CHAPTER 5

Ecofacts and related studies

INTRODUCTION

Els Cornelissen[1]

This chapter explains the potential and requirements of specialized analysis of the soils and sediments that provide the context of archaeological excavations, animal and human bone, and plant remains. It also addresses the topic of dating. Specialists in the various fields of pedology, sedimentology, archaeozoology and -botany, palaeontology and dating methods, discuss what needs to be done in the field to ensure the effectiveness of the different approaches, and the important things that archaeologists need to know when seeking their advice in order to avoid unwarranted expectations. All contributors draw attention to the fact that the type of site, research questions, and funding will orient the strategies prior to – but also during and after – excavation on what, when and how to sample. In addition, they emphasise that data and samples collected out in the field are the product of both natural and cultural processes for which keys, specific to their field of expertise, are needed to define to what extent natural or cultural agents are responsible. All underline the need for interdisciplinary interplay from one specialist to another in order to draw the right conclusions.

Alexa Hohn explains how plant remains provide dietary information on a human community as well as on the natural environment the community lived in, and on how they manipulated this through various subsistence and other exploitation strategies. Methods for sampling, processing and analysing are presented, with specific attention to the fact that most plant remains are retrieved from sediment samples taken during excavation but processed in lab conditions. Plant remains collected on-site represent only a fraction of the past environment, a selection explained by depositional and post-depositional processes, such as differential preservation of hard and soft plant tissues, as well as by various human decisions on which plants to harvest or collect and to process on that specific spot.

Wim Van Neer sets out the framework for the analysis of animal remains, varying between solid bone and fragile eggshell. He underlines the importance of correct sampling and packing in the field, different issues include sieving, avoiding bias in the selection of identifiable and non-identifiable bones, and the inclusion of (or at least mention of) worked bone in the sample submitted to the archaeozoologist. As with botanical remains, fauna serve to reconstruct the environment and subsistence strategies. Reference collections of modern skeletons are essential for correct identification based on bone morphology and size. After identifications, bone material is quantified using the Number of Identified Specimens or NISPs. In order to filter out natural agents in the accumulations, a taphonomic analysis of faunal assemblages has to be conducted prior to any reconstruction of the past environment and of the subsistence strategies or any other human exploitation.

Veerle Linseele proceeds by addressing the question of domesticated animals, and discusses the frequently encountered problem of distinguishing domesticated cattle from wild bovids. The wild ancestors of sheep and goat never occurred in Africa and hence no confusion is possible between wild and domesticated forms whereas in the Mediterranean zone, the Nile Valley, and other parts of northern Africa, wild cattle or aurochs were part of the local fauna. In West Africa, a special position is occupied by the helmeted guinea fowl. Domesticated animals may provide power, raw material, companionship, food (mainly meat consumption, but also milk, eggs or blood) or serve ritual ends. She provides examples of the interpretation and spread of domesticated animals over sub-Saharan Africa.

In his contribution, **Dominique Schwartz** stresses the fact that soils are open and active environments. Special attention goes to the ubiquitous ferralsols in sub-Saharan Africa and how cultural items and ancient surfaces become buried and incorporated in the soil. The challenge is to single out natural and human agents in site formation, as well as to identify which natural processes are part of the initial formation of the deposits or sediments and which processes are due to subsequent pedogenesis. This latter distinction between geological strata and soil horizons is illustrated with three field examples. Laboratory analysis of soil components yields valuable information, as in the example of biogeochemical studies using carbon-13 for environmental reconstructions. The author draws specific attention on how to read the temporalities of the soil.

Michel Rasse focusses on the accumulative and erosive power of river systems: their capacity to construct and bury archaeological material and also deconstruct and expose archaeological sites, to move sediments from upslope to downslope or cut through previously accumulated sediments. His case study is situated in West Africa. These processes of incision and accumula-

1 Heritage Studies, Royal Museum for Central Africa, Tervuren, Belgium.

tion are climatically induced and a careful interpretation leads to the reconstruction of palaeoclimatic conditions. Importantly, an understanding of the geometry of the sequences takes into account vertical as well as lateral shifting of layers.

In both contributions, you will find a glossary that facilitates reading the specialist literature on soils and sediments.

Human bones, as **Isabelle Crevecœur** writes, are best sampled during field work, if not in the presence of a biological anthropologist, then at least in close collaboration. Here as well, before proceeding with cultural interpretation, the taphonomic agents that may have intervened in the accumulation of human bones need to be identified. She lists principles of evolution and adaptation, the most current analyses performed directly on bone and teeth (minimal number of individuals, their age, gender, health, weight and other biometric and non-metric characteristics), biochemical analyses on their organic (collagen) and mineral (hydroxyapatite) constituents for radiocarbon and ESR dating, and reconstructing their diet and environment through stable isotopes. DNA analysis serves to reconstruct migrations and to identify affiliation or even degree of kinship between individuals, but also demands great care during sampling and when handling after field work. A special note is included, on multidimensional imagery as a means of rendering visibility to features invisible to the naked eye, facilitate access to collections and enable reconstructions and detailed measuring.

Dating implies a sound comprehension of the context on the site, in order to interpret relative or absolute dating. **David Wright** has compiled an overview of the various dating methods, this volume, p. 246. Three contributions are devoted to dating, which is pivotal since the chronology of many regions is far from established in Africa, as **Pierre de Maret** rightly points out. He elaborates more specifically on C14 dating and on what materials can be dated, but also the errors, calibration, uncertainties, risks of contamination before, during, and after sampling, and how to interpret results. We provide two fictional dates to illustrate the interpretation.

In the two last contributions, **David Wright** then continues explaining six other radiometric dating methods and four relative dating methods, highlighting the enormous array of methods but also their limits and caveats.

A cautionary note on archaeology's cornerstone

David K. Wright[2]

Like any scientifically-based discipline, older methods to measure radiocarbon used chemicals and instrumentation that have now become obsolete. This does not mean that older radiocarbon dates are inherently inaccurate, but those incorporating data analysed prior to AMS should be especially mindful of potential sources of error common during the early years of using the method. Such sources of error can include carbon-based counting reagents used for bulk radiocarbon gas- or liquid-scintillation counting, non-dissolution of authigenic carbonates from samples, use of bone apatite as a datable material, carbon reservoir effects in mollusc and ostrich eggshell, and sampling of 'old wood', to name just a few considerations.

2 Department of Archaeology and Art History, Seoul National University, South Korea.

ARCHAEOBOTANICAL REMAINS

Alexa Höhn[1]

INTRODUCTION - WHY SHOULD WE CARE?

About 77,000 years ago, in a South African cave, people piled up plant beddings from sedges and grasses and topped them with aromatic laurel tree leaves with insect repellent properties (Wadley *et al*. 2011). Without archaeobotany we might have learned that Middle Stone Age people used plants and leaves to build a comfortable place, because the broken stems and leaves were visible even to the naked eye. But it was through archaeobotanical expertise that we discovered that the people of that time did not just take any leaves but carefully chose those leaves that kept their camp free from insects! Only the identification of different types of archaeobotanical remains like fragments of leaves, stems, culms and fruits, clay fragments with plant impressions, and phytoliths told the whole story.

Archaeobotany is always good for surprises: About 2,500 years ago, pearl millet was cultivated in the West Central African rain forest (Kahlheber *et al*. 2009, Kahlheber *et al*. 2014)! This was revealed by charred plant remains from sites in Cameroon and the Congo. As this was totally unexpected, the archaeobotanist had a hard time believing the identification in the beginning, but no doubt could remain: a cereal adapted to a savannah environment had been grown in places where it cannot be cultivated today because of too much rainfall. Analysis of wood charcoal from the same sites provided evidence that the cultivation took place in a disturbed but still forested environment. How was that possible? Palynological investigations in the same region attested that for several hundred years a climatic change had prolonged the dry season, not enough to replace the forest, but probably just enough for pearl millet to ripen.

Archaeobotanical remains tell fascinating stories, whether they are older than 70,000 years like the finds from Sibudu, or just a bit younger than 150 years. Maize remains from Ghana dating from around 1900 AD and associated charcoal remains point to a shift in processing technology – away from grains like pearl millet associated with grinding stones at around 1800 AD, and towards yams, cassava, and maize – crops usually prepared in wooden mortars (Logan & Cruz 2014). Archaeobotanical remains also allow reconstruction of the social and cultural role of food. Examples are feasting on the Gambia coast (Gjianto and Walshaw 2014) or the turn to Asian foodways on Pemba Island during a period of urbanization and Islamization. There, social and political rewards compelled this agricultural innovation between the eleventh and the fifteenth centuries, even though rice specialization was risky due to the scarcity of suitable land (Walshaw 2010). Archaeobotanical remains, as large as a forearm-long piece from a medieval charred house post (Höhn 2011) and as small as phytoliths that are not visible to the naked eye but indicate that wood was worked on a grinding stone (Radomski & Neumann 2011), show glimpses of everyday life in former times. Human life is always intertwined with the environment. Archaeobotanical research enables us to elucidate the botanical aspects of these interrelations. Manifold questions can be answered, depending on the sites, the time, and the context. But in order to do so archaeobotanical samples have to be taken.

I. MATERIAL : WHAT ARE WE LOOKING FOR?

Archaeobotanical remains are plant remains from archaeological contexts (as opposed to plant remains from natural soils, which are termed palaeobotanical remains). They are divided into two groups according to size: macroremains and microremains.

Macroremains are larger than 0.1 mm. They are whole or fragmented parts of plants (e.g. fruits, seeds, wood, tubers, fibres, leaf fragments). In sub-Saharan Africa most macroremains are carbonised. Due to low oxygen availability in parts of a fire they did not burn to ashes, but were charred. During this process the chemical composition of the plant part was altered to an inorganic state. This alteration is called fossil preservation. Imprints of plant parts – in ceramics for instance – are also called fossils because the original plant part was not preserved either. In subfossil preservation, the chemical composition of the plant part has not been substantially altered and still consists of organic material. This occurs through drying (in arid environments), freezing (in the mountains, in permafrost soils), or deposition in a

1 Goethe-Universität Frankfurt am Main, Institut für Archäologische Wissenschaften, Archäologie und Archäobotanik Afrikas, Germany.

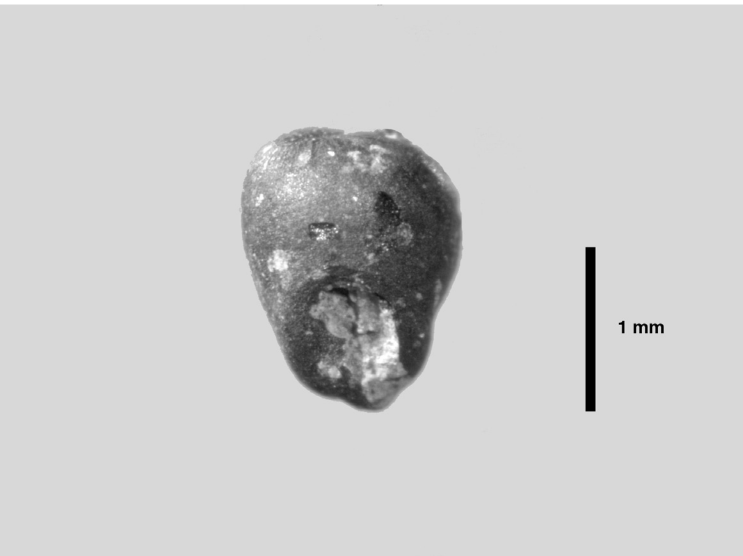


Fig. 1. Carbonized pearl millet (*Pennisetum glaucum*) from the site Bwambé-Sommet, Southern Cameroon. (Photo S. Kahlheber © Goethe-Universität Frankfurt am Main.)

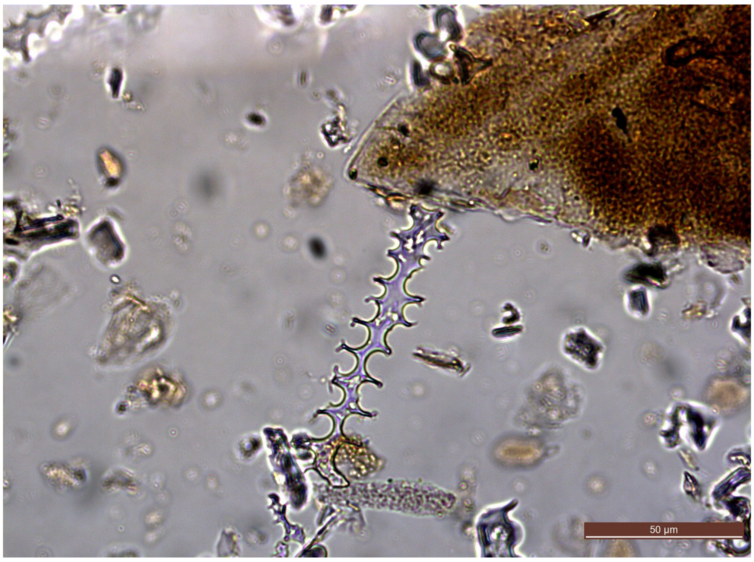


Fig. 2. Phytolith sample as seen in the transmitted-light microscope. (Photo B. Eichhorn © Goethe-Universität Frankfurt am Main.)

low-oxygen environment (in permanently wet soils). Contact with metal leads to subfossil preservation as well because the metal salts hamper bacterial and fungal activity.

Microremains are smaller than 0.1 mm and are therefore not visible to the naked eye. They can be pollen, spores, phytoliths, or starch. Pollen and spores are cells. Pollen is produced by seed plants, spores by fungi and non-flowering plants like ferns, mosses and algae. The cells themselves are not preserved, but only certain very resistant parts of the cell wall. Phytoliths and starch are produced by plants, but they are not cells. Starches are formed as sub-cellular food storage units and are organic like pollen and spores. Phytoliths are mineral microremains; they are composed of non-crystalline silicon dioxide, which was deposited by the living plant within its cells, in or on cell walls or in spaces between cell walls.

II. ANALYSIS : WHAT IS DONE IN THE LAB?

After sampling in the field (see Bosquet, this volume, pp.152-156) the archaeobotanical samples have to be processed. Macroremains are often sieved or flotated in the field, and only the processed samples reach the lab. The first step in the lab is sorting: fruit and seed remains are picked out of the sample under a dissecting microscope at low magnifications and similar remains are grouped together. Small bones or even artefacts are retrieved as well. The bulk of a processed (charred) macroremains sample usually consists of wood charcoal fragments, but modern intrusions like roots, insects and wind-borne plant parts are often present as well. Care has to be taken to separate these often partly-charred modern remains from the archaeobotanical remains.

Microremains are generally processed in the lab. Different, often chemical treatments are applied to separate the microremains from the soil particles. The isolated remains – whether starch, phytoliths or pollen – are then mounted on microscopic slides for analysis.

In the next step, the archaeobotanical remains are identified, i.e. assigned to a taxon, which can be a species (e.g. *Vigna unguiculata*), a genus (*Vigna*), a family (Fabaceae) or even groups of different taxa. These different levels of identification depend on preservation (whether it is possible to see diagnostic characteristics), but also on the possibility of differentiating between plant parts of different taxa at all. For instance, in some plant families the pollen grains of all species are very similar, or the wood anatomy of species from the same genus may look alike. In this case, it is impossible to distinguish between single plant species and we can assign the remains only to a group of plants. The identification of phytoliths is even more of a special case: Some phytoliths are typical for certain plant groups, for instance within the grass family, but in many cases different plants, even from non-related families, can produce the same kind of phytolith. This is known as 'redundancy'.

Several types of microscopes are used for the identification of archaeobotanical remains: dissecting microscopes with lower magnifications for the identification of fruit and seed remains; incident-light microscopes for wood charcoal; and transmitted-light microscopes for microremains.

Reference collections are another essential tool. The comparison of archaeobotanical remains with recent fruits, seeds, wood, phytoliths, and pollen grains is necessary for sound identification. Images in publications or atlases usually depict one sample, but plant parts are variable. In order to fully understand how different seeds of one plant species may look, it is advisable to check several samples from several individuals of one species. It is important to keep in mind that characteristic traits of plants may vary within one species (intra-specific variability) and that similarities between different species, genera or even families exist (inter-specific similarities).

After identification the data is merged into tables, evaluated and interpreted. Again different methods can be applied – quantitative, semi-quantitative, qualitative, (presence/absence) evaluations, recording of ubiquity, calculating of percentages and various statistical methods – depending on material and sampling strategies.

CONCLUSIONS: WHAT TO CONSIDER

The archaeobotanical assemblage is by no means identical to the former vegetation around a site. Anthropogenic activities, the way of harvesting, storage and processing of crops, herding, gathering, fuel selection, and trade all influence which plants and which plant parts enter the settlement and become preserved. In charred remains even more information is lost because only plant parts entering the fire – whether on purpose (e.g. fuel, like wood or dung) or by chance (e.g. refuse, parts lost or discarded during cooking, blown into the fire) – are likely to be preserved. Depositional processes and the depositional environment, like soil characteristics, further influence preservation. To stay with the example of charred remains, more remains are preserved if the fuel refuse was put into a pit and thus protected from trampling and being blown away. The nature of the remains is also a factor. Lignified remains like the hard shells of the oil palm are more likely to be preserved than soft tissues such as those from yam tubers. The archaeobotanical assemblage is thus erratically reduced even before being recovered, but processing and analysis further decrease the accessible information.

In order to reconstruct past human lifestyles and the environment, the fragmentary data has to be interpreted. The human factor has to be considered, but so should abiotic factors at the site/in the region (soil, water, light, temperature) as well as other biotic factors (like animals). When formulating a hypothesis concerning environment and land-use based on an archaeobotanical assemblage these factors have to be considered. Consequently, the presence of the same plant in two archaeobotanical assemblages from different ecological settings may have a different significance.

A way to tackle this inevitable loss of information and get a better hold of the particular conditions at a given site is to explore several different archaeobotanical archives. As different types of remains have different taphonomy, information lost for one type of remain may be present in another. Different types of archaeobotanical remains also complement each other with regard to identification possibilities; for instance, some pollen types are identifiable only to family level but the wood anatomy of the respective family is different at genus or even species level, and *vice versa*. Moreover, the climatic and environmental background from which conclusions are drawn requires the consultation of regional palaeoarchives. Most important for a successful archaeobotanical analysis, however, is close cooperation with the archaeologists: the archaeological information concerning site type, chronology, technology and society is essential for putting the archaeobotanical information into the right frame. The resulting synopsis of archaeobotanical results with on-site information from archaeology, archaeozoology, and sedimentology and with off-site palaeoenvironmental data evaluated with ecological, agronomical, ethnobotanical, and anthropological knowledge, results in a sound and specific hypothesis on man-environment interactions in the past.

REFERENCES

Gijanto, L. & Walshaw, S. 2014. ‘Ceramic production and dietary changes at Juffure, Gambia’. *African Archaeological Review* 31(2): 265-297.

Höhn, A. 2011. ‘Analysis of the charcoal finds’. In L.P. Petit, M. von Czerniewicz, & C. Pelzer (eds). *Oursi hu-heero. A Medieval House Complex in Burkina Faso, West Africa*. Leiden: Sidestone Press, pp. 141-149.

Kahlheber, S., Bostoen, K., Neumann, K. 2009. ‘Early plant cultivation in the Central African rain forest: first millennium BC pearl millet from South Cameroon’.

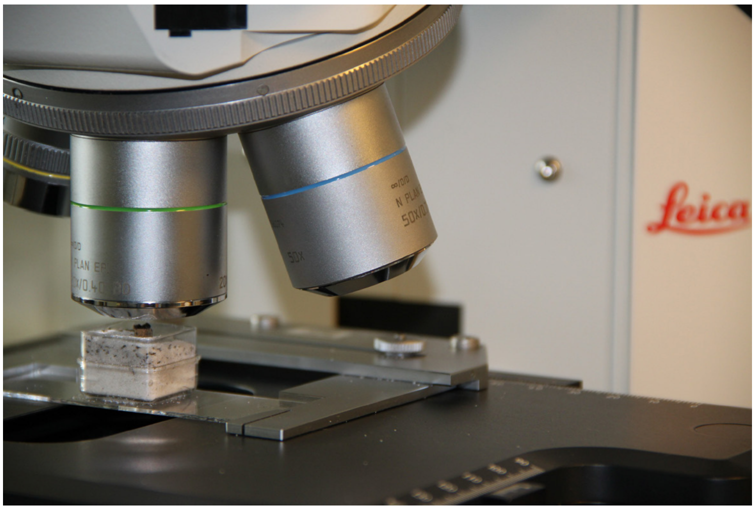


Fig. 3. Charcoal fragment under the incident-light microscope. (Photo A. Höhn © Goethe-Universität Frankfurt am Main.)

