologists identify bones (and teeth), identify the taphonomic and other formation processes, quantify, and interpret results in terms of zoology, culture, and environment.

- *Methods:* Reitz, E. J. & Wing, E. S. 2008. *Zooarchaeology.* Cambridge: Cambridge University Press.
- *Interpretations:* Russell, N. 2011. *Social Zooarchaeology: Humans and Animals in Prehistory*. Cambridge: Cambridge University Press.

Strands of research

Strands of research, or research directions, for zooarchaeology in environmental archaeology include:

- subsistence
- environment (paleoenvironmental reconstruction)
- economy (other than subsistence)
- ideology

Subsistence: which animals people ate, what animal parts people used, how they got them, and how and where they stored, processed and used the animals and parts. This includes discussions of secondary products, such as milk and the production of cheese, wool used for insulation and textiles, and traction (the use of animals to carry or pull loads).

Environment: which animals lived in and around human settlements and were available to people, and which pests lived with people, is almost as important to environmental archaeology as vegetation, although perhaps less utilized. Like archaeobotany, however, many species of animals require specific climates and ecosystems and can be used as proxies for these.

Economy includes the use of animals and animal parts in craft and industry. Hunter-forager-fishers: wild animals, fish, shellfish, insects, etc. killed for meat, skins, and bones. Early pastoralists domesticated animals to be killed for meat, skins, and bones (primary carcass products). Later, some domesticated animals were used for secondary products, meaning the expansion of exploitation to include renewable secondary products such as milk, wool, traction, carrying, riding. In all periods, animals and animal parts were traded, bought, and sold. Even in areas such as Mesoamerica, with no large domesticated mammals for subsistence or secondary products, birds and small mammals were kept. Semi-domesticated birds were used for their feathers, stingless bees for honey, and hares and turkeys kept for food.

Animals played an important role in ideology and religion, including the symbolic role of animals in cosmology, religion, and ritual, and as food items (beyond subsistence). Animals have roles in religion and cosmology. Animals exist as pets, symbols, art, wealth, objects for feasting, and sacrificial victim. Among the Maasai and Nuer cattle herders of Africa, for example, cattle are wealth. In the Bible, the books “Chronicles” and “Leviticus” contain detailed information on the kind and number of animals required for various offerings. Other examples include dogs as pets, doves as symbolizing peace, several animals gods, or human-animal hybrids in Egyptian and Mesoamerican cosmology (e.g. the Olmec Jaguar God / the were-jaguar, the Magdalenian ‘sorcerer’ wall painting at Trois Frere in France, and many Paleolithic cave paintings.

Practice of Archaeozoology

- Data collection: field and lab work
- Analysis: systematic description of species, number of individuals, and body parts represented.
- Interpretation: Theories regarding the origins of domestication, cultural use of animals, human impact on fauna, and human-animal coevolution.
    - Human-led extinction of mega-fauna?

Data collection
Field: collecting from excavations (macro), soil samples, cores

- Record context and possible taphonomic processes
- Bulk soil sampling
    - several liters in volume for flotation samples
- Core sampling
    - invertebrates

Laboratory: recording ***primary data*** such as:

- Taxonomic identification of the specimen
- Element represented by the specimen

- Side (e.g., left, right, axial, unknown, or some other description)
- Portion (e.g., proximal, distal, anterior, lateral, medial, shaft, unknown, or some other description)
- Sex (description of morphological evidence for sex such as dental attributes, presence of sexually diagnostic features such as antlers or the shape of a turtle plastron, or other characteristics)
- Age (e.g., fused or unfused long bone, degree of wear on teeth, stage of tooth eruption, or other characteristics)
- Count (number of specimens referred to the taxon, often abbreviated as NISP)
- Weight (weight of specimens referred to the taxon)
- Minimum number of individuals (abbreviated as MNI)

Record modification (description of the modification(s) including:

- state of preservation
- gnawed by a human, rodent, carnivore, or artiodactyl
- evidence for passing through a digestive system
- butchering marks such as cut, hacked or chopped, sawed
- evidence that specimen was burned, worked, trampled, weathered, or has pathologies
- description of where the mark is located and evidence that the mark was made by a metal or stone tool.

Primary data are used to estimate secondary data such as:

- body size and conformation
- age classes and sex ratios
- relative frequencies of animals
- frequencies of skeletal portions
- dietary contributions
- cause and function of modifications

Definitions

Proxies: preserved physical characteristics of the environment that can stand in for direct measurements.

- natural records such as insects, molluscs, and some mamals
- archaeological and historical data

Diagenesis: Physical and chemical modifications that can take place in bone specimens between burial and recovery.

MNI, minimum number of individuals: minimum number of individual bodies of a given taxon required to account for the NISP of that taxon in the sample.

NISP, number of identified specimens: basic counting unit in faunal analysis and refers to the numbers of bone specimens in the studied collection that are identified to a certain taxonomic or osteological category.

Animal bones

Bones and teeth of vertebrate animals (other than humans) are analyzed to address several archaeological and environmental questions. Taxonomic attribution can tell us what family or genus (or species) a specimen belongs to. Isotopic analyses can tell us about movement of animals, and what they ate. Cut marks and other modifications of bones inform about butchering and diet.

For example, chemical analysis of animal bones found in a 3000-year-old Maya city of Ceibal (Guatemala) provides insight into the role of dogs in Maya society. As many as 10,000 people lived in Ceibal. What did they eat? Evidence indicates that maize and other domestic and wild plants made up a large proportion of the diet. Wild game, such as deer, cats, opossums, peccaries, and tapirs provided protein. Butchery marks and isotope evidence indicate that turkeys and dogs were fed maize and then eaten by people. Other dogs, however, lived amongst the rulers and were treated royally. Two dogs buried near a large pyramid in Ceibal's central plaza had strontium isotope levels that suggested they had been brought from the volcanic highlands of Guatemala, c. 100 km away (Sharpe et al. 2018).

As a second example, Eurasian rats (*Rattus norvegicus and R. rattus*) were introduced into the Americas by Europeans. Rats transported themselves as stowaways on sailing ships from the 15th – 19th centuries, then jumped ship in the Americas and quickly overran the continents. Therefore, a *Rattus* specimen identified in the Americas means that the archaeological context was deposited after AD 1492, or that the rat was in an intrusive context (formation processes), or that the attribution is incorrect (the specimen is not *Rattus*).

Malacology

The study of molluscs (one type of invertebrate) is malacology. Molluscs are a durable category of biogenic finds, common in most environments / ecological zones, with the exception of acidic bogs. Molluscs occur as both human-modified and naturally occurring specimens. Their economic importance includes both human subsistence (food), as well as jewelry and other artifacts (can be imported and exported).

Molluscs form a natural environmental proxy because they respond to changing water quality and the trophic status of waterways, and can occur in marine, freshwater, and terrestrial ecosystems.

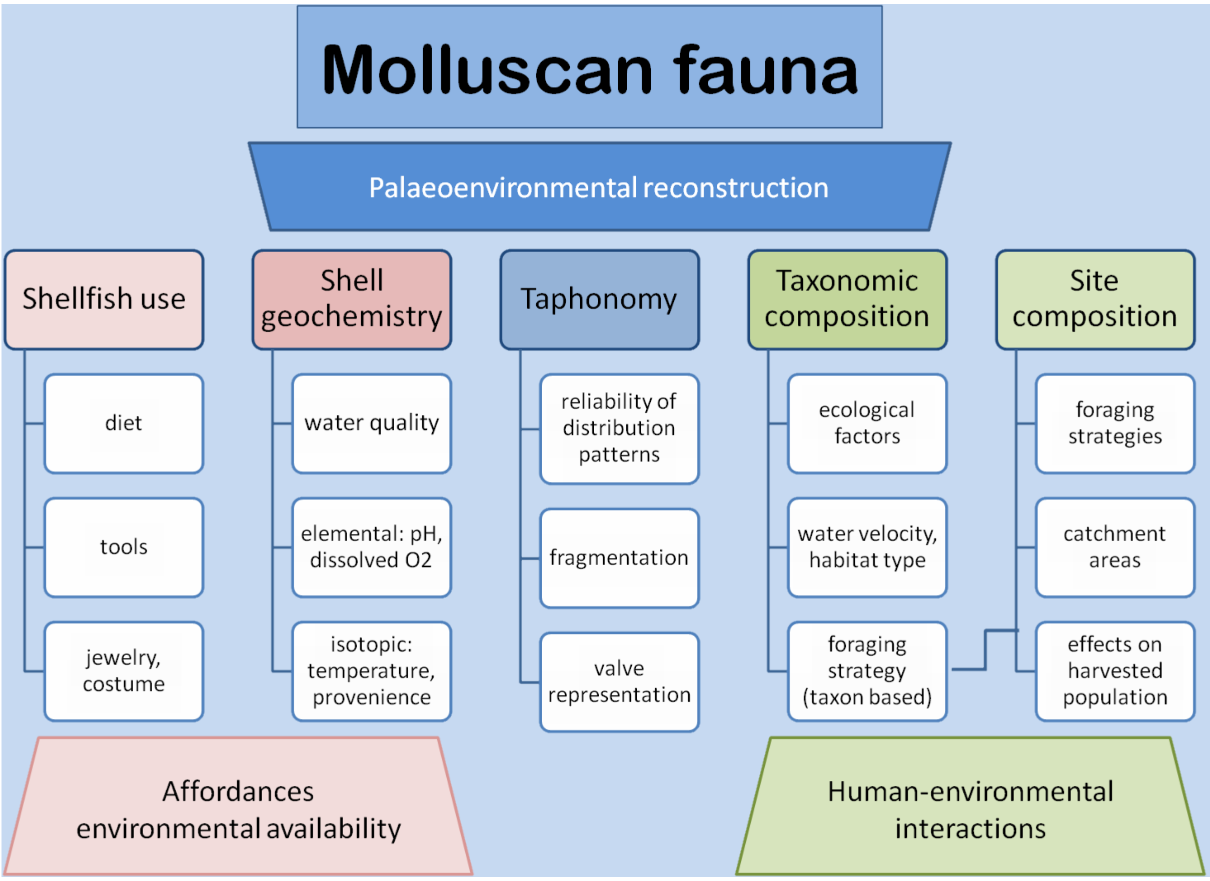

Fig. 6.1. Molluscan fauna as proxies for archaeological contexts and paleoenvironmental reconstruction (adapted from Gulyás and Sümegi 2011: Fig. 4).

At the Late Neolithic tell settlement of Hodmezovasarhely-Gorzsa, malacologists analyzed 25 kg shell material from 29 micro-horizons identified during excavations. The samples were subjected to detailed paleoecological investigations to derive information about changing water quality and human subsistence economy. Results indicated that the period was characterized by pronounced floods. People engaged in new subsistence strategies including shellfishing and fishing, as well as reordering their settlement structure (Gulyás and Sümegi 2011).

Entomology

Insects (arthropods) from archaeological contexts, usually as insect exoskeletons, provide another kind of environmental proxy. These are commonly found in waterlogged sediments at sites, commonly preserved in northern Europe (bogs, fens), in wells, cisterns, and latrines, and in very dry environments. Insects are environmental indicators of natural and anthropogenic processes. For example, for food storage and use patterns, food types, building methods, sanitation, and disease. Insects are both synanthropic (human-associated) and non-synanthropic.

Data collection involves identifying, documenting, and sampling sealed contexts. Samples come from cores and bulk sediment or peat samples. One cubic centimeter of lake sediment may contain several thousand chironomids (or non-biting midges). Disaggregation removes specimens from sediments. Once the specimens are separated from the sediment matrix, taxonomic identification and quantification can occur.

Insect species require specific habitats and climatic ranges, making them useful for palaeoenvironmental reconstruction. Entomology has been used to identify the rapid nature of global warming at the end of the last Ice Age (later confirmed by ice core data). Synanthropic species can be useful indicators of the presence of humans and animals, human habitation, hygiene conditions, disease, and trade. For example, sheep ectoparasites are common in Greenland and Iceland where bone preservation is not good; high concentrations probably represent locations used for the cleaning of wool.

Human body lice (*Pediculus humanus)* and fleas (*Pulex irritans*) are common in archaeological deposits. Bedbugs are first associated with humans in fourteenth-century BC Egypt. Scottish evidence from mid-eighteenth-century sites indicates that people in houses heated with peat fires did not have bedbugs. The natural environment of bedbugs has to be warmer and dryer than is typical in Scotland. Conversion to coal fires made buildings warmer and drier and led to bedbug infestations.

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Chapter 7. Geoarchaeology I. Soils, sediments and stratigraphy

This chapter introduces the study of archaeological soils, sediments, and the mineral world. Geoarchaeology uses earth science methods to answer the questions about ancient life-ways, economies, and human land relationships through time. It operates on the large scale to reconstruct past geological conditions and regional landscape changes, the medium scale to recognize transformations of microenvironments close to archaeological sites, and on the small scale of on-site studies to understand site formation processes, to aid identification of activities and use of space at the site, as well as to study the geological resources found on-site.

