ECOLOGICAL AND BEHAVIORAL IMPLICATIONS OF NEW

ARCHAEOLOGICAL OCCURRENCES FROM UPPER BURGI EXPOSURES AT

KOOBI FORA, KENYA

by

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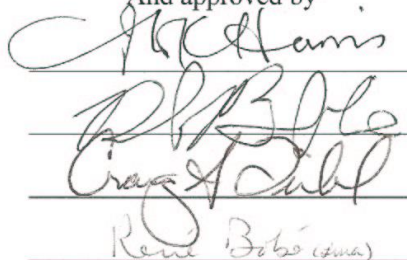In partial fulfillment of the requirements

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ABSTRACT OF THE DISSERTATION

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The appearance of the genus *Homo* is a landmark event in human evolution. While extensive research has been conducted regarding the physical evolution of this genus, there has been little research into evolving behaviors that may have differentiated *Homo* from the earlier hominins. Australopithecines were present in East Africa from about 4.4 million years ago to perhaps 0.7 million years ago, but there is presently no evidence of tool use (stone tools or modified bone) prior to 2.5 million years ago. The introduction of significant amounts of meat into the diet coupled with the use of stone tools near the end of the Pliocene may represent early behaviors that define the genus *Homo*. The exposed sediments of the Upper Burgi Member at Koobi Fora provide a

unique opportunity to study the factors that drove the onset of this behavior. Koobi Fora has yielded a continuous paleontological record of hominin evolution that extends back over 4 million years, including early *Homo* fossil skulls KNM-ER-1470 and KNM-ER-1813. However, there has been no *systematic archaeological* research conducted in the time interval prior to 1.9 million years ago when the Upper Burgi Member sediments were deposited.

This research addresses that void through a systematic ecological, geological, and archaeological study of specific Upper Burgi exposures. Surface survey and excavation produced fossil flora and fauna from these ancient sediments enabling detailed reconstruction of animal communities and hominin habitat. Fossil bones of animals exploited for food preserve unequivocal evidence of hominin modification during butchery and these modified bones are the archaeological traces that this research utilized to identify hominin presence on the landscape and associated habitat utilization. This study focuses on evolving behavior defined by these new archaeological traces to make meaningful inferences about changing diet and foraging strategies at geographically widespread locations across the ancient Upper Burgi landscape. Utilizing the data developed in this research together with published data from other late Pliocene sites in Kenya and Ethiopia, a model of this unique behavior is hypothesized for this specific region of East Africa.

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Introduction

Koobi Fora preserves an almost continuous sedimentary archive of the past four million years of human evolution; yielding some of the earliest and most complete fossils of early hominins, one of which almost certainly gave rise to modern humans. Around 2.0 million years ago populations of a new genus, *Homo*, roamed the ancient Koobi Fora landscape. And while the fossil evidence is well documented, virtually nothing is known of the behavior of these creatures or the habitat they exploited. This dissertation research aims to provide context to the existing fossil evidence and make meaningful inferences about hominin behavior and ecological interactions during this very significant time interval. Modification marks on the surface of fossil bones, which were exploited for food, are hypothesized to serve as a proxy for hominin behavior and presence on the landscape and to complement the more traditional archaeological evidence of stone tools. This research is also a multidisciplinary study with much of the field and laboratory work focused on terrestrial vertebrate fossils as indicators of habitat, paleoenvironment, and paleoecology.

Historical Background and Theoretical Basis of Research

The earliest material manifestations of culture in the form of stone tools and evidence of human modified bone first appear in the geological record at Gona and the Awash Valley, Ethiopia (Harris 1983; Semaw et al. 2003 & 1997; de Heinzelin et al. 1999) and the Lake Turkana Basin, Kenya (Roche et al. 1999; Kibunjia 1994; Kibunjia *et*

al. 1992), between 2.6 and 2.3 million years ago against a background of changing
environmental conditions. Moreover in this time interval little is known about the
function and adaptive role that the earliest stone tools played in hominin foraging strategy
and diet. Moreover during this time period the hominin lineage was experiencing a
remarkable adaptive radiation and the first members of the genus *Homo* evolved to
exploit new and different niches that were a product of environmental change.

Based upon fossils discovered at Olduvai Gorge, Tanzania; Louis Leakey *et.al.*
(1964) defined a new species that represented the earliest example of the human genus;
Homo habilis. Fossils of some late Pliocene hominins (*Homo habilis* and *Homo
rudolfensis*) found at locations in East and South Africa (Figure 1-1) are both different
and distinct from known fossils of both *Homo erectus* and the ancestral
australopithecines. Populations of hominins that continued to depend upon a diet of nuts,
grasses, tubers and roots would eventually evolve specialized body and dental
morphology to exploit different facets of this dietary niche (*Australopithecus boisei*).
Late Pliocene fossil evidence indicates that other populations followed a different
evolutionary path (*Homo habilis*). Tool use, as a major factor in diet shift towards meat
and marrow, caused evolutionary changes also. Tools functioned as substitutes for the
large canines, sharp carnassials, and powerful jaw muscles of the other members of the
carnivore guild. They were necessary in order to process a carcass so that the available
high energy fat and protein resource could be accessed and exploited. The reduction in
tooth size of early *Homo* has been interpreted as an indication of reduction in emphasis
on mastication as a means of pre-oral food preparation and breakdown (Wood, 1992). If
hominins (early *Homo*?) had indeed developed an adaptation to significant carnivory then
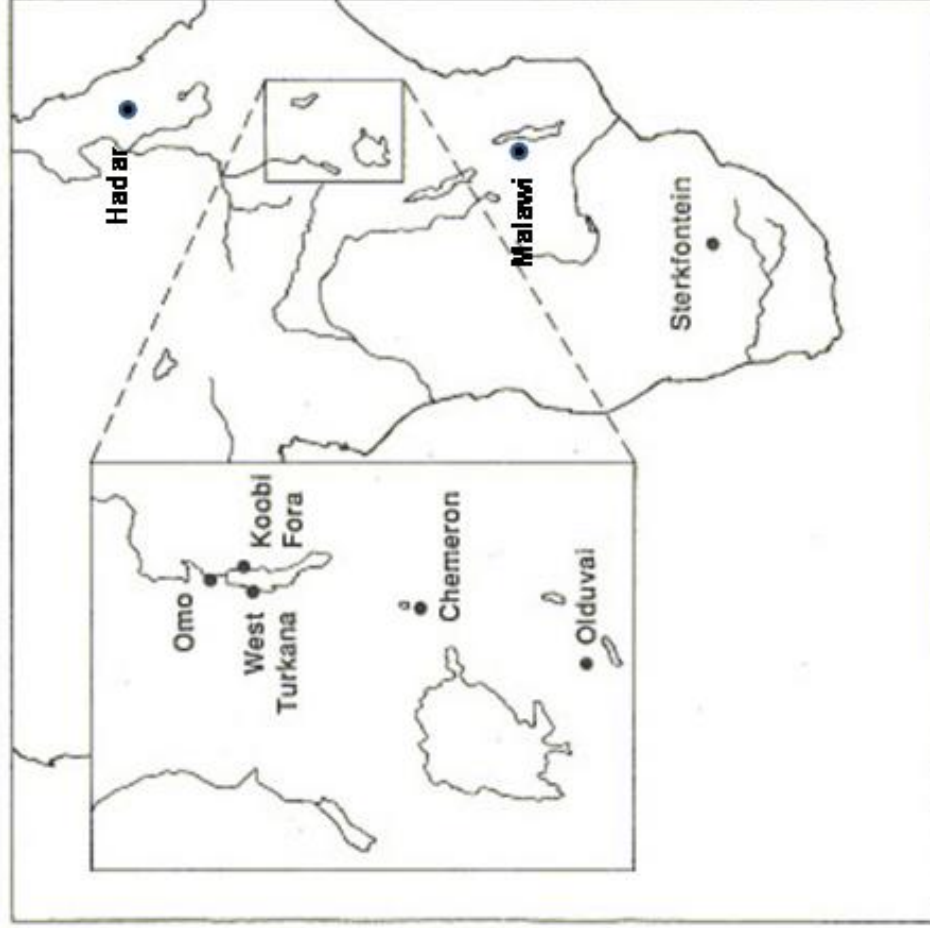
Homo habilis
Hadar
Omo
Koobi Fora
Olduvai Gorge
Sterkfontein

Homo rudolfensis
Omo
Koobi Fora
Olduvai Gorge
Malawi
(Wood & Strait, 2004)

Figure 1-1: Late Pliocene _Homo_ sites (adapted from Wood, 1992)

some kind of tools would have been required to exploit this incremental food resource because reduced canines and relatively small bunodont hominid premolars and molars were simply not capable of the slicing and crunching required. It is hypothesized that generalized *Homo* dentition is at least partially an artifact of increased dependence on meat.

Nevertheless there is still controversy regarding the taxonomic classification of early *Homo*. Cladistic analysis based on fossil morphology along with reconstructions of habitat and niche exploitation have led Wood & Collard (1999) and Wood & Strait (2004) to argue that *Homo habilis* / *Homo rudolfensis* actually should be assigned to the genus *Australopithecus*. The limited postcranial fossil evidence of *Homo habilis* makes it difficult to fully address this controversy. There are, however, abundant fossil cranial specimens and powerful behavioral evidence that supports inclusion of these new species (*habilis* and *rudolfensis*) into the genus *Homo*. Roughly simultaneous appearance of stone tools (either pre-Oldowan or threshold hypothesis) coupled with almost exponential brain expansion exhibited by *Homo habilis* / *Homo rudolfensis* after about 2.5 million years ago support the inference of a speciation event sometime prior to 2.5 million years ago that spawned the human lineage (Figure 1-2). The australopithecines also exhibited brain expansion during this same time period. The regression lines in Figure 1-2, show that australopithecine brain size exhibited slight gradual increase over time (perhaps 25% over 2.5 million years), while *Homo habilis* / *Homo rudolfensis* brain expansion (approximately 50% over 50,000 years) appears to be on an entirely different evolutionary trajectory. This figure is based on absolute brain size. However, if brain size is standardized to body size, the percentage increase of *Homo habilis* over the

Figure 1-2: Late Pliocene hominin brain expansion: Implications of stone tool use and diet change