Fig. 4. 'Tools' of an archaeobotanist (clockwise): Dissecting microscope, wood collection, fruit and seed collection, reference literature, charred samples, wood slide collection. (Photo J. Markwirth © Goethe-Universität Frankfurt am Main.)

Journal of African Archaeology 7(2): 253-272.

Kahlheber, S., Eggert, M.K.H., Seidensticker, D. Wotzka, H.-P. 2014. 'Pearl Millet and other plant remains from the Early Iron Age site of Boso-Njafo (Inner Congo Basin, Democratic Republic of the Congo)'. *African Archaeological Review* 31 (3): 479-512.

Logan, A.L. & Cruz, M.D. 2014. 'Gendered taskscapes: Food, farming, and craft production in Banda, Ghana in the eighteenth to twenty-first centuries'. *African Archaeological Review* 31 (2): 203-231.

Radomski, K.U. & Neumann, K. 2011. 'Grasses and grinding stones: Inflorescence phytoliths from modern West African Poaceae and archaeological stone artefacts'. In A.G. Fahmy, S. Kahlheber & A.C. D'Andrea (eds). *Windows on the African Past. Current Approaches to African Archaeobotany*. Frankfurt am Mai: Africa Magna Verlag, pp. 153-166.

Wadley, L., Sievers, C., Bamford, M., Goldberg, P., Berna, F. & Miller, C. 2011. 'Middle Stone Age bedding construction and settlement patterns at Sibudu, South Africa'. *Science* 334: 1388-1391.

Walshaw, S. 2010. 'Converting to rice: urbanization, Islamization and crops on Pemba Island, Tanzania, ad 700-1500'. *World Archaeology* 42 (1): 137-154.

ARCHAEOZOOLOGY IN SUB-SAHARAN AFRICA

Wim Van Neer[1]

Archaeozoology or zooarchaeology deals with the animal remains found at archaeological sites. Together with archaeobotanical studies, the faunal analysis allows reconstruction of the past environment as well as the way people interacted with plants and animals in former times. Animal bones and teeth are the most commonly encountered remains, but mollusk shells, bird feathers, fish scales, eggshell fragments, insect remains, animal droppings are other examples of material that can be found.

Preservation conditions vary a lot in sub-Saharan Africa and certain regions yield very little fauna. The acid soils in large parts of Central Africa result in the dissolution of the mineral part of animal bone, teeth and shell. Faunal remains from that region are therefore mainly from cave sites or from particular structures, such as pits, in rather recent sites. Rapid and deep burial of animal remains is essential for good preservation as it will limit surface weathering and destruction by scavengers, bacteria and fungi. The different animal tissues also have different preservation chances: tooth enamel preserves better than dentine or bone, and compact bone of mammal preserves better than thin bird bone. These so-called differential preservation chances should be kept in mind when interpreting species ratios or skeletal element representation within a single species. The exclusive presence of large bovid tooth fragments on a site is likely to reflect poor preservation conditions, for instance.

In order to not bias the faunal assemblages preserved at a site, it is vital to carry out a correct **sampling**. During the excavation, animal remains can be hand-collected in the trench (**fig. 1**) but it is important that the sediment is sieved in order to retrieve the smaller bones that will otherwise be inevitable lost (**fig. 2**). Experiments have shown that not only small species are missed when no sieving is carried out, but that also smaller bones of medium-sized and even large mammals are lost. Depending on the type of soil, dry (**fig. 3**) or wet sieving can be done preferably with a mesh width of 2 mm. This will guarantee the retrieval of most mammal, bird, and fish bones. Smaller volumes of sediment can be sampled separately for finer sieving on a 1 mm and 0.5 mm mesh and will allow correcting of values obtained on the 2 mm screen. Such sediment samples can also be shared with archaeobotanists interested in macrobotanical remains and charcoal, and it is therefore useful to agree on the sampling strategies with other specialists prior to the excavation. When retrieving faunal remains in the field, it is important that no selection is carried out by the excavators. All animal remains, including those that may seem undiagnostic or too small to be identifiable have to be kept for analysis by the archaeozoologist. Moreover, the proportion of unidentifiable remains in an assemblage is also important as it is a measure of the degree of fragmentation and thus the state of preservation. It is evident that to prevent further breakage, care needs to be taken to wrap and bag the material adequately and to always include labels. When the bones are still humid, they should be allowed to dry slowly, avoiding exposure to the sun as this will result in splintering of the bone. On wet bones that are packed in plastic bags, mould will develop and labels may also be destroyed if they are not protected by plastic. There is no need to sort the faunal remains by animal group, which will be done by the archaeozoologist. However, making sure that smaller, fragile bones are packed separately from more bulky remains is vital as this will reduce damage. When worked or half-finished objects are found that are made of bone, ivory, or shell, these are often kept separate as artefacts. It is useful to show these items to the archaeozoologist so that information can be provided on the type of raw materials used.

Identification of the faunal remains is the next step: finding out, for each fragment, the animal species it comes from and the skeletal element from which it is derived. Identification is based on the morphology of the bones and on their size. Other information that can sometimes be retrieved from isolated bones is the age and the sex of the individual. Pathologies as well as traces left on the bones – by humans and animals – are recorded. All these data provide interesting information useful for the reconstruction of subsistence practices (hunting strategies, herding and culling strategies of domestic species, seasonality etc.). For an adequate

1 Royal Belgian Institute for Natural Sciences, Brussels.

Fig. 1. Hand-collected bone, consisting mainly of domestic cattle and large Nile perch, from a food preparation facility in predynastic Hierakonpolis, Egypt. The colours vary from yellow to brown, black, grey and whitish, illustrating different degrees of exposure to fire. The scale bar is 5 cm. (Photo © W. Van Neer.)

Fig. 2. Minuscule fish bones retrieved with a fine meshed sieve. Provenance: early Roman Quseir al-Qadim, Egypt. (Photo © W. Van Neer.)

Fig. 3. Dry sieving at an excavation in north-eastern Nigeria. (Photo © P. Breunig, Frankfurt, ref. SFB 268.)

Fig. 4. Modern skeletons of fish with known body length are used as comparison for the identification of archaeological fish bones . This allows establishment the skeletal element, the species, and an estimation of the length of the corresponding fish. (Photo © RBINS Brussels.)

identification, reference collections consisting of modern skeletons of animals that were correctly identified are needed. Ideally, faunal remains should be studied in a lab, institute or museum that holds extensive collections of comparative specimens (**fig. 4**). In Africa a few such places exist, for instance the National Museums in Kenya, or the IFAN at Dakar that also have the facilities to prepare skeletons. A well trained archaeozoologist can also do a major part of the identification on site, using a limited reference collection that he/she can bring. Identification guides, atlases, publications dealing with osteometry are helpful tools for the identification both in the field and in the lab, but their sole use by an unexperienced researcher should definitely be discouraged. Atlases (**fig. 5**) provide information in two dimensions only and do not reflect the morphological variation that exists within a single species. Identification of African archaeofauna can be problematic for particular animal groups because they may consist of numerous species of similar size and morphology. This is the case, for instance, for antelopes or for catfish. Certain skeletal elements can be very diagnostic (for instance jaws, teeth, or horn cores) but others, such as ribs or vertebrae, can usually only be attributed to a size class, and will then for instance be labeled as 'medium-sized bovid'. Besides the very varied African wild fauna, the archaeozoologist often also may have to take into account the possible presence of domestic animals. Recognising them is not always straightforward (see Linseele, this volume, pp. 214-217): in the case of domestic cattle, overlap in morphology and size may occur with African buffalo or the larger antelopes. In the case of sheep and goat, they will need to be discriminated from medium-sized antelopes (such as duiker, oribi, etc.). Identifying domestic chicken is not easy either because they need to be distinguished from the numerous wild galliforms that exist in Africa (guinea-fowl, francolin, partridge). Because so much importance is attached to domestication and the propagation of domestic animals, basic comparative anatomical studies need to be carried out that define the diagnostic criteria enabling the recognition of the domestics. This has been done already for distinguishing cattle and African buffalo, but other animal groups such as the galliforms still need to be analysed in detail. The fact that this has not yet happened is mainly due to an absence of sufficient comparative skeletons of the various species. Advances in our knowledge about domestic fowl will hence not only depend on the availability of new faunal assemblages, but also on parallel efforts to expand modern reference collections.

Once identifications are carried out, the data can be quantified and interpreted. **Quantification** usually consists of counting the number of identified fragments (the so-called Number of Identified Specimens or NISPs). An additional, alternative method involves the weighing of the individual bones, starting from the assumption that there is a relationship between bone mass and the amount of meat that was provided by that species. The establishment of the minimum number of individuals (MNIs) is no longer a current practice and is usually only done in cases where complete animals are encountered. This can be animals that were intentionally placed in burials or carcasses of individuals that died naturally and that were deposited in a structure that may have acted as a trap. The data are presented in tabular form and typically consist of species lists, indicating how many remains of each species were identified, and lists with skeletal element distribution per species.

The first step in the **interpretation** of faunal remains consists of understanding how the faunal remains were deposited and what happened to them between the moment that an animal died and when its remains were discovered during the excavation. This so-called '**taphonomical analysis'** should precede the reconstruction of the past environment and of the subsistence strategies. Although humans are usually the main accumulator of faunal remains on an archaeological site, other agents can contribute as well. This is particularly obvious in cave sites where animals can die naturally. This includes not only cave-dwelling species such as bats, but also wounded or sick animals that may have sought refuge in caves. Such animals can be recognised by the fact that their skeletons are more or less complete and by the intact state of preservation of the individual bones. Several raptor bird species can roost near cave entrances and the contents of their regurgitation pellets (bones of small mammals and birds) can accumulate under their resting places. Skeletal remains of larger animals can be brought in by carnivores such as leopards and hyenas; these are usually recognisable by typical modifications: gnaw and puncture marks, bones showing etching or polishing as a result of gastric juices. Another accumulator that also produces typical marks is the porcupine. This large rodent collects bone (and soft stone) on which it gnaws to sharpen its incisors (**fig. 6**). Another thing worth remembering is that not all the faunal material found associated with cultural remains is necessarily contemporaneous. Certain species are burrowers and can not only disturb the stratigraphy of a site, but also contribute skeletal material when individuals die in their burrows. Besides these so-called late intrusives, a faunal assemblage can also include geological intrusives, i.e. remains of much older animals that were already present in the substrate when humans started occupying the site, and that were reworked afterwards. It is obvious that late and geological intrusives should not be used for the **environmental reconstruction**. The so-called pene-contemporaneous species that were not intentionally deposited by humans, but that lived and died naturally at the site at the time of human occupa-

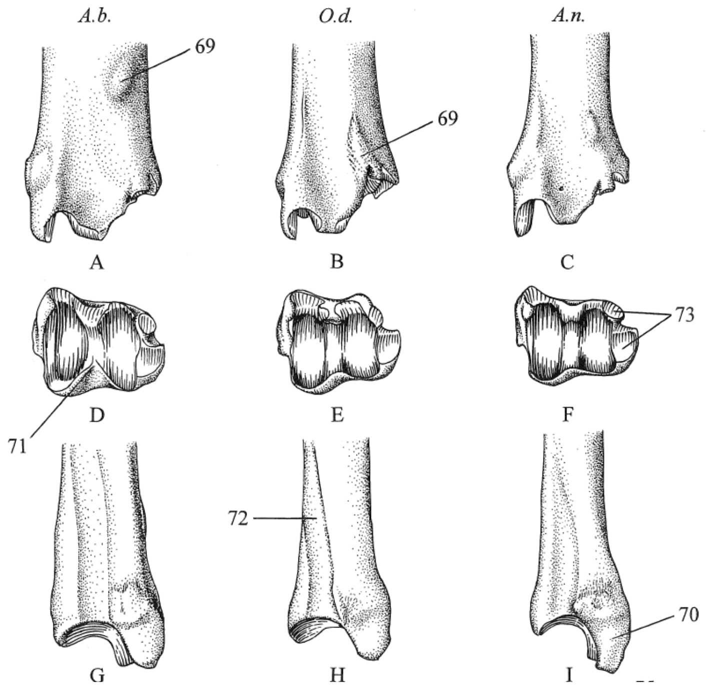


Fig. 5. Part of an identification atlas that illustrates diagnostic criteria for the distinction of three African antelopes: hartebeest, oryx and addax. This plate shows the distal tibia of hartebeest (*A.b.*), oryx (*O.d.*) and addax (*A.n.*). (From de Peters, J., Van Neer, W. & Plug, I. 1997. *Comparative postcranial osteology of Hartebeest* (Alcelaphus buselaphus)*, Scimitar Oryx* (Oryx dammah*) and Addax (*Addax nasomaculatus*), with notes on the osteometry of Gemsbok* (Oryx gazella) *and Arabian Oryx* (Oryx leucoryx*).* Series « Annales de Sciences zoologiques », no. 280. Tervuren : RMCA, 83 p.)

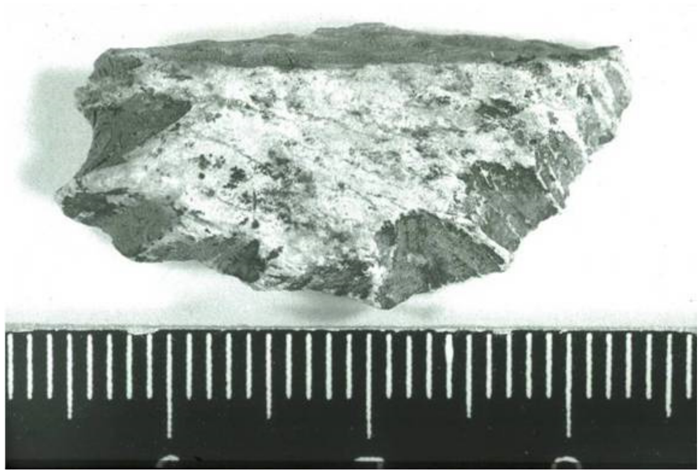


Fig. 6. Modified long bone fragment of a medium-sized mammal from a LSA level at Matupi Cave (Congo). The piece resembles to some extent a lunate tool, but is in fact a bone that was gnawed by a porcupine and is thus a pseudo bone tool. Porcupines are large rodents that sharpen their ever-growing incisors on soft stone and bone. (Photo © W. Van Neer.)

tion (small rodents, birds, lizards, etc.) can be included in the paleoecological analysis. Using the ecological requirements of the encountered animal species, it is possible to reconstruct the past environment, although this is generally less precise than using archaeobotanical data. However, often the fauna gives complementary information and, in cases where no plant remains are preserved, it is the only find category available for reconstruction.

The anthropogenic material of a faunal assemblage allows documenting the **interaction between humans and the animals** in their environment. This includes reconstruction of the food provisioning: was food obtained through scavenging, hunting and fishing or was domestic stock-keeping part of the subsistence strategies? Besides being a source of food, animals can also provide raw materials such as bone, ivory, horn, tendons, skins etc. Finished as well as half-finished objects or refuse of artisanal activities are worth studying as they allow reconstruction of the manufacturing process. Animals and their products often play a role in religious or ritual practices although proving this is not always straightforward. Obvious cases are animal burials or animals found associated with human bodies. Sometimes sites yield remains of animal species that do not occur in the region and in that case provide information on trade and exchange mechanisms in the past. Cowries are a typical example of such items that were exchanged over large distances. In the case of food animals, long distance transport will only be possible when some kind of conservation method has been applied (drying, smoking, salting).

CASE STUDY: DOMESTICATED OR WILD?

Veerle Linseele[1]

I. WHAT ARE DOMESTICATED ANIMALS?

After several generations of breeding and selection under human control, wild animals will become domesticated, showing different biological and behavioural traits than their wild ancestors. While domesticated animals can have had multiple purposes depending on the species, it is mainly those used as food resources that have profoundly changed human life ways. Their introduction marks the start of food-producing or 'Neolithic' economies. The main domesticated food animals in Africa are cattle, sheep, goat, and chicken. Stock keeping is often, although not necessarily, associated with crop cultivation. The identification of remains of domesticated animals from African archaeological contexts is in many cases not straightforward, but is crucial, particularly when studying the appearance of food production. However, also in later periods, it is of important interpretative value to know the domesticated animal species present at a site and their role in the economy.

II. IDENTIFYING BONE REMAINS OF DOMESTICATED ANIMALS

In African archaeology, there are some specific issues in the identification of domesticated animal species. The most frequently encountered problem is probably distinguishing between domesticated cattle, sheep and goat and wild bovids in their respective size range. Because of the difficulties in differentiation, in the species lists categories of unspecified bovids can often be found, usually divided by size class: small bovid, medium-sized bovid, etc. Another recurrent problem is the distinction between domesticated dog and jackals, its local wild relatives (but not ancestors!), which is in fact possible on only very few skeletal parts. Separating domesticated fowl (chicken) and guinea fowl from wild birds of the same biological order, the galliforms, on bone remains is also problematic. Depending on the part of the continent, other issues may arise.

The wild ancestors of sheep and goat have never occurred in Africa and no confusion is therefore possible between the wild and domesticated form. In the Mediterranean zone, the Nile Valley and other parts of northern Africa, wild cattle or aurochs were part of the local fauna during the Holocene. Therefore, when cattle are found in archaeological contexts, their status as either wild or domestic needs to be determined. On the bones themselves, size is the main criterion applied. The domesticated form is on average smaller than the wild one, but they overlap in size. Circumstantial evidence is therefore also often used. The importance of correct identifications is illustrated by the much debated domestic status of the early cattle from Nabta Playa and Bir Kiseiba in the Western Desert of Egypt (8th millennium BC). These cattle are not smaller (yet) than the wild form. They supposedly could not have survived in the area without humans taking care of them, hence the conclusion that they are domesticated. The whole argument in favour of local African cattle domestication revolves around these cattle. Only in the 6th millennium BC cattle that are commonly accepted as being domesticated appear in the Nabta Playa/Bir Kiseiba area. They are from then metrically distinct from the wild form and also accompanied by domesticated sheep and goat. In northern and eastern Africa, distinguishing between wild and domesticated donkey can also be problematic.

In West Africa, a special position is occupied by the helmeted guineafowl (**fig. 1**). The living conditions of animals kept in captivity are very close to those in the wild and the status of the animal as a domesticate is therefore debatable. Nevertheless, the West African subspecies has been named as ancestral to domesticated guinea fowl, now spread over many parts of the world. No criteria have been described to distinguish between wild and domesticated guinea fowl from their bones. Only one prehistoric site in West Africa, Gajiganna BII in Nigeria (early 1st millennium BC), is known with a relatively high proportion of guinea fowl bones. Although species spectrum change can be an indication for domestication, this criterion alone is probably insufficient. For now, the archaeological evidence does not allow researchers to decide whether the exploitation of guinea fowl in West Africa was an entirely local development, or if it was triggered by the introduction of the exotic chicken, as has been suggested.

Other issues when dealing with domesticated species is the separation of related taxa, like sheep and goat or horse and donkey. The latter can moreover produce

1 KU Leuven and Royal Belgian Institute of Natural Sciences, Brussels.

Fig. 1. 'Captive' guineafowl in northern Nigeria. (Photo © V. Linseele.)

Goliath heron (*Ardea goliath*)	1
Helmeted guineafowl (*Numida meleagris*)	1
Pigeon or dove (Columbidae)	2
Identified wild birds	**4**
Identified domestic birds: domestic fowl (*Gallus gallus* f. domestica)	**4**
Identified wild or domestic birds: large galliform	**56**
Unidentified birds	**17**
Eggshell unidentified bird	30
African hedgehog (*Atelerix albiventris*)	4
White-toothed shrew (*Crocidura* sp.)	1
True hare (*Lepus capensis/saxatilis*)	19
Unstriped grass rat (*Arvicanthis niloticus*)	2
Small rodent	76
Mongoose (Herpestidae), genet or civet (Viverridae)	2
Sandfox (*Vulpes pallida*)	2
Common warthog (*Phacochoerus africanus*)	2
Bush duiker (*Sylvicapra grimmia*)	1
Oribi (*Ourebia ourebi*)	1
Bush duiker (*Sylvicapra grimmia*) or oribi (*Ourebia ourebi*)	8
Red-fronted gazelle (*Eudorcas rufifron*)	4
Medium-sized antelope	1
Identified wild mammals	**123**
Dog (*Canis lupus* f. familiaris)	176
Horse (*Equus ferus* f. caballus)	1
Horse (*Equus ferus* f. caballus) or donkey (*Equus africanus* f. asinus)	2
Sheep (*Ovis ammon* f. aries)	7
Goat (*Capra aegagrus* f. hircus)	11
Sheep (*Ovis ammon* f. aries) or goat (*Capra aegagrus* f. hircus)	89
Cattle (*Bos primigenius* f. taurus)	46
Identified domestic mammals	**332**
Medium-sized carnivore	77
Small bovid	284
Identified wild or domestic mammals	**361**
Unidentified mammals	**6400**
Human (*Homo sapiens sapiens*)	**8**
TOTAL	**7848**

Fig. 2. Identified bird and mammal taxa of Saouga 95/7. Since among the canids, all diagnostic bones were of dog, they have all been classified as such. (Excerpt from table D.11 in Linseele 2007.)

hybrids (mules and hinnies) which further complicates identification. A precise identification is also important here for the interpretation, horse being for example usually associated with wealthy people contrary to donkey.