Readings

- Dincauze 2000 Ch. 11 Basic Principles of Sedimentology and Soils Science (or Reitz and Shackley 2012 Chapter 5 Sediments and Soils)
- Dincauze 2000 Ch. 12 Archaeological Matrices
- Goldberg & Macphail 2006 Ch. 15 Field methods
- Goldberg & Macphail 2006 Ch. 16 Lab techniques

Case studies

- Butzer & Harris 2007 Geoarchaeological approaches to the environmental history of Cyprus
- Butzer et al 2013 Urban geoarchaeology environmental history Lost City of Pyramids
- Dincauze 2000 Did the Classical civilizations destroy their own agricultural lands?
- Salisbury 2012 Soilscapes and Settlements

Geoarchaeology is the study of archaeological questions using concepts and methods of the earth sciences (geology, geography, geomorphology, hydrology, sedimentology, pedology, and exploration geophysics). This includes the identification of formation processes, soilscapes, rocks, and sediments to reconstruct the environment, human activities, and changes to the soil by human activity. Evidence from soils, sediments and solid geology contributes to understanding the development, preservation, and destruction of archaeological sites (formation processes), and for regional-scale environmental change and the evolution of the physical landscape, including the impact of human groups.

Methods:

- Goldberg, P. & Macphail, R. I. 2006. *Practical and Theoretical Geoarchaeology.* Oxford: Blackwell.

Interpretations:

- Boivin, N. & Owoc, M. A. (eds.) 2004. *Soils, Stones and Symbols: Cultural Perceptions of the Mineral World.* London: UCL Press.

Strands of research

Geoarchaeology is sometimes seen as a separate discipline and sometimes as a subdiscipline of environmental archaeology. Karl Butzer (1982) considered geoarchaeology as the study of archaeological contexts and human ecosystems, and therefore subsumed most palaeoenvironmental analyses within geoarchaeology. In any case, strands of research, or research directions, for geoarchaeology, in contributing to environmental archaeology, include

- Site formation processes
- environment
- economy
- ideology

Site formation processes are studied to gain insight into how the archaeological context – the archaeological record that we see today – formed and changed over time (see Chapter 4).

Environmental reconstruction, from a geoarchaeological perspective, focuses on questions such as what types of soils and rocks existed in and around human settlements, and which mineral resources were available. That is, what was in the site catchment area? These questions are accessible to earth science methods.

Economy, in geoarchaeology, involves reconstructing the use rocks and minerals in trade, exchange, market economies, and human land-use. Which mineral resources were available in a given region is important. Both finished products and raw materials were traded. For example, obsidian, flint, marble, copper, tin, clay, and limestone for plaster were all extracted and used, In many cases, these materials were transported over long distances. X-Ray fluorescence spectrometry (XRF) and other methods are used to identify the chemical signature of artifacts and compare them to geological sources (e.g. Tykot et al. 2013).

Ideology involves the symbolic role of soils or rocks in cosmology, religion, and ritual. Soils and sediments are often connected to identity, e.g. the Hungarian coronation mound (in fact) and the Dracula story (in fiction). Soils/sediments are also connected to location and memory, for example, the vials of "Cape Cod sand" that are available in most souvenir shops on Cape Cod, Massachusetts (Salisbury 2012b).

Soils are also connected to many origin myths. The Iroquoians attributed the origin of their most important plants and herbs to a handful of soil pulled from the Sky World. Cultures around the world include clay or dirt as the main ingredient in the origin of people. Examples range from the Pima "well-baked man" to the Genesis story in The Bible and Prometheus in Greek mythology. Other examples come from ancient Egypt, Assyria, Sumeria, and the Hopi. Soils are also connected to ideas of fertility and renewal (Boivin 2004).

Practice of Geoarchaeology

- Data collection: field and lab work
- Analysis of materials (soils, sediments, rocks) and remotely sensed data
- Interpretation: theories regarding soil formation, site formation processes, human-soil interactions, ideology.

Data collection

Field: collecting samples from excavations (macro), soil samples, cores

- Record context and possible taphonomic processes
- Bulk soil sampling
- Core sampling
- Column sampling

In the field, geoarchaeology usually begins with a more or less formal geoarchaeological survey. This process involves recording observations of stratigraphic profiles, cuts, bank deposits, exposed rocks and sediments, and formation processes (e.g., erosion, colluviation). Although not always factored into excavation planning, a geoarchaeological survey is essential for making informed decisions about formation processes, lithic resources, and landforms.

The aim of sampling is to recover a reasonable representation of the remains present in a context. A good sampling strategy should address three basic questions: why take samples, what contexts or deposits to sample, and how to collect the samples (see

Chapter 3). Why sample? To answer a research question, and to save a representative part of the sediment archive.

- Reconstruct local environment
- Functional use of space and/or archaeological contexts
- Identify agricultural or other subsistence activity
- Food preparation and consumption
- Use of plants or other environmental resources for purposes other than food
- Chronology
- Social and cultural questions: ideology, ritual, inter alia

What to sample is complicated by project resources. Optimally, every context and deposit would be systematically sampled using a random distribution of sample points. Every context (systematic): every layer, feature, surface; every stratigraphic unit.

- Positive – preserves data from destroyed contexts; offers the opportunity to ask new questions or reanalyze samples in the future.
- Negative – costly in terms of time, money, and other resources; requires lots of storage.

Targeted contexts: sample only contexts that will answer an existing question.

- Positive – easy to justify based on research design; less expensive in terms of time and money.
- Negative – highly subjective, inflexible, and leads to data loss; permanent destruction of an archive.

How to sample considers the types of context to sample (all of them?), the recommended density of sampling, and sample size. A detailed discussion of sampling, including bulk sampling, core sampling, and monoliths is covered in Chapter 3.

Field: In-field measurements

As with all scientific research in the field, geoarchaeologists should always document where they are, what they do, and what they see. Record the location (latitude/longitude, UTM, etc. using a GPS), temperature, light, weather, and general conditions. That is, in addition to weather, what does the location look like? What are the topography, vegetation, and human infrastructure? On one day you might visit a smooth, grassy lawn next to a quiet country road lined with power lines overhead, enjoying a light breeze and warm sunshine. A week later you might be trudging through a marshland, with muck up to your knees, as a light rain falls on your notebook. These factors will influence all other information that you record, both analog and digital, as well as what samples you are able to collect. Therefore, describing them is essential for later data interpretation.

Next, describe the deposit, context, or layers. Descriptions of sections in trenches, excavation profiles, exposures, and cores aid in understanding the soils and sediments, stratigraphy, and the context of any samples collected. Typically, descriptions include

- soil/sediment color;
- texture – using soil nomenclatural terms (e.g. silty sand);
- moisture content (e.g. moist);
- structure (e.g. platy; subangular blocky);
- consistency – cohesion, compactness, firmness (e.g. soft, friable);
- inclusions – composition with sizes and abundance of rocks (common siliceous pebbles), organics, artifacts;
- lower boundary, with degree of transition (distinctness) and topography (morphology, e.g. abrupt wavy).

In addition to the careful recording of observable soil horizons, stratigraphic layers, and sample locations, geoarchaeologists can take in situ measurements. Hand-held portable devices are changing the ways that geoarchaeologists collect basic data in the field, enabling greater data collection and collection of samples targeted at specific research questions and deposits. In situ measurements can include

- Multi-element chemistry, rare earth elements (REEs) using a hand-held portable X-Ray fluorescence spectrometer (pXRF);
- Soil/sediment color using a portable spectrophotometer;
- Magnetic susceptibility: how much the soil can be magnetized by an applied magnetic field; usually result of burning or heating. Generally done with a Bartington instruments susceptibility meter
- Structure from motion photography

Laboratory Methods: Materials analysis

Away from the field, there are two basic areas of geoarchaeological analysis. The first is the analysis of materials and samples (soils, sediments, rocks). These include

- Soil carbon: for organic carbon, plant and animal residues at various stages of decomposition, and inorganic carbon (carbonates). Wet or dry combustion, Loss On Ignition (burn of carbon in muffle furnace), or thermogravimetric analyzers;

- Total C and N: percent total organic C and percent total N ($\delta^{13}C$ and $\delta^{15}N$) using combustion and elemental analyzers, often linked to isotope-ratio mass spectrometers;
- Magnetic Susceptibility: how much the soil can be magnetized by an applied magnetic field; usually result of burning or heating. Generally done with a Bartington instruments susceptibility meter.
- Soil phosphate content: colorimetric analysis of soil/sediment samples for available phosphates (Pav). Several approaches, including spot tests and spectrophotometers.
- Trace element geochemistry: multi-element chemistry, rare earth elements (REEs)
    - weak acid or hot acid extraction
    - measurements: ICP-MS, ICP-OES, XRF
- Soil pH: numeric scale where 7 is neutral, <7 is acidic, and >7 is basic
    - organic decay – pH goes down (more acidic)
    - ash, shell, bone – pH goes up (more alkaline)
- Particle size analysis: grain size; correlate archaeological layers, evaluate soil formation intensity, detect discontinuities in soil profiles, and aid paleoenvironmental reconstructions.
    - Laser granulometry, sieving, pipette method
- Clay mineralogy analysis: raw material sourcing; understand the various manufacturing techniques
- Thin-section microscopy: the use of microscopic techniques to study the nature and organization of the components of soils (soil micromorphology)

Definitions

Soils: unconsolidated material, composed of water, air, inorganic (mineral) and organic elements. Forms in situ at the earth's surface through various atmospheric, biological, chemical, geological and hydrological processes (**pedogenesis**).

- develop in place and require time and a stable ground surface

Sediments: a collection of geological and/or organic materials, including soils, which have been removed from their original source, transported, and redeposited elsewhere by natural or human activities.

- the largest class of material remains at archaeological sites

Anthropogenic soils: have been influenced by human activity, as indicated by a concentration of phosphorus, organic matter, debris, or artifacts. The different soil and sediment components are physically mixed through cultivation, deforestation, or construction.

Buried soil: any ancient land surface buried and undisturbed under a structure or within a deposit, such as peat. Buried soil reflects the nature of the soil, at least at a very local level, at the time the structure was erected or the natural deposit laid down.

Sterile soil: one with no evidence for human occupation or activity, and no cultural materials.

Paleosol: ancient soils formed on landscapes of the past. Generally buried in the sedimentary record, covered by flood debris, landslides, volcanic ash, or lava.

Laboratory Methods: Digital data analyses

The second set of geoarchaeological bench-top methods employ computers and digital datasets (digital geoarchaeology), typically using the power of GIS. These GI Systems include algorithms for creating digital elevation models (DEMs, DTMs) and a wide range of analyses of terrain, hydrology, networks, and point patterns.

Datasets:

- satellite and aerial images
- geological and soils maps
- analysis of geophysical prospection data(e.g. ERT, GPR)
- other digital datasets

Site Formation Processes

As readers should remember from Chapter 4, archaeological site formation processes are the events and processes that affect the characteristics of the archaeological record (Schiffer 1972). These introduce variability into the archaeological record through human activities and/or natural processes, during and after the deposition of archaeological materials. Formation processes have been defined as the ***current expression*** of the cumulative effects of anthropogenic and environmental formation processes (Sullivan 2008). "An appreciation of sources of variability is essential to determining the appropriateness of certain kinds of archaeological phenomena for particular research questions (Sullivan and Dibble 2014)" because understanding these processes "functions to reduce distortions or biases and enhance the image of past behavior contained within archaeological deposits". These are the total of the processes – natural and cultural, individual and combined – that affect the formation and development of the archaeological record. Cultural formation processes include the deliberate or accidental activities of humans, both depositional and post-depositional. Cultural depositional processes, originally called "Cultural (trans)formation processes", or C-transforms (Schiffer 1983), are covered in Chapter 4.

Post-depositional cultural processes include

- *Agricultural activities*: plowing, harrowing,
- *"Soil recovery"*: a term used in Sicily for grinding bedrock into a regolith
- *Construction*: roads, bridges, buildings
- *Archaeology*: excavation, large-scale topsoil removal, surface collection, coring … radiation?

Non-cultural syn-depositional and post-depositional formation processes

Non-cultural formation processes refer to 'natural' or environmental events that govern the burial and survival of the archaeological record. Syn-depositional processes are non-cultural processes that occur within the living cultural system during deposition' i.e. synchronous with the formation of a deposit. Post-depositional processes occur after the deposit has been formed and abandoned.

There is much more to site formation than just human activity. Sites are disturbed by a variety of events and agents over time, and these processes are how the archaeological context is formed, and generate what archaeologists will find at most sites. A cemetery might be invaded by burrowing animals (moles, marmots), trees might grow (tree-root action), and soils might be affected by freeze/thaw and wetting/drying actions.

- *Catastrophic burial*: think of a settlement covered by lava and volcanic ashes [the site of Pompeii is a good example of that], a sand dune or even a mudslide/rockslide;
- *Bioturbation*: disturbance caused by tree roots or animals (like rodents and even earthworms) disturbing the soils by digging tunnels and burrows, which eventually lead to soil instability and mixing
- *Cryoturbation:* soils disturbance by freezing and thawing.
- *Vertic mixing:* wetting and drying of clay-rich soils can result in deep vertical cracks that mix soils and reposition artifacts and ecofacts down profile. Some soils are so prone to this that they are called vertisols.
- *Pedogenesis*: the modification of mineral soils to incorporate organic elements (soil formation) is an ongoing natural process – soils constantly form and reform on exposed natural sediments, on human-made deposits, or previously formed soils. Pedogenesis causes changes in color, texture, composition, and structure: in some cases, it creates immensely fertile soils such as terra preta and Roman and medieval urban dark earth.
- *Erosion*: the wearing away of rocks and soils by the action of wind, water, ice.
- *Chemical modifications:* also a factor in site preservation. Processes include cementation of deposits by carbonates from groundwater, iron precipitation/dissolution, or diagenetic destruction of bone and organic materials.

Solid Geology

Rocks are naturally formed, heterogeneous solid materials, composed of minerals, rock fragments, volcanic glasses, or remains of organisms and also include solid organic materials (e.g. coal). Minerals (minare lat. = mining) are naturally formed solid materials with characteristic chemical composition, 3-dimensionally highly ordered atomic structures and anisotropic properties. c. 4660 minerals are known at present (2020).

