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Geologists Probe Hominid Environments

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ABSTRACT

The study of an early Pleistocene "time slice" in Olduvai Gorge, Tanzania, provides a successful example of a reconstructed paleolandscape that is rich in detail and adds a small piece to the puzzle of hominid evolution in Africa. The reconstruction required multidisciplinary interaction of sedimentologists, paleoanthropologists, paleoecologists, and geochronologists. Geology plays an increasingly important role in unraveling the record of hominid evolution. Key questions regarding paleoclimate, paleoenvironment, and perhaps even hominid land use are answered by geology, and these answers provide a basis for multidisciplinary work. Landscape paleoanthropology integrates these data from several disciplines to interpret the ecological context of hominids during a narrow window of time. The multidisciplinary approach creates a "snapshot" with the highest temporal resolution possible. Inevitable limitations remain because of spatial variability of erosion and deposition and because of intrinsic time averaging of the sediment record.

INTRODUCTION

The questions of how and where humans evolved capture our attention and spark our curiosity. Recent applications of a variety of precise dating tools and the use of DNA typing have provided a strong case for Africa being the site of hominid evolution during the Pliocene, with waves of migration out of Africa as early as 1.8 Ma. However, primate populations are naturally small and their fossil record meager. Luckily, rifting has been active on the African continent since at least the Miocene. Rifting creates low areas that commonly contain the rivers and lakes so critical to life. Rifts also are sites of active volcanism and focused sedimentation and thus make ideal natural tombs.

There seem to be as many hominid family trees as there are anthropologists. Figure 1 illustrates three important aspects of hominid evolution about which there may be the most consensus (Wood, 1994). First, there was a common ancestor to humans and chimps ~5–7 million years ago. Second, *Australopithecus* (the earliest hominid group) evolved into two major lines, one *(Paranthropus)* dying out and the other leading to *Later Homo*. Third, the fossil record indicates that two and perhaps three or more species were living at one time.

In the early years of discovery, the study of hominid evolution was carried out by archaeologists and anthropologists. Geologists were usually relegated to answering the question, How old is the fossil? Few other data were collected from the geologic record that could be used to interpret paleoenvironments or paleoclimate. How the animals lived was often left to the imagination. Most scientists now agree that humans evolved with other primates in Africa. The important questions being asked about their evolution are: What were the climate and environment like? Did climate fluctuate or show trends? Were hominids vegetarians or omnivorous scavengers? Did they hunt or were they hunted?

We can focus the expertise of sciences such as geology, chemistry, biology, and hydrology on the same problems. The challenging areas of research often lie at artificially imposed discipline boundaries. Here lies the potential for synergy and perhaps even the generation of a new science (Fig. 2). However, integrating sciences is not as easy as it might first appear. It requires people to learn language, theories, methodologies, and a bit about the "culture" of the other science and to continually walk in the other person's shoes. Simply having lots of scientists with different backgrounds working in parallel on the same project doesn't produce the same end result as integrative science.

This paper describes a study at Olduvai Gorge, Tanzania (Fig. 3), using a relatively new approach, landscape paleoanthropology, that attempts to interpret the landscape during a geologic instant in time. The project is the Olduvai Landscape Paleoanthropology Project (OLAPP), involving a multidisciplinary team. Teamwork is needed to determine the environmental context, to flesh out the details of topography, hydrology, and biota, and to provide insights into hominid land use (Peters and Blumenschine, 1995).

LANDSCAPE PALEOANTHROPOLOGY

Landscape paleoanthropology depends on experts applying to the problem the major sciences like geology, biology, anthropology, and hydrology in concert. At least 12 disciplines have been used to answer key questions about hominid evolution and to interpret the paleolandscape (Table 1).

The rich fossil and cultural records at Olduvai were made world famous by Louis and Mary Leakey, starting in the late 1930s. Most of the systematic excavation and publication of the Olduvai record was carried out by Mary (Leakey, 1971). The Leakeys' pioneering work helped put branches on the hominid family tree and gather important data on the evolution of tool making. Their approach to studying paleoanthropology, typical of the time period, was to make a "space slice" through time by looking at temporal changes in relatively small areas (square meters) (Fig. 4). In landscape paleoanthropology, data are collected over a large area (square kilometers) representing very little time, in order to answer some of the questions about the nature of the environment in which hominids lived and how they might have interacted with it.