III. DOMESTICATED ANIMALS IN SPECIES LISTS OF ARCHAEOLOGICAL SITES

In the species lists, domesticated and wild animals are usually separated, often with a third category of which the status as either wild or domesticated is not clear, due to identification issues. As an example the species list of Saouga 95/7, a late Iron Age site (1000-1400 AD) in northern Burkina Faso is given (**fig. 2**). There are two main systems of scientific names for domesticated species. Dog, for example, is called *Canis lupus* f. familiaris in the first system. The first two parts, in italic, refer to the wild ancestor, wolf in this case, after f. follows the specification of the domesticated form. In the second system dog is *Canis familiaris.* The first system emphasises the relation between the domesticated form and its wild ancestral species, while the second one, the so-called Linnaean system, involves a typological approach putting more emphasis on the morphological differences between the domesticated and wild form.

IV. ARCHAEOMETRIC STUDIES OF DOMESTICATED ANIMAL BONES

Analysis of ancient DNA (aDNA) has proven particularly useful in studies of (early) domesticates. A striking example is a study of South African canid bones from multiple sites, identified as dog based on the fact that they were associated with other domesticated species, but that turned out to be jackal after aDNA analyses. Because it is important to adequately sample and store samples to be used for genetic studies, protocols should be planned ahead together with the specialists and taken into account during the excavations. When studying the early appearance of domesticated species, running radiocarbon dates directly on diagnostic bones should be considered. This allows researchers to finely and reliably reconstruct the timing of their introduction. Relatively new techniques, such as stable isotope studies, are also generally more frequently applied on remains of domesticated than of wild species. They can be used to reconstruct feeding and herding strategies. An interesting application from Africa was performed on horn preserved on cattle bucrania from the Classic Kerma period (1750-1500 BC) at Kerma in Sudan. The results suggest that the numerous cattle offered were brought to Kerma from different parts of the realm. In many parts of Africa, preservation issues will complicate the application of archaeometric techniques. Often only the mineral fraction of a bone is preserved, which means for example that aDNA studies are no longer possible.

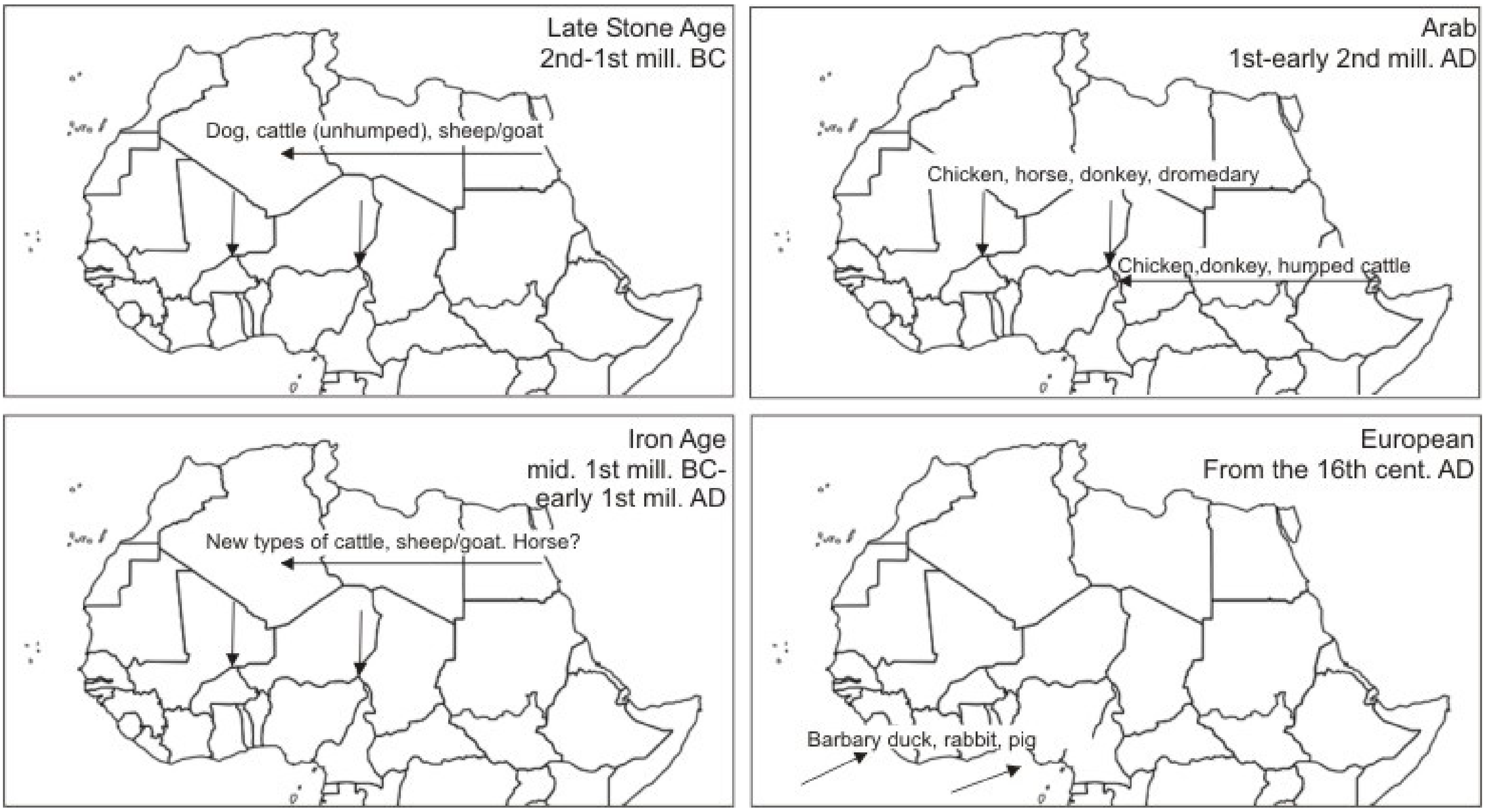


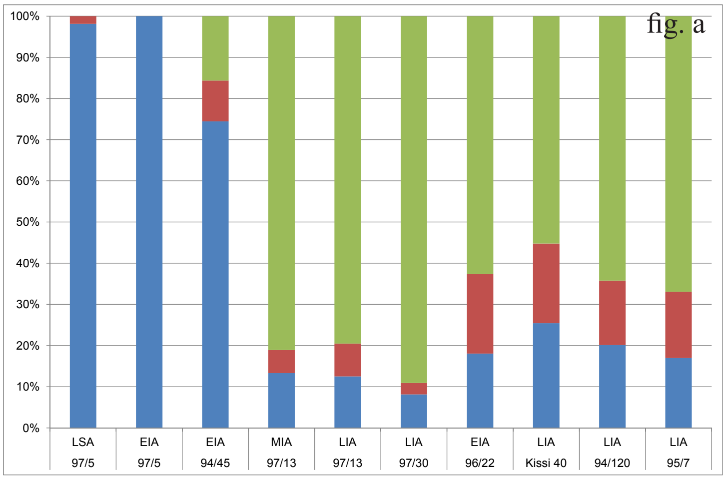
Fig. 3. The four 'waves' of introduction of domesticated animals into Sahelian West Africa (figures made by V. Linseele.)

V. THE TAPHONOMY OF DOMESTICATED ANIMALS

Before the actual interpretation, it should always be considered how and why the animals ended up at the site, which is part of the taphonomical studies. Domesticated animals may have been used for the power they can provide (horse, donkey, but also cattle), as a source of raw material to make all kinds of objects, or they may have been simply companion animals (e.g., dogs, cats). Most of the time, however, they have been consumed. It is a misconception among archaeologists that traces of butchery and/or burning are needed to prove that. Such marks are often missing, especially in prehistoric sites, and the simple fact that the animals are found disarticulated, and mixed in with other species, can be used as an argument for consumption. Nevertheless, for more unusual consumption animals, traces are useful. Cut marks on dog bones were for example used to argue that the species appeared on the menu at Saouga 95/7 in Burkina Faso (1st half second millennium AD). Burning is usually not related to food preparation, as meat adhering to the bones protects them from being directly exposed to the fire. Most of the animals found at archaeological sites are food remains and species that were of importance but not consumed can be difficult to trace. Carcasses of horse and dromedaries, for example, were probably most of the time dumped outside of the settlement areas, and have therefore little chance of being recovered.

VI. INTERPRETING REMAINS OF DOMESTICATED ANIMALS

While in north-eastern Africa a few species – including cattle, donkey and cat – (may) have been locally domesticated, no animals were domesticated in sub-Saharan Africa before the modern era, except for guinea fowl perhaps. This should most probably be explained by a lack of wild species with biological traits that make them suitable for domestication. The domesticated animal taxa from sub-Saharan Africa have all been introduced from elsewhere at some point. For the major species (cattle, sheep and goat), dates become generally younger as one moves away from north-eastern Africa but many gaps remain in our knowledge on their spread. The introduction of new taxa in a certain region at a certain time can be connected to movements of people and/or interregional contacts. For West Africa, four waves of introductions have been proposed for example (**fig. 3**). In domesticates, many types ('races') of one species exist. These types have often locally developed as adaptations to the local circumstances. In the more humid parts of West Africa, for example , dwarf forms of cattle, sheep, goat, and horse



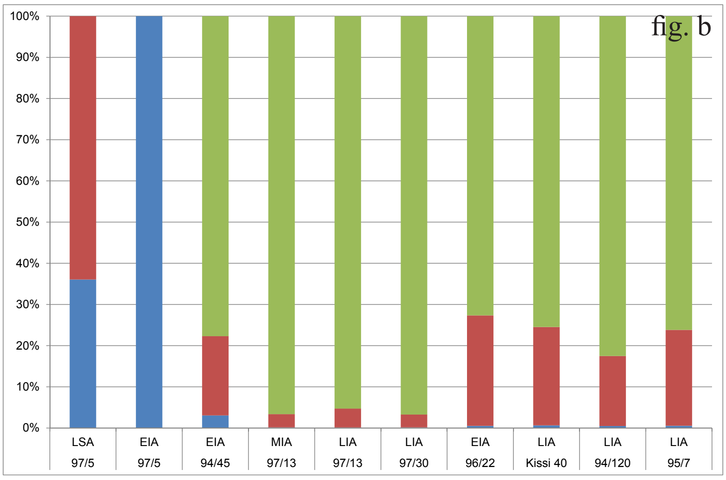


Fig. 4. Relative importance of different economic strategies for Late Stone Age (2200-1000 BC) and Iron Age (0-1400 AD) localities in northern Burkina Faso. Blue: fishing; red: hunting and fowling; green: domestic stock keeping. **a.** based on NISPs (numbers of identified specimens); **b.** based on NISP x average live weight (excerpt from fig. 49a and fig. 50b in Linseele 2007.)

occur . There seems to be a link between dwarfism and resistance to humidity-related diseases. Archaeozoological data, mainly metrical ones, allow tracing of the different types in the past.

In the interpretation, the quantitative importance of domesticated animals in the total faunal sample is usually considered. This can be done by looking at numbers of bones (**fig. 4a**), which mainly reflects frequency of consumption, or at numbers of bones multiplied by live weight, which reflects amounts of meat (**fig. 4b**), although multiple other ways are possible as well. There is a correlation with how suitable the environment is for keeping domesticates, and the numbers by which they are represented in the archaeological samples. In the wetter, lusher zones of West Africa, wild game is typically more important as livestock is prone to diseases. Furthermore, the proportion between the different domesticated animal species is investigated. More sheep/goat than cattle usually means more harsh environments, as these species are less demanding. A predominance of sheep/goat is the pattern seen for example at settlement mounds from the first and early second millennium AD in Burkina Faso. Animals kept by sedentary people are dependent on local circumstances, while nomadic herds can move in function of where the most suitable resources occur. In the archaeological record, the sedentary farmers are overrepresented compared to the nomadic herders, as the latter leave much fewer traces.

Age-at-death distributions, presented as mortality profiles, are made to reconstruct whether domesticated cattle, sheep, and goat were used for milk in addition to being slaughtered for meat. These require large sets of precise data on ages at death, preferably obtained from series of (complete) tooth rows. Unfortunately, preservation conditions in sub-Saharan Africa usually do not allow the gathering of sufficient data of that kind. However, other ways exist to trace the use of milk, like organic residue analysis of pottery, which has proven the extensive use of milk in the Libyan prehistory (5th millennium BC). Judging from data on modern breeds, most West African cattle are not very productive for milk. Blood is also sometimes used from living animals, but seems to play only a marginal role in the human diet. Eggs of domesticated fowl were probably also not important in the past, but this is hard to prove as precise identifications of bird eggshell remains are problematic.

From ethnographic evidence, for example from Tallensi in Ghana, we know that (some) domesticated species must have been favoured for animal sacrifice. Particularly chicken is supposed to have been a popular animal in ritual spheres. The archaeological evidence is very limited, probably due to the sacrifice practices themselves, useful products that are taken away, and waste that is quickly removed by different kinds of predatory animals. Burials of domesticated animals, cattle but also dogs, are well-known from the Sahara and its southern fringes, for example at Adrar Bous in Niger.

REFERENCE

Linseele, V. 2007. *Archaeofaunal remains from the past 4000 years in Sahelian West Africa. Domestic livestock, subsistence strategies and environmental changes*. Oxford: Archaeopress.

SOIL COVER IN CENTRAL AFRICA: EXAMPLES OF GEOARCHEOLOGICAL APPROACHES, CONSTRAINTS, AND ASSETS

Dominique Schwartz[1]

Like sediments, soils conceal archaeological sites and record paleoenvironmental dynamics. But reading soil archives requires special keys, because soils are open environments. In addition, the soils of equatorial Africa (ferrallitisols: Baize & Girard 2008) have specificities that must be taken into account.

I. KEY FEATURES OF EQUATORIAL SOIL COVER

Ferrallitisols are very thick: a layer rising 2 to 5 m above the regolith is common. Their history is long, as they take about 100,000 years to form. The potential length of the soil record is therefore long, sometimes several hundreds of thousands of years. In Central Africa, however, we note that Acheulian or older occurrences are very rarely found in soils, unlike those of the Middle Stone Age which are very common in the two Congos, Gabon, and Cameroon and which are dated in the region between 40,000 and 70,000 years. With the exception of fresh excavations during the construction of roads, these remains are generally not observable because they are hidden deep in soil covered with forest. It is only in the eroded savannas (Nyanga, Lope, Niari, etc.) that they can be observed on the surface, albeit reworked and mixed with other, more recent materials. Furthermore, the general acidity of ferrallitisols – the pH varies from 4.5 to 6 –, the rate of water flow, and the intensity of weathering and biological activity limit artefact preservation and are likely to induce taphonomic biases. They preserve wood and bones very poorly, and they quickly alter ceramics and sometimes even stone.

II. BIOLOGICAL ALTERATIONS AND THEIR ARCHAEOLOGICAL IMPLICATIONS

The considerable churning of the soil by macrofauna, particularly termites, is one of the most remarkable aspects of biological activity in ferrallitisols. Some species have a tendency to bring large quantities of materials, collected at several metres' depth, to the surface. Soil can gradually cover large items, both natural and anthropogenic, which can be buried slightly. In temperate environments, the distribution of charcoal in soils has been explained by the activity of earthworms (Carcaillet & Talon 1996). The model also applies to the distribution of charcoal, pottery and lithics in ferrallitisols.

Two cases at least must be distinguished:

Archaeological sites from more recent times through the Neolithic are generally found under less than a metre of soil. Artefacts are often vertically dispersed over a span found 30 to 50 cm deep. This type of dispersal can be a sign that objects have moved due to biological activity in the soil, and that the level of artefact concentration doesn't correspond to an ancient surface covered by more recent sediments: rather, the ancient surface corresponds to the present soil surface and the objects originally on that ancient surface have been subject to a slight downward movement. Careful field study of the individual positioning of objects, especially of pottery sherds, is therefore required, and should afterwards be supplemented by granulometric and/or mineralogical analyses of the levels above, below, and surrounding each artefact. Such movement can also explain why structures such as postholes are not visible.

It has also been suggested that termite activity could explain the creation and covering of stone-lines, which occur so often in central African ferrallitisols. Schwartz (1996) discusses possible or impossible stone-line formation processes based on the nature of the terrain and their analytic characteristics. Their formation is complex. No single mechanism (biological activity, erosion, gravitationally-induced movement through the soil column, etc.) can explain their existence. In fact, they consist of an erosion level on which the Stone Age industries lie. Their covering of over more than a metre is due to the resurfacing, by termites, of fine materials, which are then transported by colluvial activity along watersheds.

III. THE NEED FOR A PEDOSTRATIGRAPHIC APPROACH

These two examples demonstrate the need to apply a pedostratigraphic approach in the field in Africa. This requires identifying, based on a study of the morphological characteristics of surface formations, which processes are part of the initial formation of the deposits and which are due to subsequent pedogenesis. This distinction is not trivial. Any confusion between geological strata and soil horizons can lead to serious misunderstandings, both in the

1 Faculty of Geography and Environmental Planning, University of Strasbourg LIVE - UMR 7362, France.

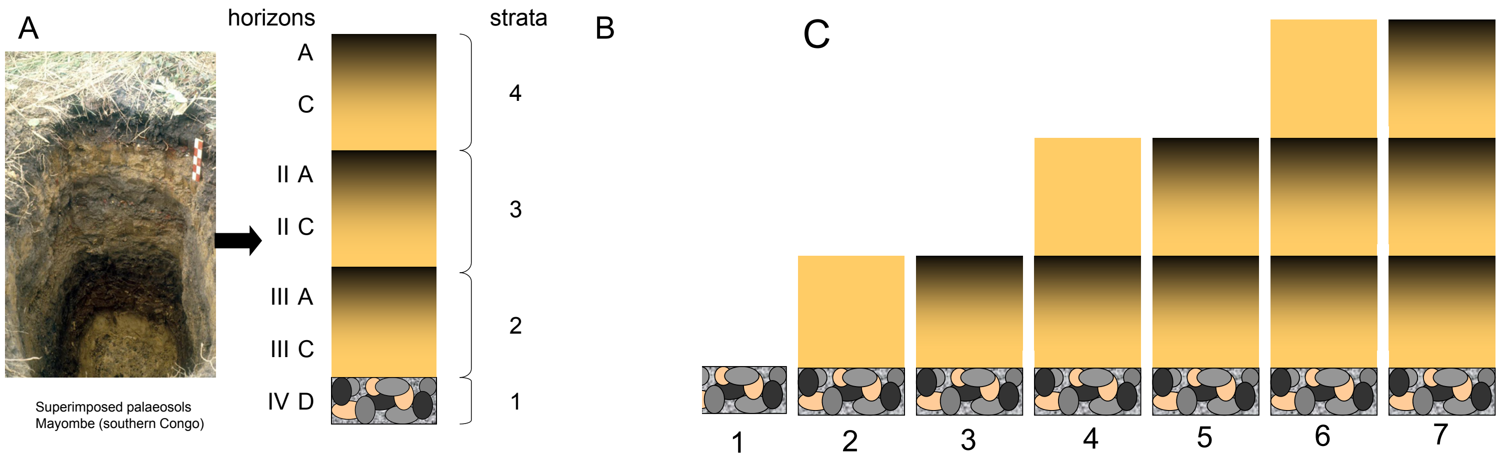


Fig. 1. Paleosols of Makaba (central Mayombe, Congo). **A**. soil profile; **B.** pedological nomenclature (left) and stratigraphic nomenclature (right); **C.** the different phases of material deposit and soil formation. (1): coarse alluvial deposits; (2) deposit of the first layer of colluvium; (3) soil formation and individualisation of horizons A and C; (4): cover by a second level of colluvium; (5) ditto (3); (6): burial under a third layer of colluvium; (7) same as (3) and (5). (Adapted from Schwartz 2012.)

understanding of the formation of the geological and pedological units as well as in the resulting chronologies and paleoecological interpretations.. The following examples serve to illustrate this.

