Archives of paleoclimatic and paleoenvironmental data: The importance of temporal and spatial scales in outcrop contexts

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Layered sediments are the primary **archives** of paleoclimatic and paleoenvironmental data important to answering questions related to framework of human evolution. Sedimentary archives occur in three distinct contexts: (1) outcrops containing paleoanthropological materials, (2) drill core records from continental basins that contain large lakes, and (3) drill cores from the deep ocean. Archive types vary greatly in terms of both the temporal and spatial scales over which they integrate records of environmental change. Each type of archive can entomb multiple types of **indicator records** from biological remains, geochemical fingerprints, geophysical properties, sedimentary facies, and bulk lithological records (e.g. paleosols) that yield information on the paleoecology and paleoclimate.

Until recently outcrop records were used exclusively for determining the age of and paleoenvironmental context of paleoanthropological and archaeological sites. The research advantages of utilizing outcrop information are that the deposits are the actual record of the environment or in close proximity to human "habitats" and outcrops generally offer two- and three-dimensional data arrays, allowing landscape reconstruction. The disadvantages are that outcrops are essentially randomly distributed in terms of their orientation and location. In addition, elevated continental settings are subject to erosion events leading to sedimentary archives that are discontinuous in both time and space.

By comparison, core records from the ocean or from continental depositional basins, offer one dimensional sampling arrays, but with greater stratigraphic continuity than outcrops. Ironically, the highest resolution and most continuous records typically occur in a lake or oceanic site far from areas of hominin occupation. Marine drill core records (millions of years in length) have been available for comparison with the emerging human evolutionary story for several decades, whereas long (>1 Ma) continental drill core records from lakes (especially in Africa) are only now becoming available for comparative study.

There are for five fundamental constraints on interpreting the multiple indicator records contained within layered sedimentary archives:

(1) Continuity of record. Is the sedimentary record more-or-less complete (continuous sedimentation), or are there large time gaps created by no sedimentation or erosion.

(2) Duration of record: What is the length of the archive?

(3) Temporal resolution of the multiple indicator records, How finely can each indicator record be subdivided and still provide temporally-ordered information?

(4) Spatial resolution of multiple indicator records. Over what geographic area is the signal integrating information?

(5) Numerical dating resolution. What is the resolution of the dating method(s) with respect to the resolution of the paleoclimatic and paleoenvironmental records?

Indicator records indicate temperature; water balance (P-ET); chemical composition of air or water; volcanism; and biomass information (plants and animals). However, sediments usually contain multiple indicator records. Each source of data may represent an independent record of environmental change or stasis, records of different aspects of change or stasis, or simply records that cannot be compared. For example, a time series at the local outcrop scale of stable isotopes in a paleosol is probably sampling variability in local vegetation over a spatial scale of 100s of m^2, with a temporal resolution on the order of 10^{2-3} yr. In contrast, stable isotopes and trace elements of ostracodes carapace shells are sampling ambient water chemistry in the life time of the crustacean. However, a time series of ostracode geochemistry can track changing water temperature and salinity over the life of the wetland or lake.

Accurate dating is of critical importance in the interpretation of all archival records. It is key to establishing the geochronology and in the correlation and interpretation of paleoenvironments and paleoclimate from outcrop data. Without accurate dating it is impossible to determine if events occurred synchronously or if certain events led or lagged others (Bradley, 1999). Accurate dating is required in any assessment of the rate (variability) at which past environmental changes occurred. In some cases, the duration of such events may be shorter than the normal error associated with many dating methods.

A fundamental challenge for earth scientists and paleoanthropologists in collaborating to make maximum use of these varied (and not always comparable) types of archives is to identify the temporal and spatial scales of environmental information required for testing specific hypotheses of human evolution.