GEOLOGIC SETTING

Olduvai Gorge is located just south of the equator in northern Tanzania. It lies in a shallow basin just west of a large Pliocene-Pleistocene volcanic complex (Ngorongoro) that occurs at a point of bifurcation in the East African Rift (Hay, 1976). The gorge was incised into the eastern edge of the Serengeti Plain during the late Pleistocene. Figure 3 shows photos of the modern Gorge.

Olduvai Gorge exposes ~100 m at its deepest section (Fig. 3B). It is floored by basalts and comprises interbedded volcanic tuffs and reworked volcaniclastic sediments. It is a record of the past 2 m.y. At first glance it looks like a simple layer cake with ideal sequences for correlation over great distances. However, a detailed study of the geology of Olduvai Gorge revealed that the

TABLE 1. SUBDISCIPLINES USED TO ANSWER QUESTIONS IN OLDUVAI LANDSCAPE PALEOANTHROPOLOGY PROJECT

Fundamental questions being asked	Subdiscipline
What was the paleolandscape like?	Geomorphology, sedimentology, clay mineralogy
What are the age and duration of the time slice?	Geochronology, volcanology, paleontology
What were the climate and vegetation like? Did they vary through time?	Paleobotany, geochemistry, soil science
What were the fauna like?	Paleontology, archaeology, paleoanthropology
Were hominids present?	Paleontology, archaeology, paleoanthropology

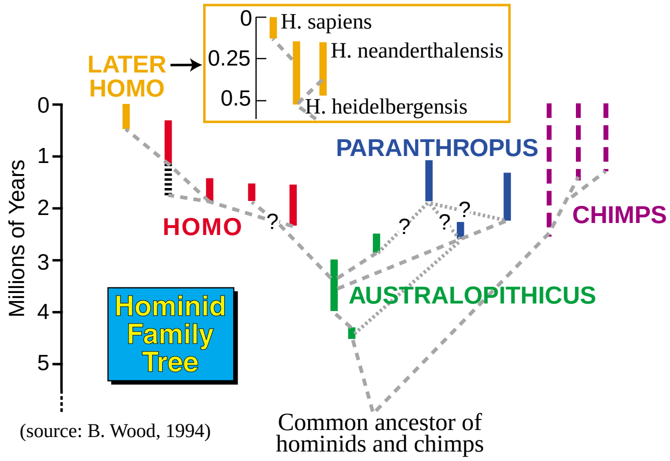

Figure 1. Hominid family tree suggests that hominid and chimpanzee clades diverged ~4–5 Ma and that a major hominid group *(Paranthropus)* died out, leaving *Homo* and *Later Homo* lines (modified from Wood, 1994).

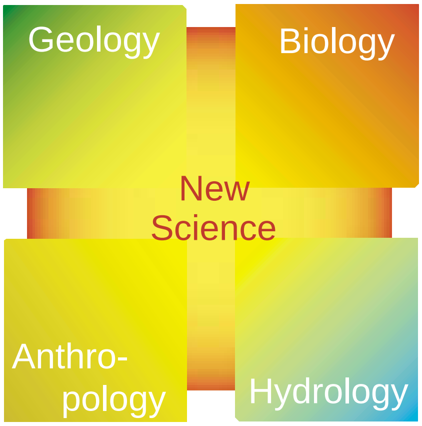

Figure 2. Interdisciplinary approach involving geology, biology, hydrology, and anthropology is needed to interpret early Pleistocene landscape and how hominids might have interacted with their environment. This approach may even lead to a new science. Figure by J. S. Delaney.

geology was anything but a "piece of cake"; the layers were chopped up by rift-parallel faults (Hay, 1976, 1990). Hay showed that the stratigraphy could be separated into four major chronologically based units. The time slice that we chose to study is early Pleistocene in the lowermost part of bed II. Our approach was to study the geologic record between two mappable tuffs (Fig. 5); 103 trenches, 4–6 m deep and 1–2 m wide, were excavated within a 20 x 20 km area. The section was meticulously excavated centimeter by centimeter, all sediment was sifted, and all bones and artifacts were collected. The step trenches created by this tedious process provided wonderful exposures for studying sedimentology, soil development, and the fossil record.