A. The paleosols of Mayombe (Schwartz 2012)

In the savannas of Mayombe, we can observe superimposed paleosols at the bottom of slopes. In the section shown in the **figure 1**, we see at the base a layer of alluvial pebbles (IVD) covered by an initial layer of colluvial material (III), in which a minimally evolved soil has developed: above the colluvium undergoing pedogenesis (IIIC horizon) can be seen a surface humus horizon (IIIA). This soil is buried under a layer of colluvium, in which a soil layer (II) with an AC profile can be seen, and then the process repeats itself one more time. We can thus distinguish seven soil horizons, and four strata. To describe seven stratigraphic units would in this case be an error.

B. The 'white sand and peaty sandstone' of Bateke country (Schwartz 1985; 2012)

The 'white sand and peaty sandstone' of Bateke country and Malebo Pool were first described in the first half of the 20th century (Babet 1933; de Heinzelin 1952). For a long time, loose sand and 'sandstone' – in fact, spodic horizons cemented into hardpans by humic matter – were described as strata (**fig. 2**). Various interpretations have been put forward over the years by geologists and geomorphologists: Cretaceous strata and, after the discovery of stone tools, Quaternary formations. In fact, they are Bateke sands transformed by pedogenesis into podzols around 40,000/30,000 years ago. White sand and peat sandstone are two horizons, E and BP, which are of exactly the same age: the bleaching of the sand (E) by the destruction of clays, elimination of iron, and migration of soluble organic materials is accompanied by the formation of a humic accumulation horizon (BP) that later cemented. A stratigraphic reading of the two levels leads to errors in chronological interpretation that can damage archaeological interpretations.

C. Podzol in the ORSTOM concession in Brazzaville (fig. 3)

These two examples illustrate the need to understand soil processes for stratigraphic interpretation and its use in archaeology. The last case shows how archaeological indices can in fact help interpret pedogenesis. The podzol mentioned had a very complex history, revealed by the presence of a Tshitolian lithic industry (Later Stone Age) sitting on the humic hardpan (Schwartz 1988; Schwartz & Lanfranchi 1990). The presence of this industry, perfectly in place, undisturbed by biological agents, suggests that the hardpan was a circulation surface, and that there was no genetic relation between the overlying white-sands horizon E and the underlying spodic indurated BP-horizon. This 'pedogenetic heresy' was nevertheless confirmed by the phosphorus content of the hardpan, 30 times higher than normal, and the fact that this humic hardpan extends under the ferrallitisol, an environment in which it could not have formed. The explanation lies in the fact that an initial podzol was removed by erosion that stopped on the more resistant hardpan. After being covered by material resulting from a laterally weathering ferrallitisol, a second podzolisation took place, followed by other discrete phases of pedogenesis. In this case, it was the presence of the lithic artefacts that alerted the soil scientist and led to these conclusions. Without this evidence, these phenomena would have been impossible to interpret.

IV. IN ADDITION TO FIELDWORK, THE ANALYSIS OF SOIL COMPONENTS IN SUPPORT OF ARCHAEOLOGY

Field observations are extremely valuable if you can tell the sediment (deposit of materials) from the soil (post-depositional evolution). It is nevertheless clear that we must supplement these with laboratory analyses. Some are standard: granulometric analysis, or measurement of total phosphorus, levels of which are an indicator of human activity: for example, the content of 12‰ in the hardpan of the ORSTOM concession is 30 times higher than the average contents of soils the region and can be explained only by anthropogenic enrichment, probably related to a campsite. Other analyses, such as anthracological analysis, identification of pollen and phytoliths, are common practice and complement the archaeological research. It is always important in the case of these studies to clearly identify the nature, soil or sediment, of the studied material. Indeed, in soils, biological churning results in a particularly drastic mixing and degradation of biological evidence, due to the small size of these constituents.

Moreover, Central Africa is an ideal environment for biogeochemical studies using carbon 13. Indeed, forests, which consist exclusively of C3 photosynthetic-cycle plants, and savannas dominated by C4 plants, have a very different ^{13}C isotopic composition, which is transmitted to the organic matter in the soil. It is thus possible, using analysis of these organic materials, to know in what environment, forest or savanna, past populations evolved. Thus, coupled with carbon 14 age measurements, carbon 13 analysis of organic matter in the paleosols of Mayombe (see section A above) shows that they formed under savannas, and must be at least 1,800 years old. This demonstrated that, contrary to an opinion popular in the 1970s, savannas are not recent human creations caused by clearing. Spatially more substantial studies revealed that the forest diminished significantly in the late Holocene, which might have facilitated migration of Bantu technical skills, peoples, and cultures from north to south of the equatorial forest (Schwartz 1992).

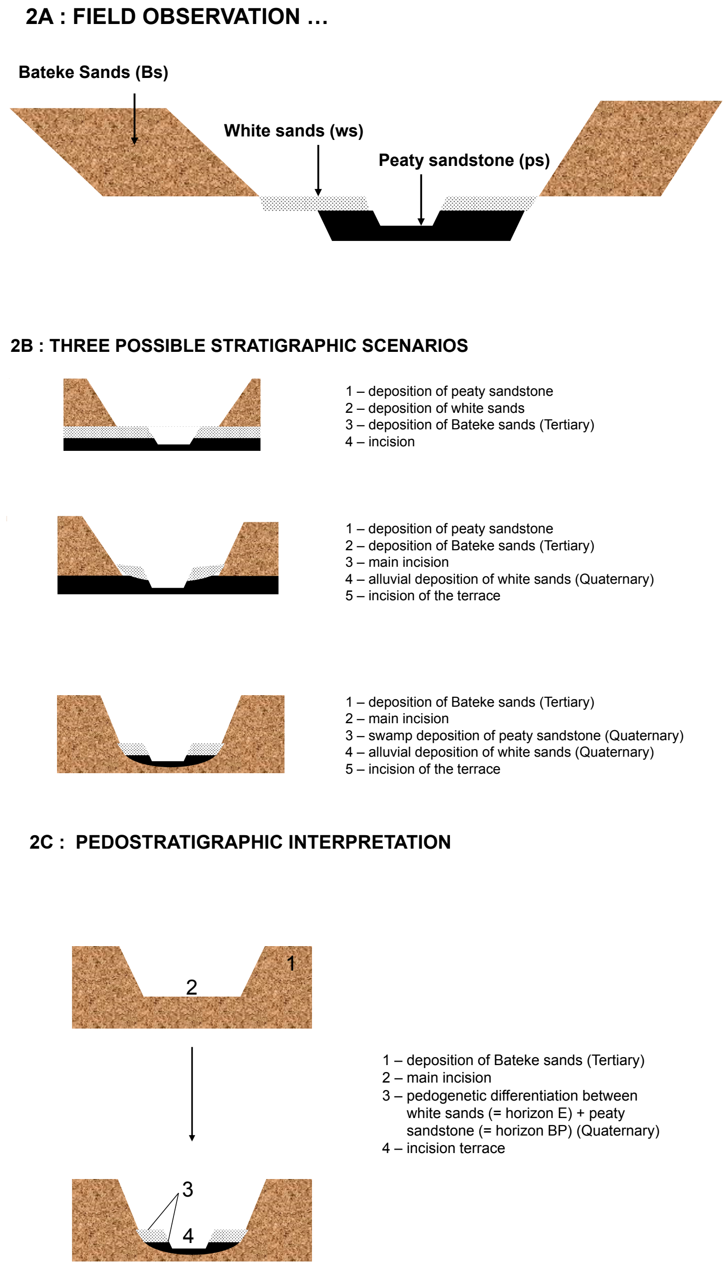


Fig. 2. 'White sands' and 'peaty sandstone' of Bateke country (Congo and Democratic Republic of the Congo). From field notes (**A**) to stratigraphic interpretation (**B**), to the proper explanation (**C**). (Extract from Schwartz 2012.)

V. THE NEED TO UNRAVEL THE THREAD OF TIME

A final important point should be emphasised: the need to know how to read the specific temporalities of the soil. These are fundamentally different from those of sediments, because, with the notable exception of buried paleosols, soils are open environments whose constituents have very different dynamics. Some of these constituents enter it only rarely or sporadically (charcoal, archaeological artefacts), others accumulate (the organic matter of humic hardpans), and still others are continuously renewed (organic matter in biologically active horizons, pollen, etc.).

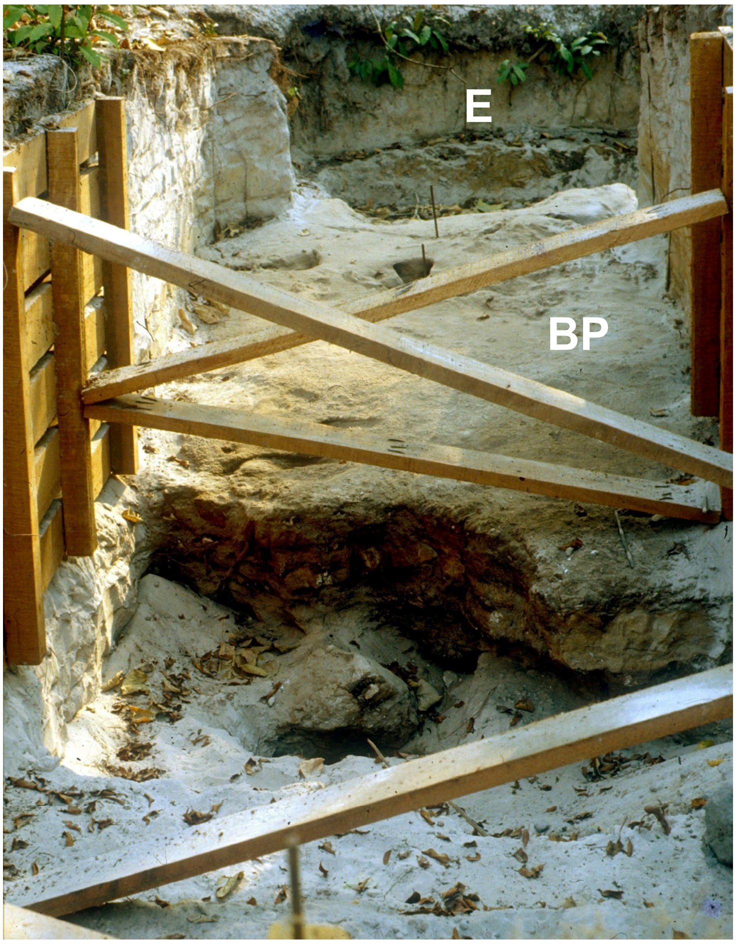


Fig. 3. Podzol in the ORSTOM concession (Brazzaville, Congo) in the course of being cleared (R. Lanfranchi excavations, 1982). Below, the eluvial horizon E ('white sands'); in the middle-ground, the indurated spodic horizon in humic hardpan (BP), exposed during excavations and corresponding to an ancient surface; in the foreground a rocky escarpment fossilised below the current topography. (Photo © D. Schwartz.)

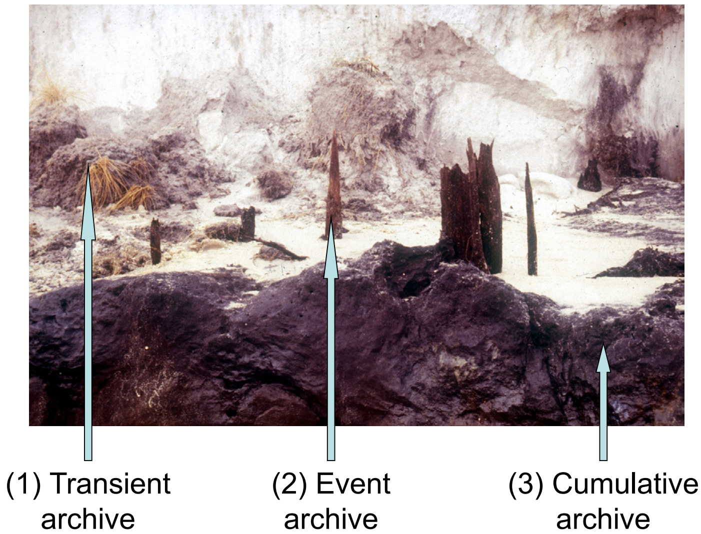


Fig. 4. Pedological archives (taken from Schwartz 2012). The three examples presented here are organic constituents. (1) Organic matter from surface horizons (here in crumbling lumps) is constantly renewed: it is typically a transient archive; (2) fragments of fossilised wood (or charcoal) enter into the ground and remain there very episodically, discontinuously: these are event archives. Carbon 14 dating of these root pivots range between 3000 and 7500 BP; (3) after migration from surface horizons in a soluble state, organics flow into spodic horizons where they form very stable organometallic complexes, and continue to accumulate. Over time, the stock increases: these are cumulative archives. (Photo © D. Schwartz, coast at Pointe-Noire.)

We can therefore define three types of soil archive (**fig. 4**): event archives, cumulative archives, and transient archives (Schwartz 2012). This last type corresponds to constituents present in the soil for a variable period of time before being removed by dissolution, mineralisation, or other processes. This phenomenon is expressed by the notion of mean residence time, which measures life expectancy. Thus, it is important to interpret age measurements based on material type. Carbon 14 dating of charcoal does not have the same meaning as C14 dating of organic matter, and to use for instance a C14 age on charcoal to give a time value to a carbon 13 measurement of organic matter is irrelevant (Schwartz 1997).

In conclusion, the examples discussed here illustrate the wealth of approaches that combine soil science and archaeology. Each discipline can be complementary to the other, allowing both to enhance the interpretation of field observations. Is it necessary to make any additional plea for more consideration of this complementarity in the training of researchers?

REFERENCES

Babet, V. 1947. 'Exploration de la partie méridionale des plateaux Bateke (1933)'. *Bulletin du Service des Mines A.E.F.*, 3: 23-56 (+ photos in annex).

Baize, D. & Girard, M.C. (eds). Association française pour l'étude du sol (Afes). 2008. *Référentiel pédologique*, Paris: Quae, 405 p.

Carcaillet, C. & Talon, B. 1996. 'Aspects taphonomiques de la stratigraphie et de la datation de charbons de bois dans les sols: exemple de quelques sols des Alpes'. *Géographie Physique et Quaternaire*, 50 (2): 233-244.

de Heinzelin de Braucourt, J. 1952. *Sols, paléosols et* *désertifications anciennes dans le secteur nord-oriental du bassin du Congo*. Brussels: INEAC, 168 p. (+ additional illustrations).

Schwartz, D. 1985. 'Histoire d'un paysage: le Lousseke. Paléoenvironnements quaternaires et podzolisation sur sables Bateke (quarante derniers millénaires, région de Brazzaville, R.P. du Congo)'. Doctoral thesis, University of Nancy I, 211 p., appeared in 1988, collection 'Études et Thèses'. Paris: ORSTOM, 285 p.

Schwartz, D. 1988. 'Some podzols on Bateke sands and their origins, People's Republic of Congo'. *Geoderma*, 43 (2/3): 229-247.

Schwartz, D. 1992. 'Assèchement climatique vers 3000 B.P. et expansion Bantu en Afrique centrale atlantique: quelques réflexions'. *Bulletin de la Société géologique de France*, 163 (3): 353-361.

Schwartz, D. 1996. 'Archéologie préhistorique et processus de formation des stone-lines en Afrique centrale (Congo-Brazzaville et zones périphériques)'. *Geo-Eco-Trop* 20 (1/4): 15-38.

Schwartz, D. 1997. 'Commentaire à la note de Richard Oslisly, Bernard Peyrot, Salah Abdessadok et Lee White, Le site de Lopé 2: un indicateur de transition écosystémique ca 10 000 BP dans la moyenne vallée de l'Ogooué, C.R. Acad. Sci. Paris, 323, IIa, 1996, 933-939'. *Comptes rendus des séances de l'Académie des Sciences de Paris*, 325, IIa, 5: 389-391.

Schwartz, D. 2012. 'Les temps du sol: interprétations temporelles de l'archivage pédologique dans les approches paléoenvironnementalistes et géoarchéologiques'. *Étude & Gestion des Sols*, 19 (1): 51-65.

Schwartz, D. & Lanfranchi, R. 1990. 'Les remaniements de sols sur sables Bateke dans la région de Brazzaville (Congo): une mise au point'. In R. Lanfranchi & D. Schwartz (eds), *Paysages quaternaires de l'Afrique centrale atlantique*. Paris: ORSTOM, pp. 167-182.

CASE STUDY IN A SUDANO-SAHELIAN FLUVIAL SETTING: EXAMPLES FROM THE YAME VALLEY (DOGON DISTRICT, MALI) AND THE FALÉMÉ VALLEY (SENEGAL)

Michel Rasse[1]

When working with archaeological records in Africa – as elsewhere – one must take into account the sedimentary conditions of their burial. When reconstructing past environments in an African fluvial setting, the coupled presence of water and of humans is associated with the coupling of erosion and accumulation so characteristic of river bank networks in the Sudano-Sahelien area. A nuanced understanding of how the archaeological layers fit into the stratigraphy* permits an understanding of site burial phases, but also of the phases of erosion that the banks experienced and the subsequent movements of artefacts. This might appear obvious, but we should not underestimate the difficulties of approaching sites in this context, and experience has shown that, as each study will have its specificities, each must be approached with great care and organisation if certain pitfalls are to be avoided.

Dealing with one or more prehistoric sites in a fluvial setting involves study of regional geomorphology* and stratigraphic conditions. An understanding of the site requires in-depth surveys in an environment that is sometimes difficult to access, and these surveys often benefit from the participation of a multi-disciplinary team (**fig. 1**). A 'reading' of the landscape made simultaneously by a geomorphologist, a pedologist,* an archaeologist, etc., in addition to raising questions that will be largely beneficial to all, broadens observations so that a research scenario can be implemented quickly, even if this will need to be changed in light of later discoveries. A rough understanding of the thickness, size, and geometry of the different stratigraphic units of the Pleistocene sediments of the Yame Valley (Bandiagara plateau, Mali) therefore required a minimum of three multi-week missions. The resulting stratigraphy could only be certified with the establishment of an absolute time frame using the OSL method.*

Understanding these topographies and the geomorphological processes that govern site evolution is also imperative. It is even more important because in the tight, often monotonous profiles typifying African landscapes, the processes must be understood prior to any explanation of deposits. Topographical analyses linked to fluvial activity permit researchers to distinguish several levels of *glacis** and terrace,* which also show evidence of the influence of lateral colluvial processes. Generally, the base *glacis* is followed by one, two, or even three secondary *glacis* (**fig.2**) which, cross sections show, are associated with the levels of alluvial terraces,* themselves multiple and often difficult to correlate laterally. Thus along the Falémé (Senegal), the level of recent terraces is recorded in the topography of bank erosion , which began in the early Holocene; structural characteristics (resistant bedrock*) and the lateral dynamic of water flow shaped their distribution. A simple reading of topographic levels based solely on altitude is therefore far from simple.

In addition to the fluvial effects are those of run-off, which occur at the expense of the main *glacis* formations. The *glacis* therefore appear successively as 'erosional *glacis*' located at the foot of the main terrace edges and exposing artefacts, and accumulation *glacis* downstream, where the colluvium* of each rainy season covers and fossilizes the most recent artefacts. In Ounjougou (Mali), the erosion of the fringing *glacis* revealed bifacial points from the eighth millennium BC, while only a few metres away the colluvium of recent centuries had covered protohistoric remains, thus creating a terrace fitting neatly into the landscape. It is therefore important to consider the surface differences between the erosion and accumulation zones. These same processes are of course responsible for shaping previous formations, and paleotopographies demonstrate the same processes that have been fossilised by recent events (with a former edge *glacis* completely fossilised by recent lateral deposits in Kokolo; **fig. 2**).

Understanding pedological processes is also extremely important in interpreting formations, as a single stratigraphic element can present itself in very different ways, with leaching* introducing variations both along the vertical axis and laterally, depending on water flow in the sediment. Variations of colour, bioturbation,* concretions, induration, and even important laterite must be considered in order to avoid misinterpretation. These considerations can often help in the recognition of different stratigraphic units, which are the result of periods of accumulation and erosion which were marked to greater or lesser extent by successive phases of soil evolution. Any unit might present pedological characteristics that could be looked for elsewhere, where the survey con-

1 Université de Lyon 2 et Archeorient, UMR CNRS 5133, France.

Fig. 1. Multi-disciplinary team survey in the gullies of the banks of the Falémé (eastern Senegal). The stratigraphic information (from *Colluvions* or colluvium to *Us* where U indicates Pleistocene formations) corresponds to the upper portion of the Toumboura I section from **figure 3**. (Photo © M. Rasse.)

ditions are less clear. Discrepancies related to surface stripping or major periods of erosion are almost always represented by lines of crushed stone, altered pisolites,* and sometimes by archaeological artefacts, which must also be considered in order to understand both the succession of sedimentary events and the extent to which the artefacts found have moved.