(Data from: Klein, 1999; Fuentes, 2001)
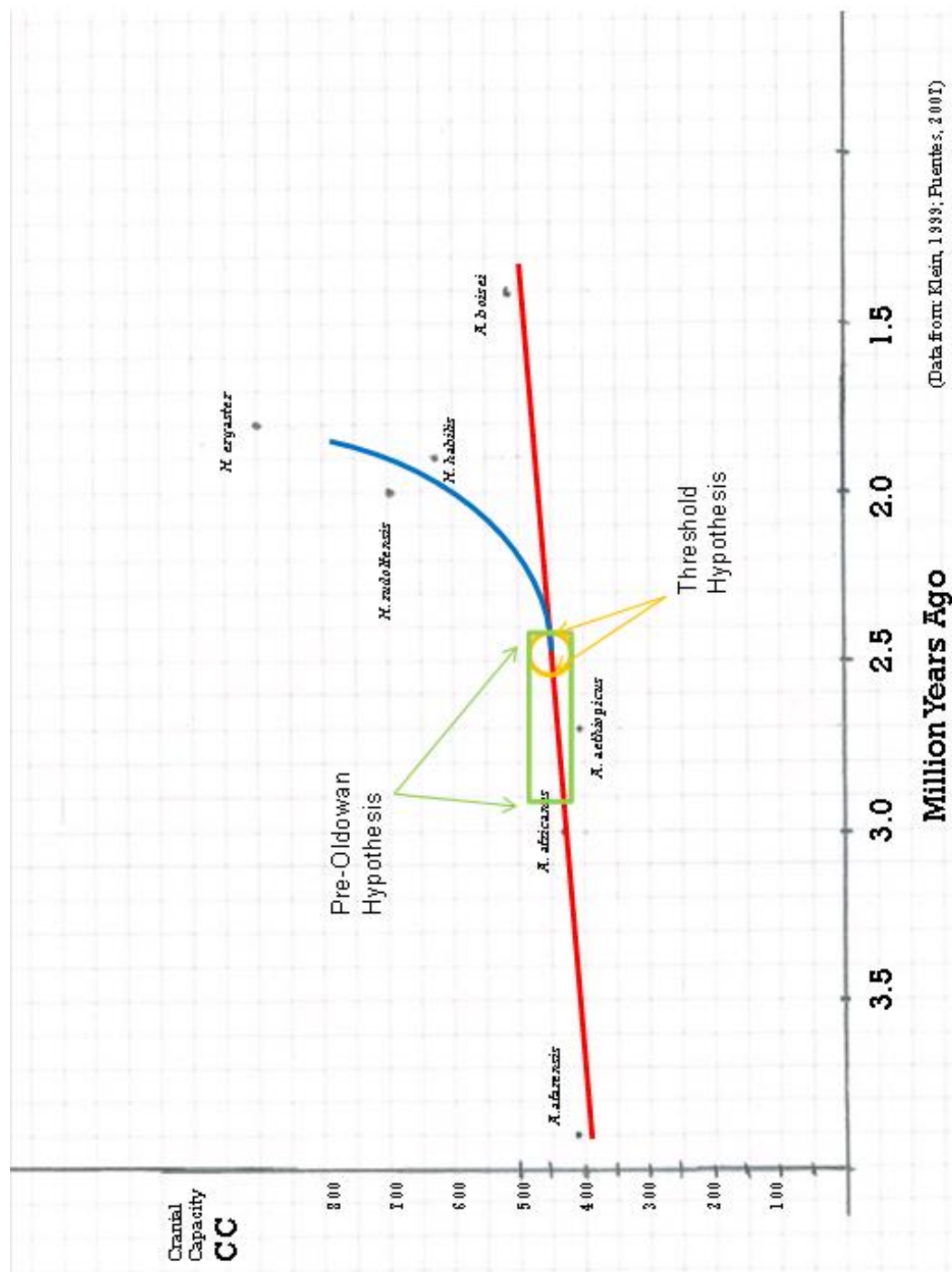
australopithecines is even more dramatic. Interestingly, the genus *Theropithecus*,
representing large body terrestrial primates that shared the Plio-Pleistocene landscape
with *Homo habilis* and *Australopithecus boisei* in East Africa exhibited no increase in
brain size over the same time period (Elton *et al*., 2001). This data can be interpreted as
three distinct genera evolving differently in response to different selective pressures
present in the same general environment.

Even with this larger brain, early *Homo* was still a diminutive creature (as shown
in Table 1-1) that maintained many of the postcranial features and adaptations of the
ancestral australopithecines.

		Body Weight			Stature	
		Male	Female		Male	Female
A. afarensis		45 kg	29 kg		151 cm	105 cm
East African Robust Australopithecines		49 kg	34 kg		137 cm	124 cm
H.habilis/H.rudolfensis		52 kg	32 kg		157 cm	125 cm

Table 1-1   (adapted from Klein 1999)

This dissertation research provides one of the first opportunities to study, on a
landscape scale, basic ancestral behaviors that are humanlike rather than apelike. These
behaviors, that we can begin to recognize for the first time in the archaeological record,
include stone tool use, the incorporation of meat into the diet (carnivory), and new
foraging patterns where certain tracts of the ancient landscape were exploited
infrequently while others were intensively used, as evidenced by modified bones and the
discard of stone tools. Whereas the Koobi Fora region has yielded a continuous
paleontological record of hominin evolution that extends back over 4 million years (M.G.

Leakey *et al*. 2001), there has been little systematic archaeological research conducted in the time interval prior to 1.9 million years ago when Upper Burgi Member (2.2-1.9 million years ago) sediments were deposited (Isaac *et al*. 1976). This was a period of environmental variability in East Africa (Potts 1996) and an important period in hominin evolution that includes the first appearance of the genus *Homo*. Although little of the behavioral dynamics or details of new foraging patterns has been reported an established pattern of hominin carnivory, dependent upon stone tool technology, already existed to the north in the Middle Awash Valley at Bouri, Ethiopia (de Heinzelin *et al.* 1999) and only a short distance to the west on the other side of the Turkana basin at Lokalalei, Kenya (Roche *et al.* 1999; Kibunjia *et al.* 1992). And yet, at Koobi Fora, where the fossil remains of over three dozen hominins (genera: *Australopithecus* & *Homo*) have been recovered from Upper Burgi exposures (Appendix 1-1) virtually nothing is known of hominin carnivory, ecology, or material culture during this period. This research is designed to address this lack of knowledge through a systematic ecological, geological, and archaeological study of specific Upper Burgi exposures where vast tracts of the ancient landscape are exposed. Stone tools are the archaeological traces that have traditionally been used to reconstruct hominin behavior. Testable hypotheses about hominin behavior can only be formulated if the hominins can be spatially and temporally located on the landscape. Fossil bone preserves unequivocal evidence of hominin modification during butchery (Binford 1981; Bunn 1981; Maguire & Pemberton 1980; Blumenschine 1995). This study will concentrate on evidence of hominin ranging patterns on the landscape and changes in hominin diet through the proxy of stone tool modified fossil bone. Fossil flora and fauna are preserved in the ancient sediments

allowing for the detailed reconstruction of ancient habitats and animal communities, therefore making it possible to take an ecologically based landscape approach to the investigation of hominin foraging behavior and diet during Upper Burgi Member times.

In the 1970s most of the archaeological studies at Koobi Fora were focused on the younger, early Pleistocene deposits of the KBS Member and Okote Member where some of the richest and most informative archaeological traces have been found in the time interval 1.8-1.4 million years ago (Isaac & Harris, 1978). With the exception of FxJj-13 (Isaac *et al.* 1976), a small surface occurrence, no stone tools have been recovered *in situ* from the Upper Burgi Member, although these deposits have yielded some of the most important hominin finds; including the almost complete early *Homo* fossil skulls, KNM-ER-1470 and KNM-ER-1813 (Leakey, R. E. *et al*. 1978; Feibel *et al*. 1989). However, the absence of stone tools does not necessarily mean the archaeological record does not exist. In the absence of stone tools, hominin modified bone is a valid archaeological trace indicative of stone tool function and a probable shift in hominin diet. Evidence of modified fossil bone is a major component of this research. Bone is modified by hominins and other carnivores as they feed, and also as the result of a wide variety of other biotic as well as abiotic environmental agents. In the case of hominin modified bone, this research builds upon the major field and experimental studies undertaken by investigators such as Binford (1981), Blumenschine (1995, 1989), Bunn (1997), Capaldo (1994), Marean (1991), and Selvaggio (1994). At Koobi Fora, paleoanthropologists have been able to reconstruct many aspects of hominin behavior found in the archaeological record beginning approximately 1.9 million years ago based largely on the traditional evidence of stone tools. In contrast, this research at Koobi Fora is designed in an

innovative way to elucidate hominin ecological interactions and behaviors such as diet, ranging patterns and even changes in cognitive ability for the period immediately prior to 1.9 million years ago where the traditional evidence of material culture so far appears to be absent.

Koobi Fora Research

This research builds upon nearly three decades of multi-disciplinary investigation at Koobi Fora that produced extraordinary scholarship significantly increasing the understanding of all aspects of human evolution and the emergence of material culture. Richard Leakey organized and coordinated the initial interdisciplinary research team and was instrumental in many of the significant hominin fossil discoveries at Koobi Fora (Leakey, R.E *et al*. 1978). Glynn Isaac and Jack W. K. Harris developed new approaches and techniques to study the archaeology of Koobi Fora that extended back 1.89 million years and was scattered over an area of more than 3,000 square kilometers (Isaac & Harris 1978; Isaac *et al*. 1976). Their innovative "landscape approach" introduced the "scatters between the patches" methodology to the study of the archaeological record allowing for the development of new testable models of evolving hominin behavior. The distribution of many sites across the ancient landscape, rather than single sites, became the points of reference. This was accomplished in conjunction with field studies conducted by Behrensmeyer (1978, 1975) enabling the archaeological evidence to be put into a meaningful taphonomic and ecological context. Bunn (1981), Potts and Shipman (1981), Toth (1982), and Schick (1984) expanded the initial studies of Isaac and Harris with more detailed investigations of bone modification, stone tool technology, and site formation processes respectively. Detailed geological studies of the sedimentary history

of the East Turkana basin conducted in the 1980s and 1990s (Brown & Feibel 1986, 1991) made it possible to reconstruct vast tracts of the ancient landscape and describe paleogeographic changes through time; facilitating the study of archaeological traces of behavior at specific time intervals with a basin wide or regional scale of reference. This type of study was undertaken in the Okote Member (1.6-1.4 million year ago) by Stern (1994) and Rogers (1997, 1994) and more recently in the KBS Member (1.8-1.6 million year ago) by Braun (2006). This dissertation research was conducted in the oldest body of deposits (Upper Burgi Member) yielding archaeological traces discovered as part of preliminary pre-doctoral field research conducted in 2001.

The exposures at Koobi Fora present a unique opportunity to investigate hominin behavior during a critical period in human evolution (2.2-1.9 million years ago) from a landscape perspective. The nature of fossil bone preservation at Koobi Fora is such that traces of hominin modification can be unequivocally identified. Because of the vastness of the Plio-Pleistocene exposures at Koobi Fora and the selection of widely separated areas of investigation it will be possible to develop an almost regional view of hominin activities and movements during this time period, utilizing modified bone and stone tools as markers on the landscape within a context of faunal evidence of paleoecology and sedimentary evidence of paleoenvironments. Recognition of the distribution patterns of these markers across widely different geographic locations and paleoenvironments makes it possible to begin to address theoretical questions of hominin habitat preference, movement across the paleolandscape, and changes in diet and behavior at this early stage of human evolution that have not been addressed elsewhere. This research will expand the breadth and depth of the previous work done at Koobi Fora by opening the Upper

Burgi Member period to new archaeological study and will add perhaps an additional 300,000 years to the continuous archaeological record of hominin behavior in the East Turkana basin. This research goes beyond the discovery and initial description of the archaeological traces. Specifically the circumstances that made stone tools adaptive at the onset of a novel new hominin behavior (carnivory) that would eventually become habitual, is examined. On a broader perspective, this project has the potential to confirm the usefulness of modified fossil bone as an unequivocal proxy for stone tool use and may provide a new perspective from which to investigate the "pre-Oldowan" and define the true onset of the archaeological record.

The Archaeological Evidence

The onset of the archaeological record is currently defined by the presence of stone tools. Much of the earliest field research involving hominin behavior revolves around the manufacture, use, and discard pattern on the landscape of Oldowan stone tools. Stone is an almost perfect medium to preserve definitive evidence of hominin activity because of its durability. Stone fractures in a unique manner when modified by hominins and is likely to preserve evidence of modification over an almost unlimited span of time and a wide array of geological and environmental conditions. A significant number of behavioral inferences have been formulated from the existing lithic evidence. Several decades ago it was discovered that these stone tools produced a use trace on the fossilized bones of exploited fauna. Bone modified by hominins can preserve an unequivocal hominin signature in a manner analogous to stone tools. Research on cut marks (Bartram & Marean, 1999; Blumenschine *et al*., 1996; Capaldo & Blumenschine, 1994; Bunn & Kroll, 1986; Shipman & Rose, 1983; Binford, 1981; Bunn, 1981) and bone

fracture patterns (Blumenschine & Selvaggio, 1988; Capaldo & Blumenschine, 1994; Blumenschine & Marean, 1993; Bunn, 1989; Maguire & Pemberton, 1980; Pickering *et al*. 2005) suggests that modified bone has the potential to provide significant new archaeological data relating to early hominin behavior. As hominin exploitation of large vertebrates for food increased during the Pliocene it is heuristically reasonable to assume that a great number of modified bones and bone fragments were produced as a result of this behavior. Valuable behavioral information would be preserved in these modified bones. In order to retrieve this information it is necessary to understand the nature of the damage hominins inflicted upon fresh green bone while extracting meat and marrow; how the modification by hominins differed from that of other modification agents, and how to mediate the possible equifinalities. Unfortunately for paleoanthropologists, bone does not survive as well as stone over time. While various taphonomic factors will filter and reduce much more of the faunal archaeological record than the lithic archaeological record, the total taphonomic history of a faunal assemblage has the potential to add context to the behavioral information contained in the individual fossilized bones that survive and are recovered (Behrensmeyer, 1991).