RESULTS AND DISCUSSION

We asked many fundamental questions about the chosen time slice and called on a range of specialties to help with the answers (Table 1).

What Was the Paleolandscape Like?

Hay's original interpretation of the landscape described a basin with streams flowing into it from the Serengeti on the west and an alluvial fan reworking the volcaniclastic sediments on the east (Hay, 1976). In general, we saw similar features, but the high-resolution study of the depositional environments revealed that surface runoff on the volcaniclastic fan was intermittent and that a large and persistent groundwater-fed spring system occurred at the eastern lake margin, freshening the lake (Fig. 6). Freshwater wetlands, several square kilometers in area, fringed the springs. We used both modern environments and sedimentary evidence from our time slice to visualize what the springs and wetlands were like. Carbonate spring tufa likely formed by carbonate precipitation when CO_2 degassed as groundwater disgorged (Fig. 7A). A highly siliceous earthy claystone contains abundant paleobotanical remains (Fig. 7B). We find from modern studies that springs can be relatively small, but highly reliable throughout the year, and can support hundreds (maybe thousands) of animals daily (Deocampo, 1997).

A synthesis of the 103 trenches revealed that the environments varied dramatically across the basin. Using modern analogs as a guide, we interpreted the sedimentary records found in our time slice to reconstruct a landscape dominated by a lake that expanded and contracted with time, by an active volcano that periodically disgorged sediment, and by a groundwater-fed spring system that seemed to persist despite short-term changes in climate (Fig. 8). The sedimentary sandwich contains the record of the large saline-alkaline lake in the center of the basin that had distinctly fresher water on the eastern margin. There were two major expansions of the lake. Unfortunately, the western part of the sedimentary record appears to have been subsequently eroded.

Hominid Environments *continued on p. 28*

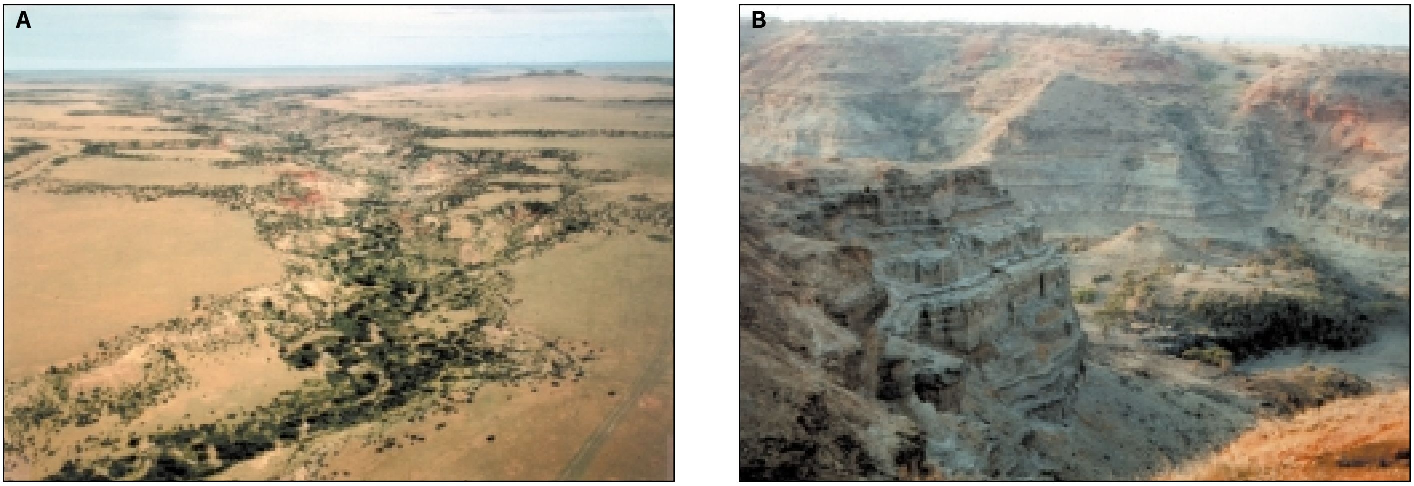

Figure 3. A: Olduvai Gorge, looking west toward Serengeti Plain away from rift valley (photo by R. J. Reeder). B: Two m.y. record of primary air-fall and reworked volcaniclastic sediments containing rich biological and cultural records are exposed in 100-m-high outcrops.