With this approach, the stratigraphy of formations helps to reconstruct (and often, in fact, to locate) the major stages of the fluvial dynamic. During Isotope Stage 3* of the last glacial period, the Sudano-Sahelian zone received large quantities of dust from arid regions subject to major soil erosion through deflation.* These wind-carried deposits overloaded the hydrographic networks, which, during the rainy season and then when rainfalls were reduced, deposited large quantities of sediment in the valleys, certain areas of which filled up for structural reasons. At Ounjougou, Isotope Stage 3 is represented by several stratigraphic units (U3, U4, and U5; **fig. 2**) featuring sedimentary discontinuities that seem to be attributable to Heinrich-type* events (Rasse *et al.* 2004; Lespez *et al*. 2008). Dates are not yet available for the Falémé valley, but the current study suggests that the watercourse, flowing from the south, was always fed by precipitation falling in regions further to the south (even during stage 2, characterised in Sudano-Sahelian Africa by extreme aridity) and therefore suffered less from the drier climate. The Falémé moved large amounts of silt and loam from watersheds, and deposited them downstream in areas with very little slope, between the last landforms in the southeast of the region and its confluence with the Senegal. The units referred to between Utp and Uc can be attributed to this period when watersheds received a great deal of material, and can likely be correlated with Isotope Stages 4, 3, and 2 (**fig. 3**).

The early Holocene, on the other hand, is marked by a rather sharp incision of rivers, development of fringing *glacis**, and major erosion of anterior formations. These

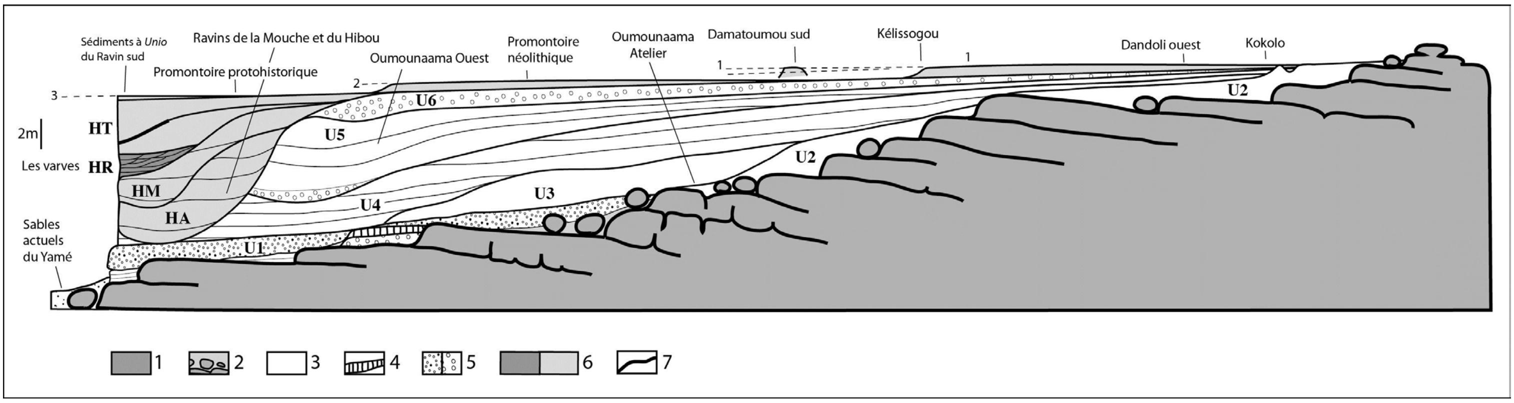


Fig. 2. Pleistocene and Holocene formations in the Yame valley (Dogon district, Mali). Cross-section based on various archaeological and stratigraphic sites. Key: 1: sandstone; 2: sandstone regolith; 3: Pleistocene formations (from U1 to U6); 4: ferruginous crust/laterite;* 5: coarse alluvium; 6: Holocene formations (from HA to HT); 7: crusting (from HR to HT). From Rasse *et al.* 2004.

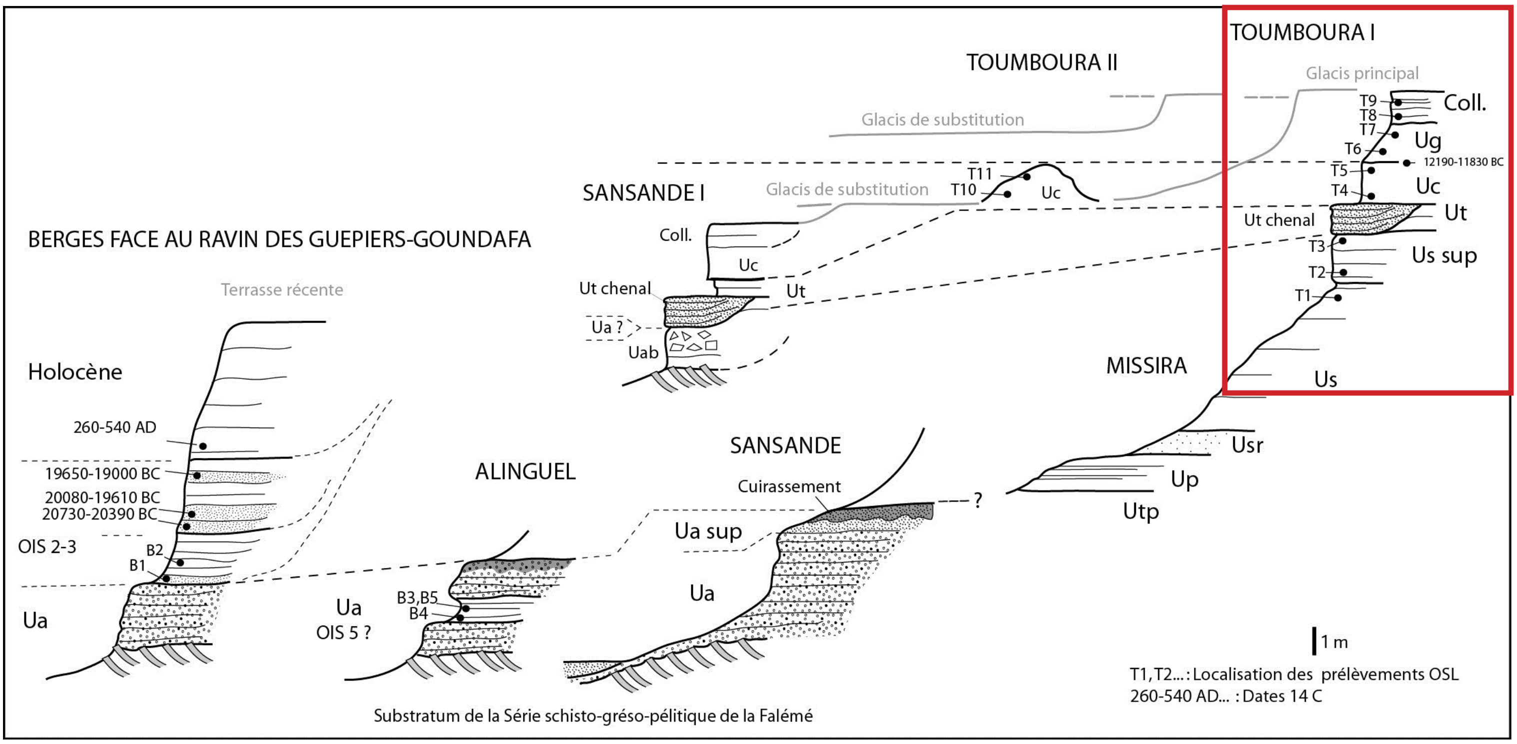


Fig. 3. First geometric reconstruction of the shapes and formations of the banks of the Falémé. Study from different sites with tentative correlations. Insert in red = **fig. 1**.

testify to a decrease in the amount of wind-borne dust, an increase in rainfall, and a concentration of more abundant flows of water. The sedimentary record of larger watercourses is not always the most interesting to study, however.

The case of the Yame, which runs through a valley more or less deeply incised into the sandstone of the Bandiagara plateau, allowed a very detailed study of the stratigraphy of the various Holocene sequences. Study has shown that, especially for the last ten millennia, fluvial records can demonstrate great paleoclimatic resolution, similar to the well-known lacustrine or marine sequences (Lespez *et al.* 2008; 2011).

After a phase of rapid incision into Pleistocene deposits, the first Holocene formations (11.5-8.5 ka cal BP) are coarse, interrupted twice by finer sediment, and are evidence of a greater capacity of the upper Yame than is seen today. After a sedimentary hiatus between 8.8 and 7.6 ka cal BP, the middle and recent Holocene (8.5-4 ka cal BP) are characterised by three sedimentary sequences that testify to a very different environment. Micromorphological and palynological studies indicate

the filling of relatively narrow channels in a valley covered with dense gallery-forest of Guinean type. The most recent period (4-0.1 ka cal BP) displays a more rhythmic sedimentation that is clearly seasonal, and for which the rainfall conditions become progressively more and more irregular, progressively becoming more similar to current conditions, with rather long lulls interspersed with highly morphogenic episodes.
In contrast, along the Falémé, surveys so far suggest weaker signs of the Holocene, the dynamic of the waterways during the two last millennia having doubtless partially eroded the sedimentary record. Future research will surely bring answers to this question; we can in fact never exclude that, in the case of a better-fed watercourse, a number of traces have been conserved, buried in the sediment of the last great centennial floods.

Understanding the long-term of the sedimentary records in their geometry is absolutely not trivial. Not only does this multi-disciplinary approach allow an understanding of the succession of episodes of sedimentation and erosion, but it 'frames' the work done by the rest of the team. In fact, an understanding of the geometry of the sequences must precede – or at least be done concomitantly with the specialists in question – any sediment sampling for granulometry,* soil micromorphology, or analysis of bio-indicators for paleoenvironmental reconstructions, and for the purposes of absolute dating (charcoal for radiocarbon 14 and radiometric measurements for OSL). We know how much these laboratory techniques cost, and it is essential that they be as targeted as possible in keeping with the priorities and objectives of the mission.

If it is easy, for example, to understand how samples will be taken for paleoenvironmental reconstruction (pollen, phytoliths,* plant macrofossils, for establishing past vegetation regimes), the sampling methods for OSL dating (the method best suited for studying the Pleistocene in these valleys) vary according to the methods and goals of the mission and the precision required (see, for example, the localisation of samples in **figure 3** for chronostratigraphic* purposes). For this method, it is essential to take into account the thickness of the sediments that buried the levels under study. Reconstruction of the successive periods of accumulation and erosion allows the volume of sediments and the potential duration of sedimentary cover to be refined, and moreover allows a more precise definition of the proposed chronological units.

In order to understand the geometry of formations, therefore, we recommend a long period of fieldwork undertaken, to the extent possible, by a multi-disciplinary team. This work must precede all the in-depth chronostratigraphic and paleoenvironmental studies that archaeology today requires.

REFERENCES

Lespez, L., Rasse, M., Le Drézen, Y., Tribolo, Ch., Huysecom, E. & Ballouche, A. 2008. 'Signal climatique et hydrosystèmes continentaux entre 50 et 4 ka en Afrique de l'Ouest: l'exemple de la vallée du Yamé (pays Dogon, Mali)'. *Géomorphologie, Relief, Processus, Environnement* 3: 169-186.

Lespez, L., Le Drézen, Y., Garnier, A., Rasse, M., Eichhorn, B., Ozainne, S., Ballouche, A., Neunmann, K. & Huysecom, E. 2011. 'High-resolution fluvial records of Holocene environmental changes in the Sahel: the Yamé River at Ounjougou (Mali, West Africa)'. *Quaternary Science Reviews* 30: 737-756.

Rasse, M., Soriano, S., Tribolo, Ch., Stokes, S. & Huysecom, E. 2004. 'La séquence pléistocène supérieure d'Ounjougou (pays Dogon, Mali): évolution géomorphologique, enregistrements sédimentaires et changements culturels'. *Quaternaire* 15(4): 329-341.

GLOSSARY

Alluvium: any deposit (clay, sand, gravel, etc.) deposited by a river on its banks, on its floodplains, at its mouth, in a delta or estuary, etc.

Bioturbation: the disturbance of soils and sediments by biological agents, especially by burrowing and digging animals such as termites, ants, worms, or rats.

Chronostratigraphy: study of strata or terrestrial rocks for the chronological reconstruction of various geological stages. Modern dating methods mean this is now very precise.

Colluvium: relatively fine deposits at the bottom of a slope, made from elements stripped from the slope and having undergone small-scale transport by geomorphological processes (runoff, gravity, etc.).

Deflation: erosion by the wind carrying away the finest particles of sediment unprotected, by vegetation, as in a desert setting.

Fluvial competence: the capacity of a river in terms of its ability to transport sediment: torrential waters could transport large elements, such as pebbles, in suspension, while calm waters will only carry the finer portion of clay in suspension.

Geomorphology: the study of landforms and the physico-chemical processes that shape them.

Glacis: gently sloped surfaces on which sheet runoff occurs, eroding areas near the landforms and accumulating colluvium in the nearest part of the watercourse. *Glacis* can develop through destruction of other, older formations.

Granulometry: study of the size of the particles making up sediment (clay, silt, sand, gravel, pebbles), which permits its characterisation and the study of how the sediment was deposited.

'Heinrich': Heinrich-type events are short-lived climatic episodes associated with the calving of a large number of icebergs in the north Atlantic (first observed by H. Heinrich in the 1980s). These correspond to phenomena probably affecting the entire hemisphere and therefore must have repercussions at lower latitudes in some form or other.

Isotopic stages: paleoclimatic episodes defined by the isotopic ratios of oxygen ($^{18}O/^{16}O$) in cores of marine sediment or ice caps.

Laterite (ferruginous crust): in equatorial and tropical soils of a warm and humid climate (at least a part of the year, during the rainy season), pedological processes can cause an accumulation of iron (in the enriched 'B' or 'illuvial' horizon) which can, if the process is prolonged and intense, give rise to a real ferruginous indurate (or 'laterite') level which will look like a 'crust' if there is erosion.

Leaching: pedologic term indicating vertical movement of smaller particles (especially clay) from higher to lower levels as a result of rains infiltrating the soil.

Micromorphology: laboratory analysis (using a microscope) of thin sections of soil and/or sediments, allowing their history to be precisely reconstructed.

OSL: optically stimulated luminescence; a method of radiometric dating of sediments which can determine the time of deposit, and therefore the age of a formation. This method is very often used for the Pleistocene (see Wright, this volume, pp. 237-239).

Pedology: scientific study of soils, their structures, their evolution, and their history.

Phytoliths: microscopic pieces of silica that develop in certain cells in various types of plants. By their nature, phytoliths last for very long periods after the death and decomposition of the plant; the discovery of phytoliths allows the reconstruction, at least in part, of the vegetation cover, and thus, indirectly, of the climate.

Pisolite: ferruginous concretion (measuring millimetres or centimetres) in iron-rich soils in the tropics (see 'laterite crust').

Stratigraphy: study of the deposition, distribution, and deformation of sedimentary rocks in the earth's crust.

Substratum: bedrock (here referring to the substratum below the Quaternary sediments that may contain archaeological records).

Terrace (alluvial or fluvial): nearly horizontal sloping surface associated with sedimentary deposits by a watercourse. A terrace *stricto sensu* corresponds with the level of alluvium accumulation (floodplain); this becomes stepped when the watercourse erodes the deposit that it has previously deposited. This causes a 'terrace edge', which refers to the tiers.

HUMAN REMAINS

Isabelle Crevecœur[1]

The study of human remains found in an archaeological context makes no sense unless the field phase was completed under the best conditions for recording and sampling (see Ribot, this volume, pp.134-137). In this sense, it seems necessary that a physical anthropologist be present during the excavation phase, and for any interaction in the context of funerary deposits. Many synthetic works deal with recording and various analyses of human remains after the field phase (for example, Buikstra & Uberlaker 1994; Dutour *et al.* 2005; Jurmain *et al.* 2013). If these are indispensible to the proper analysis of data, the work of the physical anthropologist should nevertheless not be limited to an application of methodological recipes. Knowledge of human anatomy, of its variability, its evolutionary and adaptive mechanisms, as well as a comprehension of taphonomic processes, are all essential when choosing methods and interpreting biological data. We present here an overview of the analyses most commonly performed (1) directly on bone and teeth, (2) on their organic (collagen) and mineral (hydroxylapatite) components, and (3) using multidimensional imagery, in order to understand burial practices, biological identity, and the lifestyles of individuals and populations.

I. OSTEOLOGICAL AND DENTAL ANALYSES

A. MNI (minimum number of individuals)

Estimating the minimum number of individuals at a site, or within a structure, is the first stage in osteological analysis. Taphonomic and/or anthropological phenomena can be at the origin of anatomical under-representation that implies an under-estimation of the numbers. Counting each bone provides an initial estimate of the number of individuals present; this will serve as a basis when considering the integrity of the deposit. Calculation of the MNI is based on the frequency of the most common type of bone. In the case of paired bones,[2] the side found most often will be counted.

This MNI of frequency can then be refined through associations and exclusions. Through the association of paired bones belonging to the same individual, it is possible to exclude the left-side or right-side elements whose pairs can't be found. Exclusion by age at death also allows the addition to the MNI of those individuals who are not present in the category of retained bones, but are represented elsewhere.

B. Age at death and sexual diagnosis

Many methods exist in anthropology for estimating the age at death and determining sex (cf. Bruzek *et al.* 2005; White & Folkens 2005). We present here only those that are most reliable and take into account biological variability.

1. Estimation of the age at death

Techniques are based mostly on dental maturation or bone growth processes for immature individuals. The aging processes used to estimate age at death of adults are less reliable.

a) Immature individuals

Determining the age at death from dental maturation has the double advantage of being based on the human remains that are often best preserved – the teeth – and of being a more reliable indicator than bone maturation. The method by Moorrees *et al.* (1963a; 1963b) is the most common. It gives the standard deviation for estimates, which means the results are 95% reliable.

Estimating age at death based on bone maturation (*i.e.* the degree of epiphyseal fusion and diaphyseal length) is less precise, because growth is closely linked to environmental and nutritional conditions, as well as to population factors. There are several standards (including Buikstra & Uberlaker 1994), but they should be used carefully.

b) Adults

Estimating the age at death of adults (≥ 30 years; *i.e.* after the age of skeletal maturity) is a major obstacle in anthropology, given the intra- and inter-populational variability of senescence of the human skeleton. Areas of late ossification (*i.e.* after adolescence and dental maturity) in the pubic symphysis and the clavicle allow us to identify adults who died prematurely (that is to say, between ages 20 and 30). After the age of 30, estimates of the age at death are based on observation of morphological changes to the pubic symphysis or the sacroiliac surface. The

1 CNRS, UMR 5199 PACEA - A3P, University of Bordeaux, France.

2 Pairs: bones are described as paired if two versions (left and right) exist in the body.

Schmitt method (2005) is interesting because it takes into account European intra- and inter-populational variability. The scoring method uses four characters to calculate the probability that the individual belonged to a greater or narrower time period. This method favours reliability over accuracy.

2. Determining sex

The hipbone is the most important when determining sex, as in women its morphology is determined, whatever the population of origin, by the dual constraints of locomotion and parturition (Bruzek *et al.* 2005). Reliability decreases when we look at bones whose sexual dimorphism is linked to format and not function. In addition, there is no method for estimating the sex of children, as the sexual dimorphism of the pelvis appears only during puberty.

The sex of adults whose pelvis has been preserved can be determined based on its morphology or dimensions. The visual method developed by Bruzek (2002) is based on observation of morphological characteristics with 95% accuracy. The probabilistic sex diagnosis method uses a large body of data and is accurate to more than 97% (Murail *et al.* 2005).

C. Health status

By identifying and studying diseases affecting the bones, joints, and teeth, as well as traumas, it is possible to discuss the living conditions and the health status of populations or exhumed fossils.

Joint diseases such as arthritis and enthesitic changes[3] have multifactorial origins (genetic, biological, environmental, or behavioural).

Nevertheless, a study of the frequency, intensity, and localisation (for example, specific to an anatomic region, or to one side) can highlight important behavioural differences between individuals of the same group associated with a certain type of activity, such as archery (Thomas 2014). Given their interaction with the environment, teeth are an excellent indicator of an individual or population's health and diet. Dental disease can have a variety of origins: infection, degeneration, development, or genetics. The type and degree of development of a periodontal disease, an abscess, cavities, tartar, or hypoplasia, must be estimated according to established standards, which can be found in the specialist literature (see Hillson 2008).