Bedrock geology: the subsurface geology is the source material for soil formation (pedogenesis) and sedimentation (e.g., loess). Bedrock geology also partly determines water capacity, vegetation types, and geomorphology. Three types of rock form the geology:

- Igneous (magmatic)
- Metamorphic

- Sedimentary

Igneous rocks originate from molten rock (magma), which cools comparably fast at or close to Earth´s surface. Commonly very fine-grained or glassy, or commonly porous. Igneous rocks include volcanic (extrusive) and plutonic (intrusive) rocks. Volcanic rocks form from the 'extrusion,' or eruption, of lava from a volcano. When lava meets cooler temperatures, it cools rapidly and solid crystals form. The cooling occurs so quickly that the crystals cannot grow very large; the crystals are microscopic (microcrystalline). Plutonic rocks are formed when magma pushes (intrudes) into rock crevices and slowly cools under high pressure. Slower cooling results in larger crystals, e.g. granite. Igneous rocks are commonly found as portable artifacts.

- Examples[1]: basalt, rhyolite, obsidian.

Metamorphic rocks are crystalline rocks that change due to high temperature, pressure, and fluid activity in Earth´s crust – without melting – over time. Commonly they show foliation, or folding, or include recrystallization.

- Examples[1]: gneiss, amphibolite, marble.

Sedimentary rocks form from layers of solid particles and dissolved minerals over thousands of years. These range from coarse to fine-grained textures and were frequently used as construction materials, especially in later prehistory and historically.

- Examples[1]: limestone, shale, breccia.

Diagenesis: Chemical and physical processes that transform loose sediments into solid sedimentary rocks.

- Compaction – pressure packs grains together
- Cementation – dissolved minerals bind clasts together as water evaporates

Beyond geology, rock identification is essential for resource identification and provenancing using mineralogy and trace elements. Materials of interest include, but are not restricted to,

- building materials
- grinding stones
- ground stone tools
- flaked stone tools: micro- and crypto-crystalline rocks

[1] Examples from https://geology.com/rocks/; links worked as of 1 December 2021.

- obsidian, flint, chert, radiolarite, quartzite

Sedimentology & Pedology

Sedimentology is the study of sediments to determine the processes that control the temporal and spatial distribution of different sediment types, their provenance, erosion, transport and deposition.

The size of sediment particles is used to determine energy of deposition, environment of deposition, and type of sediment source. Methods to analyze grain size include laser granulometry, wet or dry sieving, and the pipette method. Laser granulometers can determine the particle size distribution of sediments or soils in ranges from 0.04 to 2000 microns. Optical alignment is carried out every few samples for quality control. Sieving quantifies particle size distribution of sediments, soils or other types of unconsolidated material using nested screens. This can be done wet or dry, and either manually or on a shaker. Sieving measures particle size ranges from 63 microns to 10 cm.

Pedology is the study of soil formation, or pedogenesis. Soil development is regulated by the effects of place, environment, and time. A well-developed soil profile will have a distinct sequence of zones, called horizons.

- A horizon: the zone where organic and mineral matter accumulates and is transported slowly over time vertically down the profile by water.
- B horizon: below the A, represents the accumulation of clay and mineral compounds originating from the horizon above, minus the organic matter.
- C horizon: Weathered and broken bedrock material.

Stratigraphy

Alterations in soils lead to the development of layers, distinguished by differences in color, structure, texture, and chemistry. Stratigraphy is what we get when we remove the natural and cultural layers that make up an archaeological deposit. This is one of the most complex material reconstructions we deal with. Lyell's *Law of Superposition* states that soils found deeply buried were laid down earlier—and therefore are older—than the soils found on top of them. Formation processes, as discussed above, can change these relations, so superposition is the null hypothesis. Many archaeological sites show exceptions that need to be explained by cultural or environmental effects. An excellent discussion of the history and development of stratigraphy and excavation in North America can be found in Lyman and O'Brien (1999).

Stratigraphic Unit is the preferred name for ‘layer’. This is the basic unit of stratigraphic analysis, a distinct and homogeneous area of soil, whether formed by natural or cultural means, or a combination of these. Layer, the established term in English, is actually misleading, since it implies a smooth, even deposit across a large area. Such a deposit is unlikely. Moreover, layer has other common-sense meanings in English. Most European archaeologists use ‘stratigraphic unit’.

Deposits and Contexts

A deposit is a “3D segment of a site (or other area of analytical interest) that is distinguished in the field on the basis of observable changes in sediments and artefacts.” (Schiffer 1987: 265).

Context is the provenience and associations of an artifact, feature, or archaeological find in space and time. Something in primary context was deposited by people who made it, and has been undisturbed since deposition. Secondary contexts have been altered by transformational processes, so provenience and/or association are affected.

Provenience refers to the 3D location of an artifact or feature (portable or non-portable artifacts). Association refers to two or more items occurring together, usually in the same level, feature, etc.

- e.g. artifacts associated with burial
- e.g. projectile points found with extinct animals

Soil chemistry

Soil chemistry can be used for site prospection, the function or formation of deposits, and interpreting the use of space within sites. For prospection, samples are taken at regular intervals and tested for chemical enrichment (usually phosphorus). Phosphates (P) are used because elevated P is usually related to areas of archaeological interest. P exists in all organic matter and is deposited via urine, excrement, bone, meat, fish, plants, and other organic materials. Phosphates have low solubility and mobility, fix quickly within the soil profile, and in the right soil conditions can remain in place for millennia (see Holliday & Gartner 2007).

Activity areas research is the interpretation of the functional use of space within archaeological deposits and sites. One method for such analysis is based on geochemical signatures. Specific human activities result in specific chemical signatures. Quantitative results, given in parts per million (ppm) and mg/kg-1, can be achieved through Inductively Coupled Plasma Mass Spectrometry (ICP-MS) or Optical Emission Spectroscopy (ICP-OES). Soil/sediment samples are first digested in acids and then introduced to the ICP as an aerosol. The plasma ionizes the aerosol, and the ions are counted by a detector (see Salisbury 2020).

Both inorganic (trace elements) and biomolecular methods can assist in reconstructing past environmental conditions and human land use (Table 7.1). Biomolecular methods focus on four basic sets of biomolecules: lipids, proteins, starches, and nucleic acids (DNA).

Thin-section microscopy

Thin-section microscopy is the most widely used method for analyzing the micromorphological structures of deposits. As such, it is often referred to as micromorphology, even though the two terms are not synonymous. The integrated use of various microscopic techniques for studying the arrangement and the nature of components that form sediments and soils provides key information to help discriminate the sedimentary signatures diagnostic of human-related activities from those resulting from natural processes (see Nicosia & Stoops 2017).

Table 7.1. Principal geochemical and biogeochemical methods used in environmental archaeology

Type	Target	Method	Process
Inorganic P	available (Pav)	Ring-chromatography; Colorimetry	Air-dried samples crushed; weak acid digestion; spot-test
	quasi-total	Colorimetry	Air-dried samples crushed; molybdate colorimetry (Mehlich II or other weak extractant)
	total (P_{tot})	ICP (MS or OES)	Air-dried samples crushed; strong acid digestion
Inorganic	Multi-element / Trace element	ICP (MS or OES)	Air-dried samples crushed; strong acid digestion or chelating or sequential extraction
		pXRF	In situ or laboratory (pellet)
Inorganic	pH	pH meter	Soil and deionized water in 1:1 ratio
Inorganic	Magnetic Susceptibility	Susceptibility meter	In situ or laboratory (canister)
	Total Organic Carbon (TOC)	IRMS	Sample combustion, elemental analyzer linked to isotope-ratio mass spectrometer
	Total Nitrogen	IRMS	Sample combustion, elemental analyzer linked to isotope-ratio mass spectrometer
	Soil Organic Matter (SOM)	Loss On Ignition (LOI)	Samples weighed, heated in oven, weighed
Biomolecular	*sed* aDNA		DNA extraction; data generation through (i) metabarcoding, (ii) shotgun sequencing, or (iii) enrichment of DNA
Biomolecular	Proteins	LC-MS/MS	extraction of proteins from sample; digestion by a protease into peptides, separation of peptides by LC-MS/MS
Biomolecular	Starches / carbohydrates	GC-MS	extraction from sample
Biomolecular	Lipids – animal (5β stanols; bile acids)	GC-MS	extraction into a solvent to acquire a total lipid extract (TLE); chromatographic separation of the TLE; derivitization
Biomolecular	Lipids – plants (leaf wax; *n*-alkanes)	GC-IRMS	extraction into a solvent to acquire a TLE; chromatographic separation; derivitization

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Chapter 8. Geoarchaeology II. Geomorphology and landscapes

Geomorphology deals with the surface we live on. Knowledge and quantification of the processes acting on and shaping some area of the Earth's surface is an important part of reconstructing a total environment and possible anthropogenic (human) influences on these processes. Therefore, geoarchaeologists contribute to landscapes and regional scale archaeology. Methods and evidence for studying topography, hydrology, geomorphology, and landscape change are similar to analyzing portable artifacts and understanding the formation of archaeological sites and deposits. These methods contribute to understanding processes such as flooding, erosion, deposition, deflation, and other forms of geomorphological landscape change.

Readings

- Dincauze 2000 Ch. 9 Landforms
- French 2003 Ch. 3 Geomorphological processes
- French 2015 Ch. 2 Approaches to investigating landscapes

Case studies

- Ayala & French 2005. Erosion modeling of past land-use practices
- Butzer 2005 Environmental History in the Mediterranean World: Cross-Disciplinary Investigation of Cause-and-Effect for Degradation and Soil Erosion
- Contreras 2010 Reconstructing an Engineered Environment in the Central Andes- Landscape Geoarchaeology
- Dincauze 2000, p. 251 Landform reconstruction at Laetoli, Tanzania
- Draganits et al. 2015 Landscape reconstruction Royal burial site Borre

Strands of Research

Strands of research in landscape geoarchaeology and geomorphology include

- Landscape history
- Environmental reconstruction
- Economy
- Ideology: the symbolic role of landforms

As with archaeobotany and zooarchaeology, researchers focus on both methodological applications and evidence-based social interpretations.

Methods:

- Huggett, R.J. 2007. Fundamentals of Geomorphology. Routledge.

Interpretation:

- Bradley, R. 1998. The Significance of Monuments. Routledge.
- Bradley, R. 2000. An Archaeology of Natural Places. Routledge.

Landscape history focuses on how topography, the shape of the land, developed its current form. This involves the study of the characteristics, origin and evolution of landforms. Landforms are the geographical contexts of human habitation and activities. At large scales, landforms define the physiography and other elements of the environment in which humans live. At intermediate scales, landforms partly determine the availability and condition of available resources, as well as constraining communication and mobility. Sedimentary landforms and soilscapes (the soil part of the landscape) at small scales comprise the matrix or physical context of sites.

The study of landforms, their form (shape), formation processes, and geological contents is therefore essential for reconstructing past landforms, which in turn is essential for understanding the world that past people inhabited. This includes topographic and bathymetric features created by physical, chemical, biological or anthropogenic processes and landform dynamics. Furthermore, analysis must include recognition of cultural remains as part of past and present landscapes.

Environment: what are the non-cultural environmental processes that affect the landscape? e.g., climate, weather, endogenic earth processes, wind, water, plants, animals.

Definitions

Landform: natural features that together make up the earth's terrain.

- **Terrain**: the third (vertical) dimension of the earth's surface.

Topography: study of the shape, relief and features of the surface of the Earth.

Bathymetry: study of underwater depth and surface features of lake or ocean floors

- unseen landscapes - under the sea

Landform: an individual feature, such as a slope, valley, or estuary.

- 4 major landforms: mountains, hills, plateaus, plains.
- 100s of minor landforms: basins, canyons, deltas, eskers, waterfalls, *inter alia*

Landform dynamics: the evolution of landforms; long-term response of landforms to disruption, either anthropogenic or natural.

Economy: how have people used the landscape, and how has this influenced landform development? What are the cultural processes that affect the landscape?

Ideology of landscapes, or how people think about the landforms, topography, and terrain that they live on and in is important, but evidence is difficult to find. Nevertheless, geoarchaeologists should consider the cultural importance of landscapes and landforms and their influence on cosmology, identity, origin, and art.

Landscape

Landscape is a social construct that develops through the joining of human cognition and landforms. A landscape is not only topography, but also how people see it, think about it, and understand it. Caves, mountains, springs, and rivers assumed a sacred character in prehistory, as recorded for example in Mesoamerican depictions of caves, or the deposition of hoards in watery places. In Australia, people navigated paths across the land by repeating the words of songs (e.g. Chatwin, B. 1987. *The Songlines*, London/New York, Viking Penguin).

The landscape that people see and experience is the combined effect of numerous landforms, such as mountainous or desert terrain, along with the non-cultural processes that alter the land. Therefore, a holistic study of landscape is a study of the complex ways that people consciously and unconsciously shape the land around them, and how they perceive the land around them. The focus must eventually be on both the ***geographical features*** of the landscape (through GIS, remote sensing, geomorphology, and vegetation reconstruction) and landscape as a ***social construct*** (through oral histories, affordances, and phenomenology).