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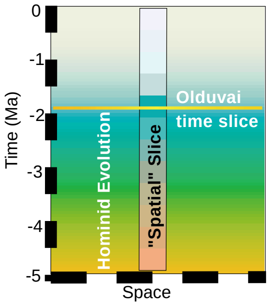


Figure 4. Traditional approach to studying hominid evolution was a "space slice" that examined representative sites (small excavations of fossils and artifacts) and studied the change of record with time. New approach, a "time slice," attempts to interpret a paleolandscape as a snapshot in time to highest resolution possible, given limitations of time averaging of sediment record. Olduvai time slice is at ~1.75 Ma.

Figure 5. Archaeological step trench placed between two isochrono-stratigraphic tuff beds, Tuff IF (lower arrow) and Tuff IIA (upper arrow). The 103 trenches that were excavated in sediments (between these tuffs) likely represent ~50,000 yr period.

What Are the Age and Duration of the Time Slice?

We take advantage of the bracketing volcanic tuffs (which were deposited in an instant of geologic time) to define ages. Feldspar crystals from the lower tuff (which is a trachyandesite deposit) were analyzed by argon-argon single-crystal laser dating technique (by Alan Deino at Berkeley Geochonology Center). Dating revealed an age slightly older than 1.75 Ma. (A. Deino, personal communication) for the lower tuff. The upper tuff appears to have been mixed and contaminated by surficial processes, and at present we do not have reliable dates on it. The vertebrate fossil record, which is useful for paleoenvironmental information, cannot be used for high-resolution time analysis. However, the evidence for major expansions of the lake can be used as a tentative means of estimating time. The dominant Milankovitch signal recorded in the world's marine records during this early Pleistocene time is ~41,000 yr (deMenocal and Bloemendal, 1995). Research with eolian dust levels in marine cores off the coast of Africa suggest that wet-dry cycles at low latitudes may occur in sympathy with the 41 k.y. cold-warm cycles seen at higher latitudes. If that is true, then the one major lake cycle within our time slice would represent the 41 k.y. cycle and our time slice would be ~50,000 yr long.

What Were the Climate and Vegetation Like? Did They Vary Through Time?

The lake margin was a key area for recording climate. The lake periodically flooded the margin and the groundwater exited at the base of the slope. The fossil evidence for grasses and sedges is abundant, but woody plant preservation is sparse. Some root casts and remains of fossilized wood up to 6 cm in diameter are preserved.

An impressive red soil developed on the lake margin (Fig. 8). Steven Driese (University of Tennessee) and I have determined that the red soil records a major fluctuation in the water table during the early part of our time slice; it went from wet to dry to wet, creating the strong red coloration. Subsequently the climate became quite arid. Soil-forming processes at the top of the red soil were dominated by alkaline conditions and zeolite formation. Geochemical profiles through the soil detected three volcanic eruptions, suggesting that new material was frequently added to the surface during its formation.

What Were the Fauna Like? Were Hominids Present?

Several thousand bones were collected and identified during the excavation of the 103 trenches. A large proportion can be identified, and a story of the animals that lived there is gradually emerging. One hominid tooth, probably belonging to the extinct *Paranthropus* branch of the hominid family tree, was found. Additional evidence for hominids on the landscape is clear. Thousands of stone tools representing Oldowan culture were collected and are being analyzed. These tools are similar to the thousands collected by Mary Leakey (1971).

About 10%–15% of the long bones showed evidence of cut marks made by hominids with stone tools. About 40% of the bones either had carnivore tooth marks or the bone ends showed ravaging by carnivores. Bone and artifact density is plotted as a function of depositional environment in Figure 9. The highest concentrations are associated with potable water sources. The highest density of bones and stones occured in a river draining the Serengeti. This is not surprising, but the previously unrecognized presence and importance of springs and the groundwater-fed wetlands as a focus of hominid activity on the eastern shore of the lake were not anticipated. Apparently hominids were attracted to this freshwater habitat for water, root stocks, and fruits, and to scavenge carcasses (Bunn, 1981; Blumenschine, 1995).