Modified fossil bone from the Pliocene is rare (Table 1-2). This may be because the behavior itself was not common, evidence may have been deleted from the sedimentary archive by taphonomic factors, or simply that little field research focused on modified bone has been undertaken. The following is a brief review of the existing evidence. One of the goals of this dissertation research is to significantly increase the sample of modified bone from the Pliocene.

Late Pliocene Modified Bone Sites

Site	Age (mya)	Artifacts	Modified Bone (#)
OGS6Ounda Gona, Ethiopia	2.6	Yes	Yes (1)
EG13Kada Gona, Ethiopia	2.6	Yes	Yes (1)
WG9Kada Gona, Ethiopia	2.5	Yes	Yes (2)
Bouri, Ethiopia	2.5	No	Yes (3)
Lokalalei 2CWest Turkana, Kenya	2.34	Yes	Yes (NR)
DAN2Kada Gona, Ethiopia	2.1	Yes	Yes (5)
Kanjera South Kenya	2.0	Yes	Yes (NR)
FwJj20Koobi Fora, Kenya	1.95	Yes	Yes (16)
FLK "Zinj"Olduvai Gorge, Tanzania	1.76	Yes	Yes (172)

Table 1-2   Bunn & Kroll, 1986; de Heinzelin *et al*. 1999; Plummer, 2004; Dominguez-Rodrigo *et al.* 2005; Braun *et al*., in press)

Biostratinomy

The potential for preservation of evidence of bone modification is a function of

bone chemistry, bone micro and macro structure, as well as a host of taphonomic and

diagenetic processes. Traces of carnivore and early hominin modification of bone are

almost exclusively limited to the initial part of the taphonomic period of biostratinomy

when muscle, organ and marrow are still fresh and exploitable as food. This nutritive

phase, or resource life, is the time period from the death of the animal until all edible

tissues are consumed or destroyed by decay, autolysis or putrefaction (Capaldo &

Blumenschine, 1994; Lyman, 1994). From a behavioral standpoint, the most interesting

and important taphonomic aspects of bone depend upon the energetic properties (food

value) during its resource life. During this perimortem period, the physical and chemical

properties of bones are virtually identical to those of living bone. Fresh or green

mammalian bone when subjected to external stress and strain will react in a predictable

way and within a specific range of variation according to the principles of biomechanics.

Fresh green bone has a high moisture content and fresh marrow. It is viscoelastic and

able to absorb significant amounts of stress and strain before failure. Stress applied to

bone can consist of one, or the sum of any of the following force components: tension

(stretching apart), compression (squeezing together), shear (oblique tear). Increasing

stress results in strain (deformation) and exceeding the strain limit will eventually result

in failure (fracture). Bone is stronger in compression and shear than in tension and

therefore all fracture is initiated in the region of highest tensile strain (Johnson 1985,

1989). Being viscoelastic, bone does not deform elastically up to fracture point but rather

exhibits plastic strain in response to stress which results in irreversible damage at the

micro level. This micro cracking is a cumulative process that causes localized

mechanical failure (fracture) where there is excessive tensile strain. As an initial tensile

fracture propagates through compact bone matrix, strain is relieved at the initial fracture

site but new waves of stress flow through the bone matrix causing a *fracture front* that

follows a helical path at an angle of approximately 45 degrees to the long axis of the bone

(spiral fracture). The phenomenon of spiral fracture in fresh bone is due to a complex

interaction of factors such as the shear component of the stress wave vector and the spiral

helix structure of the collagen/hydroxyapatite scaffolding in green bone (O'Connor,

2000; Johnson, 1985; 1989). Spiral fractures readily propagate through the compact

matrix of long bone shafts producing fragments. However, the stress waves do not pass

freely into the epiphyseal ends but rather are reflected or diffused by the cancelleous bone

that is predominant in the epiphyses.   Spiral fracture of green compact bone can be

produced by a high momentum impact of a stone cobble {*dynamic loading* with the

application of a concentrated force over a very short time (high df/dt)} or by application

of the focused constant pressure of carnivore teeth {*static loading* with the application of

a concentrated force over relatively long time (low df/dt)} (Johnson, 1985). Spiral

fracture is roughly analogous to conchoidal fracture of stone but lithics and bones differ

structurally and mechanically and conchoidal fracture of stone is a useful but imperfect

analogy for spiral (helical) fracture of bone.

Weathering and Diagenesis

The nutritional utility of consumable tissues associated with bone does not

survive long in the heat of Sub-Saharan Africa. "Bone is evidently a very short-lived

material in surface environments and must be left in actively aggrading depositional

situations in order to survive intact. If bones are to maintain a fresh and unweathered

appearance, they must be buried soon after the death of the animal" (Behrensmeyer,

1975, p. 480). After death, bone tissue (whole bones as well as fragments) begins to

rapidly change with a resulting alteration of chemical and physical properties (Hedges,

2002). Postmortem changes in bone tissue are a function of a complex suite of

environmental factors such as temperature, humidity, exposure to sun, acidity or

alkalinity of the surrounding soil matrix, anoxic or aerobic conditions (Behrensmeyer, 1978). When stripped of surrounding tissue and exposed to sun and air, bone begins to desiccate. Desiccation causes bone surface to exfoliate and fracture patterns to change. Desiccated bone is no longer viscoelastic or anisotropic but rather is a brittle material with specific fracture characteristics. Desiccated bone does not fracture in a spiral manner but rather tends to fracture either parallel or perpendicular to the long axis of the bone (Johnson, 1985; Behrensmeyer, 1978). Within weeks to months of initial exposure, bones left on the surface begin to exhibit these effects of chemical and physical weathering and will disintegrate within 3 to 10 years under almost all surface conditions. Using modern observations of bones on the East African landscape, Behrensmeyer (1978) defined "stages" of disintegration of these bones based on the time the bone remained on the surface and the amount of damage present. These weathering stages can be a useful analog for examining fossilized bone since weathering damage may be preserved in the fossilization process providing taphonomic evidence as to the environment of the bone assemblage prior to fossilization. Care must be taken when applying weathering stages to bone assemblages as equifinalities exist due to the extreme variability in environments and the complexity of the fossilization process.

The period of diagenesis can be defined as the chemical and mechanical action after burial when faunal remains are no longer food sources for other organisms (Marean 1991); "from burial to reexposure" (Johnson 1985); or simply "post-depositional taphonomic processes" (Lyman 1994). "One reason that postdepositional factors have attracted so little explicit attention is that they are difficult or impossible to recreate or to observe directly" (Klein & Cruz-Uribe 1984). Marean (1991) agrees that there is a lack

of methodology to measure the impact of post-depositional destruction of faunal

assemblages but he also cites a lack of awareness of the problem and a belief held by

many researchers that it is insignificant. It is usually possible to differentiate between the

biostratinomic and diagenetic agent/context of bone fragmentation based upon the

appearance or morphological structure of the fracture itself. Fresh green bone fractures

differently than desiccated bone and differently than mineralized bone. Spiral fracture

implies breakage in a fresh state but does not necessarily define the actor or effector

(Johnson 1985). The following criteria can be used to distinguish between fresh fracture

and dry/mineralized fracture and can hence be an indication of biostratinomic versus

digenetic fragmentation (Johnson 1985):

Fresh Fracture	Dry/Mineralized Fracture
Radial pattern circling around diaphysis	Perpendicular to horizontal single fracture surface cutting across long axis of diaphysis
Smooth fracture surface	Rough fracture surface
Homogeneous color: external cortical surface to compact bone	Heterogeneous color: exterior cortical surface to compact bone
Obtuse & acute angles formed by fracture and cortical surfaces	Right angles formed by fracture and cortical surfaces
Loading point present	Loading point absent
Fracture front never crosscut epiphyseal ends	Fracture front can crosscut epiphyseal end

Villa & Mahieu (1991) state that bone fracture morphology attributes (fracture angle,

fracture outline, shaft circumference, and breadth/length ratios) are useful in diagnosing

post-depositional destruction but only when considered on an assemblage basis and in the

absence of diagnostic modification marks created prior to burial (cut marks, percussion

marks, trample marks, etc.). If it is the goal of zooarchaeology to make meaningful

behavioral inferences from zooarchaeological assemblages, then it is necessary to

identify those characteristics of an assemblage that are attributable to the biostratinomic

period when behavior is a factor. It is possible to detect post-depositional destruction in

an assemblage if the following reasonable, but not experimentally proven assumptions

are accepted: 1.) post-depositional processes will increase the fragmentation of bone and

decrease the identifiably of the fragments; 2.) bone elements will be fragmented or

destroyed as an inverse function of bone density (Klein & Cruz-Uribe 1984; Marean

1991), and 3.) high NISP:MNI ratios of a skeletal element are indicators of significant

post-depositional destruction (Abe *et al*., 2002). Whole or well preserved bones with no

signs of diagenetic fragmentation are an indication that the matrix deposit enclosing the

assemblage has not been extensively reworked (Behrensmeyer, 1978).

It is, however, important to remember that a diagenetic process is primarily

responsible for the preservation of most of the Plio-Pleistocene zooarchaeological record.

Permineralization, or petrifaction, is a diagenetic process whereby bone elements are

literally turned into stone. It is a process that begins at or shortly after burial and

proceeds according to two separate mechanisms (impregnation and replacement) as

mineral rich ground water percolates through the permeable pores and voids of bones.

Minerals carried by the ground water infill the interstices created in bone by the decay of

the organic collagen matrix and impregnate the voids with these minerals (Black, 1970).

Replacement or mineralization occurs as the natural minerals in the bone are removed by

dissolution in percolating ground water followed by virtually simultaneous deposition of

some other mineral substance dissolved in the ground water, usually $CaCO_3$, Fe_2O_3 or

SiO2 (Behrensmeyer, 1991: Matthews, 1962). Both processes result in a heavier, harder and stronger fossil bone that is more resistant to destructive diagenetic agents. The fossil bone usually preserves much of the original shape and macrostructure of the original bone. Under certain favorable conditions where replacement is the primary process, the original microstructure of the bone and any modification marks inflicted are preserved in great detail. The burial environment most conducive for bone preservation is slightly alkaline with available CaCO3 (Behrensmeyer, 1978).

Marks on Bone

Bone modification can be defined as "any alteration in the size, structure or texture of bone by an external agent" (Marshall, 1989 p.8). This involves both a process (activity, agent, cause, force) and a pattern (effect) and it is now often possible to unequivocally assign the process from the pattern evident on the fossil bone. Close association with stone artifacts in the archaeological record is no longer sufficient evidence that modification marks on fossil bone are the primary result of hominin activity (Marshall, 1989).

