The Biological and Cultural Evolution of Homo sapiens:
Early Humans of Dar Es-Soltan 2 and Contrebandiers Caves in Morocco

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December 2024

The biological and cultural evolution of *Homo sapiens* is one of the greatest research subjects of evolutionary science. When, where, and how did our species emerge and disperse across the continents? How did it adapt behaviorally to different landscapes and climates? What was the extent of interaction with archaic humans like Neanderthals and Denisovans shaping our behavioral and genetic diversity? These are the major questions of our evolution. Over the last twenty years, northwestern Africa has emerged as one of the most important regions for the study of our origins and evolution. Especially in present-day Morocco, the rich record of human fossils including the earliest known *Homo sapiens* and artefacts is not only generating new, cross-African, models of our species' speciation (Hublin et al. 2017), but is also producing new knowledge about our early behavior, adaptation, and survival. Sites like Jebel Irhoud (Hublin et al. 2017 ; Richter et al 2017), Ifri N'Ammar (Nami and Moser 2010), Taforalt (Barton et al. 2016), and Rhafas (Bouzouggar et al. 2019); caves on the Atlantic coast of Rabat-Temara (Bouzougar and Barton 2012; Debénath 1976; Dibble et al. 2012; El-Hajraoui 1994; Nespoulet et al. 2008), around Essaouira (Sehasseh et al. 2021), and in the vicinity of Casablanca (Reynal et al. 2010); and areas such as Ain Béni-Mathar Basin (Sala-Ramos et al. 2022), have been providing an invaluable record of the evolution of human morphological traits, of one-million-year developments in stone toolmaking and other technologies, of diversity in hunting and food procurement, of the earliest exploitation of marine resources, and of evidence of some of the earliest human symbolic behavior, cultural signaling, and abstract thought.

We are focusing on two cave sites in Rabat-Temara: the cave of Dar Es-Soltan 2 and the cave of Contrebandiers. Our overall research subject is tracing developments in the biological and cultural evolution of *Homo sapiens* in northwestern Africa from 130,000 until 10,000 years ago to develop precise absolute chronological and paleoenvironmental conditions for some of the major events in this evolution. These two caves are among several in calcareous sandstone that were formed during the Marine Istotope Stage 11 (425,000-375,000 years ago) in a system of lithified ancient dunes along the Atlantic coast. Since the mid-20th century, several scholars have intermittently excavated these caves to various extents. Hence, they are known already to contain rich, well-preserved fossils and other material records. Both caves have a similar history of sediment deposition and site formation (Schwenninger et al. 2010). They contain long, continuous cultural sequences starting from about 130,000 years ago, with several Middle Stone Age occupations that are overlain by several occupations of the Later Stone Age (the so-called the Iberomaurusian culture), and extending to the beginnings of the Holocene, about 12,000 years ago (Debénath 1976; Dibble et al. 2012; Schwenninger et al. 2010). The caves are notable for the rich human fossil remains in several layers (Ferembach 1976, 1998; Hublin et al. 2012; Roche and Texier 1976) attesting to continuous early human presence in this region, abundant faunal and marine shell remains (limpets, mussels), marine Tritia shells with traces of ochre used for symbolic purposes as pendants, distinctive stone tools across all the occupations (pedunculates, bifacial points, microlithic implements) (Debénath 1978; Dibble et al. 2012), numerous hearths and remains of plants, and bone tools used for the earliest manufacture of clothing (Hallett et al. 2021). Among the most unique finds denoting the behavioral versatility of those human groups is the tooth of a sperm whale that was likely collected on the shore sometime between 120,000 and 90,000 years ago and used for applying pressure when fashioning stone tools.

The human remains from Dar Es-Soltan 2 found in the past include an approximately 110,00-year-old adult cranium, the calvarium of an infant, and the mandible of a teenager, but these are only the most complete fossils in the collection (Ferembach 1976). Deposits from about 20,000 years ago yielded several complete individuals in a burial context (Debénath 1978). From Contrebandiers, the most notable fossil find is a complete skull with clavicles and vertebrates of a six-year-old child from the 115,000-year-old layer, found in 2009. The recent analysis of its maxilla (Freidline et al. 2024) using three-dimensional geometric morphometric methods and its growth simulation show that while its shape and size for the age of that individual is characteristic for other Middle Stone Age specimens found in North Africa and the Dead Sea region, its facial growth pattern is more similar to that of Neanderthals than of recent humans. This suggests that the unique facial growth pattern of *Homo sapiens* developed after the Middle Stone Age. Analyses of the other parts of this skull (dentition, cranium) are in progress, but it is clear that this fossil find is extremely important for addressing the ontogenetic variability of our Middle Stone Age ancestors and the history of the development of our present-day variability, because the human fossil record from that age across Africa is extremely scarce and fragmentary. All of this evidence together shows how critical it is to investigate these two cave sites as they represent a link between the earliest known *Homo sapiens* at Irhoud (310,000 years ago) and thoroughly modern humans (anatomically and behaviorally) towards the end of the Pleistocene.