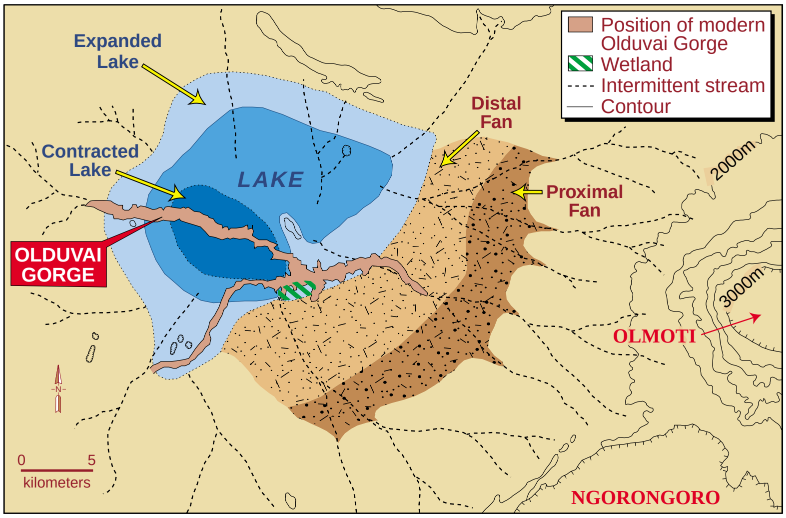
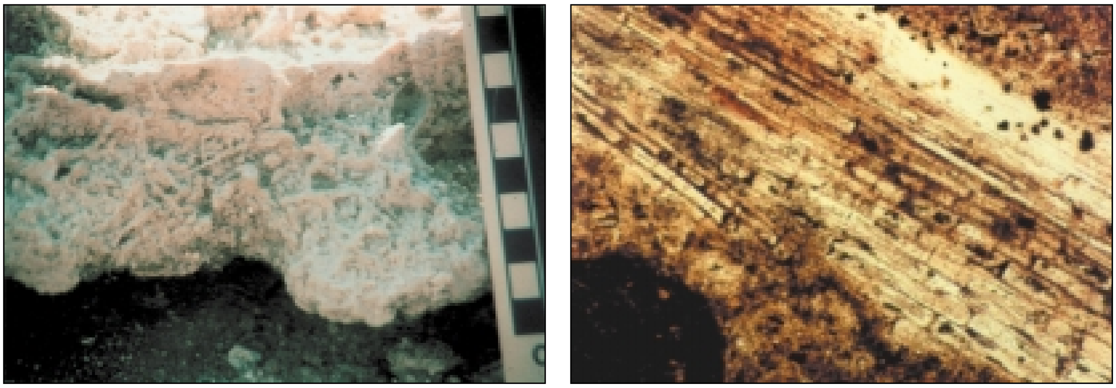


Figure 6. Paleogeographic reconstruction of landscape at 1.75 Ma. Lake in center of basin expanded and contracted with climate. Pyroclastic fan built from the east, and small groundwater-fed wetland occurred on lake margin.

Figure 7. Left: Tufa. Fenestral carbonate-encrusted roots and stems in localized deposits (1–2 m^2). Interpretation is that tufa represents precipitation of $CaCo_3$ at spring heads resulting from degassing of CO_2 at spring orifice. Right: Paleobotanical remains. Thin section of silicified plants in earthy claystones thought to represent sedimentary record of lake margin wetlands. Micrograph width is 1.9 mm.



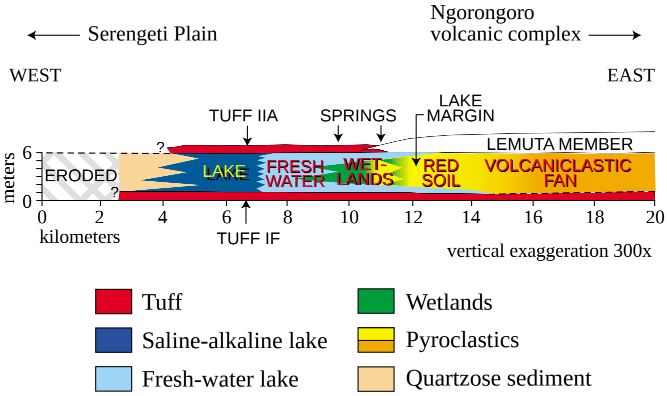


Figure 8. Time slice of Lowermost Bed II is 20 km wide and 6 m high. Sedimentary facies analysis reveals a volcaniclastic fan building from east into saline-alkaline lake that was freshened slightly in vicinity of the wetlands. Streams drained into western part of lake from Serengeti.