3 Entheses: places where tendons, ligaments, and muscular fascia meet the bone.

D. Biometrics

The acquisition of metrics on cranial and infra-cranial bones allow characterisation of intra- and inter-populational variability. Two references are currently used: Martin (Braüer 1988) and Howells (1973). The latter has even published a free online database with the measurements of more than 2,000 skulls and fossils from all over the world (Howells 1996). The size of infra-cranial bones can be used to estimate the height and weight of individuals using current standards.

E. Non-metric anatomical variations

Non-metric anatomical variations (or discrete characteristics) are numerous minor non-pathological phenotypic variations of the bones or teeth. They are observed on the cranial bone (*e.g.*, extra sutural ossicles) and infra-cranial (*e.g.*, olecranon perforation) and the teeth (*e.g.*, the number of cuspids) (Berry & Berry 1967; Finnegan 1978; Turner *et al.* 1991). To the extent these characteristics are transmitted in part by genetics, they are an asset when researching familial groupings or phylogenetic links between populations. The exact determinism for the great majority of these characteristics is unknown, however. They are not all hereditary and factors linked to lifestyle can be responsible for their transmission.

II. BIOCHEMICAL ANALYSES

Bone, enamel, and dentin all possess an organic compound (collagen) and a mineral (hydroxylapatite) which vary depending on type, with enamel being the most mineral. A study of stable isotopes and the trace elements contained in these components allows dating, but can also reconstruct the lifestyles of individuals and their environment (Katzenberg 2008). Recent technological developments for extracting and sequencing ancient DNA offer new perspectives for understanding phylogenetic inter- and intra-populational relationships.

A. Direct dating

1. Organic compounds

Collagen extracted from bones or dentin are an excellent material for carbon 14 dating using accelerator mass spectrometry (for the dating method, see de Maret, this volume, pp.232-235).

2. Inorganic compounds

Radiocarbon dating using the contents of enamel and the mineral parts of the bone or dentin is an alternative to using carbon from collagen when the latter has been prematurely destroyed, as is often the case in arid environments.

The electron spin resonance (ESR) technique can also be used with enamel (Grün 1989). During diagenesis, electrons are trapped in the crystalline defects of the apatite. These electrons come from radioactive materials in the deposit or from bone and dental tissues. The intensity of the ESR signal depends on the number of trapped electrons, that is to say the irradiation dose and intensity. These two parameters must be identified to achieve ESR dating.

B. Diet, paleoclimate, and mobility

Diet is reconstructed based on the ratio of stable carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) isotopes present in the collagen. These ratios are associated with those recording the protein fraction of ingested food and distinguish sources of dietary protein (plant and animal). The $\delta^{13}C$ of hydroxylapatite carbonate represents carbon from throughout the diet.

It is also possible to study stable oxygen isotopes ($\delta^{18}O$) to reconstruct paleotemperatures, and therefore paleoclimates.

Lastly, several trace elements become attached to bones and teeth throughout the life of the individual. Among these, strontium (Sr) has the advantage of demonstrating an individual's mobility.

C. Ancient DNA

Thanks to recent developments in molecular genetics, it is now possible to analyse DNA from fossilised bone and teeth. The preservation of DNA depends to a great extent on the environment in which fossilisation takes place. Unfortunately, the fossil data are nearly non-existent for Africa (Campana *et al.* 2013).

Studies of ancient DNA focus on mitochondrial DNA (mtDNA), the Y chromosome, and nuclear DNA (locus, or complete genome). Analyses of polymorphisms of mtDNA and the Y chromosome are used to determine phylogenetic and phylogeographic links in the maternal or paternal lines of human populations. When nuclear DNA is well preserved, the analysis of short tandem repeats (STRs) can test the parental relations of an individual. Samples for DNA testing must be taken following very strict rules, starting in the field phase, to limit contamination of human remains by exogenous recent DNA.

III. ANALYSYS USING MULTIDIMENSIONAL IMAGING

Imaging methods using X-ray tomography (CT scan, microtomography (μ-CT), synchrotron) are a considerable contribution to the study of internal anatomical structures of human bone and dental remains, as well as to their preservation. In addition to accessing and visualising internal structures, these methods permit reliable measurements thanks to imaging software, reconstruction of missing sections, correction of deformations, and the virtual cleaning of remains found in a sedimentary matrix.

REFERENCES

Berry, A.C. & Berry, R.J. 1967. 'Epigenetic variation in the human cranium'. *Journal of Anatomy* 101: 361-379.

Braüer, G. 1988. 'Osteometrie'. In R. Knussman (ed.), *Anthropologie. Handbuch der vergleichenden Biologie des Menschen, 4. Auflage des Lehrbuchs des Anthropologie begründet von R. Martin. Band I. Wesen und Methoden der Anthropologie*, Stuttgart: Gustav Fisher Verlag, pp. 160-232.

Bruzek, J. 2002. 'A method for visual determination of sex, using the human hip bone'. *American Journal of Physical Anthropology* 117: 157-168.

Bruzek, J., Schmitt, A. & Murail, P. 2005. 'Identification biologique individuelle en paléoanthropologie: détermination du sexe et estimation de l'âge au décès à partir du squelette'. In O. Dutour, J.-J. Hublin & B. Vandermeersch (eds), *Objets et méthodes en paléoanthropologie.* Paris: CTHS, pp. 217-246.

Buikstra, J.E. & Uberlaker, D.H. 1994. *Standards for Data Collection from Human Skeletal Remains*. Arkansas: Arkansas Archaeological Survey Report Number 44.

Campana, M.G., Bower, M.A. & Crabtree, P.J. 2013. 'Ancient DNA for the Archaeologist: the Future of African Research', *African Archaeological Review* 30: 21-37.

Dutour, O., Hublin, J.-J. & Vandermeersch, B. 2005. *Objets et méthodes en paléoanthropologie*. Paris: CTHS.

Finnegan, M. 1978. 'Non-metric variation of the infracranial skeleton'. *Journal of Anatomy* 125: 23-37.

Grün, R. 1989. 'Electron Spin Resonance (ESR) dating', *Quaternary International* 1: 65-109.

Hillson, S. 2008. 'Dental Pathology'. In M A. Katzenberg & S.R. Saunders (eds), *Biological Anthropology of the Human Skeleton*. New Jersey: John Wiley & Sons, pp. 301-340.

Howells, W.W. 1973. *Cranial Variation in Man:a Study by Multivariate Analysis of Patterns of Difference among Recent Humans Populations*. Cambridge: Harvard University Press, 259 p.

Howells, W.W. 1996. 'Howell's craniometric data on the internet', *American Journal of Physical Anthropology* 101: 393-410.

Jurmain, R., Kilgore, L., Trevathan, W. & Ciochon, R.L. 2013. *Introduction to Physical Anthropology*, 2013-2014 edition. Stamford: Cengage Learning; 14th edition, 576 p.

Katzenberg, M.A. 2008. 'Stable Isotope Analysis: a Tool for Studying Past Diet, Demography, and Life History'. In M.A. Katzenberg & S.R. Saunders (eds), *Biological Anthropology of the Human Skeleton*. New Jersey: John Wiley & Sons, pp. 413-442.

Moorrees, C.F.A., Fanning, E.A. & Hunt, E.E. Jr. 1963a. 'Formation and Resorption of three Deciduous Teeth in Children', *American Journal of Physical Anthropology* 21: 205-213.

Moorrees, C.F.A., Fanning, E.A. & Hunt, E.E. Jr. 1963b. 'Age Variation of Formation Stages for ten Permanent Teeth', *Journal of Dental Research* 42: 1490-1502.

Murail, P. 2005. 'DSP: a tool for probabilistic sex diagnosis using worldwide variability in hip-bone measurements'. *Bulletins et Mémoires de la Société d'Anthropologie de Paris*, 17 (3-4): 167-176.

Schmitt, A. 2005. 'Une nouvelle méthode pour estimer l'âge au décès des adultes à partir de la surface sacro-pelvienne iliaque'. *Bulletins et Mémoires de la Société d'Anthropologie de Paris* 17: 89-101.

Stone, A.C. 2008. 'DNA Analysis of Archaeological Remains'. In M.A. Katzenberg, S.R. Saunders (eds), *Biological Anthropology of the Human Skeleton.* New Jersey: John Wiley & Sons, pp. 461-484.

Thomas, A. 2014. 'Bioarchaeology of the Middle Neolithic: Evidence for Archery Among Early European Farmers'. *American Journal of Physical Anthropology* 154: 279-290.

Turner II, C.G., Nichol, C.R. & Scott, G.R. 1991. 'Scoring Procedures for Key Morphological Traits of Permanent Dentition: the Arizona State University Dental Anthropology System'. In M.A. Kelley & C.S. Larsen (eds), *Advances in Dental Anthropology*. New York: Wiley-Liss, pp. 13-31.

White, T.D. & Folkens, P.A. 2005. *The Human Bone Manual*. New York: Elsevier Academic Press.

RADIOCARBON DATING

Pierre de Maret [1]

Dating a specific event or phase or establishing a sequence is still of particular importance in Africa, as the chronology of many regions is far from established.
Close reading, detailed analysis, and extensive study of the stratigraphy, as well as the identification of sealed archaeological contexts such as graves or refuse pits, remain the basis for all reasoning on dating, whether relative or absolute.

I. ABSOLUTE DATING

Choosing from among the ever-expanding range of absolute dating methods requires taking into account the time range under consideration, the feasibility of this kind of analyses, and of course the cost.

In practice, for research that concerns the last 50,000 years, radiocarbon (carbon 14) dating is most often used. As we know, this measures the amount of radioactive carbon 14 remaining in organic matter, from which the time since death is estimated. To ascertain the amount of residual ^{14}C, the radioactivity of a specific quantity of the sample is measured for a specific period. This is the most commonly used and cheapest method.

But to analyse very small or very old samples, a much finer method was developed: accelerator mass spectrometry (AMS). This technique directly counts the amount of ^{14}C atoms present in the sample (and not only those that degrade during the counting).

The AMS technique allows researchers to:

- date samples of only 1 mg of carbon (a small piece of charcoal measuring only a few millimetres, a bone fragment only a few centimetres long, a seed, a nut fragment),
- be more selective when choosing which samples to date and therefore, ideally, date the object itself (pottery, slag, skeleton) without damaging it, rather than associated charcoal or nuts,
- date samples faster (less than 24 hours of counting time),
- push the limits of the method beyond 50,000 years,
- reduce statistical error through greater precision (particularly interesting in the case of small and/or very ancient specimens).

But this is costly. AMS should therefore be used sparingly.

Generally, we must develop a dating strategy depending on the specific problem, available resources, and the quantity and quality of available samples (size, risk of contamination, uncertainty about the context, etc.).

II. ERRORS, UNCERTAINTIES, CONTAMINATION, AND OTHER PROBLEMS

A. Statistical uncertainty

As the measurement of the specific radioactivity of a given sample is not an absolute measurement but a statistical measure (since the amount of disintegration varies over time), the result always reflects this statistical imprecision. This expresses the probability in % that the result falls between two time limits on either side of the average. This is equally true of AMS dating. Conventionally, a date is expressed with +/- 1 σ imprecision (its standard deviation), which is to say that there is a 68% chance that the date is within the ‘confidence interval’ thus defined.

As this is not accurate enough – at 68%, there is just under a one-in-three chance that the date is not within the range of +/- 1σ – we need to work with 2 σ. By doubling the interval, there is a 95% chance that the date is within the range.

By convention, laboratory results are given in years BP (before present [1950]), with an error of 1 σ. The smaller the error, the smaller the σ value, the smaller the time interval will be and therefore the more accurate the estimated date will be. Some laboratories can obtain high-precision dates (by counting longer, or reducing as much as possible the background noise by also measuring the radioactivity of carbon 13, etc.).

B. Need for calibration

We also know that, contrary to what was initially assumed by the inventor of the radiocarbon method, the proportion of ^{14}C in the atmosphere has not remained constant. Laboratories today therefore usually provide a corrected result that takes into account these changes and the requirement for an interval of 2 σ.

Generally – although not always – non-calibrated dates are given in lower case (bp, bc, ad), whereas calibrated dates are capitalised (BP, BC, AD). In order to avoid con-

1 Université libre de Bruxelles. Belgium.

fusion, it is preferable to add 'Cal' to calibrated dates. Calendar dates are therefore in bc and ad if they are not calibrated, and BC, Cal BC, AD, or Cal AD if they are. For distant prehistoric dates, it makes little sense to use calendar dates, so we mostly use BP or cal BP because the result always needs to be calibrated.

When comparing dates obtained more than ten years ago with results measured more recently, it is appropriate to calibrate the earlier dates using programs available on the web (www.radiocarbon.org; http://www.calpal-online.de/; https://c14.arch.ox.ac.uk/). The program and version used should be specified upon publication. In the southern hemisphere, dates should be a little aged, generally 30 to 50 years. Specific calibration curves are available.

These programs produce 'cloud diagrams' which demonstrate visually the interval corresponding to the date and probability variations within this range. The two horizontal lines that appear under the cloud diagram correspond to the confidence intervals 1 σ and 2 σ.

C. Consequences of calibration

As the calibration curve has significant oscillations (wiggle) during certain periods, calibration can have very different results. In some cases, the calibration will reduce the time range, and in others – where there are oscillations – it can extend the range of calendar dates. Sometimes, the probability distribution curve becomes so irregular that it cannot be expressed as an average with its confidence interval.

This is why dates between 2500 BP and 1900 BP, a crucial period for the start of metallurgy, cannot be separated, and are found in a range that goes from 800 cal BC to cal AD 100. Similarly, it is almost impossible to separate samples chronologically in the range of from about cal AD 1650 to cal AD 1950, which makes, for example, correlations between archaeological data and recent historical sources very risky. On the other hand, after 1950, 'thanks' to the atomic bomb tests, dating is easy, often to within a decade.

While these inaccuracies are inherent in the radiocarbon method, it has nevertheless steadily improved since its discovery over 60 years ago. Many problems and errors encountered result mainly from the choice of samples and the interpretation of the results by the archaeologist.

III. SELECTION OF SAMPLES TO DATE USING CARBON 14

Choosing among available samples depends on the size of the sample, the type of material, the risk of contamination, and its context.

A. Amount needed for a sample

This concerns the material used most frequently.

Usual method		AMS dating
- wood charcoal (preferably of large calibre)	10 g	1 mg to 20 mg is enough!
- carbonised bone	50 g	
- unburnt bone	300 g	
- seed	10 g	
- wood	20 g	
- shell	50 g	

Peat, soil loaded with organic matter, teeth, calcium concretions, pottery, slag, mortar, etc., can also be dated.

Larger specimens are always preferable.

B. Sample material

Any sample of organic material submitted for dating has always stopped living before being buried and becoming associated with other objects. The date obtained will precede the date of deposit. To keep the age difference as low as possible, the preference is therefore for sample materials with short lifespans. Seeds, nuts, grass, and bone are better than charcoal. For the latter, short-lived species (less than 100 years) are preferable to long-lived species (over 100 years), but for that, one must be able to determine the species of wood, and therefore have a fragment large enough that one part can be used for anthracological analysis while another is dated. In desert conditions, dead wood can survive for a long time and be used as fuel centuries later. Similarly, a beam from an older building can be re-used.

We must also remember that wood grows on the outside, and so the oldest parts are at the centre. The opposite is true of ivory.

C. Risks of contamination

Before taking samples	While taking samples	After taking samples
Ground water can either dissolve organic materials, or otherwise add more recent carbon. Bioturbations (termites, ants, burrowing animals) and soil movement – especially in sand – can mix charcoals of different ages.	Avoid ash (cigarettes, fires, especially late in the dry season at the time of controlled bush fires). Use a clean trowel, knife, pliers, and put in a pre-marked plastic bag. Avoid taking samples where various stratigraphic units meet if there is a risk of mixing samples of different ages.	Dry away from the sun (condensation) and avoid ashes or dust. Remove soil, roots and rootlets. Pack large samples in aluminium foil, then in a clearly labelled plastic bag. Keep a separate register of samples that can be used for dating with a system of labels, different if possible. Store in a dark and, if possible, cool place, to prevent the formation of condensation or green mould.

D. Sample context

When selecting samples to date, great attention should be paid to an understanding of the stratigraphic context (see also this volume Schwartz pp. 218-222 and Rasse pp.223-227).

A sample from a secured context (pit, tomb, under a rock slab, in baked clay) is always preferred to one from a simple combustion structure. Small fragments of charcoal scattered in a layer within an artificial stratigraphic level are the most likely to be problematic. Unfortunately, we often have no other choice!

The relationship between what is being dated (charcoal, seeds, bones, etc.) and the remains of human activity is rarely clear, since there is a degree of uncertainty in the association (Waterbolk 1971, p. 16, groups A-D; 1983). The ideal is when the archaeological relic itself provides the sample (bones from a skeleton in a grave, the wooden beam of a house, a wooden sculpture, charcoal from slag, etc.). In this case there is *full certainty* of association (A).

There is *high probability* (B) of association when there is a direct and functional relationship between the sample and the archaeological remains (e.g., seeds in a pot, coffin in a tomb). *Probability* of association (C) is when there is no demonstrable functional relationship but the quantity, concentration, and size of the fragments of organic matter are thought to indicate a relationship (e.g., area of combustion, concentration of bones). The degree of association is a *reasonable possibility* (D) with small fragments scattered at the level of occupancy or of a grave. On the other hand, if the fragments are small and scattered and do not come from a detectable archaeological structure, but are simply dispersed in an archaeological layer, the association between sample and dated archaeological material present in this level is likely, but the degree of certainty of association is the lowest.

Sometimes charcoal from an older archaeological level is mixed with clay later used for building, and thus finds itself embedded in the walls of a much more recent construction.

IV. INTERPRETING RESULTS

A. Basic principle:

An isolated date has no significance. At least three convergent dates are needed to date an archaeological phenomenon with any certainty.

Checking the consistency of the results

The best form of verification is a series of dates the order of which corresponds to the sequence of stratigraphic levels, the deepest unit being the oldest. Slight discrepancies, with age inversions, are negligible so long as the confidence intervals of 2 σ for the dates concerned overlap. If this is not the case, more explanation will be required: contamination, "old" sample at the time of abandonment, laboratory error, stratigraphic inversion, error in reading the stratigraphy?

Comparisons with dates obtained by other methods (TL, OSL, etc.) are also always useful.

B. Processing a significant number of dates

A range of dates calibrated to the same phase, period, culture, or tradition can be grouped into a table using a time scale as ordinate with proportional vertical lines to the margin of error.

A range of dates can also be grouped into a single cloud chart for easy visualisation of the probable temporal boundaries of an occupation or culture.

Finally, the shape of the probability curves obtained by adding the probability curves of a large number of calibrated dates should be interpreted with caution. The shape of curves resulting from this kind of calculation may indicate changes in human activities over time, e.g., population growth, but their form is also partly a reflection of the calibration curve itself.

REFERENCES

Waterbolk, H.T. 1971. 'Working with Radiocarbon Dates.' *Proceedings of the Prehistoric Society* XXXVII: 15-33.

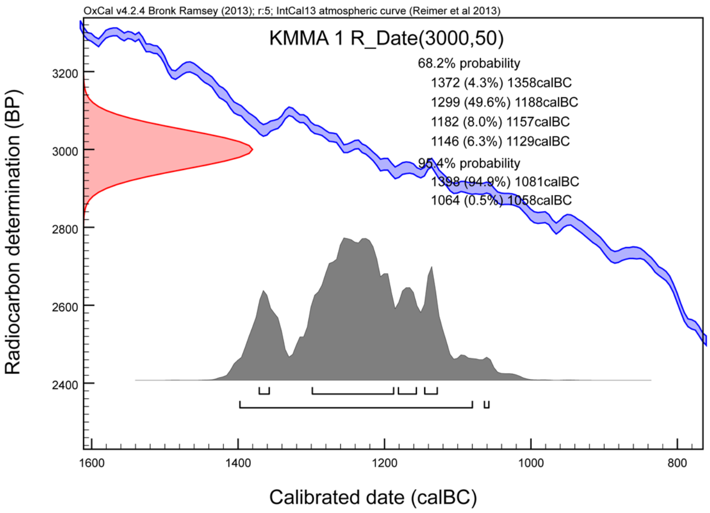
Waterbolk, H.T. 1983. 'Thirty years of radiocarbon dating: the retrospective view of a Groningen archaeologist.' *Pact 8* (*14C and archaeology: symposium held at Groningen, August 1981*): 17-27.