Practice of Geomorphology

Geomorphology is the study of landforms, their processes, form and sediments at the surface of the Earth. Research includes looking at landscapes to work out how the earth surface processes, such as air, water and ice, can mould the landscape. Landforms are produced by erosion or deposition, as rock and sediment are worn away by these earth-surface processes, then transported and deposited to different locations. Different climatic environments produce different groups of landforms. For example, landforms of deserts include sand dunes and ergs. Post-glacial landscapes include U-shaped glacial valleys and deposits such as moraines and drumlins.

- Data collection: field and lab work
- Analysis: a systematic description of features
- Interpretation: theories regarding soil formation, erosion and deposition, human impact on the landscape

Field: survey, coring, collecting soil samples

In the field, landscape geoarchaeology usually begins with the same strategy as site geoarchaeology; with a regional survey. This process involves recording observations of stratigraphic profiles, cuts, bank deposits, exposed rocks and sediments, and formation processes (e.g., erosion, colluviation). Although not always factored into excavation planning, a geoarchaeological survey is essential for making informed decisions about formation processes, lithic resources, and landforms.

- Geomorphic surveying: record context and possible taphonomic processes to detail the evolution of landforms and land-water relations.
- Examine open profiles: record context and possible taphonomic processes.
- Coring and sampling: core drilling in coastal areas, lakes, and wetlands. Radiocarbon or OSL dating of the sedimentological sequence establishes the chronology of changes in geological environments. Cores are then directly measured (XRF, color, MS, photos) or subsampled for analysis of chemistry, grain size, pollen, phytoliths, biomolecules, microfauna, and others.
- Coring and geomorphological surveying in marine, riverine, and lacustrine environments contribute to determining the original coastline settings and relationship to archaeological structures that are now submerged or elevated. At inland sites around small lakes and wetlands, the methods contribute to understanding the trophic status and life history of inland waterways.

Field: remote sensing data

- Micro-topographic surveys: portable real-time kinematic positioning systems (RTK) enable precise micro-topographic surveys; in conjunction with differential global positioning systems (dGPS), sub-centimeter accuracy is possible. These systems can also be mounted on mobile geophysical surveying equipment.
- Geophysical surveys can be used to extract data about ancient landforms, identify subsurface features, and quantify the depth, thickness, and vertical shapes of buried deposits. e.g. Electrical Resistivity Tomography (ERT), Electromagnetic Induction (EMI), Ground-penetrating radar (Georadar; GPR), and seismology.

Lab methods: materials

As with geoarchaeology of sites and deposits, landscape geoarchaeologists analyze geo-materials and samples (soils, sediments, rocks). The major difference is the scale of application – samples might come from across several hectares with the aim of understanding large mass wasting events (landslides), the divergence of rivers, or changes in trophic status from open water to marshlands. For example, the integration of high-resolution digital elevation models, geotechnical rotary drilling, sedimentological analyses, and radiocarbon dating near the ancient salt mine at Chehrābād (Iran) revealed the long-term effects of centuries of irrigation on a fluvial landscape (Draganits 2020). Analytical methods include

- Soil carbon
- Magnetic susceptibility
- Soil phosphate content
- Trace element geochemistry
- Particle size analysis
- Soil pH
- Clay mineralogy

Lab methods: digital data

Landscape geoarchaeology also employs desktop-based methods using digital datasets in a GIS computing environment. These GI Systems include algorithms for creating digital elevation models (DEMs, DTMs) and a wide range of analyses of terrain, hydrology, networks, and point patterns. For example, historical maps, aerial images, and airborne laser scanning data (ALS) were used to produce historic terrain models and calculate changes in land use and associated patterns of soil loss and gain (Sevara et al. 2018).

Datasets:

- satellite and aerial images
- geological and soils maps
- analysis of geophysical prospection data(e.g. ERT, GPR)
- LiDAR and DEMs, DTMs
- other digital datasets
- erosion modeling
- hydrological modeling

Geomorphologic Processes

Earth-surface processes are forming landforms today, changing the landscape, albeit often very slowly. Most geomorphic processes operate at a slow rate, but sometimes a large event, such as a landslide or flood, occurs causing rapid change to the environment, and sometimes threatening humans. Geomorphological processes are typically grouped into endogenic (earth-powered, e.g. volcanoes), exogenic (external powered, such as wind or water), and the recent addition of anthropogenic processes. Advancements in remote sensing from satellites and GIS mapping has benefited geomorphologists greatly over the past few decades, allowing them to understand global distributions.

Endogenic processes

Endogenic processes are those deriving from energy inside the Earth. The most obvious of these are rapid processes; either igneous or tectonic. Igneous processes, much like the rocks that they form, are either volcanic (eruptive) or plutonic (intrusive). Volcanoes cover old land surfaces with lava and tephra, release pyroclastic material, force rivers through new paths, and build new topographic features volcanic cones), as well as burying human settlements. Plutonic rocks intruding then solidifying at depth can cause the surface to either uplift or subside.

Tectonic processes involve the effects of plate tectonics. Earthquakes can submerge large areas of land creating new wetlands, causing rock or mud-slides, and changing the physical topography in seconds. Isostatic rebound, the uplift of tectonic plate as a result of glacial melt or removal of water or oil from underground, can likewise account for significant changes.

There are also slow, gradual processes, called diastrophic. These include orogenic, or horizontal processes of mountain building, through folding or faulting, and vertical forces generated by the movement of the solid material of the earth's crust upwards (uplift) or downwards (subsidence). Orogenic belts are large mountain chains that form when tectonic plates press against each other and one rises, such as the Alps. These are focal points for high rates of fluvial and hillslope processes and thus long-term sediment production. As a subsidence example, the Carpathian Basin has been subsiding (sinking) for millions of years.

Exogenic processes

The study of geomorphology can be broken down into the study of various geomorphologic processes (Fig. 8.1). Most of these processes are interconnected and are easily observed and measured with modern technology. The individual processes are considered to be erosional, depositional, or both. An erosional process involves the wearing down of the earth's surface by wind, water, and/or ice. A depositional process involves the laying down of material that has been eroded.

Aeolian processes are related to the action of winds, which may erode, transport, and deposit materials. Such processes are particularly effective agents in regions with sparse vegetation and a large supply of fine, unconsolidated sediments (e.g., deserts, western Sicilian *sciara*). Examples of aeolian processes include deflation, or the erosion of sediments by the wind (e.g. western Sicilian *sciara*) and deposition, when airborne sediments are deposited (e.g. loess).

Fluvial processes relate to the actions of rivers and streams. Flowing water moves across a landscape, cutting and eroding its channel and depositing this eroded sediment as floodplain deposits and alluvial fans. The river generally grows in size during this process, meandering across the landscape, and sometimes merging with other rivers forming a network of braided rivers, again reshaping the landscape. Paths rivers take depend on the topology of the area and the underlying geology or rock structure found where it's moving.

Hillslope processes involve the movement of soil, sediments, or rock down slope due to topography (slope), energy (water, tectonic movement), and gravity. French (2003) identified three basic types:

- rapid mass movement (e.g. rockfall, mudslide);
- slow and seasonal mass movements that produce slow down slope translocation (e.g. creep, solifluction); and

- water flow processes such as overland flow, alluviation, erosion, and colluviation.

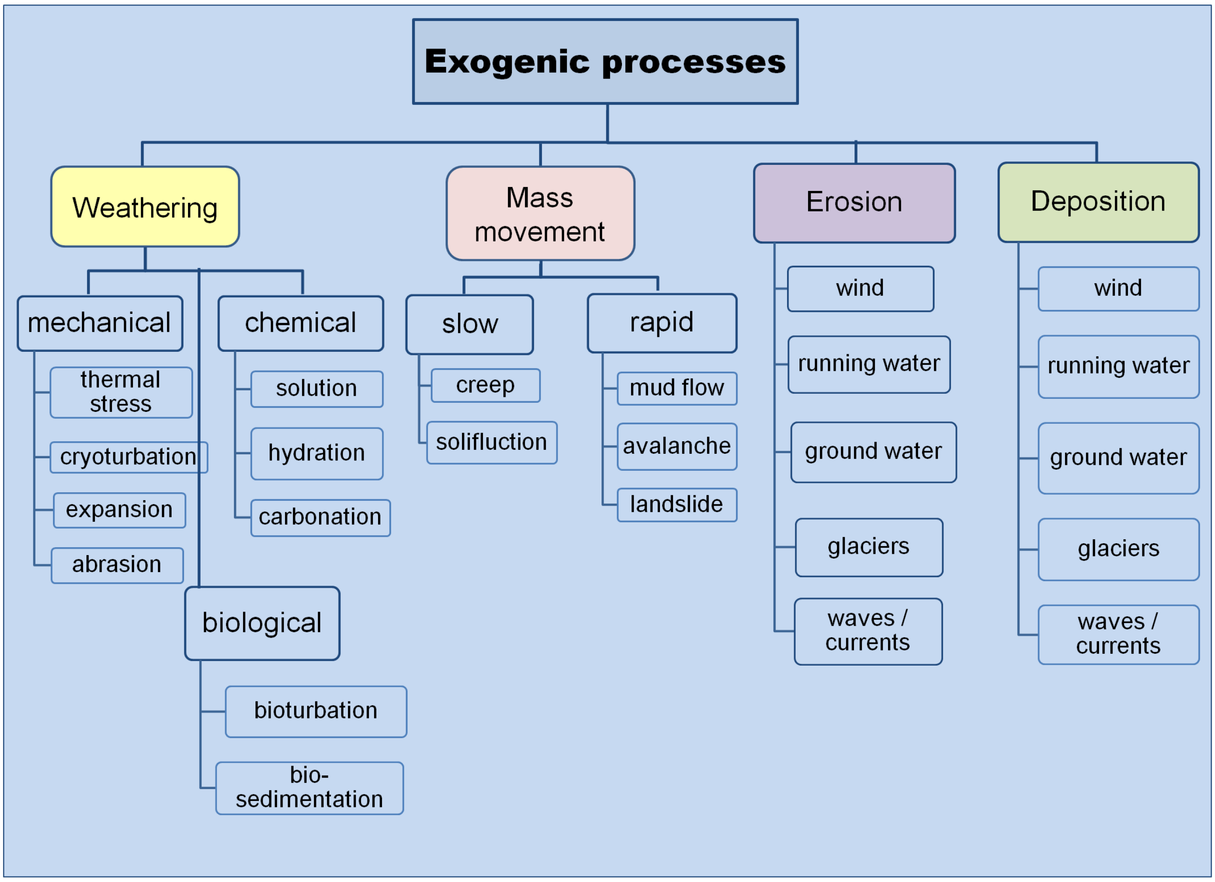

Fig. 8.1. Exogenic (external) forces derive energy from the earth's exterior or originate within the earth's atmosphere. This includes wind, water, heat, plants, and animals, among others.

Glacial processes involve the gradual movement of ice, which causes abrasion and movement of debris. Ice is an erosional force because ice carves the ground beneath and on the sides (abrasion). Ice is also depositional because glacial movement pushes rocks and other debris into new areas, and as glaciers melt, they drop their accumulated debris. Melting glaciers can yield environmental data, such as ancient trees and animals. Debris released by melting glaciers also create landforms such as drumlins, eskers, and moraines. In some cases, people used glacial landforms, for example, burials in glacial kames and the associated Glacial Kame Culture of North America.

Marine and coastal processes are related to the action of waves, marine currents, and seepage of fluids through the seafloor. These processes can result in mass wasting, sedimentation, the creation of deltas, and the removal or movement of beaches. Coastal settings are particularly dynamic, constantly changing ecosystems.

Biological processes involve the interaction of living organisms with landforms (biogeomorphologic processes). These can be of many different forms ranging from biogeochemical processes controlling chemical weathering, mechanical processes like burrowing, root action, and tree throws, to limiting erosion.

Anthropogenic processes

Anthropogenic processes, or human activities, are exogenic, but typically treated as a separate category because they combine biological and cultural actions and influences. In terms of impact, people are now equal in importance to other geomorphic factors, so they are treated as the third geomorphologic agent in the modern world. According to Szabó (2010 "Anthropogenic Geomorphology: Subject and System"), "Although the energy released by human society is insignificant compared to the endogenic forces of the Earth (tectonic movements, volcanic activity, earthquakes)", the impact of human activities now surpasses the influence of exogenic processes (biological, fluvial, weathering)."

Some examples of anthropogenic processes include

- human activities like tunnel projects, mining and blasting can result in mechanical disintegration or stress-release crack, aggravating physical weathering processes;
- emissions (air pollution) can result in new or increased chemical weathering of stone;
- removal of the underground aquifer can increase isostatic rebound effects;
- anthropogenic removal and deposition of sediments.

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Chapter 9. Environmental isotopes

This chapter introduces the application of isotopic techniques in environmental archaeology. Isotopes of carbon, nitrogen, oxygen, and strontium, along with the mechanisms by which they vary in the biosphere, contribute to a range of environmental and archaeological questions. Archaeological case studies will be used to show how isotopic analyses can aid in the reconstruction of past diets, environments, patterns of mobility, and chronology. In addition to the ways that stable isotopic ratios are measured and the types of materials that can be sampled, we will briefly consider the chemical evidence for pollution from ancient societies.