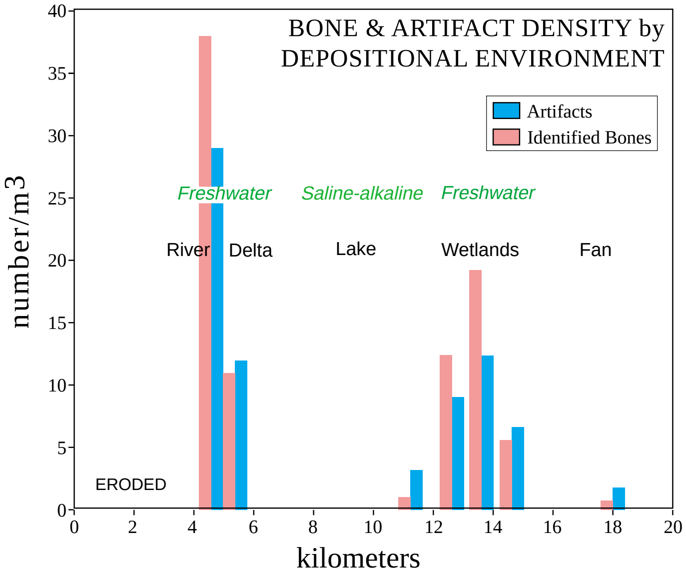


Figure 9. Preliminary results of density of identified bone and artifacts as a function of depositional environment. Greatest density is in a river draining from Serengeti, but a surprisingly large concentration was found in spring-fed wetlands located on eastern lake margin. This suggests focus of hominid activity that had not been recognized before.

CONCLUSIONS

This example from East Africa demonstrates that multidisciplinary approaches and integrative science are absolutely critical to answering the many questions of paleoenvironmental reconstruction. The high density of bones and artifacts in the wetland environment strongly suggests a focus of hominid activity at the lake margin directly related to the appeal of the wetland rather than the presence of the saline and alkaline lake. The importance of wetlands to the ecology of hominids at Olduvai was not recognized before. This linkage might not have been noticed by geologists or archaeologists or anthropologists working alone.

ACKNOWLEDGMENTS

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REFERENCES CITED

Blumenschine, R. J., 1995, Percussion marks, tooth marks and experimental determinations of the timing of hominid and carnivore access to long bones at FLK Zinjanthropus, Olduvai Gorge, Tanzania: Journal of Human Evolution, v. 29, p. 21–51.

Bunn, H. T., 1981, Archaeological evidence for meat-eating by Plio-Pleistocene hominids from Koobi Fora and Olduvai Gorge: Nature, v. 291, p. 574 –577.

deMenocal, P. B., and Bloemendal, J., 1995, Plio-Pleistocene climatic variability in subtropical Africa and the paleoenvironment of hominid evolution: A combined data-model approach, *in* Paleoclimate and evolution, with emphasis on human origins: New Haven, Connecticut, Yale University Press, p. 262–288.

Deocampo, D. M., 1997, Modern sedimentation and geochemistry of freshwater springs: Ngorongoro Crater, Tanzania [Masters thesis]: New Brunswick, New Jersey, Rutgers University, 140 p.

Hay, R. L., 1976, Geology of the Olduvai Gorge; a study of sedimentation in a semiarid basin: Berkeley, University of California Press, 203 p.

Hay, R. L., 1990, Olduvai Gorge; a case history in the interpretation of hominid paleoenvironments in East Africa, *in* Laporte, L. F., ed., Establishment of a geologic framework for paleoanthropology: Geological Society of America Special Paper 242, p. 23–37.

Leakey, M. D., 1971, Olduvai Gorge: Excavations in Beds I and II; 1960–1963: Cambridge, UK, Cambridge University Press, 309 p.

Peters, C. R., and Blumenschine, R. J., 1995, Landscape perspectives on possible land use patterns for Early Pleistocene hominids in the Olduvai Basin, Tanzania: Journal of Human Evolution, v. 29, p. 321–362.

Wood, B., 1994, The oldest Hominid yet: Nature, v. 371, p. 280–281. ■