Tooth marks on fossil bone can provide unequivocal evidence of carnivore exploitation of a carcass for nutrient extraction during the biostratinomic phase of a bone's existence history. Tooth marks on dense compact bone appear as "roughly circular to equilateral depressions (pits) or more linear marks (scores)" (Blumenschine & Marean, 1993, p.280). In cross section, the pits appear bowl-shaped and the scores are U-shaped. The internal surfaces of pits and scores usually show evidence of crushing when viewed under minor magnification in strong, low-incident light. These marks are often isolated, inconspicuous, and shallow but can be identified with a great deal of certainty

following experience and practice with control collections (Blumenschine & Marean, 1993). Tooth marks on cancelleous bone (many axial elements and epiphyses of long bones) are far more conspicuous and easily identified. Punctures and Furrows are created when the carnivore bites through the thin compact bone covering the grease-rich cancelleous bone creating surface marks that are deep, circular, semicircular, and linear depressions (Binford, 1981). These marks are often associated with heavily gnawed ends or edges of bones. A previously ignored source of carnivore tooth mark damage was addressed by Njau and Blumenschine (2005) with their research involving crocodile feeding on large mammals. As they feed, crocodiles create very specific damage patterns on the large mammal bones that they fail to ingest. Tooth scores produced are often linear and sometimes "V-shaped" in cross section. Fortunately they are almost always associated with distinctive hook-shaped scores and/or bisected punctures and pits along with a complete lack of gross gnawing on the epiphyses. This suite of characteristics is specific to exploitation by this large carnivorous reptile.

Cut mark evidence has long been used to define hominin involvement in fossil bone assemblages. The use of stone tools to disarticulate a carcass or remove skin, meat, or tendon from bone results in distinctive damage to the surface of fresh green bone. Cut marks produced by stone tools are generally very fine isolated, or sets of sub-parallel, linear grooves scratched into the bone surface that are usually several millimeters to several centimeters in length. When viewed macroscopically, the grooves are straight sided and V-shaped with a relatively flat bottom (Bunn, 1981). When examined with a hand lens under strong light, parallel microstriations are visible on the bottom and internal surfaces of the grooves (Blumenschine *et al.*, 1996). Based on scanning electron

microscope (SEM) studies, a slicing mark on bone is defined as "an elongate groove

containing within its edges multiple, fine, parallel striations oriented longitudinally.

Slicing marks sometimes appear to be V-shaped in section, especially when viewed from

above, but their actual cross section is of variable shape" (Shipman & Rose, 1983, p.64).

The diagnostic traits of stone tool cut marks are apparently independent of the raw

material of the tool or the relative sharpness of the edge (Shipman & Rose, 1983)

although this observation has yet to be subjected to rigorous actualistic testing. With

experience, cut marks are easily distinguished from carnivore produced marks such as

tooth scores and furrows that are shallow, U-shaped, usually in low-density patches and

often not linear. Also, microstriations within the edges of carnivore produced marks are

rare (Blumenschine *et al.*, 1996; Potts & Shipman, 1981). The location and frequency of

cut marks can also be diagnostic. Archaeological evidence, ethnographic and actualistic

studies have shown that cut marks usually exhibit a frequency and location pattern on a

specific skeletal element that is related to the anatomical location of muscle, tendon and

ligament attachments of the animal being exploited (Binford, 1981; Bunn & Kroll, 1986;

Lyman, 1994).

Cut marks are an excellent diagnostic indicator of hominin behavior. Through

solid relational analogies it is possible to track from the trace (cut mark) to the causal

agent (stone flake) to the effector (hominin hand) and all the way to the actor (the

hominin) with a great deal of inferential confidence (Gifford-Gonzalez, 1991).

Actualistic studies show that many cut marks appear on or near epiphyseal surfaces

where major muscle and tendon anchor points are located and also on mid-shafts where

flesh scraps still remain on scavenged limb bones. Of limb bones scavenged from felid

kills, "only 10% of the bones bearing any flesh scraps had scraps on the mid-shafts. Thus, 90% of the scraps on limb bones occurred on the proximal/distal sections" (Dominguez-Rodrigo, 1999, p. 382). Unfortunately these sections of bone do not survive well in the archaeological record because of carnivore ravaging for grease; and also post-depositional processes that differentially destroy less dense, cancellous bone that dominates in epiphyseal ends (Blumenschine & Marean, 1993; Lyman, 1994; Marean, 1991). There is also the possibility of equifinality because marks, virtually identical to stone tool cut marks, can be produced when bones are trampled in sandy sediment (Behrensmeyer *et al*., 1986). This equifinality can often be mediated by examining the location, orientation and frequency of the mark in relation to other suspected cut marks.

Hammer-related fracture for marrow on the long bones of larger land mammals is the focus of the following discussion. The fossil record shows that these long bones were frequently exploited for meat and marrow by both hominins and large carnivores, and because segments of these bones are more likely to be preserved in the fossil record, they have formed the basis of much of the existing zooarchaeological research (Johnson, 1985). The general structure of mammalian limb bones consists of a cylinder of dense compact bone or diaphysis capped at both ends by grease enriched cancelleous bone epiphyses. Fat-rich marrow, encased within the diaphysis, fills the medullary cavity (Johnson, 1985). Marrow is a high quality food resource routinely exploited by hominins and most of the African carnivores. The marrow is well protected by the dense compact bone of the diaphysis. An

investment in energy coupled with some kind of technology, or the proper

dental morphology, is required to harvest marrow from limb bones. Many

African carnivores, including the large African felids, have dental morphology

which evolved to grasp and tear or rip flesh away from bone but is not

suitable to fracture the limb bones of any but the youngest or smallest

mammalian prey (Marean, 1989). As a result of this, largely intact limb bones

(defined here as the humerus, radio-ulna, metacarpal, femur, tibia,

metatarsal) often remain on the landscape after a primary non- bone-

crunching carnivore has finished feeding from a carcass and are therefore

available for scavenging. When hammerstones are used to fracture these

bones to extract marrow, a distinctive and unequivocal signature is often

preserved on the bone fragments. There is considerable competition for this

rich food resource. Large bone crunching hyenas also exploit the remains of

felid kills. They possess the teeth and powerful jaw muscles necessary to

fracture long bones for marrow. The fracture signature produced by

carnivore gnawing is different from that produced by percussion fracture and

also distinctive [(Maguire & Pemberton, 1980; Pickering *et al.*, 2005;

Alcantara Garcia, (in press)]. Compact bone fracture can be defined as

localized mechanical failure in response to concentrated stress. In order to

fracture a long bone, carnivores usually chew off the epiphyseal ends first and

then, between opposing teeth, apply constant compressive pressure (static

loading) to the bone diaphysis until mechanical failure occurs. Hammerstone

percussive fracture is accomplished by a different mechanism. With

percussive fracture, mechanical failure is caused by high velocity point impact

or dynamic loading (Johnson, 1985). Both types of bone fracture produce

notches on shaft fragments that extend through the entire depth of the

diaphyseal cylinder wall and tend to preserve the original shape and

character of the fracture mechanism even in advanced stages of bone

weathering or bone surface erosion (Capaldo & Blumenschine, 1994).

Notches can be defined as "semicircular to arcuate indentation on the fracture

edge of a long bone that are produced by dynamic or static loading on cortical

surfaces. This force removes a single bone flake or nested series of flakes,

leaving a negative flake scar that extends through the entire thickness of the

bone and onto the medullary surface" (Capaldo & Blumenschine, 1994, p.

730). The differences between percussion fracture produced notches and

carnivore gnawing produced notches can be described qualitatively.

Percussion notches are broader and more shallow (arcuate) whereas

carnivore notches are more semicircular in shape. Flakes produced by

percussion fracture are generally thinner and leave broader negative flake

scars than those produced by carnivore fracture and the release angle for

these flakes is generally more obtuse than carnivore produced flakes

(Capaldo & Blumenschine, 1994). More significantly, percussion marks can

be distinguished from carnivore gnawing quantitatively. Working with

controlled bone assemblages, each produced by a single actor, Capaldo and

Blumenschine (1994) established metric criteria to define notch morphology.

Ratios of notch breath to maximum notch depth, flake scar breadth to

maximum notch depth, along with platform angle were shown, statistically, to

differentiate the actor responsible for the creation of notches on limb bone

fragments of Size 1 & 2 bovids. Notch shape was shown to be more diagnostic

than notch size. Fortunately it is possible to identify, with a high degree of

certainty, the actor responsible for producing a specific notch without the use

of sophisticated equipment or rigorous statistical evaluation. All that is

required is a hand lens, bright light and a few hours experience with a control

sample of bones that demonstrate the notch characteristics of bone

modification by different actors and effectors (Blumenschine *et al.*, 1996).

Also, it has recently been demonstrated that long bone shaft fragments in the

archaeological record produced by dynamic loading (percussion fracture)

may be differentiated from those produced by static loading (carnivore

feeding) based upon the angle formed between the cortical surface of the

shaft fragment and the smooth release surface of the green fracture plane

[Pickering *et al.*, 2005; Alcantara Garcia *et al.* (in press)].

Percussion marks on bone surfaces have also been shown to be diagnostic of

hominin activity. Pits or grooves are created on the bone surface at anvil support points

by hammer blows that do not result in fracture. Percussion pits are roughly circular in form and superficially appear similar to carnivore tooth marks. However, percussion pits are consistently associated with patches of macroscopically visible microstriations whereas carnivore tooth marks are rarely associated with these patches. These microstriations are caused by slight slippage of the hammerstone or anvil at the time of impact with the cortical surface of the bone. The patches of microstriations extend out from the pit or are located within a few centimeters of it. They are generally "shallower, narrower and usually shorter and occurring in dense unidirectional patches" (Blumenschine & Selvaggio, 1988, p. 763) and therefore easy to distinguish from cut marks and trample marks.

Like cut marks, percussion marks are excellent diagnostic indicators of hominin behavior. However, because most cut marks tend to be on the less robust epiphyseal ends, percussion marked long bone shaft fragments have much higher probability of achieving visibility in the archaeological record (Bunn, 1989). Hominin breakage of large terrestrial vertebrate limb bones for marrow, perhaps associated with a non-ephemeral affordance (e.g. large shade tree, collection of basalt clasts for use as hammer or anvil), could result in dense shaft fragment accumulations. It is hard to imagine any other process that would produce a similar concentrated pattern of percussion marked shaft fragments (Blumenschine, personal conversation, 2000). When hominins break vertebrate mammal limb bones to extract marrow, the debris that remains consists of shaft fragments, epiphyseal fragments and fragments with sections of both shaft and epiphyses. The epiphyseal fragments contain grease that early hominins would have no way of extracting. The broken shaft fragments have virtually no remaining nutritive

value. Actualistic studies show that scavengers and carnivores will almost universally ravage this kind of bone debris accumulation once it is abandoned. Hyenas routinely scavenge modern abandoned kill and camp sites; consuming or removing the low density, grease rich epiphyseal fragments in direct proportion to the grease they contain. Long bone shaft fragments tend to be ignored by carnivores because they lack food value and therefore are neither consumed nor removed but remain intact on site (Bartram & Marean, 1999; Blumenschine & Marean, 1993; Marean & Spencer, 1991). Because long bone shaft fragments are pieces of dense robust compact bone and are unattractive to ravaging carnivores, their probability of surviving in place long enough to enter the archaeological record is relatively high. Therefore the most abundant and also most unequivocal archaeological trace of early hominin tool use is likely to be percussion fractured long bone fragments of Size 1, 2 & 3 terrestrial vertebrates. One possible source of equifinality would be long bone shaft fracture caused by natural rock falls. This rather remote possibility would probably be associated with cave or cliff locations where natural rock falls are common. Percussion fractures resulting from rock fall would be virtually indistinguishable from hominin produced fractures. Archaeological context will determine if equifinality resulting from high impact rock falls is a realistic consideration.

Faunal Analysis

In paleoanthropology, a zooarchaeological assemblage can be defined as a modern trace of past hominin behavior that consists of at least one non-hominin skeletal element. In this anthropological context, fossil faunal remains are studied in order to reconstruct aspects of hominin paleoecological interactions and changing patterns of

hominin subsistence (Lyman, 1994). Paleoanthropologists collect and record details of the sedimentary context and comprehensive data about the elements in a bone assemblage such as; taxon, element, side, portion, size, age, weathering stage, modification marks. Their goal is to draw behavioral inferences from the analysis of this data. Simple association with stone tools or hominin fossils was once considered sufficient evidence to identify fossil animal bones as a zooarchaeological assemblage. Innovative ethnographic and actualistic research (Binford, 1981; Brain, 1981) have demonstrated that the Plio-Pleistocene fossil record was likely far more complex.