BY MEANS OF EXAMPLE: INTERPRETING C14 DATES

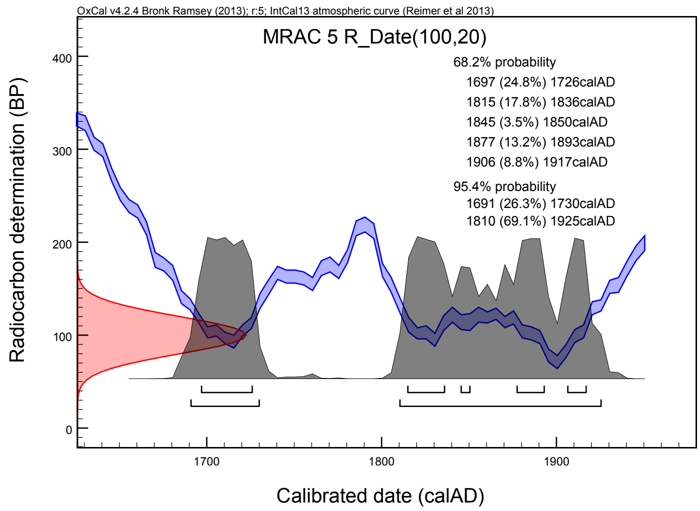
E. Cornelissen[1], P. de Maret[2] & D. Wright[3]

The calibration curve used here is available for free at https://c14.arch.ox.ac.uk/oxcal/OxCal.html. Registration for a username and password is required prior to using the service. Fill in the name, date and 1-σ interval of statistical uncertainty based on the results obtained from the laboratory where your sample was analysed. The view chosen below is the ‘single plot’. The examples provided here are fictitious.

- At the 68.2% probability level there is almost 50% chance that the event dates from the 13th century to early 12th century BC. There is a very small chance (4.3%) that it is older and dates from the 14th century or that it dates to the 12th century (14.3%).[t]



- At the 95.4% probability level the date may fall anywhere between the beginning of the 14th and beginning of the 11th century BC, and 0.5% probability that the date is in the middle of the 11th century BC.
- Of course, there is a 4.6% chance (statistically) that the age falls outside the range of these dates.
- Under no circumstance can the result be taken to conclude that the event took place *from* the beginning of the 14th *until* the beginning of the 11th century BC or that the feature/artefact was used throughout the entirety of this timespan.



- At the 68.2% probability level there is an approximate 25% statistical probability that the item or event dates between 1696 and 1726 AD, or at the turn of the 17th-18th century. Similarly, there is a 43.4% probability that the event may date to much later periods in the 19th century and early 20th century.
- Increasing the probability level to 95.4% shows that there is a 26.3% probability that the date of the death of the organism associated with the sample occurred between 1690 and 1730 AD, but there is a concomitant higher probability of 69.1% that the date is situated anywhere between the early 19th century and the first quarter of the 20th century.
- Conclusive evidence may come from other sources of dating such as a coin or an item of which the production is clearly set at a given time.
- Under no circumstance can the result be taken to conclude that the event took place *from* the end of the 17th *until* the beginning of the 20th century AD or that the feature/artefact was used throughout the entirety of this timespan.
- In fact, this hypothetical date illustrates the major weakness of C14 dating whereby items cannot be dated after the advent of the Industrial Revolution when annual emissions of tonnes of carbon into the atmosphere began and before the event of exploding nuclear weapons (1944 AD). Therefore, the organism died sometime between 1700 AD and 1950 AD. There is now a post-bomb calibration curve established for more recent artefacts based on the implementation of the nuclear test ban treaty in 1963 and progressive decline of atmospheric concentrations of C14 to the present day 1950 AD calibration curve established for more recent artefacts, that allows stating that the organism did not die prior to 1950 AD (Hua and Barbetti 2004, Review of tropospheric bomb (super 14) C data for carbon cycle modelling and age calibration purposes, *Radiocarbon*, vol. 46, Nr. 3, 2004, pp. 1273-1298 also available at https://journals.uair.arizona.edu/index.php/radiocarbon/article/view/4182.)

1 Heritage Studies, Royal Museum for Central Africa, Belgium.

2 Université Libre de Bruxelles, Belgium.

3 Department of Archaeology and Art History, Seoul National University, South Korea

OTHER RADIOMETRIC METHODS OF DATING

David K. Wright[1]

INTRODUCTION

While radiocarbon dating justifiably remains the most common way to date archaeological sites in Africa, other methods have gained acceptance as providing accurate means of estimating the timing of past site occupations. Optically Stimulated Luminescence (OSL), in particular, has become a standard bearer for dating archaeological sites in a wide variety of depositional settings. However, like radiocarbon dating, these methods will not provide site chronologies without a certain amount of critical application. Archaeologists must approach site chronology carefully, and the following chapter provides a review of the possibilities and limits of other dating methods besides radiocarbon.

I. OPTICALLY STIMULATED LUMINESCENCE

Whereas radiocarbon dating is applied directly to carbon-bearing artifacts, OSL is normally performed on sediments that bury archaeological sites. Sedimentary minerals (normally, quartz and feldspars) possess trace amounts of radioactive elements such as uranium (U), thorium (Th) and potassium (^{40}K), which are constantly shedding electrons to achieve a stable (non-radioactive) state. In the absence of light, the electrons fill defects in the crystal lattice* of the minerals known as 'traps'. Once the mineral is exposed to sunlight, most of the electrons stored in the traps normally vacates within 10 seconds, leaving the mineral devoid of stored energy. Once the sediment is removed from light, the process resumes and traps begin to fill again (fig. 1). Additional sources of radiation accumulating in the minerals come from cosmic rays ('muon*s'), which constantly bombard the surface of the earth and from beta radiation* emitted from the surrounding sediments. Thus, OSL measures the last time sediments were exposed to sunlight by measuring the equivalent dose (D_e) of radiation present in a sample and dividing that by the reconstructed rate of radioactive dosing the sample was subjected to during burial (D_r).

The primary advantages of using luminescence dating over radiocarbon are that one does not need to have carbon to obtain an age estimate and the range of age estimation begins from <10 years from the collection date to >100,000 years, in many cases. In the African context, this extends far back into the Middle Stone Age in which there are many significant archaeological sites outside of volcanic areas that have almost no other means of obtaining a reliable estimation site age. Experimental research using potassium feldspars suggests that age estimates as far back as 1,000,000 years may be possible using OSL, but it will be some time before routine age estimations at this time scale are made.

The primary considerations for using OSL dating are as follows:

(1) It is absolutely critical to know whether the sediments being dated were fully solar reset prior to burial. Geomorphic conditions that are normally safe to assume this process has occurred include eolian (wind blown) environments and alluvial river terraces comprised primarily of fine sands. Less safe are alluvial fan environments and bedload* sediments from river terraces. Generally unacceptable depositional environments are colluvial or a mass wasting* hillslope process. If archaeological remains are somehow being dated from sediments that were not solar reset, the result will be a significant over-estimation of site age.

(2) Sites with exceptional bioturbation from roots or animals are poor candidates for OSL dating. OSL works on the theory that once a sediment is buried, it has more or less remained in its same position throughout the time it has been buried. If a termite carries a grain of sand from deeper in the profile up into an overlying stratum, then a grain that was solar reset further back in time has now entered the sample environment. Or, if a root pushes a sand grain from the top of a profile into the lower portion of the profile, younger contaminants can provide under-estimates of site age. Additionally, the 'dosing environment*' of a sample includes radiation contributions from other minerals emitting radiation in beta decay*, so as plants or animals bring new minerals into this ecosystem, the potential for errors increases.

(3) Related to the above point, it can be difficult to obtain a reliable age estimate for heavily weathered soils. Soil-bearing horizons occur when landform stabilization has resulted in the translocation of minerals from the upper portion of the solum* into the lower portion. As this weathering process occurs, the dos-

1 Department of Archaeology and Art History, Seoul National University, South Korea

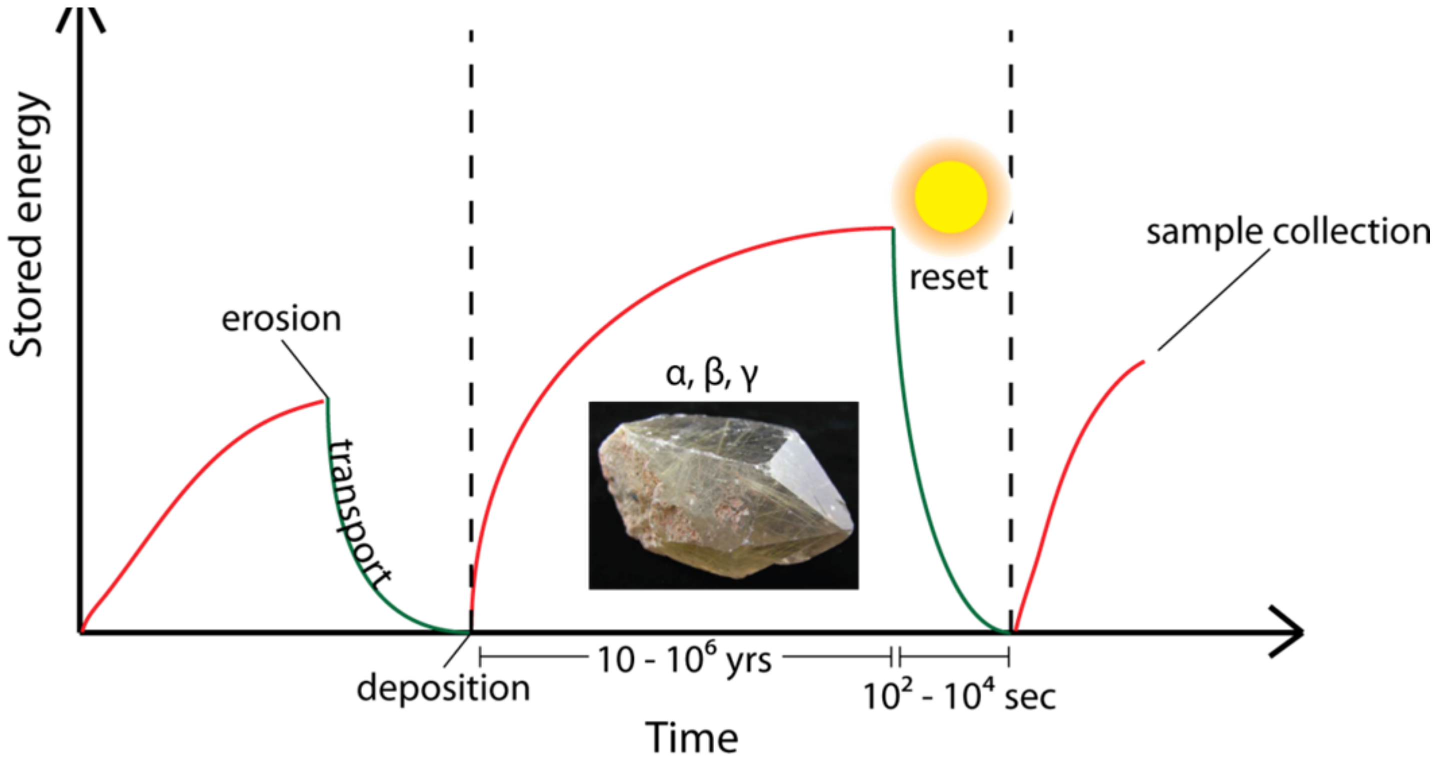


Fig. 1. Schematic view of the process of luminescence accumulation within sedimentary minerals.

ing environment is altered, particularly in well-developed soils. Authigenic* mineral formation occurs when groundwater percolates upwards and these minerals also alter the dosing environment. In saprolitic* environments where bedrock is breaking down from water perching, one needs to be particularly cautious whether an OSL sample is to be collected.

(4) Geochemistry of the sample environment is another factor that is important to consider, although often this knowledge does not come until long after the fieldwork has concluded. The minimum amount of quartz needed to obtain a reliable OSL age from a landform is about 10%. In volcanic ash environments, especially in the Rift Valley of Africa and environs, there are many areas where obtaining a sample is completely untenable. It is also well known amongst OSL analysts that many of the quartz-bearing minerals from the Rift Valley have a significant 'medium component' in which the electron traps are difficult to vacate in a laboratory setting. Archaeologists working in or near the Rift Valley need to plan on using at least one other method of dating a site besides OSL in order to make sure that accurate ages are obtained.

(5) Another major source of error introduced into OSL dating comes during the collection process. When samples are collected, they must not be exposed to light in any form. Samples collected in lateritic tropical soils, which are common in Africa, are troublesome because they are so cemented and tend to be difficult to pound a sediment collection tube into cleanly. If it is suspected that a sample has been exposed to sunlight while pounding the tube into the profile wall, it is far better to discard the sample and start over than spend US$1,000 on a sample that will give an erroneous result.

The five points provided above should serve as cautionary notes for archaeologists thinking about using OSL. In that regard, it is critical that personnel experienced in OSL collection and/or analysis are involved before fieldwork commences. Many OSL labs will not accept samples from non-experienced personnel.

When having samples analyzed, there are two broad categories of analysis now being performed by laboratories. The first method analyzes multiple grains of sand glued onto up to 48 aluminum disks. In recent years, this method has assumed the name 'small aliquot*' (SA) because there are usually <100 grains of sand, each measuring between 100-250 μm in diameter on each disk. This method is losing popularity as the single-grain (SG) method of analyzing individual grains of sand, one-by-one, is seen as providing the most reliable estimates of burial time. This is because by analyzing the luminescence properties of individual grains, analysts can detect whether or not there is a high degree of bioturbation moving grains or pedogenic alteration affecting the radiation dose over time. Additionally, it is thought that the analysis of individual grains accommodates potential changes in the sensitivity of the minerals to absorb radiation induced by the instruments themselves.

The primary disadvantage of the SG method is that the analytical time is significantly higher than when using SA, thus it is more expensive and harder to get samples processed in a timely manner. There have also been reports of under-estimation of ages compared to radiocarbon chronologies when using the SG method. It is important to consider these factors when choosing an analytical method appropriate for dating an archaeological site. As a general rule, if OSL is the only method used to date a site, and it is not in an eolian or well-sorted fluvial setting, SG is the safest method to choose. On the other hand, comparing one or two SA samples to the results from another dating method could potentially improve the efficiency of analysis over the duration of a project.

II. THERMOLUMINESCENCE (TL)

The physics behind TL dating is identical to OSL except that the measurement is taking place from the resetting of electron traps during heating, rather than light stimulation.

Normally, thick pieces of pottery or bricks are the materials dated using TL, however, it is critical that environmental samples be collected from the adjacent 20 cm of sediment matrix in order to determine the natural dosing environment. These can be exposed to light and a 100 g from N, S, E, W and underneath a TL sample will suffice.

III. ELECTRON SPIN RESONANCE (ESR)

Similar to luminescence dating methods, ESR measures the presence of free electrons that have separated from their magnetic field and become trapped in tooth enamel, speleothems* or other soluble carbonates. The age of a sample is determined through changes in the paramagnetic* centers of ^{238}U, ^{232}Th and ^{40}K isotopes using microwave absorption spectroscopy*. The changes detected in the magnetic field from the original state are assumed to be a proxy for increasing amounts of time since ESR began. Light has no effect on ESR, but if teeth come into contact with carbonate-rich water common in cave environments, uranium is at risk of dissolving, which frees the trapped electrons and the resonance process is restarted.

ESR has been applied to dating fossil teeth from caves in southern Africa and is normally cross-checked using uranium-series dating methods. There is a limited direct application to archaeological deposits outside of caves, but ESR can be used to date the formation of corals or carbonates that may be associated with archaeological artifacts.

IV. COSMOGENIC RADIONUCLIDE DATING

Dating using cosmogenic nuclides* (normally ^{10}Be, ^{26}Al, ^{36}Cl, ^{21}Ne) is similar to OSL in that it measures the accumulation of charged particles within the crystal lattice* of minerals. As cosmic rays hit the earth, they can induce chemical reactions both in atomic-sized particles in the atmosphere and within the atoms of rocks and minerals. The collision of subatomic particles can form new isotopes through loss or addition of neutrons and electrons. Because they are ubiquitous atoms in rocks and minerals, the most common cosmogenic nuclides* measured are those formed from $^{16}O>^{10}Be$ and $^{28}Si>^{26}Al$ spallation* or muon* capture events.

The theory of dating these recombinations operates on three central premises:

(1) The minerals being dated have been present at or near to the surface throughout the entire period of interest for dating. Because sediments retard the attenuation of cosmic rays, the relative distance that the sample is from the surface through time is important for modeling the amount of cosmogenic nuclides* that have been produced. So-called 'inherited' components that are residual from previous depositional settings can be tricky to mathematically model.

(2) The rate of cosmic ray flux can be modeled through time and spallation/muon* capture events occur constantly relative to the rate of cosmic ray flux. Radiocarbon (^{14}C) is also a cosmogenic nuclide and must be calibrated using the same datasets.

(3) Spallation* and muon* capture occur within the confines of the mineral and are not released outside of the sample and the mineral has not absorbed more or less than it has shed through this process.

Unlike OSL, surface exposure dating is useful on colluvial landscapes or for measuring surface artifact scatters on fluvial terraces. However, the analytical time and cost is high and meeting the first condition above often discourages potential users from attempting the method. Samples must be collected in a depth column and exact geographic position and surrounding topography must be recorded if the samples are going to be analyzed properly.

V. URANIUM-BASED DATING

Uranium-based dating comes in various forms, but the general purpose is to measure the decay of unstable uranium (U) isotopes into stable lead (Pb) isotopes. The decay of radioactive isotopes in the uranium series ($^{238}U>^{206}Pb$, $^{235}U>^{207}Pb$ and $^{232}Th>^{208}Pb$) occurs in half-lives of 4.5, 0.7 and 14 billion years, respectively, and measuring this stage of this process in which a sample occurs is called U-series dating. Uranium-thorium dating relies on detecting a specific phase of the $^{238}U>^{206}Pb$ decay series in which the parent ^{234}U and daughter ^{230}Th are analyzed with respect to the emission of an alpha particle emitted from the nucleus of the atom. Radiocarbon dates between 10,000 and 50,000 years ago are now calibrated using U-series ages from corals due to the high accuracy and precision of the method.

For archaeologists, the practical knowledge needed is that materials such as bone, cave travertine, terrestrial and marine carbonates can be dated with high precision. However, the primary assumption in the method is that there has been no isotopic exchange of minerals with the environment. This is a difficult assumption to make since uranium is highly soluble in water and easily reprecipitates.

The value of the method comes from the deep time perspective possible and high precision when the circumstances are right. Cave sites are important repositories of human evolution across southern Africa, and the dark conditions and lack of volcanic deposits leaves few alternatives for dating the sites. U-based dating has been increasingly used to date soil carbonates (which are abundant in the dry regions of Africa) by laser ablation as a means of constraining deposition of sediments on archaeological sites. Dating teeth and bone is far more problematic due to the easy exchange of uranium between the environment and decaying organism.

VI. POTASSIUM-ARGON (K-AR) AND ARGON-ARGON (AR-AR) DATING

K-Ar dating measures the decay of radioactive ^{40}K into inert ^{40}Ar, but has all but been replaced by $^{40}Ar/^{39}Ar$ dating, due to the latter's improved accuracy. Samples are irradiated in a nuclear reactor and the short half-lives of ^{39}Ar are analyzed as a proxy for the potassium content upon formation of the mineral. As such, these dating techniques are useful only for measuring the formation of volcanic rocks.

In Koobi Fora, Olduvai Gorge and the Hadar Valley of Ethiopia, volcanic ashes are common and using K-Ar/Ar-Ar dating has proven critical for narrowing down the timeframe of early human evolution. Error ranges can be <1% even in young volcanic deposits, but chances to compare Ar-Ar ages directly to radiocarbon ages are exceedingly rare due to the different preservation environments. Half-lives of $^{40}K>^{40}Ar$ are 1.3 billion years, so the application of the method is suited throughout the duration of human history in Africa, which is, of course, where the human story begins.

REFERENCES

Aitken, M.J. 2014 Science-Based Dating in Archaeology. Routledge.

Bahain, J.J., Laurent, M., Falguères, C., Voinchet, P., Farkh, S., & Tissoux, H. 2002 'Datation par résonnance paramagnétique électronique (RPE) des formations fluviatiles pléistocènes et des gisements archéologiques ou paléontologiques associés'. *Quaternaire* 13(2): 91-103.

Carvajal, E., Montes, L., & Almanza, O.A. 2011 'Quaternary dating by electron spin resonance (ESR) applied to human tooth enamel'. *Earth Sciences Research Journal* 15(2): 115-120.