Readings

- Krigbaum 2008 Stable Isotope analysis, or
- Moffat 2014 Isotope Geochemistry in Archaeology
- Reitz & Shackley 2012 Stable Isotopes, Elements, and Biomolecules
- Schoeninger 2010 Diet Reconstruction and Ecology Using Stable Isotopes

Case studies

- Chazin et al 2019 Isotopes pastoralist mobility LBA Caucasus
- Dunne et al 2019 Feeding Vessels
- Harrison et al 2009 Metallurgy, environmental pollution, and decline of Etruscans
- Schurr 1997 Stable nitrogen-isotopes to study weaning behavior
- Schulting 2018 Dietary Shifts at the Mesolithic-Neolithic Transition

Isotopes in Archaeology

The earth and its atmosphere, hydrosphere, geosphere, and biosphere are composed of atoms of different elements, such as oxygen, carbon, silicon, and nitrogen. Each of these elements has several variants, or isotopes, that share the same number of protons but have varying numbers of neutrons. That is, they have the same chemistry, but different physics. This difference determines their atomic weight (the number of neutrons in each atom). For example, 99 % of all carbon in our atmosphere exists as Carbon-12 (^{12}C) with an atomic weight of 12, made up of 6 protons, 6 neutrons, and 6 electrons (electrons do not contribute to atomic weight). The remaining one percent carbon is made up of two different variants; ^{13}C and ^{14}C.

Isotopic methods measure the relative abundance of the variants of the same (or derivative) element. The quantity of these variants, particularly in relation to other variants or derivative elements, provides information about the environment, diets and water sources, and the spatial origin of materials, plants, animals, and people (Krigbaum 2008; Moffat 2014).

Isotopes are stable or unstable depending on whether they undergo radioactive decay. Stable isotopes do not change, or change very slightly and slowly, while unstable isotopes decay in predictable and measurable ways. For example, ^{13}C has 6 protons and 7 neutrons, so it can be differentiated from ^{12}C. In contrast, ^{14}C has 6 protons and 8 neutrons, which make it too heavy to hold together. It emits energy, radiating neutrons, to get rid of the excess weight. Unstable isotopes are therefore very useful for absolute dating. Isotopic analysis can be performed directly on archaeological materials or geological materials.

Environmental archaeologists study both

- stable isotopes: O, C, N, Ca, Sr, Cu, Pb, S, and
- unstable isotopes: C, U, Th, K, Ar

Table 9.1. Common Research Question and Associated Isotopes

Research Q	**Stable/Unstable**	**Elements**
Chronology	Unstable	14C, K/AR, U
Mobility	Stable	Sr, O, S
Diet	Stable	C, N
Environmental change	Stable	O, H, C, N
Pollution	Stable	Sr, Pb, S, Hg
Material sourcing		Pb (metal, paints)
		Sr (ceramics, textiles)

The scope of isotope research in environmental archaeology, and archaeology in general, is very broad. There are many overlaps with other fields of archaeology, particularly regarding raw material sources and human diet and mobility. Overlaps with other geosciences and ecology include paleoclimate and paleoenvironmental reconstructions, climate change, and absolute dating, to name the most common.

Methods

Sample preparation typically begins with grinding or otherwise reducing sediments to a powder. Grinding can be done by hand, using a clean ceramic mortar and pestle, or in a ball grinder. The powdered sample is then chemically cleaned to remove impurities (organics) and carbonates.

Measurement is typically through various applications of Mass Spectrometry, which measures the masses of molecules within a sample to identify chemical elements. A mass spectrometer ionizes the atoms in a sample, speeds them up, and deflects them with a magnetic field. Lighter elements (with lower mass) are deflected more. The beam of ions is measured electrically. Isotope Ratio Mass Spectrometry (IRMS) is used to measure the relative abundance of isotopes in different materials. It measures ratios by separating isotopes on the basis of their mass to charge ratio. That is, it measures more variability than normal mass spectrometers.

- Light elements, such as O, H, C, and N are measured with Gas Chromatography – Isotope Ratio Mass Spectrometry (GC-IRMS). The components of a sample are dissolved in a solvent and vaporized into gas, then injected into the IRMS.
- Heavy elements, such as Ca, Sr, Pb, S, U, and Th can be measured with Thermal Ionization Mass Spectrometry (TIMS), or Multi-Collector - Inductively Coupled Plasma Mass Spectrometry (MC-ICPMS).

Isotopic compositions of materials analyzed on mass spectrometers are usually reported relative to some international ***reference standard***. For example, the standard for Oxygen-18 is the Vienna - Standard Mean Ocean Water (VSMOW); a bunch of ocean water kept in Vienna. This standard is also used for Hydrogen. The Carbon-13 standard is the Vienna - PeeDee Belemnite (VPDB) standard, a fossil of a belemnite from the Pee Dee formation in Canada. One sample is kept in Vienna. Standards for some elements are more general; marine carbonate is arbitrarily set at 0, while the standard for Nitrogen is AIR – literally atmospheric air.

Baselines are essential for many isotopes (Bataile et al. 2020). Thorough environmental sampling strategies should be conducted to document regional variability. This is particularly important for Sr, which is used to identify the source of origin for humans, animals, and raw materials such as clay and wool. Establishing baseline data using modern plants and animals is not optimal. Water, soil, and associated archaeological remains are somewhat better.

Unstable Isotopes

Unstable elements undergo ***radioactive decay***, from one isotope to another, and in some cases from one element to another (e.g. U, Th, K, Ar, ^{14}C). Decay speed can be calibrated to time and is usually expressed as a "half-life". Carbon-14, or radiocarbon, is the dating of material containing carbon, such as organics (carbon), calcium carbonate, and igneous rocks. Potassium/Argon dating (K/Ar) measures the ratio of potassium to argon because K decays to Ar. Examples include lava beds at Olduvai Gorge in Africa. Uranium-series dating calculates the degree to which equilibrium has been restored between the parent Uranium-234 and Thorium-230, for example, the calcite deposits on paintings at Altamira and El Castillo caves in Spain. The analysis of unstable isotopes is most commonly used as a geochronological tool – e.g. for establishing absolute age – which will be covered in Chapter 10.

Stable Isotopes

The isotopic abundances of elements such as O, H, C, and N were fixed when Earth was formed and, on a global scale, have not changed. Stable isotope compositions of low-mass (light) elements such as oxygen, hydrogen, carbon, nitrogen, and sulfur are normally reported as delta (δ) values. That is, $\delta^{13}C$ = "delta Carbon-13" = the stable isotope ratio of ^{13}C to ^{12}C. Isotopes of carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$), strontium ($^{87}Sr/^{86}Sr$) and oxygen ($\delta^{18}O$) have received the most research.

Waters that have recharged at different times or in different locations are often isotopically distinct; i.e., they have distinctive "fingerprints". Biological cycling of solutes and water/rock reactions often change isotopic ratios in predictable and recognizable directions. Stable isotopes of strontium and lead vary geologically. As mentioned earlier, there is a constant ratio of ^{12}C to ^{13}C in the atmosphere, and the ratio of C in plants is related to climate. Sunny, dry climates have plants with lower ^{12}C values compared to wetland or forest environments. Research involving the analysis of stable isotopes can focus on mobility, diet and health, climate and environmental change over time, or establishing the source of raw materials.

Mobility

Mobility studies generally focus on strontium (Sr), oxygen (O), and sulfur (S). For Sr, studies begin from the assumption that prior to any post-burial diagenesis the $^{87}Sr/^{86}Sr$ ratio of bones and teeth reflect the geological environment of food and water consumed by the individual. The methods can be applied to humans and animals (e.g., Chazin et al 2019; Price et al. 2000). Generally, migratory herd animals (caribou, bison), or domestic animals herded and moved by people (cattle, sheep), are amenable to this method. Short-lived animals with small ranges (e.g. packrats, moles) can provide Sr baseline data because their food and water are assumed to come from a single Sr region.

Samples taken are generally tooth enamel or bone. Teeth mineralize in the first 12–13 years of human life. After that, no additional Sr is added. In contrast, bone is constantly regenerating, and therefore Sr is added throughout life. This results in teeth providing signals for place of birth and bones for the last few years of life. A major requirement is that isotope composition of samples be compared with a regional map of bioavailable Sr values. Significant challenges include post-depositional contamination from groundwater and the consumption of imported food and drink.

A case study example is the identification of "foreign" residential neighborhoods, or *barrios*, at Teotihuacan in Mexico, AD 1-360 (Price et al. 2000). The $^{87}Sr/^{86}Sr$ ratio was measured for human bone and tooth enamel from 62 individuals buried in various areas of the city, plus 9 rabbits. Samples were abraded with a modeling drill to remove contaminants, washed multiple times in deionized water and acetic acid, then ashed in a furnace, then dissolved in HCl, and isolated using cation exchange chromatography. Isotopes were measured using thermal ionization multiple collector mass spectrometry. Results in tooth enamel samples suggest different origins, while bone values suggest they all lived at Teotihuacan for many years (Price et al. 2000).

As an additional note, Sr isotope ratios in marine foods reflect the $^{87}Sr/^{86}Sr$ signature of the ocean water. If inhabitants of ancient coastal regions consumed mostly food from the sea, their Sr ratios will reflect the strontium composition of the sea, even if the coastline has moved since the samples were deposited. Conversely, if people consumed mostly imported or terrestrial foods, then their strontium isotope ratios will reflect the geologic region where the food was grown (Slovak et al. 2009: 159). This represents an extreme version of the imported food challenge. However, analysis of nitrogen (N) values can help ascertain whether people consumed mainly seafood or terrestrial food in their diets; from this, the Sr values can be contextualized.

Diet, nutrition, health

Assumptions for the analysis of C and N isotopes ($^{13}C/^{12}C$, $^{15}N/^{14}N$) in diet are that the isotopic composition of body tissues reflects the food you eat. Animals have enriched $\delta^{15}N$, ergo protein (meat, milk) raise the $\delta^{15}N$ value. The photosynthetic pathway is the key to $\delta^{13}C$ variability. Most plants are C_3 (herbs, shrubs, wheat, barley, and most trees). Some grasses have adapted to dry tropical environments by photosynthetic adaptations to reduce photorespiration; these are C_4 (maize, amaranth, and chenopodium).

Analysis focuses on bone collagen from humans and large mammals. $^{13}C/^{12}C$ ratios are a byproduct of radiocarbon (^{14}C) analysis, as well as a separate analysis (e.g. Schoeninger 2010; Schulting 2018). Challenges include the industrial effect of elevated CO_2, and that more than one factor could result in the same signal.

An interesting case study example combining mobility and diet is King Richard III, whose body was discovered in a car park in Leicester, England. Isotopic analyses were conducted on bioapatite and collagen from two teeth that formed during Richard's childhood, and from two bones: a femur, which averages long-term conditions and a rib that represents the last few years of life (Lamb et al. 2014). Strontium, oxygen, carbon, and nitrogen were analyzed. $^{87}Sr/^{86}Sr$ were analyzed for diet, based on geology and $\delta^{18}O$ for drinking water. $\delta^{13}C$ and $\delta^{15}N$ for variations in diet based on plants and animals, respectively. Results of $\delta^{13}C$ and $\delta^{15}N$ suggest that Richard ate a lot of meat and fish, and probably observed all the Christian fast days by eating fish instead of meat. $\delta^{18}O$ values suggest that he drank a lot of wine – because we know where he was born and where he died, we know that the non-local $\delta^{18}O$ values do not reflect migration. Liquids transported from other $\delta^{18}O$ environments provide the best explanation (Lamb et al. 2014).

Stable isotopes and the environment

Aside from carbon pathways being used to infer vegetation types, stable isotopes are used to infer past climate patterns (e.g. Leng & Lewis 2016). Stable hydrogen isotope values reflect the extent of precipitation, and vary based on climate and geography. Geography can be controlled for, with climate the variable being tested for. Hydrogen is usually reported as δD, representing the ratio $^{2}H/^{1}H$; D is deuterium, a name for ^{2}H. Stable oxygen isotope values vary mainly by temperature, and secondarily by precipitation. $\delta^{18}O$ is used as a principal proxy to infer ocean temperature based on CO_2 derived from the shells of marine organisms, including zooplankton and foraminifera. The ratio of ^{16}O to ^{18}O in the shell calcite ($CaCO_3$) reflects the ratio in seawater at the time the shells formed. Greater $\delta^{18}O$ values ($^{18}O/^{16}O$) correlate with warmer conditions, due to the ease of movement of the heavier oxygen isotope. That is, warmer temperatures enrich ^{16}O relative to ^{18}O to generate isotopically negative signatures, while cooler temperatures produce positive signatures (Krigbaum 2008; Moffat 2014). Stable isotopes can also be used to study patterns of ancient pollution (Harrison et al 2009), δ18O is more widely used as a climate proxy. Assuming that stable oxygen isotope values vary by mostly temperature, as well as the amount of precipitation, the oxygen isotope analysis of marine carbonates or ice cores allows global ice volume to be estimated through time. Mollusc shell samples intended to investigate seasonality in $\delta^{18}O$ are usually taken from cleaned shell cross-sections using either a hand drill (dentist or modeling type) or a computer-driven micromill. At sizes of a fraction of a millimeter, samples weighing less than 100 micrograms can be drilled from individual growth increments to a depth of a few hundred micrometers. Oxygen isotope ratios are then measured using GC-C-IRMS (Leng & Lewis 2016).

An example using hydrogen to infer paleoclimate focused on comparing modern and ancient bison populations in North America (Leyden et al. 2006). δD from bone collagen samples collected from geographically distinct populations of modern bison in North America varied consistently with the modern isotopic and climate gradients at each sampled geographic location. Temporal climatic patterns revealed by the δD values of ***prehistoric*** bison population bone collagen compares well with other climate indicators. This study demonstrates that δD acts as a paleoclimate proxy that can be directly linked to the ^{14}C age and lifetime of the sampled animal (Leyden et al. 2006).