Historically zooarchaeological analysis has been tied to skeletal part profiles. Zooarchaeological assemblages were assumed to have been created when hominins transported segments of carcasses to specific locations on the landscape. The basic assumption behind the analysis was that bones (carcass segments) were transported and accumulated in ways that were specific to a given agent and produced a diagnostic signature that could be recognized in the archaeological record (Dominguez-Rodrigo, 2002). Based on this type of analysis, consistent patterns of skeletal elements do appear to exist at most archaeological sites. Zooarchaeological assemblages dominated by head and limb bones were hypothesized to be diagnostic of hominin created bone accumulations. The "schlepp effect" [first described by Perkins & Daly (1968) and loosely based on concepts of rational behavior, maximization of resources, minimization of effort along with an anecdotal modern analogy] described a transport strategy where a carcass (of a large prey animal) was partially butchered, with meaty limb bones defleshed at the kill site and those bones discarded there. The meat and head were transported back to a central location carried in the hide with the lower limbs and feet still attached and

utilized as handles. Variations of the schlepp effect became the accepted explanation for

hominin involvement in zooarchaeological assemblages dominated by head and limb

bones.

A second important assumption was that the zooarchaeological accumulation

would be representative of the skeletal elements originally encountered. The timing of

access to a carcass would dictate the skeletal elements that were available for transport

and eventual accumulation. This too had behavioral implications. With early access all

or most skeletal elements would be available for transport while late access to a carcass

would limit the skeletal elements encountered. Also at issue were the functions of these

accumulation sites and the specifics of hominin involvement with the carcasses. The

degree of meat transport and consumption was central to addressing these issues. If

hominins were transporting carcass elements with large amounts of meat, this might

indicate excesses of food which could imply the early appearance of aspects of cultural

behavior such as hunting or aggressive scavenging, food sharing, home base activities,

and division of labor. If the assemblages only represented transport of defleshed bones

for marrow extraction with no excess meat available, scavenging was assumed to be the

mode of acquisition and many of the cultural and behavioral implications would no

longer be applicable. Skeletal part frequencies and taxon lists were the principal tools

employed to assign meaning to the zooarchaeological sites. Assemblages dominated by

"meaty limb bones" were deemed to be home bases or central place locations attributed

to hominins that had early access to a carcass (hunting or aggressive scavenging) (Bunn

& Kroll, 1986; Isaac, 1986, 1983). Assemblages dominated by lower limb and foot

bones (non-meaty) we attributed to individual hominins that were marginal foragers

(Binford, 1981). Taxon lists were used to define the diversity of species exploited and to identify the "meaty" limb elements available from a given species. Additional useful analytical techniques were developed such as; a carcass disarticulation sequence (Hill, 1979), a carcass consumption sequence based upon comprehensive field observation of carnivore feeding behavior (Blumenschine, 1986), and the realization that hominin butchery produced unique marks that were preserved on fossil bones (Bunn, 1981; Potts & Shipman, 1981; Shipman & Rose, 1983). These techniques were often considered tangential and were usually only employed to buttress existing analyses based primarily on skeletal parts profiles. Remarkably analysis of zooarchaeological assemblages, such as the bones from FLK-Zinj at Olduvai Gorge, based on the same assemblage elements, often led to conflicting interpretations by different investigators (Bunn & Kroll, 1986; Binford, 1981; Blumenschine 1995). It became obvious that there were weaknesses associated with this type of approach.

Fortunately actualistic and ethnographic research based solidly in the principles of ecology pinpointed many of the possible equifinalities in a parts profile approach to the interpretation of archaeological bone transport and accumulation.

1.) A growing number of ethnoarchaeological investigations (Dominguez-Rodrigo, 2002; O'Connell *et al*.,1990) of modern hunter-gatherer peoples showed that there really was no one universal way that carcass parts were exploited or transported. From the fossil record, it is impossible to differentiate between what was selected and transported as opposed to what was originally available.

2.) It was demonstrated that investigator bias was a factor in many excavated assemblages. If the zooarchaeological collection emphasis was based on taxon specific

elements, the resultant assemblage was likely to be dominated by the most species

specific elements: heads (teeth, horn core, occipital condyle) and limbs (metapodials,

limb epiphyseal ends). It was demonstrated that the character of an assemblage changed

dramatically if previously ignored and not easily identified elements such as shaft

fragments were considered in the analysis (Marean, 1991; Marean & Spencer, 1991).

3.) Skeletal elements are subject to abiotic destruction during biostratinomy and

diagenesis as a function of taphonomically relevant mechanical properties such as size,

shape, articulations, and density (porosity). Elements of the head (teeth, occipital

condyles) and feet (metapodials) are among the most resistant to this destruction. Tooth

enamel is the most dense and durable material in the mammalian skeleton. Skeletal

elements of the head (occipital condyles) and feet (individual bones of ungulate manus

and pes, such as the astragalus, calcaneum) consist of dense compact bone with sizes and

shapes that differentially resist destructive processes such as weathering, fragmentation

and compaction.

4.) Skeletal elements are also subject to biotic destruction during biostratinomy. Bone

crunching hyenas can produce bone assemblages dominated by limbs and feet. Hyenas

have been shown to prefer axial elements such as vertebrae, ribs and pelves for intense

consumption. Limb bone epiphyses are also consumed but shaft fragments and

metapodials usually remain (Marean *et al*., 1992). Hyena kills as well as hyena ravaged

carcasses scavenged from other carnivores could both result in this pattern.

5.) Most bone accumulations are not the result of only one agent (actor). The refuse of

hominin hunted or scavenged carcasses that were processed for meat and marrow would

still have nutritional value to hyenas and other scavengers (Marean & Spencer, 1991;

Blumenschine, 1988). Axial elements and the epiphyses of fractured limb bones would

be exploited by hyenas for the grease they contained. This would produce a bone

assemblage dominated by limbs and feet if the bone refuse was subsequently ravaged by

bone crunching hyenas.

Meaningful inferences from zooarchaeological assemblages (eliminating the equifinalities)

Continued actualistic and ecological research has produced analytical procedures

that allow for the mediation of many of the equifinalities inherent in skeletal parts profile

analysis. The new research is centered on bone modification and the marks produced by

different actors as they feed on a carcass. It builds from a foundation of research which

has defined and quantified the characteristics and unequivocal signatures that these actors

produce on bones, and integrates this data into an ecological framework of competition

for the nutritional potential of a carcass. Different parts of a carcass are attractive to

different actors at different times during the resource life of the carcass.   Carnivore

competition plays a major role in the creation and taphonomy of faunal remains in the

archaeological record and it is likely that most zooarchaeological assemblages carry the

traces of multiple actors. Even in the absence of cut or percussion fracture marks, it is

still possible to characterize the onset of hominin-carnivore ecological interactions based

upon competition for carcasses determined via skeletal part profiles (long bone epiphysis

to shaft fragment ratios) and the locations and frequencies of carnivore tooth marks on

the fossil bones (Blumenschine & Marean, 1993). The presence of cut and percussion

marks makes it possible to track increased hominin encroachment on the carnivore guild,

as a result of the hominin diet shift towards increasing carnivory, by examining changes

in the ratios of tooth marks to cut and percussion marks in the fossil record (Selvaggio, 1994).

Increasing Inferential Confidence

Making inferences about hominin behavior, or any past or present biological system for that matter, is a risky endeavor. It is fortunately possible to make higher level behavioral inferences about prehistoric biological systems if the inferences are based on a nested series of hierarchal cause and effect relational analogies that tie an archaeological trace to a behavior in question (Gifford-Gonzalez, 1991). The more complete the chain of evidence and the closer the link from the behavior to the actual trace, the higher the confidence level of the inference. Traditional skeletal parts profile analysis involves making inferences about behaviors (hunting, scavenging, transport, accumulation) that are several relational steps away from the actual traces (bones and bone fragments). These gaps in the inferential chain are the reasons that the equifinalities described earlier plague this type of analysis. The only way to break the equifinalities of skeletal parts profiles is through the inclusion of bone modification marks in the analysis. Marks on bone reflect an actual consumption event and the trace is directly and causally related to the actor and effector. From this level, and integrated with other evidence, it is possible to construct a behavior inference without equifianalties and with a high level of inferential confidence.

The models of hominin-carnivore interaction designed around modification marks on bone have proven to be quite robust. The research cited above has been conducted by researchers with a great deal of first hand naturalistic experience with African wildlife ecology, hands-on butchery practices, and bone modification marks. They adhered to

standardized definitions of modification marks and long bone segment portions making their data compatible for statistical analysis and allowing for easier verification by future researchers. Because the models of assemblage characteristics are based on simple relational analogies, they do not appear to be subject to the equifinalities that have haunted analyses based on skeletal parts profiles.

Lupo & O'Connell (2002) and Dominguez-Rodrigo (2002) question the significance or potential of an analytical approach based on modification marks on bone. They cite inconsistencies in research results among investigators and question the validity of the research conclusions. However, they ignore the underlying reasons for the inconsistencies; the inexperience of some investigators with the subtleties involved in the recognition of all tooth marks and butchery marks, and the lack of standardized procedures to describe and measure important attributes in a bone assemblage. It is no longer sufficient to simply measure, describe and count attributes. That may be a good way to create interesting statistical relationships but it isn't good biological science. The research described above proves that there is a wealth of behavioral information contained in the fossil bones themselves, but that the "*bones are not enough*" (Gifford-Gonzales, 1991). This research was conducted based on the following principles of analysis:

1.) Start with the understanding that the bones being studied are evidence of a series of past consumption events.

2.) Understand that this behavior occurs in the general context of wildlife ecology and can be best explained within that context.

3.) Understand that consumption behavior is driven by the food value of the resource and consumption will proceed in a sequence related to the nutritional value of the segment and is a function of taxon and technology.

4.) The behavioral evidence contained in the fossil bones can only be extracted through analysis of the tooth marks and butchery marks on them.

5.) Standardization of the definitions of segment portions and mark identifications.

6.) Inclusion of all the evidence. Shaft fragments and fragmentary axial elements can often be identified by refitting or osteological landmark analysis and should not be excluded from the analysis. All marks, no matter how subtle, are usually identifiable (with experience with controlled collections) and must be included in the analysis.

7.) Conduct middle-range research based on actualism and wildlife ecology in order to construct relation analogies which will enhance the probability that higher level behavioral inferences are meaningful.

Organization of Dissertation

Chapter One begins with a statement of the research objective and follows with a review of paleoanthropological research in the East Turkana Basin. The theoretical basis for employing the analysis of the fossil fauna in order to recreate the paleoenvironments, paleoecology and hominin habitat utilization is discussed in detail.

Chapter Two focuses on the geologic history of the Turkana Basin and the processes that led to the creation of the sedimentary archive that preserves a record of human evolution and the contextual information about paleoclimates and paleoenvironments that extends from the Pliocene to the Holocene.

Chapter Three provides details of the field research that is the foundation of this dissertation. Each specific research location is identified both geographically and geologically. Research protocols are described and a summary of data collected is reported.

Chapter Four focuses on the analysis of the faunal material collected and its implications for the paleoecology and habitat reconstruction of each research location. A baseline for Upper Burgi Member times is established, in conjunction with the work of other researchers, employing a multi-disciplinary approach in area 41 (including analysis of fossil wood and stable isotopes of oxygen and carbon from tooth enamel).

Chapter Five is a detailed description of the modified bone from each research location.

Chapter Six presents an overview of the data developed in the previous chapters and a hypothesized model of hominin foraging behavior during the Late Pliocene. Future design opportunities are discussed.