There are six specific questions related to human biological and cultural evolution directing our research. What were the morphological trajectories in the evolution of *Homo sapiens*' face, dentition, and skull, and how are the morphological features of the *Homo sapiens* of northwest Africa related to those of early human groups in eastern Africa and the Levant? What was the genetic structure and diversity of early *Homo sapiens* populations and did the transition between the Middle and the Later Stone Age about 30,000 years ago include population continuity or a demographic replacement? What was the course of evolution and innovation in technologies of stone and bone toolmaking and in the management of fire? What were the strategies of terrestrial and marine resource exploitation and prey (animal taxa) and plant targeting? What was the scope of some of the earliest human symbolic behavior and can its material presence and absence in the archaeological record over time be related not only to social and cognitive but also to paleoenvironmental factors? For example, can the presence and absence of symbolically used marine shells be related to the availability of those shells on the shore to be collected by those human groups only during periods of low sea levels)? What is the absolute chronology (by the methods of optically-stimulated luminescence, electron-spin resonance, and tephrachronology) and paleoenvironmental context (by plant leaf-wax biomarkers, C3 and C4 grass pyhtoliths, and environmental correlations based on remains of tephra, micro-volcanic sherds, in the excavated sediments) behind the major events in the Middle and Late Pleistocene human evolution of this region?

In collaboration with the Institut National des Sciences de l'Archéologie et du Patrimoine (INSAP) in Rabat our work involves field excavation and post-excavation laboratory analysis of excavated finds and collected samples. During the excavation, we usually individually record the precise 3D position of all bones, shells, and artifacts measuring 2 cm and larger, including all non-artifactual samples (dating, DNA, plant wax, etc.), and collect smaller size objects in provenienced 7-liter aggregate samples that are then dry-screened using nested 5 mm and 2 mm screens. For this in-field recording we use handheld data collectors connected to a total station.

For the analysis of human fossil morphology and DNA, we 3D-scan every fossil find and analyze it with geometric-morphometric standard procedure. The library of the 3D scans will be made publicly available after the completion of the project and publication of the results. At the Max Planck Institute of Evolutionary Anthropology in Leipzig, our collaborators are performing DNA profiling of human bone samples. We already have a large library of 3D morphological data from the fossils of *Homo sapiens* found in other regions of Africa and southwest Asia and the ancient DNA data for some of the later specimens. Both morphological and DNA data enables us to undertake comparative studies and to reconstruct some parts of our species' early population structure and diversity.

All bones and marine shells will be analyzed macroscopically for species identification, cut marks, traces of heating, as well as polish and shaping for bone tools, and perforation and use-wear for *Tritia* shells. In addition to faunal morphological and macrotrace analysis, since the largest component of bone collections at archaeological sites in general are small bone fragments that are morphologically non-diagnostic, we are applying zooarchaeology-by-mass-spectrometry (zooMS) to identify additional human bones among fauna. More specifically, this method mass-fingerprints the collagen type-1 peptide protein. We are also using zooMS to identify species used for bone tools to assess the level of animal selectivity and preference among those early humans. For the questions of paleodiet and mobility in resource procurement of these early human groups, we are applying multiisotope analysis using zinc ($\delta^{66}Zn$), strontium ($^{87}Sr/^{86}Sr$), carbon ($\delta^{13}C$), and nitrogen ($\delta^{15}N$) isotope on dentin and bone collagen from the human fossils to assess the levels of plant-based food reliance. This is complemented by the analysis of macrobotanical remains (mostly seeds and fragments of nuts extracted from sediments by flotation).

The evolution of technology is another major aspect of our research. We analyze stone tools using standardized technological and metrical attribute analysis to inform on the evolution of efficient flaking stone, tool making, and management of stone raw material resources. Furthermore, as both caves contain hearth features across a number of occupations, we are sampling these hearths for micromorphology to study their formation and anthracology (analysis of a kind of fuel) to better understand diachronic changes in the earliest human fire technology. In addition, we are applying carbonate clumped isotope thermometry and Fourier transform infrared spectroscopy on burned mollusks shells and burned bone fragments that are present in these hearths to reconstruct the differences in the temperatures reached and burning intensity.

Our colleagues are using optically stimulated luminescence (OSL), tephachronology, and combined Uranium series and electron spin resonance (US-ESR), to obtain absolute ages for the finds, events, and occupations. OSL measures the time since naturally occurring minerals, such as quartz and feldspar, were last exposed to light. After exposure, these minerals accumulate a charge. Measuring this charge and dividing by the dose rate from environmental sources of ionizing radiation yields an age. Tephra (volcanic glass) shards extracted from the sediments will subsequently be identified with polarizing light microscopy. After their sectioning, we will subject the shards to electron probe microanalysis and the process known as laser-ablation-inductively coupled plasma mass spectrometry (LA-ICP-MS). This will allow us to geochemically match the identified tephra horizons either directly with tephra volcanic sources or with tephra-containing and well-dated paleoenvironmental archives. Both caves are located approximately 1700 km and 900 km from the Azores and Canary Islands, respectively. Volcanoes on these islands (e.g., Sete Cidades volcano) have generated numerous large explosive eruptions over the last 500,000 years dispersing tephra over wide areas of northwestern Africa.

For the reconstruction of the paleoenvironment, in addition to the analysis of macrobotanical remains our colleagues will analyze the leaf wax n-alkanes of terrestrial plant leaves that can be found microscopically in the soil sediments. The stable hydrogen isotopic composition (δD) of these hydrocarbon compounds is a powerful tool to reconstruct hydrological fluctuations in precipitation and the water supply in the environment. Additionally, owing to physiological differences during CO_2 acquisition for photosynthesis, leaf wax $\delta^{13}C$ measurements can be used to differentiate C_3 versus C_4 vegetation. Consequently, leaf wax carbon isotopic composition ($\delta^{13}C$) is an excellent proxy for determining changes in the composition and origin of continental vegetation.

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