Darvill, C.M. 2013 'Cosmogenic nuclide analysis.' In *Geomorphological Techniques*, Ch. 4. British Society for Geomorphology.

Gebrekirstos, A., Bräuning, A., Sass-Klassen, U., & Mbow, C. 2014 'Opportunities and applications of dendrochronology in Africa'. *Current Opinion in Environmental Sustainability* 6: 48-53.

Ivy-Ochs, S. & Kober, F. 2008. 'Surface exposure dating with cosmogenic nuclides'. Quaternary Science Journal 57(1-2): 179-209.

Joannes-Boyau, R. 2014 'Electron Spin Resonance (ESR) Dating in Archaeology'. In C. Smith (ed.). *Encyclopedia of Global Archaeology*. Springer, pp. 2352-2358.

Jourdan, F., Mark, D. F. & Verati, C. (eds) 2014 'Advances in $^{40}Ar/^{39}Ar$ Dating: from Archaeology to Planetary Sciences'. *Geological Society Special Publications* 378, http://dx.doi.org/10.1144/SP378.24

Malainey, M. E. 2010 *A Consumer's Guide to Archaeological Science. Analytical Techniques*. Springer.

Morgan, L.E., Renne, P.R., Kieffer, G., Piperno, M., Gallotti, R. & Raynal, J.-P. 2012. 'A chronological framework for a long and persistent archaeological record: Melka Kunture, Ethiopia'. *Journal of Human Evolu-*

tion 62: 104-115.

Rhodes, E.J. 2011 'Optically stimulated luminescence dating of sediments over the past 200,000 years'. *Annual Review of Earth and Planetary Sciences* 39: 461-488.

Tribolo, C., Mercier, N., & Valladas, H. 2005 'Chronologie des technofaciès Howieson's Poort et Still Bay (Middle Stone Age, Afrique du Sud): bilan et nouvelles données de la luminescence'. *Bulletin de la Société préhistorique française* 102(4): 855-866.

Vogel, N., Nomade, S., Negash, A. & Renne, P.R. 2006 'Forensic $^{40}Ar/^{39}Ar$ dating: a provenance study of Middle Stone Age obsidian artifacts from Ethiopia'. *Journal of Archaeological Science* 33: 1749-1765.

Yukihara, E.G. & McKeever, S.W. 2011 *Optically Stimulated Luminescence: Fundamentals and Applications*. John Wiley & Sons.

WEB RESOURCES

OSL/TL

University of Oxford, Luminescence Dating Laboratory at the Research Laboratory for Archaeology and the History of Art (http://www.arch.ox.ac.uk/luminescence.html)

United States Geological Survey, Crustal Geophysics and Geochemistry Science Center (http://crustal.usgs.gov/laboratories/luminescence_dating/what_is_tl.html)

University of Georgia, Luminescence Dating Laboratory (http://osl.uga.edu/index.php)

Technical University of Denmark (DTU), makers of the Risø TL/OSL reader (http://www.nutech.dtu.dk/english/Products-and-Services/Dosimetry/Radiation-Measurement-Instruments/TL_OSL_reader)

L'Université du Québec à Montréal, Département des sciences de la Terre et de l'Atmosphère, Laboratoire de luminescence (Lux) (http://lux.uqam.ca)

ESR

Geographisches Institut der Universität zu Köln (http://www.geographie.uni-koeln.de/elektronenspin-resonanz.338.de.html)

Université Paris Descartes, Imagerie de Résonance paramagnétique électronique (http://irpe.parisdescartes.fr/ressources/observables-applications-RPE.php)

Cosmogenic radionuclide dating

Purdue University, Department of Physics and Astronomy, PRIME Laboratory (http://www.physics.purdue.edu/primelab/rosetest/plresearch.php)

University of Washington, Quaternary Research Center, Cosmogenic Nuclide Laboratory (http://depts.washington.edu/cosmolab/)

Lecture by Ramón Arrowsmith, Professor of Geology at Arizona State University, 'Methods in Active Tectonics' delivered in the summer of 2013 at LIPI in Bandung, Indonesia, sponsored by LIPI, IT Bandung, and the GREAT program. (https://www.youtube.com/watch?v=FcPAlZWow9s)

L'Université Aix-Marseille, Centre de Recherche et d'Enseignement de Géosciences de l'Environnement (https://www.cerege.fr)

Uranium-based dating

British Geological Survey, NERC Isotope Geosciences Laboratory (http://www.bgs.ac.uk/nigl/quaternary.html)

Centro Nacional de Investigación sobre la Evolución Humana, Uranium-Series Laboratory (http://www.cenieh.es/en/laboratories/uranium-series)

Universität Wien, Department of Lithospheric Research (http://lithosphere.univie.ac.at/geocosmchron/geochron)

$^{40}Ar/^{39}Ar$ dating:

Berkeley Geochronology Center (http://bgc.org/facilities/argon_lab.html)

Scottish Universities Environmental Research Centre, Argon Isotope Facility (http://www.gla.ac.uk/research/az/suerc/nercfacilities/argonisotopefacility/)

Australia National University, Argon Geochronology Facility (http://argon.anu.edu.au)

GLOSSARY

Aliquot: sample or portion of a larger whole.

Authigenic minerals: constituent minerals formed in a primary context (e.g., below the ground surface or in a rock) in response to geochemical reactions taking place in that context.

Bedload: the sediment that moves along the bottom of fluvial channels typically comprised of particles with diameters ≥250 µm. Bedload is contrasted from 'suspended load', which is typically comprised of fine silts and clays that move in fluvial channels via the upper portion of the water column.

Beta radiation: Electrons or positrons shed from the nucleus of radioactive isotopes, typically as a byproduct of having too many neutrons compared to protons.

Beta decay: the process of beta radiation emission.

Cosmogenic nuclides: isotopes formed from the collision of cosmic rays with the nucleus of atoms. Nuclides are formed via neutron spallation, capture of those neutrons by other adjacent atoms and capture of the muon isotopes (cosmic rays) themselves within the atoms comprising rock-forming minerals.

Dosing environment: the total amount of beta decay occurring around a sampled area. Some beta radiation will be absorbed by positively charged isotopes or trapped in the crystal lattice of surrounding mineral structures. Typically, the rate of beta decay is analyzed from bulk samples in order to determine how much ambient radiation a sample has been exposed to over time.

Lattice: the structural defects present in all naturally occurring minerals. These appear as cracks or holes under view of a microscope. The crystal lattice of minerals provides traps for beta particles, which get stuck in the traps. Once the traps are full, no more beta particles can be absorbed and the mineral is said to be 'saturated'.

Mass wasting: when soils, sediments and/or bedrock move downslope as a coherent unit as a result of failure of the underlying sediments to hold the overlying unit in place. Mass wasting often occurs in devegetated landscapes and where heavy amounts of precipitation saturate the ground surface, decreasing the tensile strength of clastic materials.

Muon: negatively charged particle that forms following collisions with atoms in earth's atmosphere. Muons travel to earth's surface close to the speed of light but decay as they ionize through the heavy atmosphere and penetrate the lithosphere.

Paramagnetic centers: the loss of radioactive particles from isotopes and subsequent trapping in the adjacent environment creates secondary sources of energy in the lattice of a mineral. These charged particles force changes in the magnetic fields of the parent isotopes causing their magnetic poles to shift to accommodate the outside force. The more free radical particles present in a given mineral, the more distortions in the paramagnetic centers will occur.

Saprolite: chemically weathered regolith (bedrock). During saprolite formation, the rock breaks down into sediment in situ.

Solum: portion of a sedimentary environment that has undergone soil formation processes. The solum does not include parent materials and 'C-horizon' sediments, which are often included as part of a soil classification.

Spallation: the process in which portions of a material are fragmented as a result of some kind of mechanical process. In the context of cosmogenic nuclides, this occurs when a fast-moving cosmic ray collides with an isotope either in earth's atmosphere or lithosphere.

Spectroscopy: the study of how physical matter absorbs or emits waves of electromagnetic radiation, including visible light.

Speleothems: soluble calcium carbonates that precipitate inside cave formations.

RELATIVE DATING METHODS

David K. Wright[1]

INTRODUCTION

Unlike radiometric dating methods, which measure radioactive decay or accumulation within samples, techniques that are calibrated from the present day using counting or comparisons to present day phenomena are classified as relative dating techniques. Seriation techniques* are also forms of relative dating, but are not discussed in detail here. For reasons explained below, the techniques have been employed sparingly on archaeological sites in Africa. As advances are made in applying these techniques and the need grows for new dating methods in Africa, Africanist archaeologists should be aware of these potential alternatives.

I. DENDROCHRONOLOGY

By counting the growth rings inside trees, dendrochonologists can offer a precise and accurate estimation of when a tree was cut down in the past. Typically, trees growing in the same region will receive roughly the same amount of rainfall and sunlight in a given season, which affects the relative thickness of the rings. Reference samples are collected through coring extant trees in a specific region. Those samples are compared with wood or charcoal recovered from archaeological sites to produce a key linking the present to the past. In many parts of the world, posts supporting structures are dated because they are amply thick to have a dendrochronology matching reference collections.

The disadvantage of using dendrochronology is that this method only dates the time when a tree was cut down. In the abundant semi-arid regions of Africa where wood can be preserved in the archaeological record, the most common form of subsistence was mobile pastoralism for much of the last 2,000 years. Using large trees for structural supports was not a common enough occurrence to build a dendrochronological database. High mobility does not lend itself to transporting heavy logs from place to place.

The longest dendrochronology in the world comes from oak (*Quercus robur*; *Q. petraea*) and pines (*Pinus sylvestris*) from central Europe spanning 12,640 years (Friedrich *et al*. 2004), but the African dendrochronologies do not have a near equivalent in time depth. Nevertheless, a nascent database is being constructed for the African pencil cedar (*Juniperus procera*) and *Acacia* sp. in Ethiopia extending the last ~100 years (Krepkowski *et al*. 2012). There are other regional chronologies on *Brachystegia* sp. in central Africa, Karkloof Yellowwood (*Podocarpus latifolius*) in southern Africa and limba trees (*Terminalia superba*) from tropical central and western Africa, to name a few. This research has yet to be applied in an archaeological context, but is useful for interpreting rainfall patterns over the historical period for which there are many missing records.

II. FISSION TRACK DATING

The decay of uranium (^{238}U) into lead involves the fission of the nucleus into two roughly equal sizes. In volcanic glass such as obsidian, the fission process leaves a scar (or 'track'). When the volcanic glass is heated, the fission tracks disappear with annealing*. Therefore, fission track dating measures the last time a glassy volcanic rock was heated by counting the scars left behind during the rather constant fission of ^{238}U. In order to date the annealing, the number of tracks are counted from the sample rock, the sample is then heated to anneal the tracks and then observed for an extended period of time to determine the rate of fission within the sample. Finally, the number of tracks present in the sample before heating is divided by the rate of fission to estimate the time of the previous heating event.

Assumptions made in fission track dating include: (1) the uranium content is significant (>0.1 ppm) and homogenous throughout a sample being analyzed, (2) there is no loss of tracks due to chemical weathering, and (3) other potential sources of fission tracks, most commonly ^{235}U, are minor contributors to the total number of tracks being counted.

Fission track dating in Africa is mostly performed on glassy tuff sediments from the volcanic regions of the Rift Valley to constrain occupation layers between volcanic eruptions. The inherent imprecision of the method (±10%) normally necessitates a cross check by more precise argon-based methods of dating volcanic rocks.

1 Department of Archaeology and Art History, Seoul National University, South Korea.

III. OBSIDIAN HYDRATION DATING (OHD)

When a piece of volcanic glass is flaked into a tool, the freshly exposed surface of the rock begins to slowly absorb moisture from the atmosphere that creates a rind of water, coating the outside of the rock observable under a microscope or measurable by spectroscopy* or spectrometry. An obsidian artifact is notched using a diamond tipped saw and the growth rate of a new water rind is measured on the cut edge over a period of several months to a year, then compared to the rind present on the sample. Time since the artifact was flaked is estimated by dividing the length of the prehistoric rind by the time elapsed since the experiment began, multiplied by the length of the rind from the experimentally-flaked edge.

The primary problem with OHD is that the ambient temperature and humidity content must be known since the artifact was flaked because these factors affect water absorption in obsidian. The less that is known about these factors, the more imprecise the method. If an artifact has been buried for a long period of time, this is easier to estimate compared to those artifacts recovered in near-surface or surface contexts.

According to Ambrose (2012), the only obsidian hydration studies conducted in Africa to date took place in Kenya and Ethiopia by Joseph Michels and with limited success. More chemical fingerprinting studies are needed to develop a baseline dataset for hydration rates and effective temperature and moisture across the region.

IV. ARCHAEOMAGNETIC DATING

When rocks are heated into viscous states above 400°C, magnetic minerals become dislodged from their matrix. As they cool, magnetic particles in the rock align with the position of the North Pole. Magnetic north is not a fixed point and its movement has been tracked using archaeomagnetic dating with differing degrees of precision since the advent of the Pleistocene. The difference between 'true north' and magnetic north is called declination. Magnetic reversals occur approximately every 450,000 years in which earth's polarity reverses between the northern and southern axes. Between the reversal episodes, though, the North Pole wanders tens to hundreds of km per decade. Thus, the application of archaeomagnetic dating can be applied on hearths from recent periods to volcanic sediments with magnetic minerals.

When a sample is collected, special care must be made to record the exact sample location and extract the sample orientation from a level context with a precise accounting of the location of magnetic north and slope of the landform from which the sample is being collected. The sample is normally encased in plaster, resin or a special plastic cylinder and must not be jostled during transport to the lab. Multiple samples from a location need to be collected in order to homogenize local magnetic anomalies that may have affected the sample's magnetic orientation.

The primary disadvantage of archaeomagnetic dating occurs due to 'multiple intercepts', where the geomagnetic pole is aligned with the sample numerous times due to its non-stationary position. Typically, a consumer will receive a multitude of potentially applicable ages and so a relative idea of a sample's age must be known prior to sample submission. The geographical position of the African continent related to the North Pole is also problematic as the region lies south of a geomagnetic flux patch* that occurred during the Middle Holocene, which created large non-axial-dipolar variations of intensity that need to be calibrated.

Archaeomagnetic dating has primarily been applied to hominin fossil sites at broad time scales by analyzing geomagnetic reversals in magnetic volcanic rocks. These studies are normally combined with radiometric dating techniques like argon-argon and are intended to improve the precision of the geochronology, while the radiometric technique provides the accuracy. A study by Mitra *et al*. (2013) suggests that there is potential to apply archaeomagnetic studies toward building Holocene site chronologies in sub-Saharan Africa on burnt clays, but more knowledge is needed to determine geomagnetic fluctuations over the region.

REFERENCES

Ambrose, S.H. 2012. 'Obsidian Dating and Source Exploitation Studies in Africa'. In I. Liritzis and C.M. Stevenson (eds). *Obsidian and Ancient Manufactured Glasses*. University of New Mexico Press, pp. 56-72.

Bayélé-Goma, R. 2011 *Interdatation par la dendrochronologie applicable en milieu tropical: Procédure type*. Editions Publibook.

Djindjian, F. 2011 *Manuel d'archéologie: méthodes, objets et concepts*. Armand Colin.

Friedrich, M., Remmele, S., Kromer, B., Hofmann, J., Spurk, M., Kaiser, K.F., Orcel, C., & Küppers, M. 2004. 'The 12,460-year Hohenheim oak and pine tree-ring chronology from central Europe – a unique annual record for radiocarbon calibration and paleoenvironment reconstructions'. *Radiocarbon* 46(3): 1111-1122.

Hannaford, M.J., Bigg, G.R., Jones, J.M., Phimister, I., & Staub, M. 2014. 'Climate variability and societal dynamics in pre-colonial southern African history (AD 900-1840): A synthesis and critique'. *Environment and History* 20(3): 411-445.

Krepkowski, J., Bräuning, A., & Gebrekirstos, A. 2012. 'Growth dynamics and potential for cross-dating and multi-century climate reconstruction of *Podocarpus falcatus* in Ethiopia'. *Dendrochronologia* 30(4): 257-265.

Liritzis, I., & Laskaris, N. 2011. 'Fifty years of obsidian hydration dating in archaeology'. *Journal of Non-Crystalline Solids* 357(10): 2011-2023.

Mitra, R., Tauxe, L., & Keech McIntosh, S. 2013. 'Two thousand years of archeointensity from West Africa'. *Earth and Planetary Science Letters* 364: 123-133.

Wagner, G. & van den Haute, P. 2012. *Fission-Track Dating (Solid Earth Sciences Library)*. Springer.

WEB RESOURCES

Tree ring dating

Department of Geography, University of Tennessee, Knoxville (http://web.utk.edu/~grissino/principles.htm)

University of Montréal, Groupe de Recherche en Dendrochronologie Historique (GRDH), (http://www.grdh-dendro.com/index.html)

Fission track dating

University of Ghent, Vakgroep Geologie en Bodemkunde, Geochronology Group, Fission Track Dating (http://www.minpet.ugent.be/fission.htm)

Personal webpage of Tristan Ferroir, Professor of CPGE BCPST – Lycée Janson de Sailly (http://tristan.ferroir.fr/index.php/2008/10/13/la-datation-par-traces-de-fission-en-geologie/)

Obsidian hydration dating

University of Arizona, Department of Geosciences (http://www.geo.arizona.edu/palynology/geos462/11datingmeth.html)

Bieling & Psota Archaeological Consultants (http://www.sonic.net/~dbieling/obsidian_hydration.html)

Archaeomagnetic dating

University of Bradford, Division of Archaeological, Geographical and Environmental Sciences (http://www.brad.ac.uk/archaeomagnetism/archaeomagnetic-dating/)

English Heritage, Archaeomagnetic Dating Guidelines, online pdf (http://www.english-heritage.org.uk/publications/archaeomagnetic-dating-guidelines)

La Trobe University, The Australian Archaeomagnetism Laboratory (http://www.archaeomagnetism.com)

University of California at San Diego, GEOMAGIA50 database of archaeomagnetic data (http://geomagia.ucsd.edu)

Institut Français de l'Éducation (http://acces.ens-lyon.fr/acces/terre/limites/Temps/datation-isotopique/enseigner/paleomagnetisme)

L'Université Laval, Département de Géologie (http://www2.ggl.ulaval.ca/personnel/bourque/s1/magnetisme.terr.html)

GLOSSARY

Annealing: heating a material above a threshold where it remains structurally intact. When the material cools, the molecular constituents are realigned. In fission track dating, the annealing process results in the erasure of fission tracks. As it relates to archaeomagnetism, annealing results in the magnetic particles realigning to face the geomagnetic North Pole.

Geomagnetic flux patch: an area in the magnetosphere with intense magnetic field activity. The earth's magnetic field is generated from electrical currents that travel through iron particles that predominate the outer core and is not distributed evenly through the magnetosphere, and varies in intensity and spatial extent through time.

Seriation techniques: Obtaining a chronology by using culturally-specific and temporally diagnostic artifacts.

Spectroscopy: the study of how physical matter absorbs or emits waves of electromagnetic radiation, including visible light.

Method	Age range (years BP)	Precision (1-σ)	What can you date?
Radiocarbon (^{14}C)	250 - 50,000	<1-2%	things that used to be alive (bone, wood, seeds, shell, etc.)
Cosmogenic nuclide	2000 - 10,000,000	1% (rocks) - >10% (sediment)	exposed ground surfaces
Dendrochronology	rarely conducted in Africa	0% (when done right)	trees
K-Ar/Ar-Ar	2000 - 4,600,000,000	1-2%	volcanic rocks
U-series	50,000 - 500,000	1-10%	travertines (limestone caves), bone, shell, carbonates
Fission track	2000 - 1,000,000+	10%	young samples = glass or ceramics; old samples = volcanic glass (obsidian)
Thermoluminescence (TL)	100 - 50,000	5-10%	ceramics or heated sedimentary stones (flint, quartz)
Optically Stimulated Luminescence (OSL)	10 - 150,000	3-7%	sedimentary rocks that have been buried (not exposed to light or extreme heat)
Electron Spin Resonance (ESR)	0 - 150,000	10-20%	teeth in thermally stable environments (caves)
Obsidian hydration	0 - 120,000	10%	the time of manufacture of obsidian artifacts
Archaeomagnetic dating (a-mag)	0 - 2,000,000+	it depends on number of intercepts	magnetic minerals that have been heated (hearths and volcanic deposits are most commonly dated)

Common methods of radiometric and other dating of archaeological sites, timespans covered, precision of the method and materials able to be dated.