Chapter 2:   Geologic History of the Turkana Basin

Introduction

The saga of human evolution had its beginnings in East Africa. According to the present fossil evidence, the first members of the hominin lineage evolved there sometime before 6.0 million years ago (Leakey *et al*., 2001; Pickford & Senut, 2001; Leakey & Walker, 1997; White *et al*., 1996) and produced an adaptive radiation that spawned several hominin species. It is also likely that our own genus, *Homo*, first evolved in East Africa, culminating in the appearance of the first hominin species (*Homo ergaster*) at 1.8 million years ago with the size, strength and intelligence to migrate out of the African continent and eventually colonize vast areas of Europe and Asia. Hominin evolution was driven by complex interactions among global, regional, and local factors. Regional geological phenomena, associated with rifting, are hypothesized to have been among the strongest drivers of this process in East Africa (Coppens, 1994) and the geologic residues of these phenomena are largely responsible for the preservation and subsequent exposure of the fossil evidence upon which the reconstruction of this incredible saga is based.

In this chapter the tectonic events that transformed the East African landscape and their impact upon hominin evolution are discussed. Also the origin of the depositional environments that preserve indications of paleoenvironments, paleoecology, and the fossil evidence of hominin evolution is explored. However, the main focus of the chapter is the formation and depositional environments of the Turkana Basin.

Africa

The continent of Africa sits astride the equator and extends almost equally north (latitude 37 degrees North) and south (latitude 35 degrees South). However, the land surface area north of the equator is roughly two times that south of the equator. Much of the interior of the continent consists of elevated plateau, especially in the south. The Great Rift Valley dominates the eastern sub-continent. Associated with rifting and geologic uplift in this area are volcanic highlands, with peaks that exceed 6,000 meters in elevation, depressions in Egypt and Ethiopia that descend to 120 meters below sea level and extensive drainage basins with large saline and alkaline lakes. The only true mountain chains are located in the extreme north (Atlas Mountains dating to the Late Mesozoic/Early Cenozoic) and the far south (Cape Ranges dating to the Middle Paleozoic/Early Mesozoic). Other continental mountains are really the erosional remains of continued continental uplift or constructive volcanic features. North of the equator the largest hot desert in the world, the Sahara, extends from the Atlantic Ocean to the Red Sea. Extensive tropical forests, with annual rainfall in excess of 2,500 mm per year cover much of western equatorial Africa (Butzer, 1982).

Africa was once part of Gondwanaland which was in turn part of the "Super-Continent" Pangaea. As Pangaea broke apart, the tectonic forces acting on the African plate produced plate movement with respect to the earth's axis. Based on paleomagnetic data and evidence of glaciation in Africa, we know that the region that is now West Africa was located over the South Pole in the early Paleozoic. In the Carboniferous Period the African plate continued to move so that what is now South Africa was located over the South Pole. By the end of the Cretaceous, Africa was about 15 degrees south of

its present position and by the mid-Miocene it had reached its current location (Butzer,

1982). The geomorphic history of the continent is one of generalized uplift since

separating from Gondwanaland. For hundreds of millions of years, the interior of the

continent has resisted crumbling and folding except in the extreme north and south.

Tectonic forces have instead taken the form of uplift and depression referred to as "basin

and swell" and the modern morphology across the continent reflects this pattern. Since

the Cretaceous, uplift has been the greatest in the south and the east. Major portions of

southern and eastern Africa were uplifted as much as one kilometer during the Cenozoic

in a geologic event known as the "African Superswell" (Partridge, *et al.*, 1995). In the

south, this uplift coupled with marginal downwarping is responsible for the distinctive

Great Escarpment that runs from Angola to the Zimbabwe-Mozambique border.

Northern Africa has generally seen less uplift and the geomorphology there has been

impacted by periodic inundation by the sea.

Over 500 million years ago, the African continent took on its present form. Since

then continued progressive uplift, gentle warping, volcanic and faulting activity, erosion

and deposition have worked to create the existing landscapes. Since the end of the

Precambrian most of Africa has behaved as a rigid block. There has been almost no

strong mountain building with associated folding and dislocation. Rock formations over

one billion years old can still be observed almost horizontal with little alteration. Most of

the continent consists of relatively thin Phanerozoic sediments on top of eroded

Precambrian rock referred to as the "basement". The basement contains some folded

schist, gneisses and granites but is mostly a thick sequence of essentially horizontal

sediments. By the end of the Precambrian most of the continent could be classified as a

stable craton. The central region of Africa has never been covered by the sea but regions

of western and northern Africa contain lower and middle Paleozoic marine sequences

related to fluctuations of the ancient Tethys Sea (Cooke, 1978). The entire continent sits

in the middle of the African tectonic plate. Until rifting began to create the Red Sea

Trough in the Oligocene, Arabia was still part of the African plate. Arabia was separated

by the mid-Miocene. The late Oligocene also saw the start of the tectonic activity that

marked the origin of the Great Rift Valley in East Africa (Denys *et al*., 1986).

Rifting

The exact mechanism that results in rifting or the breakup of continental crust is

still not completely understood and several hypotheses have been proposed (Ebinger *et*

al., 2002; Strahler, 1978; Courtillot & Vink, 1983; McGeary & Plummer, 1994):

1.) A drifting continental plate gives rise to a line of volcanoes at the surface as it passes
over a hot spot or "thermal anomaly" in the upper mantle. The continental crust is
thinned and weakened as it passes over the thermal anomaly making it prone to rifting.
2.) Continental rifting occurs along a line of serial meteorite impact craters.
3.) Passive rifting driven by remote stresses of diverging plates causing a thinning of the
continental crust which then results in a regional doming and eventually faulting with
graben formation that is followed by the release of mafic magma in the form of flood
basalts, earthquakes and volcano formation. This process is analogous to ocean basin
opening (early Wilson Cycle). (Figure 2-1)
4.) Active rifting with the continental plate stationary with regard to mantle hot spots
(thermal anomalies). A rising mantle plume heats and lifts the lithosphere in a doming
action which causes the arching and thinning of the continental crust and the rupture
under tension stress in three-armed pattern of tension rifts (two active and one aborted
branch). (Figure 2-2)

The empirical evidence from the East African rift is mixed with regard to these

hypotheses and it is likely that the actual driving mechanism is some hybrid of the above
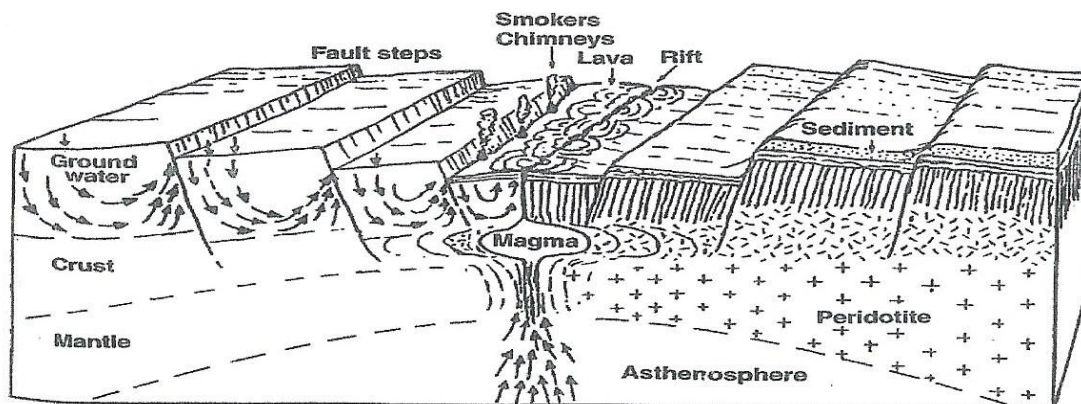
Figure 2-1: **Passive Rifting as result of Tectonic Plate Divergence and Crust Thinning (Early Wilson Cycle).**   **(from Strahler, 1998)**
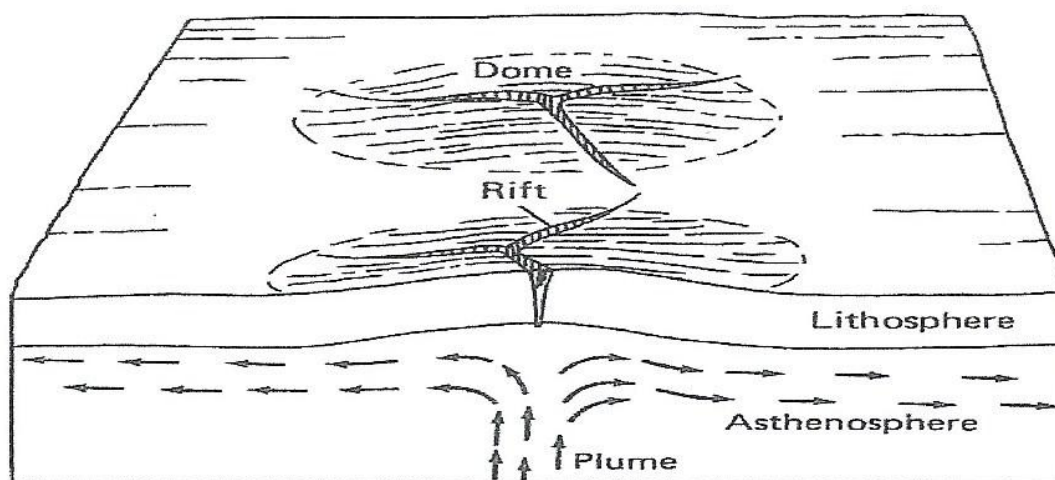
Figure 2-2: **Mantle Hot Spots as Mechanism of Rifting.**
                                    (from Strahler, 1998)

(Ebinger *et al*., 2002). The rifting that created the Red Sea and resulted in the separation of Arabia from the African plate in the Oligocene produced the classic three-branched pattern of rifts and there is evidence that this pattern is being repeated along the East African rift. Strahler (1998) proposes that a chain of these lithospheric domes with three-armed rifts will eventually connect along active rift arms to cause the continent to rift (Figure 2-3).