Many studies have demonstrated the long-term records of human-induced environmental pollution. The most widely known example is probably the identification of Roman lead (Pb) pollution in the Greenland ice cores (McConnell et al. 2018). Examples of anthropogenic pollution extend far beyond the Romans, however, often affecting relatively small areas, but persisting for many thousands of years. Sediments from Palaeolithic hearths in cave sites on Gibraltar contain levels of heavy metals sufficient to meet present-day standards for contaminated soil (Nocete et al. 2011). Anthropogenic signatures of early copper mining and cold processing come from soils sample off Isle Royale in Lake Superior, North American c. 4550 and 3450 BC (Pompeani et al. 2013).

Anthropogenic signatures of early metallurgy in Southern Iberia indicate lead pollution caused by metallurgical activities since ca. 1950 BC (Early Bronze Age) and continuing through the Late Bronze and Early Iron Ages. Lead ores are abundant in southern Iberia, especially in the Southeast, and lead appears naturally with copper minerals. These results come from a 137.5 cm-long sediment core collected from the center of Laguna de Río Seco. Sixty-four samples taken from the core at c. 2 cm intervals were analyzed for Pb using ICP-MS (García-Alix et al. 2013).

Sourcing

The characterization of archaeological materials involves determining the isotopic composition of the material and comparison with possible source materials, such as geological bodies containing ores, stone or clay, or biological organisms. Analyzable archaeological materials range from metals and lithics, glass, ceramics, and lead-based pigments to textiles. While this approach might not appear to be particularly environmental when focused on trade patterns or unequal access to materials, the extraction and processing of raw materials always include some human impacts on the environment, for example as outlined in the section on pollution.

One example involves the use of lead isotopes ($^{208}Pb/^{206}Pb$, $^{207}Pb/^{206}Pb$) which has been useful for determining the ore sources of metals, especially in the Bronze Age Mediterranean. The ratio of these isotopes varies between ore bodies and is not affected by anthropogenic processing; thus, they can be used to identify the source of ores. For example, copper oxhide ingots and bronze tools from Sardinia can be traced to both Sardinian and foreign copper ores. Most ingot fragments have a lead isotope signature similar to those of Cypriot copper ores but some ingots have Pb isotope fingerprints suggesting local (Sardinian) production. Of the bronzes, none has lead with an isotopic composition characteristic of copper ingots from Cyprus. All contain local lead, suggesting the bronze tools were made locally (Bergmann et al. 2001).

Several challenges exist. Incomplete geographic coverage of ore sources means that several ore sources could have the same Pb isotope signature. For example, Sardinian sources have very similar signatures to sub-Alpine sources. Mixing of sources is more problematic. When objects are melted and the bronze re-used, several sources can be combined in one new artifact.

Strontium ($^{87}Sr/^{86}Sr$) can be used to source several materials, in addition to humans and animals. Marble generally proves difficult to source, especially when using petrographic methods. White marbles have been collected from some of the most famous classical quarry areas of the Mediterranean: Carrara, Paros, Naxos, Pentelikon, Dokimeion, Hymettus, Thasos, and Proconnesus. The problem for marble geochemical sourcing is the overlap in value ranges for quarries. However, some quarries show peculiar distributions in Sr values that can aid in sourcing.

Textiles can also be sourced using Sr values. For example, modern Scandinavian sheep hair has been used to develop a provenance tracer for ancient woolen textiles (Frei et al. 2009). In another example, willow and tule textiles from the western Great Basin (North America) have been sourced (Benson et al 2006).

Oxygen ($\delta^{18}O$) can be used to source archaeological fauna from Chaco Canyon (Hamilton et al. 2018) and marine shell. The oxygen isotopic composition of modern *Olivella biplicata* shells varies with ambient sea surface temperature. Oxygen isotope ratios in modern shells can be used to identify shells that grow north versus south of Point Conception, California. *Olivella biplicata* is an intertidal snail-shell used to make beads in California and the Great Basin. Researchers analyzed over 100,000 fragments of beads from a single cubic meter of excavation (Eerkens et al. 2005). The beads are clearly from coastal sources. However, researchers encountered many difficulties, including poor spatial resolution and the use of modern seawater temperatures. Perhaps more importantly, the method has to be adjusted for each type of mollusc because (a) they might be migratory and (b) shell can be calcite or argonite, and these have different isotopic ratios. Furthermore, shell growth rates change daily, seasonally, and over the lifespan of an animal.

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Chapter 10. Chronology and seasonality

Chronology has obvious applications in archaeology and is also essential for reconstructing the timing of environmental or landscape changes. Furthermore, many dating techniques are directly related to other analyses in environmental archaeology. This chapter introduces various types of dating methods used in environmental archaeology, including incremental methods (dendrochronology, lake varves, tephrochronology), radiometric methods (14C, K/Ar, Uranium-series), luminescence dating, amino acid dating, and paleomagnetic dating. In addition, a related aspect of archaeological science, seasonality, is determined by using proxy data such as insects, molluscs, animals, charcoal, pollen, and seeds to determine the season of site occupation and human activities.

Readings

- Dincauze 2000 Part II: Chronology (Chapters 5 + 6)
- Feathers 2008 Luminescence Dating
- Legge 2008 Seasonality of Site Occupation
- Nash 2008 Dendrochronology

Case studies

- Bailiff et al. 2014 OSL dating and geomorphological analysis
- Dincauze 2000 How do we read these bones?
- Kinnaird et al 2017 OSL profiling and dating historic agricultural terraces Catalonia
- Milner 1999 Pitfalls and problems in analysing and interpreting seasonality
- Pike-Tay et al 2004 Body Part Representation and Seasonality Ecsegfalva

Overview of Quaternary Dating Methods

Chronology enables us to understand the relative timing, rates, and nature of change. We can relate events to larger social and political contexts, and possibly quantify process rates (change/time). Time in the past is reported with either relative or chronometric dates. Relative dates give the timing of an event relative, or with reference to, another event. This simply states that one thing is older or younger than another is, but not when an event happened in years before the present. For example, when comparing a cross-section of archaeological or geological strata in the absence of evidence for extreme disturbances, we assume that older levels are below younger levels (see Stratigraphy in Chapter 7). In contrast, chronometric methods place events in their chronological position with reference to a widely accepted time scale, such as a calendar, and reported in years relative to that calendar. Events given the same chronometric date should be contemporaneous. There are also quasi-chronometric methods that are calibrated relative dates, meaning they are cross-dated with at least one chronometric technique so that the dates are comparable within a region. These include paleomagnetism, amino acid dating, and flour.

Another way to think of this is that scientific 'absolute' dating methods are radioisotopic, paleomagnetic correlation, organic or inorganic chemical, biological incremental (growth), or physical incremental, and all require some correlation. That is, for example, tree rings must be correlated with each other for dendro-dating, then 14C dates are calibrated by correlation with dendrochronology, or tephra is correlated with isotopic and chemical results. There are various ways for us to know when an event occurred.

- Calendrical chronology – diaries, journals, calendars, stele inscriptions
- Relative chronology – artifact typologies, geochronology, stratigraphy
- Absolute chronology
  - radiometric isotope methods (14C, K/Ar, U/Th)
  - radiometric trapped charge methods (TL, OSL, ESR)
- Calibrated relative chronology
  - incremental methods (varves, tree rings)
  - OCR, paleomagnetism, obsidian hydration

Table. 10.1. Principle dating methods used in environmental archaeology

Type	Method	Material	Precision	Range / Years
incremental	Dendro-dating	Wood with visible rings	1 year	to 11,000 yrs
radiometric	Radiocarbon	Organics with C	50-100 yrs	to 50,000 BP
radiometric	K/Ar	Volcanic minerals	± 10%	> 80,000 BP
radiometric	U-series	Calcium carbonates (shells, corals, limestone, teeth)	± 10%	10,000 – 50,000 BP
radiometric	Thermoluminescence	Heated stone, clay, ceramic	± 5-10%	to 300,000 BP
radiometric	OSL	Sediments, tephra: hi quartz; K-feldspar		to 100,000 yrs to 300,000 yrs
	Amino-acid racemization	Bone, shell, biominerals in sediments		to 300,000 yrs
radiometric	Electron-spin resonance	Quartz, flint, $CaCO_3$ (teeth, shell, coral, etc.)		5000 – 750,000+
	Archaeomagnetism	in situ ceramics, bricks, burnt earth, heated clay, volcanic rocks, Fe minerals		to 10,000 yrs

Incremental Chronology

Incremental chronologies rely on the rhythmic, periodic, annual, or seasonal layers, laminations, or rings. These can be biological, based on growth rates (tree rings, lichen) or physical, based on the deposition of layers (varves, ice, tephra).

Dendroarchaeology

Tree rings provide high-resolution chronometric, environmental, and behavioral data. Dendrochronology (tree-ring dating) is one of the most accurate chronometric dating methods. Patterns of tree growth – seen in annual tree rings – will be similar between trees of the same species growing in the same climatic region. Patterns vary each season depending on precipitation, temperature, disease, etc. The method is based on the fact that annual growth rings under the bark on shallow-rooted trees vary in width with the amount of water available each season and with temperature fluctuations from winter to summer. Weather patterns tend to run in cycles of several years, and the sequence of tree-rings in a region will reflect the same cycling. The changing pattern of tree rings provides the basis for a calendar that is often accurate to a single year.

By cross-linking core samples from living and dead trees, a master sequence of annual tree-ring widths can be compiled. Each region has its unique master sequence since weather patterns are not the same from one area to another. Ancient log samples can be compared with the master tree-ring sequence to date them to the year that they were cut down. Tree-ring sequences do not extend back very far, so dendrochronology is primarily useful for comparatively recent occupations. In the American Southwest, dendrochronology has been used extensively because wood preserves well in the extremely dry climate, and tee rings are more reliable than wood charcoal. However, the sequence goes back less than 3000 years for Douglas fir and 8500 years using Bristlecone pine. Prehistoric populations used Douglas fir extensively for construction, especially in cliff dwellings and pueblos, but Bristlecone pines are rarely found in human habitations. The Northern European master sequence goes back just over 13,000 years using oak and pine.

Lake varves

Varves are annual layers of sediment or sedimentary rock ('annually laminated'). Small-scale sedimentary events formed in a variety of marine and lacustrine depositional environments from seasonal variation in clastic, biological, and chemical processes.

- pair of layers each year – 1 coarse (sand and coarse silt) and 1 fine (fine silts and clay)

Environmental proxy

- Thicker varves indicate warmer climate years.
- Thinner varves indicate colder climate years.
- Changes in varve thickness can be plotted against time to determine climate variability.
- Varves can only be found in regions that were affected by glaciers!

Ice cores

Ice core chronologies are generated via one of two methods. The first, an incremental method, is to count the layers of ice that correspond to the annual layers of snow. The other method is to radiocarbon date the carbon in trapped CO_2. Although neither of these methods is obviously archaeological, the dates correlate well with environmental proxies, e.g., $\delta^{18}O$.

Tephrochronology

Discrete layers of tephra – volcanic ash from a single eruption – provide 'tephra horizons', or marker beds. During an eruption, ash is deposited almost instantaneously over a large area. Each volcanic event produces ash with a unique chemical fingerprint so that the deposit can be chemically identified anywhere within an affected area. Once the volcanic event has been independently dated, the tephra horizon provides a time marker. Tephra horizons are relatively easy to identify and sample in the field. Samples are analyzed for chemistry (ICP-MS), mineralogy, and morphology (microscopy). Results are compared to a **database of over 4500 samples** that have been dated (^{14}C, K/Ar, $^{40}Ar/^{39}Ar$). See Wulf (2012) for specifics of tephrochronology from sediments.

Lichenometry

Lichen growth can be used to determine the age of exposed rock, based on a presumed specific rate of increase in radial size over time. Lichen can be preserved on old rock faces for up to 10,000 years. Map lichen (*Rhizocarpon geographicum*) is the most commonly used species for lichenometry. Methods: mostly involve measuring the largest lichen.

- Single largest lichen – the lichen that is oldest or grows in most favorable conditions
- Aggregate five largest lichens
- Aggregate largest lichens in a fixed area
- Size and frequency

Problems with lichenometry have not been fully resolved, and dates are typically controversial. Problems include

- difficult to correctly identify species
- delay between exposure and colonization
- varying growth rates from region to region
- growth rates are not necessarily constant over time

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Sclerochronology

From the Greek *scleros* (hard), *chronos* (time), and *logos* (science), sclerochronology is the use of the hard parts of living organisms to order events in time. For example, growth increments in mollusc shells and coral 'rings'. The scale varies, and the method is relative unless several rings can be radiometrically dated (Twaddle et al. 2016)..

Radiometric Methods: Isotopic

Chronometric methods, frequently referred to as absolute dating, comprise any archaeological dating method that gives a result in calendar years before the present time. Dendrochronology, therefore, is both a chronometric and incremental method. Isotopic radiometric methods determine the age of materials through the decay of their radioactive elements. These include

- Radiocarbon ^{14}C
- Uranium-series
  - calculates the degree to which equilibrium has been restored between the parent Uranium-234 and Thorium-230
  - example: calcite deposits on paintings at Altamira and El Castillo caves in Spain

- Potassium – Argon (K/Ar, $^{40}Ar/^{39}Ar$)
    - measures ratio of potassium to argon (K decays to Ar), or Argon 40 to argon 39
    - example: tuff beds at Olduvai Gorge in Africa
- Fission-track dating:
    - counts the tracks, left as scratches, by the fission of ^{238}U in some volcanic glass.