The East African Rift System is part of the Afro-Arabian Rift System that originates in Turkey. It passes into the African continent at the Afar depression in Northern Ethiopia and gradually disappears about 3000 km to the south near the mouth of the Zambezi River in Mozambique. It consists of several graben-like troughs (half grabens as the result of normal block faulting), each a topographically distinct rift valley 30-60 km in width. Episodes of uplift, faulting, flood basalts, and volcanism created the varied topography along the rift system. The rift passes through the Afar depression and into the broad domelike swell that comprises the Ethiopian Highlands (Ethiopian Dome) and then forms the Ethiopian rift as it moves south towards Kenya. In Kenya, the rift forms two branches. The eastern branch is called the Gregory Rift. Lake Turkana is the dominant feature of the generally featureless northern Gregory Rift that eventually exhibits more of the striking characteristics of a classic rift valley as it passes south through Kenya and into northern Tanzania. The Western rift valley forms a great western arc as it passes along the western borders of Uganda and Tanzania. Lake Tanganyika fills most of the southern end of the Western rift valley. The eastern and western branches unite at the head of Lake Malawi and continue south as the Shire Valley until it fades out near the Zambezi River (Nyamwera, 1980; King, 1978) (Figure 2-4).
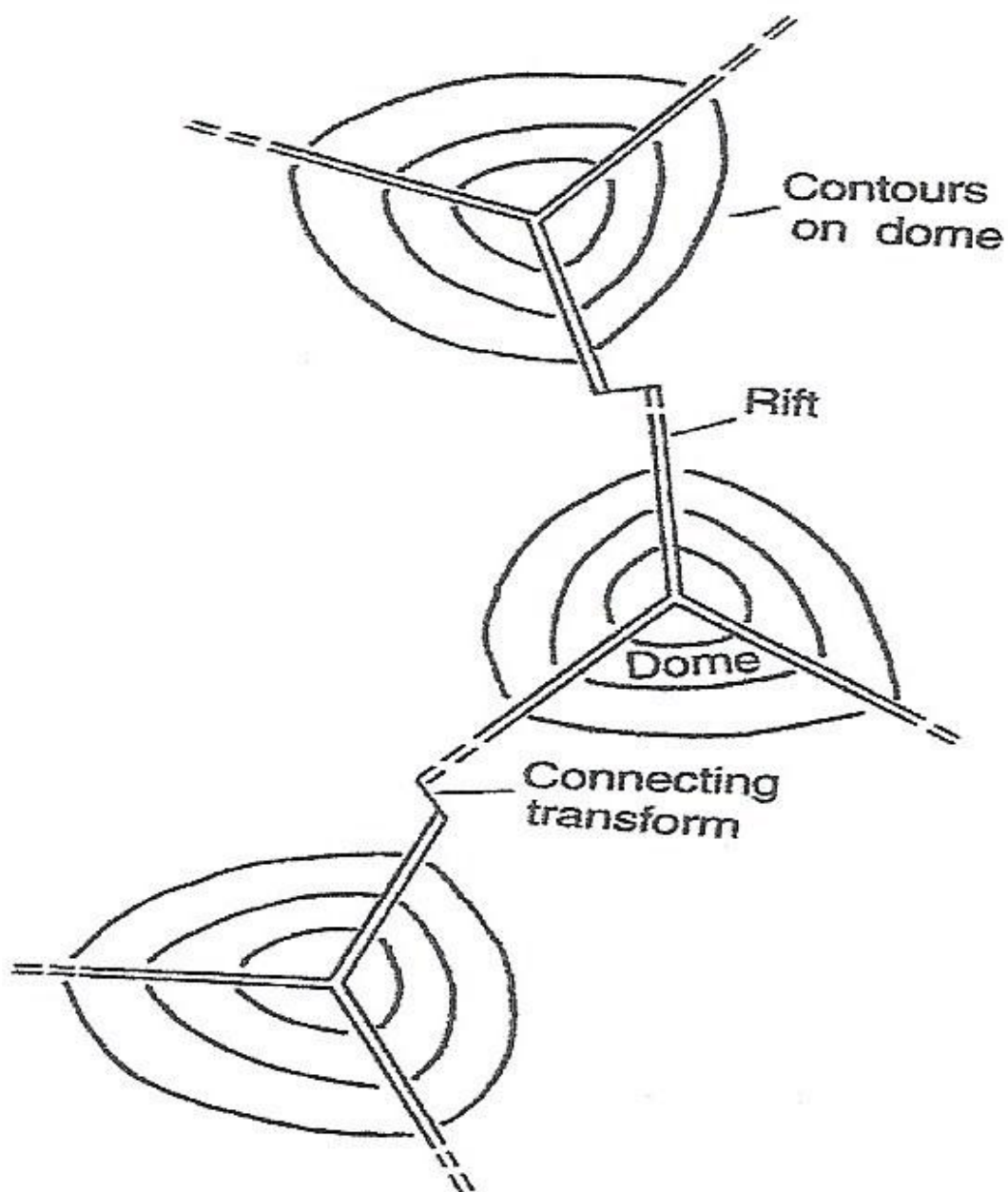
Figure 2-3: **Classic Three-Branched Rifting Pattern.**
(from Strahler, 1998)
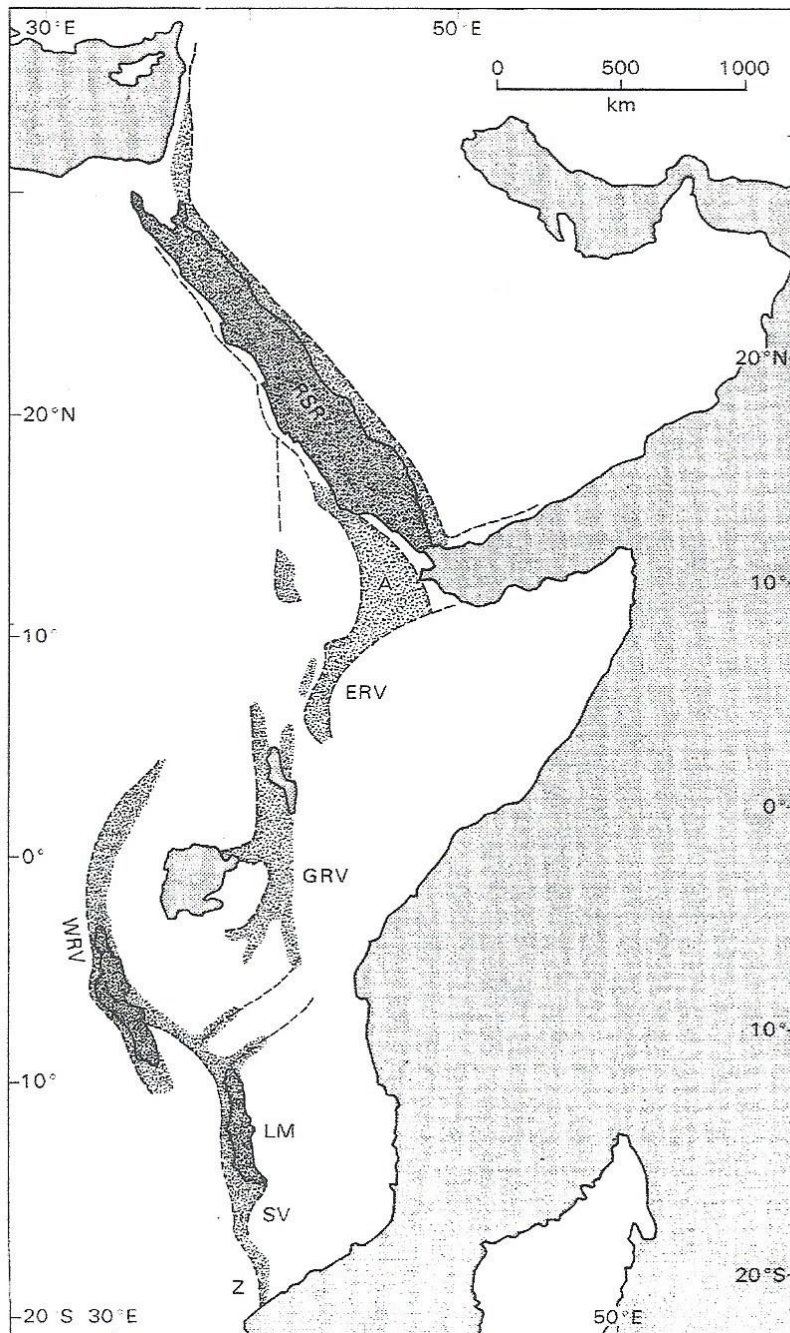
Figure 2-4: **East African Rift System**
RSR-Red Sea Rift / ERV-Eastern Rift Valley / GRV-Gregory Rift Valley /
WRV-Western Rift Valley / LM-Lake Malawi / SV-Shire Valley / Z-Zambesi River
(adapted from Nyamwera , 1980)

Local Geologic and Environmental Consequences of Rifting

The geological consequences of rifting have had an enormous effect on local

environments and also on regional climates. In what is now Ethiopia, rifting resulted in

the formation of large cone volcanoes along with fissure eruptions that produced massive

flood basalt flows. These events coupled with continued uplift created the Ethiopian

Highlands that capture moisture from the monsoon wind patterns that blow west off the

Indian Ocean. Precipitation in the Ethiopian Highlands fed the proto-Awash River. It

flowed north and east into a drainage basin created during earlier Red Sea area rifting that

formed the Afar triangle. The proto-Omo River flowed south out of the Ethiopian

Highlands and into the Turkana Basin in the Gregory Rift (Figure 2-5). Rift faulting,

with subsidence of the rift valley floor and formation of rift walls, began in northern

Kenya during the mid-Miocene, and in central Kenya and on into Tanzania by the

beginning of the Pliocene. Escarpments 1,000-1,500 meters high rise above the rift floor

in many places along the Eastern Rift (Ebinger *et al*., 2002). Seasonal monsoon weather

patterns are affected by the topographic features of the Eastern Rift; generally resulting in

abnormally low annual precipitation rates for an area in an equatorial zone. Precipitation

is more than offset by evaporation in most areas and upward tilting of escarpment

shoulders traps atmospheric moisture and therefore precipitation rates are higher on the

rift shoulders than on the rift floor. Drainages from the crest of the rift shoulders flow

east towards the Indian Ocean and west towards Lake Victoria and therefore the floor of

the Eastern Rift is generally very arid (Denys *et al*., 1986). The Western Rift is

characterized by a series of alternating swells and extremely deep troughs with steep
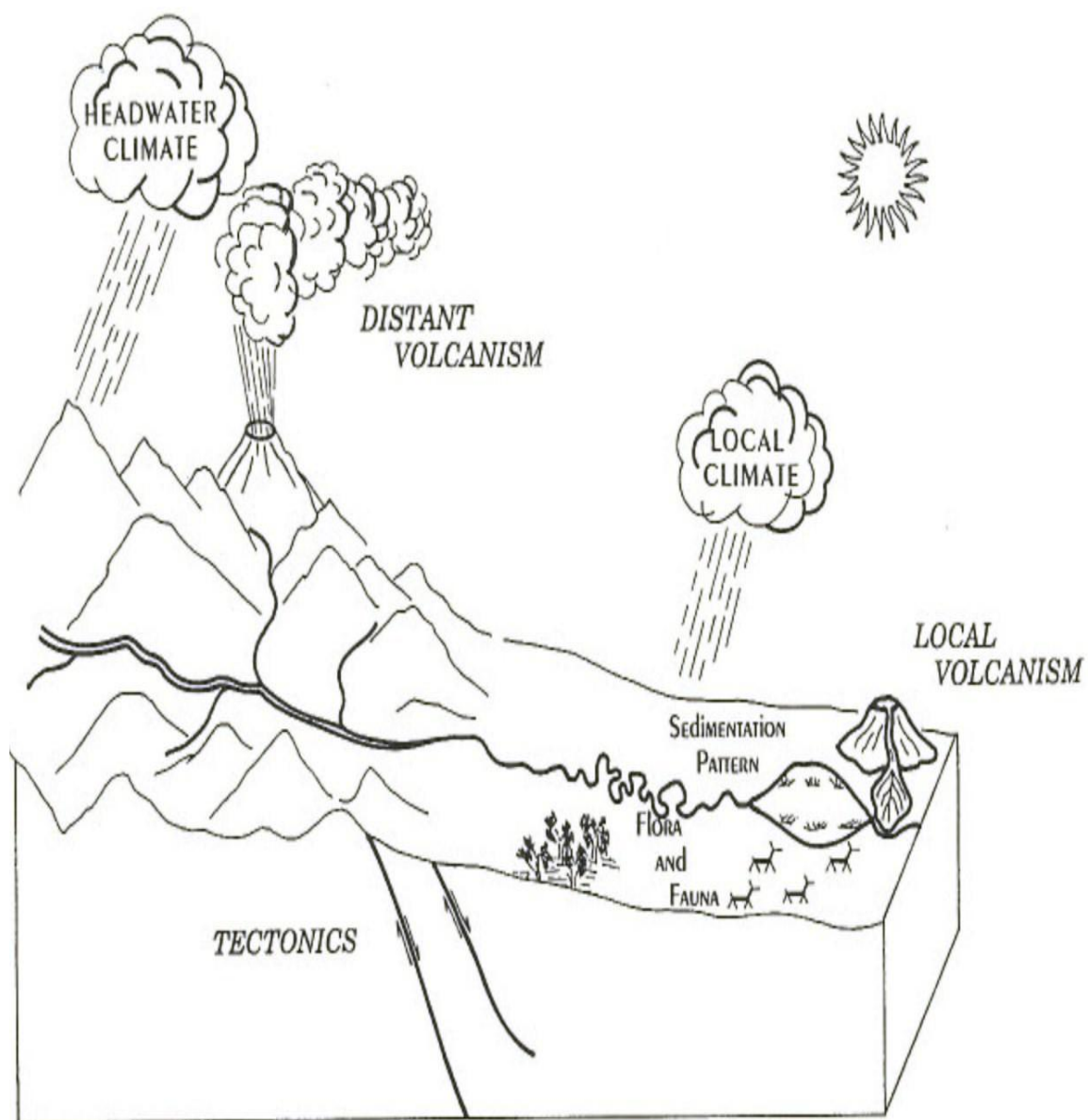
Figure 2-5: Representation of East African Sedimentary Basin.
(from Feibel, 1995)

escarpments that rise up to 3,000 – 4,000 meters.   Higher precipitation and lower evaporation rates support the formation of large deep lakes that dominate much of the floor of the Western Rift.