Radiocarbon ^{14}C

^{14}C is continuously produced in the upper atmosphere, combines to CO2, and is mixed in the atmosphere, biosphere, and also lithosphere (for example lime). At constant production rates, equilibrium can be set between production and decay, i.e. the concentration remains constant. Carbon is 99% ^{12}C, 1% ^{13}C, but only 1 in 1 billion is ^{14}C. Radiocarbon dating covers a period from 200 to about 50,000 years before today. Analyzed materials include wood, charcoal, shells, humus, bones, corals, mortar, and CO_2.

Radiocarbon dating relies on several assumptions.

- Constant content of ^{14}C in the atmosphere (constant production, rapid mixing, constant reservoir size).
- Biosphere has the same concentration (= rapid mixing of both reservoirs)
- ^{14}C exchange of an organism ends at its death; then it only contributes more radioactive decay.

Problems in radiocarbon dating include ^{14}C fluctuations in natural production (solar activity), climate (CO_2 solubility in water is temperature-dependent), volcanic activity (volcanic CO_2 is ^{14}C -free), burning of fossil fuels, and nuclear tests. ^{14}C ages show increasing discrepancy with calendar years (^{14}C -age too young) the further one goes into the past (higher ^{14}C levels in the past. Reservoir effects, such as the Marine effect (upwelling of old water) and north-south effects (southern hemisphere is 30 years older) can give results that are too old. Resolution of these problems is achieved via calibration curves. These are measurements on tree rings and other samples of known age that are compiled into calibration curves by the IntCal group (e.g., IntCal13, Reimer et al. 2013). Several research groups have developed calibration software (e.g. OxCal, CALIB).

Uranium-series

The principle of U-series dating is the measurement of the radiometric imbalance between the two decay series of the radioactive uranium isotopes ^{234}U / ^{238}U and ^{230}Th / ^{234}U. When balance is achieved, age can no longer be measured. Dating the materials that can also be used for climate reconstruction: e.g., d^{18}O in shells or stalagmites. The period covered is from 10 to about 550,000 years before today. Materials analyzed are calcium carbonates found in stalagmites, limestone, sinter, and coral, as well as bones and shells (less accurate).

One example involves ^{230}Th / ^{234}U dating of a stalagmite from Yok Balum Cave in Belize. Results yielded a precisely dated sub-annual climate record for the southeastern Maya Lowlands (Kennett et al. 2012).

Potassium-Argon

^{40}K decays into the gas ^{40}Ar and calcium-40 (^{40}Ca) at a known rate ($^{40}K/^{40}Ar$ dating). The half-life of ^{40}K is approx. 1.25 billion years. Measuring the amount of ^{40}K in a sample is the basis for age determination (also argon-argon, $^{40}Ar/^{39}Ar$ dating). K/Ar dating covers the period 100,000 to the origin of the Earth. Analyzable materials include minerals in volcanic tuff and tephra, such as sanidine, the high-temperature form of potassium feldspar, which is the most desirable. Micas, plagioclase, hornblende, clays and other minerals can yield good data.

The method takes rock samples and crushes them to a size that preserves whole grains of the mineral, and then sieves the sample to help concentrate these grains of the target mineral. Selected size fraction is cleaned in ultrasound and acid baths, then gently oven-dried. The target mineral is separated using heavy liquids, then hand-picked under the microscope for the purest possible sample. This mineral sample is then baked gently overnight in a vacuum furnace to remove most atmospheric ^{40}Ar. The amount of Ar is measured by mass spectrometry of the gases released when the sample is melted in a vacuum. A precise amount of argon-38 is added to help calibrate the measurement. The classic example is the dating of the tuff beds at Olduvai Gorge in Africa.

Fission track

Many volcanic minerals and glasses, such as obsidian, mica, and zircon, contain the isotope uranium-238 (^{238}U), which is unstable. As the uranium atoms split, or fission, it releases alpha particles that leave damage tracks in the material. The rate at which this process occurs, and therefore the number of tracks generated, is proportional to the decay rate of ^{238}U. The decay rate is measured in terms of the half-life of the element, or the time it takes for half of the element to split; for ^{238}U this is approximately 4.5 billion years. The fission tracks can be seen and counted with an optical microscope.

Challenges with this method are that the sample must contain enough ^{238}U to create enough tracks to be counted, but cannot contain too much of the isotope, or there will be a muddle of tracks that cannot be distinguished for counting.

Radiometric Methods: trapped charge

Trapped charge methods use non-isotopic effects of radioactive decay (lattice defects, electron capture). These techniques, luminescence and electron spin resonance, measure the energy emitted when a sample is excited. The stored energy is produced by the absorption of electrons from natural radioactivity; the electrons are trapped in the lattice, or crystalline structure, of common minerals such as quartz and feldspars and in some biological materials such as tooth enamel. Period covered ranges from a few 100s to almost 1 million years ago. Methods include

- TL – thermoluminescence
- OSL – Optically Stimulated Luminescence
- IRSL – Infrared Stimulated Luminescence
- ESR – Electron Spin Resonance

Analyzable materials include all quartz and feldspar containing rocks/sediments, ceramics, sinter, etc. Which method is used depends on the type of excitation during the measurement e.g., TL (thermo), OSL (light), IRSL (infrared light). An essential part of the method is an accurate calculation of the environmental radiation dose rate ($\dot{D}$), to determine the time since the traps were empty. Accuracy of measurements is about 10% of the age (Wagner 1998: 219-294).

Thermoluminescence Dating (TL)

TL is used to date materials containing crystalline minerals to a specific heating event, e.g., ceramics, to determine the date of firing and sediments that were exposed to intensive heating (hearths). Certain minerals (quartz, feldspar, and calcite) store energy from the sun at a known rate. This energy is lodged in the imperfect lattices of the mineral's crystals. Heating these crystals (such as when a pottery vessel is fired or when rocks are heated) empties the stored energy – resets the clock – after which time the mineral begins absorbing energy again. These energy charged electrons progressively accumulate over time. This works for a period from a few decades back to about 300,000 years ago. A milled sample is placed in an oven. When the sample is reheated to a high temperature, the trapped energy is released in the form of light as the electrons escape (**thermoluminescence**).

The amount of light produced is a specific and measurable phenomenon. What is actually determined is the amount of elapsed time since the sample had previously been exposed to high temperatures. In the case of a pottery vessel, usually it is the time since it was fired. For the clay or rock lining of a hearth or oven, it is the time since the last intense fire burned there. For burnt flint, it is the time since it had been heated in a fire to improve its flaking qualities. The accuracy of TL dating is generally lower than most other radiometric techniques.

Optically Stimulated Luminescence (OSL)

OSL is based on the fact that quartz and quartzite minerals in sediment grains are affected by prolonged exposure to sunlight. This provides a natural clock. Burial stops the clock, and re-exposure to light resets the clock. The method takes sediments and geological features and measures the amount of energy that is present within individual sand grains, which serves as a proxy measurement for the amount of time that the quartz grains have been buried since they were last exposed to sunlight.

Samples have to be collected so that they are not (re)exposed to sunlight. Typically, this involves using an opaque container to capture samples collected from a core or Geoprobe, or pushing (pound with hammer) an opaque PVC tube into the wall of an excavation unit or geological profile. The tube is then capped at both ends to prevent exposure to light. The method requires stratigraphy to collect and document sample locations.

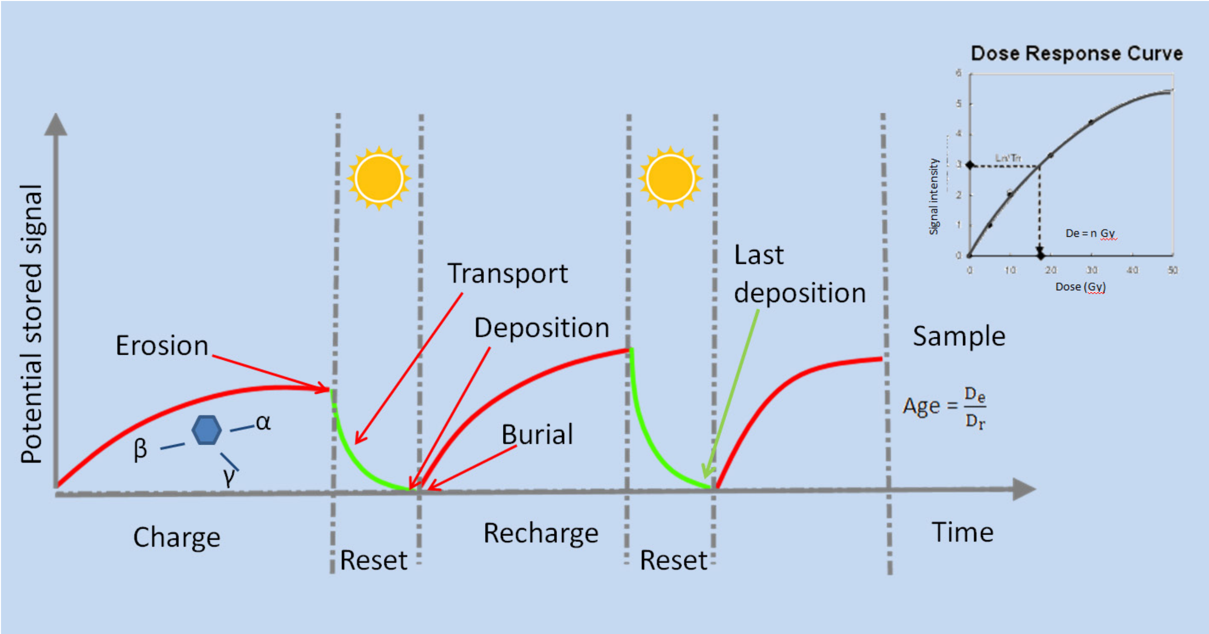

Fig. 10.2. Principles of luminescence dating.

Infra-red Stimulated Luminescence (IRSL)

A similar effect can be brought about by stimulating a sample with infrared light (IRSL). Aside from careless sampling, the greatest problem with all luminescence methods is disturbance from bioturbation. Animal burrowing can expose sediment grains to sunlight and rebury them, and can mix sediment grains of different ages.

Electron Spin Resonance (ESR)

Like other trapped charged methods, ESR is a radiometric method based on the fact that background radiation causes electrons to become trapped in the crystalline lattice of minerals, which serve as natural dosimeters. Age is obtained by calculating the dose received compared to the dose rate generated by the surrounding environment, mainly radioisotopes K, U, and Th. Therefore, special attention must be paid to depositional environments and burial history. The dating range is between a few thousand and a couple of million years.

ESR is used to date calcium carbonate in limestone, coral, molluscs, and eggshells, and is commonly applied to tooth enamel in archaeology. It also can date quartz and flint. ESR can determine the formation of calcareous sediments and organic carbonates and secondary resetting of an already existing system due to heating or exposure to light. Unlike TL and OSL, samples are not destroyed by ESR and can be redated several times (Wagner 1998: 219-294).

Calibrated relative dating methods

Some relative dating methods can be calibrated by connecting known and predictable processes to chronometric chronologies on a region-by-region basis. Some (e.g. paleomagnetism and amino-acid dating) are considered to be nearly absolute, while others (e.g. fluoride dating) are mostly relative.

- Paleo- and Archaeo-magnetics
- Oxidizable Carbon Ratio (OCR)
- Amino acid racemization
- Obsidian Hydration
- Flouride dating

Archaeomagnetic dating

Archaeomagnetic dating generally refers to paleomagnetic dating over the last 10,000 years or so. Iron-bearing sediments that have been superheated—for example, the clay lining of an ancient hearth, can be dated based on the wandering of the magnetic north pole around the rotational north pole in response to changes in the flow of liquid iron in the planet's core. Materials analyzed include fine-grained sediments, in situ ceramics, bricks, burnt earth, and volcanic rocks; any ferromagnetic minerals (mostly hematite, goethite, magnetite).

Successful applications require an undisturbed feature with sufficient mass to take samples from, and a material with adequate magnetite to hold the remnant magnetism. Samples are encased in non-magnetic plaster within non-magnetic moulds. These samples are marked for true north at the time of collection. The samples are measured in a spinner magnetometer to determine the thermal remanent magnetism of each sample (e.g. Lengyel 2010. 'The pre-AD 585 extension of the U.S. Southwest archaeomagnetic reference curve').

Oxidizable Carbon Ratio (OCR)

The OCR dating technique is based on the fact that organic carbon in soil humus and charcoal progressively converts to oxidizable carbon over time. The ratios of these two forms of carbon vary directly with the age of the material. OCR covers the period from the present to c. 35,000 years ago. Soil/sediment samples of c. 100 g can be measured for the ratio of oxidizable carbon to organic carbon (Frink and Perttula 2001).

Amino Acid Racemization Dating

Amino acid dating relates changes in amino acid molecules to the time elapsed since they were formed. All biological tissues contain amino acids, and all except glycine (the simplest one) have 2 different configurations, "D" or "L". Most living organisms keep all their amino acids in the "L" configuration. When an organism dies, the ratio of D to L moves from a value near 0 towards an equilibrium value near 1 (the process of racemization). Measuring the ratio of D to L in a sample enables one to estimate how long ago the specimen died, covering a period to c. 300,000 years ago (Grün 2008).

Obsidian Hydration

Obsidian hydration is a geochemical method of determining the age of an obsidian artifact in either absolute or relative terms. Obsidian obeys the property of mineral hydration – it absorbs water when exposed to air. Therefore, obsidian progressively develops a thin chemically altered outer layer due to the absorption of water. Obsidian contains less than 1% water and absorption occurs at a well-defined rate. A water-rich hydration “rind” forms and increases in depth with time. The hydration process continues until the fresh obsidian surface contains about 3.5 percent water (saturation point). The thickness of this hydration layer is directly proportional to the amount of time since the rock was formed or since a fresh surface was exposed. The thickness of the hydration rind can be measured in petrographic thin sections using a micrometer on a petrographic microscope (Eerkens et al. 2008), or by depth profiling with secondary ion mass spectrometry (SIMS).

The primary problems with obsidian hydration dating are that the rate of hydration is not uniform across the world (Friedman’s k) and the rind can crumble, thus changing the thickness. Samples from different obsidian sources hydrate at different rates because of variations in temperature and humidity over time from site to site which are difficult to calculate. Variations in the chemical composition of different obsidian sources is also a factor, but much more easily controlled for.

Fluoride Absorption dating

Fluoride absorption provides a relative dating method, based on the replacement of bone nitrogen with fluorine (and other trace elements) over time. Groundwater contains fluoride ions. Items such as bone that are in the soil will absorb fluoride from the groundwater over time. Scientists can estimate how long the object has been in the soils from the amount of absorbed fluoride in the object. However, the rates at which these changes occur depend on the local environment, and therefore differ from region to region. Bones from the same site with markedly different amounts of nitrogen and fluorine strongly suggest that the bones are not from the same period; the least amount of nitrogen and the greatest amount of fluorine is most likely the oldest. Guerrero et al. (2011) have attempted to time the Neolithic transition in Syria using fluoride dating, but the method is controversial.

Seasonality

Several environmental methods can be used to infer seasonality, as well as land use, paleoenvironment, and absolute chronologies. For example, dendroarchaeology can tell us not only what year a tree was cut, but also in what season. Zooarchaeologists can often determine how old animals were before butchering. Entomologists can identify seasonal insects in archaeological contexts. Plants produce flowers and pollen at known times of the year. Therefore, pollen in sealed contexts such as graves can suggest the season when the grave was open. Similarly, flowers found in archaeological contexts imply the season of deposition (Legge 2008).

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Chapter 11. Archaeological Climatology

Climate change is a compelling research field, and archaeology can provide concrete case study examples of how people reacted to climate change in the past. This subdiscipline, sometimes called archaeo-climatology, examines the major mechanisms behind climate changes and some of the evidence available for past changes at different temporal scales.

Readings

- Dincauze 2000 Part III: Climate (Chapters 7 + 8)

Case studies

- Cooper & Peros 2010 Archaeology of climate change in the Caribbean
- Magyari et al 2009 Holocene Palaeoclimate Carpathians
- Munoz et al 2015 Cahokia emergence and decline flood frequency Mississippi
- Weninger et al 2006 Climate Forcing 8200 Cal yr BP Event ENA east Med

Archaeological Climatology

What is climate? Climate is the average meteorological conditions (statistically), including temperature, precipitation, and wind, in a particular region. Weather changes quickly, but climate changes slowly. Climate is generated by the region's *climate system*, which has five components: atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere. Processes of the system are influenced by regional terrain, altitude, latitude, and hydrography. Climate change is a change in the statistically average weather of a region – from one time period to another.

Paleoclimatology is the study of changes in climate at a geological time scale and macro-regional or continental spatial scale. Weather varies at human spatial and temporal scales. Climate changes on the scale of the entire history of Earth. Quaternary paleoclimatology is our temporal scale of interest. Historical climatology is the study of historical changes in climate and their effect on human history, evolution, and development. Archaeological climatology attempts to reconstruct and study changes in ancient climate and their effect on human biological and cultural evolution.

Weather is the way the atmosphere is behaving, mainly with respect to its effects upon life and human activities. It acts at human spatial (local) and temporal (days/months) scales. Weather consists of short-term (minutes to months) changes; daily or monthly temperature, humidity, precipitation, cloudiness, visibility, wind, and atmospheric pressure. In most places, weather can change from minute-to-minute, hour-to-hour, day-to-day, and season to season.

Scale and scalar concepts are important for defining research goals and in identifying appropriate data sets and methods. For example, climatic periodicities at the scale of 1000 years or less are of interest for culture history and specific cultural adaptations. The scale of 10,000 years is interesting in terms of glacial and interglacial periods and landform development.

Proxies and Methods

Historical records

Where and when they are available, historical records such as diaries, journals, agricultural records, inter alia are useful tools to analyze climate change and weather patterns. These are usually restricted to local spatio-temporal scales. However, they are directly tied to calendric chronologies and therefore of very high resolution.

Varve analysis

Varves cover periods to ca. 13,000 years BP, with annual (high) resolution. Annual bands of seasonally differing particle size in glacial lake deposits. Thicker bands indicate warmer, wetter weather, while thinner varves indicate colder weather. Varves can be averaged over decades or centuries.

Dendroclimatology

Another contribution of dendroarchaeology is dendroclimatology. Tree ring records cover periods to ca. 10,000 years BP at annual scales. Annual rings reflect the weather conditions of that growing season, with thicker bands indicating warmer and/or wetter weather. Similar patterns exist between trees of the same species growing in the same climate region. For example, patterns of glacial advance and retreat, and associated tree line advance and retreat, have been identified in the Austrian Alps. The Pasterze glacier was smaller than it is now in many periods of the Holocene. During periods of glacial retreat, trees wash out from the front of the glacier and are available for dating (Nicolussi & Patzelt 2000).

Ice Cores

Although rarely analyzed for archaeology, ice core data can be used in archaeological research as an indicator of global climate, and therefore of large-scale changes in weather patterns. Ice cores cover periods to ca. 800,000 years BP. The scale varies from annual to periodic. In layers of differing ice crystals, thicker bands indicate snowier weather. Chemical isotopic analysis, particularly of oxygen isotope ratios and $\delta^{18}O$ provide detailed evidence for diachronic changes in precipitation.

Sclerochemistry

Linked to sclerochronology, coral 'rings' are similar to tree rings except that the bands change in thickness in response to different things, such as the water temperature, sunlight, nutrients, freshwater influx, and water pH. For example, each coral band can record the season's climate, but interpretation of the record depends on how the factors are related. Many corals may grow more slowly in cool water.

For molluscs, shells are often thicker when the water is cool because cool water rising from the ocean floor brings extra nutrients in many areas. Gastropods are molluscs with one shell or 'valve' (e.g. snails), and bivalves are two-sided shells or 'valves' (e.g. clams, oysters). The shells are formed in distinct bands (like tree rings) growing outwards along the direction of growth – the oldest shell is at the edge. Growth lines (due to slow growth) and increments (due to rapid growth) can be recorded, and the amount of growth depends on water temperature, oxygen levels, nutrients, water pH. Each species is adapted to a specific temperature range and environment. If temperatures are above or below that range, their shells stop growing. Too much variation will result in species dying out and replacement by a different species. Therefore, both species identification and interpretation of the growth rings provide environmental data.

Sclerochemistry involves the analyses of isotopic and elemental proxies (e.g., Knutson et al. 1972). The ratio of heavy and light oxygen (^{18}O / ^{16}O) in growth bands provide a record of temperature and rainfall during the growing season (molluscs and corals). Increased rainfall and higher temperatures result in a higher concentration of light oxygen in the ocean. Cold water has a higher concentration of ratio of $\delta^{18}O$ (ratio of ^{18}O to ^{16}O is higher than in warm water) and $\delta\,^{18}O$ is more easily incorporated into shells than $\delta\,^{16}O$.

Speleothems

Speleothems are secondary mineral deposits that form in caves, such as dripstone, flowstone, and cave crystals. Often called 'cave formations', these form in layers of seasonally differing stalagmite/stalactite deposits in limestone caves. Speleothems are composed of calcium carbonate ($CaCO_3$) in the form of calcite or aragonite or calcium sulfate ($CaSO_4$) in the form of gypsum. They cover a period to ca. 500,000 years BP, with high-resolution annual growth, and can be accurately dated using uranium-thorium dating. Thicker bands indicate warmer, wetter surface weather. Stable isotopes of oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) are recorded as well, and can be used for more accurate climate data (McDermott 2004). A new method uses computed tomography (CT) scanning of intact specimens to analyze density. More dense speleothem development indicates higher moisture availability.

Microfossils

Ancient ecofacts, as of a pollen grain or unicellular organism, which are too small to study with the naked eye, are called microfossils. These act as proxies for climate, environmental, and anthropogenic interferences.

- Pollen and spores
- Foraminifera: marine protozoans with $CaCO_2$ shells provide $\delta^{16}O$ evidence for ice cover and sea-level changes (MIS). Different species prefer different environments.
- Charred particles: microscopic carbon particles (charcoal) resulting from the burning of wood, grass or other vegetation. Generally, these provide additional data for land use rather than for paleoclimate reconstruction.
- Sediments: marine and lacustrine sediments are archives of microfossil proxies. In addition, they provide evidence for mineral vs. organic deposition related to seasonal variation; periodic shifts between glacial/interglacial periods.
- Diatoms: unicellular algae from marine or lacustrine environments. Different species prefer different environments, and distribution is controlled by environmental variables such as acidity, degree of oxygenation, water temperature, and salinity.
- Chironomids: non-biting midges from lacustrine settings; the distribution and abundance of chironomids are closely related to summer lake surface water temperatures.

- Cladocera: water fleas from lacustrine settings. Skeletal fragments are often abundant in lake sediments and in many cases can be identified to species level. These provide evidence of lake paleoecology and paleotemperature.
- Ostracods: microscopic bivalved crustaceans from marine, lacustrine, or riverine settings. Ostracods are indicators of temperature, salinity, eutrophication, and water level (lake and sea). Additional data can be gained by $\delta^{18}O$ isotope analysis of ostracod shells.
- Curry et al. 2016. Holocene paleoclimate inferred from salinity histories of adjacent lakes in southwestern Sicily (Italy). *Quaternary Science Reviews* 150(Supplement C): 67-83.

In an example from the eastern Carpathians, diatoms were analyzed to infer the climate around Lake St Ana. Water levels at Lake St. Ana were reconstructed based on diatoms and other proxies. Results indicate fluctuations in water depth throughout the Holocene. This lake relies on precipitation to maintain water levels, so observed fluctuations must reflect fluctuations in rainfall patterns (Magyari et al. 2009).

Macrofossils

Macroscopic plant and animal remains, called macrofossils, also serve as climate proxies. Plant remains (palaeobotany) include seeds, wood, and other plants parts (Carcuta et al. 2016). Mammal remains (zooarchaeology) include bones and teeth. In both cases, certain species prefer open or closed habitats. For example, European Red Deer (*Cervus elaphus*) prefer forested or forest-steppe environments, while the European brown hare (*Lepus europaeus*) prefers open meadows and plains. In another example, László Kordos inferred climatic changes and a temperature curve in the Carpathian Basin from vertebrate microfauna, specifically voles. The analysis of biostratigraphical analysis of voles and their relationship to vegetation and temperature has been labeled the Vole thermometer.

Insect remains (zooarchaeology) also have an application for climate. Insects tolerate a narrow range of environmental and climatic conditions. For example, beetles (order Coleoptera): preserve easily in most conditions and are identifiable to species level. This enables the quantitative reconstruction of summer, winter and average annual temperatures, as well as reconstruction of land cover, human living conditions, and economic activities.

Molluscs, marine, lacustrine, and terrestrial, are likewise adapted to a relatively narrow range of environmental and climatic conditions. For marine molluscs, these conditions are sea-surface temperatures and changes in sea level and ice sheets.

Lacustrine molluscs (freshwater) are susceptible to changes in water temperature, water level, and eutrophication. Terrestrial, or land molluscs are particularly responsive to the amount of vegetation cover and shade. Species changes have been used to infer changes n climate or long-term weather patterns at Lake Fehér (Sümegi et al. 2011).

Isotopic changes, using $\delta^{18}O$ for temperature and $\delta^{13}C$ for precipitation, have been determined from freshwater bivalves (specifically *Unio pictorum*) from Lake Balaton in western Hungary (Schöll-Barna et al. 2012). The study was initiated to help understand diachronic changes in settlement position and structure, and in domestic animals, along the Balaton. Results indicate negative shifts in C and O isotope in shell carbonate related to lower temperatures and increasing precipitation. These changes correspond with changes in settlement and subsistence and correlate with other regional data, e.g., pollen and carbonates in bulk sediments.

Alkenone

Biolipids (fats) from marine and lacustrine algae serves as a proxy for water surface temperature. This is one of an increasing number of bimolecular methods that contribute to environmental studies and archaeology. Alkenone analysis assumes that the ratios of biomarkers were actively regulated by the organisms in life according to the temperature of the water in which they grew (Toney et al. 2010). Samples are freeze-dried, crushed, extracted with solvent, and quantified by GC-FID (flame ionization detection with gas chromatography).

The Impact of Climate Change in the Present Day

In addition to the potential to provide historical case study examples for past climate fluctuations and human responses to climate change, environmental archaeologists can contribute to several other concerns . First, sea level rise, desertification, and other climatological and environmental changes are threatening important archaeological sites. For example, archaeologists have been struggling to extract data from Walakpa Bay in Alaska, where sea level rise is washing away 4000 years of Paleo-Eskimo remains.

These changes are also threatening subsistence economies for many small-scale societies throughout the world. Rural modern Cubans, for example, are increasingly faced with habitat loss, increased hurricane threats, and food shortages. Archaeology is helping to inform these populations about settlement locations and flooding, natural shelters from hurricanes, and alternative food procurement strategies (e.g., Cooper & Peros 2011; Cooper and Boothroyd 2011). Finally, environmental and geo-archaeology can produce well-dated high-resolution data that can contribute to and improve climate models.

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