Paleoanthropological Impact (Isolation, Environment, Evolution)

Hominins first appeared on the East Africa landscape at the same time that the eastern subcontinent was being transformed by the tectonic upheavals of rifting. Climate, as it impacts the ecology of an organism, is a factor in evolution. Change in environment and habitat as determined by variation in climate can bring about adaptation, speciation or extinction (Coppens, 1994). Local climates are a function of global, regional and local events. Things that impact global climate include cyclical astronomical factors, like variations in the earth's orbit around the sun or the relative tilt of the earth's axis. Random celestial events like sunspot episodes or the impact of a large meteorite can also produce dramatic changes in global climate. deMenocal (1995) developed a sequence of variations in global climate based on measurements of dust accumulations in African coastal sea floor cores. He hypothesized that increases in the amount of dust blown into the Atlantic and Indian oceans were indicative of a cooler and drier climate in the northern part of low latitude Africa. He also examined changes in different stable oxygen isotope ratios from these cores, over time, as an indication of general global temperature variations. Changes in stable oxygen isotope ratios are directly related to the amount of water trapped in the polar ice cap, which in turn is a function of global temperature. Polar ice caps tend to capture more of the "lighter" oxygen isotopes as they expand

during periods of global cooling and this changes the isotope ratios found in the African

coastal sea floor cores. A long trend over the last four million years, marked by increases

in dust and heavier oxygen isotopes found in sea floor cores was towards a cooler and

drier climate. Significant changes in global climate were noted at 2.8, 1.7, and 1.0

million years ago. This trend is also characterized by periodic oscillations (Milankovic

Cycles) that change periodicity mode over time. Prior to 2.8 million years ago climate

oscillations repeated every 23-19 thousand years; between 2.8 and 1 million years ago,

oscillations repeated every 41 thousand years; and after 1 million years ago the cycles

repeat every 100 thousand years (deMenocal, 1995).

One widely accepted hypothesis linking global climate change to hominin

evolution is the *savanna hypothesis*. According to this hypothesis, a general climate

trend towards a cooler and drier climate brought about a change in landscape from a more

forested one to one with more open type vegetation. The expansion of this drier and

more open landscape (savanna), at the expense of continuous forest, was hypothesized to

be a major factor in the evolution of bipedality and the appearance of the first hominins

(Hill, 1987). The trend towards a more arid climate, with continued reduction of the

forests is hypothesized to have led to a hominin adaptive radiation in the Plio-Pleistocene.

Stanley (1992) links this trend to the eventual extinction of the australopithecines and the

appearance of a large brain adaptation that marks the appearance of the genus *Homo*.

Vrba (1995) proposed a form of faunal punctuated equilibrium (*turn over pulse theory*)

caused by global climate events. She hypothesized that evolutionary change happens in a

series of "synchronous pulses" driven by significant global climate events such as the ice

sheet expansion in the Northern Hemisphere that began during the Miocene. Her data,

based on the fossil record, showed a faunal turn over from forest/woodland adapted taxa to those more adapted to arid, open-habitat savannas at 2.5 million years ago in conjunction with a major shift in global climate. Hominin speciation and extinction events are hypothesized to be part of this turn over pulse (Vrba, 1995).

The topographic and environmental changes brought about by rifting in East Africa had a major impact on most of the factors that drive evolution. Populations of animals were separated and isolated by the physical alteration of the landscape. Hydrological balances changed causing many existing lakes and rivers to dry up or become significantly altered. New rivers and lakes appeared. Vegetation cover changed, resulting in loss or alteration of nesting, sleeping, and feeding locations along with food resources such as roots, tubers, nuts, grasses and seeds. In some regions, virtually all ecological interactions were altered. This type of upheaval can place enormous stress on a population and it accentuates the selective pressures that drive speciation (Klein, 1999).

Coppens (1994) argues that the divergence of the hominin lineage was driven by intense tectonic activity (faulting, graben formation and rapid uplift) in East Africa beginning about 8 million years ago that produced a pronounced shift of local climates and physical separation of habitats. Before rifting, the region was one "homogeneous biogeographical province" dominated by forest and woodlands where the last common ancestor of the great apes and hominins lived. Once rifting commenced, the region west of the rift still received moisture from the Atlantic Ocean while uplift east of the rift resulted in the capture of the moisture from the Indian Ocean monsoon cycle and caused a significant reduction in precipitation rates over most of the Eastern Rift. As the rift expanded to become more of a physical barrier across the landscape, the local climate

east of the rift became drier and the vegetation trended towards open savanna while the vegetation west of the rift remained forest and woodland. Coppens cites genetic and fossil evidence to back his hypothesis. Chimpanzees are the closest living relative of humans, sharing over 99% of DNA structure. Genetic evidence demonstrates that the Hominidae and Panidae lineages split sometime after 7 million years ago but there is virtually no evidence of *Pan* or any direct ancestor of *Pan* in the East African fossil record during the time of the australopithecines. In a time period where hominins were present in what is now Ethiopia, Kenya, and Tanzania there is virtually no fossil evidence of *Pan* or any precursor of either the chimpanzees or gorillas (Coppens, 1994). In a collection of over 250,000 fossils from the region, gathered and reported by paleontologists and paleoanthropologists, from the rift and east of the rift, Hominidae is well represented but Panidae is conspicuously absent. Coppens contends that formation of the African Rift System was *the* major factor that caused the separation of the lineages and was a powerful driver of early hominin evolution east of the Western Rift.

Evidence offering confirmation of this hypothesis is provided in a study of rodent diversity and evolution in the East African Rift Valley during Plio-Pleistocene times (Denys *et al*., 1986). As rifting commenced, rapid subsidence of the rift floor formed deep drainage basins separated by areas of swell or uplift. As lakes and rivers formed in the basins and rift margins, savanna expanded on the suddenly arid rift floor margins and the number of available ecological niches expanded relative to the earlier continuous forest and woodlands. These factors resulted in greater diversity of rodent species particularly during the Pliocene. "Diversity is favoured by the isolation of small populations in basins separated by geographic barriers (allopatric speciation) or

ecological barriers (sympatric speciation)." (Denys *et al*., 1986; p. 369). Later stages of rifting in the Eastern Rift, during the Pleistocene, are characterized by infilling of troughs, disappearance of barriers between basins, erosional lowering of rift escarpments and changes in hydrological balances. These changes produced a reduced number of available ecological niches, extinctions, and a subsequent reduction of rodent species diversity. It appears from this study that the structure of the rift was *the* major factor affecting faunas during the Plio-Pleistocene in vast regions of East Africa. Even today fauna are known to migrate north and south along the rift but "the rift valley is a barrier, especially for forest taxa coming from the west" (Denys, *et al*., 1986; p.370).

Paleoanthropological Evidence (Preservation, Dating, Exposure)

It has been clearly demonstrated that rifting, driven by tectonic forces, was responsible for transforming the topography and climate of the East African sub-continent. It is also likely that the changes in local environments, weather patterns, hydrology budgets, and habitats had a major impact on hominin speciation and evolution. What is equally remarkable is the fact that many of these same geological processes were also responsible for the preservation, dating and eventual re-exposure of the fossil evidence of early hominin evolution.

Doming, uplift, and volcano formation created highlands that became moisture traps and prolific sources of flowing water. These processes also produce huge quantities of ash and volcanic rock available for erosion and transport into the basins as sediment. Adjacent to these highlands, subsidence, faulting and graben formation with steep

escarpments produced large deep drainage basins and the great vertical relief between these two features provided the potential for the movement of huge quantities of waterborne sediment (Prothero & Schwab, 1996). Great perennial rivers such as the proto-Omo and proto-Awash flowed off the highlands with heavy loads of sediments during periods of monsoon rains. Ephemeral and perennial streams and rivers flowed off the basin margins and also carried sediments into the basins. The nature of the geography and base level of a drainage basin floor changes over time as a function of precipitation rates, sedimentation loads in rivers and streams feeding the basin, uplift, faulting, earthquakes, and volcanic activity. Depending on these factors, large meandering rivers, fast moving braided streams, freshwater lakes, saline lakes, or alkaline lakes might dominate a basin at any given time (Feibel, 1999; Rogers *et al*., 1994). Explosive volcanism is also a source of sediment that eventually winds up in rift valley drainage basins. Large explosive eruptions expel tons of tephra (ash, lapilli and pumice) into the atmosphere. This tephra falls to the ground as aeolian sediments over vast areas, covering everything including bones exposed on the surface. In one remarkable instance an instantaneous record of hominin presence was dramatically preserved. A carbonatite ash from the volcano Sadiman deposited by air fall preserved the footprints of three hominin individuals as they walked across the landscape over 3.5 million years ago in what is now Laetoli, Tanzania (Hay, 1981). Tephra also washes down off the highlands and is deposited in fluvial and lacustrine environments in the drainage basin. As airborne or waterborne sediments move into the drainage basin they are deposited on the basin floor in approximately horizontal, parallel layers. These layers are deposited in an

ordered sequence and they reflect the relative and absolute timing of the depositional history of the basin.

Bones immediately begin to decay and disintegrate if they remain on the landscape surface exposed to the sun and a myriad of biotic and abiotic agents. Bones are most likely to be preserved if they are quickly covered by sediments. Rift valley drainage basins are major sediment collectors and provide an excellent environment for bone preservation. The lakes, streams and rivers typically found in rift valley settings and the vegetation associated with them provide preferred habitats for hominins and most other terrestrial vertebrates. The association of animals and water sources, coupled with preservation potential of this environment, has resulted in a comprehensive paleontological record preserved in the collected sediments of many basins associated with a rift valley (Burggraf *et al*., 1981). For example nearly all of the hominin fossils recovered from the east Turkana Basin were preserved in sediments associated with fluvial environments (Feibel *et al*., 1989) and many of the well preserved fossils from Olduvai Gorge were preserved in lake-margin sediments (Hay, 1981).

The bones of animals incorporated into the sediments are a reflection of the living animal communities at the time the bones enter the geological record. As animal community structure changes over time and as individual species evolve, these changes will be preserved in successive layers of sediment. This is the basis of dating by biostratigraphy (Klein, 1999). Changes in certain "index fossils" track the evolutionary history of an animal lineage. For example the molars of some suids have changed morphology over time. These serial changes have been documented by paleontologists and it is possible to define the relative age of a deposit by the *in situ* presence of these

trace markers (e.g. suid molar) in the sediments (Harris & White, 1979). With the development of radiometric dating (see below) it is possible to tie an actual age, in years before present, to these marker fossils. One sedimentary sequence from the Omo Basin, the Shungura Formation, contains a diverse assemblage of vertebrate fossils which have been identified in the stratigraphic sequence and have become a "standard reference for faunal and time correlations between 1.7 and 3.8 my B.P." in much of East Africa (Behrensmeyer, 1978, p.503).

Radiometric dating methods, based on the radioactive decay of certain naturally occurring but unstable element isotopes, enable quantitative dating of sediments. For example, volcaniclastics expelled in an eruption contain about 0.01% potassium isotope potassium-40. This isotope decays at consistent rate to produce argon-40 and calcium-40. Because the ash was heated to above 300 degrees Centigrade during the eruption, all of the argon-40 originally in the ash would have been driven off. The ratio of the argon-40 present to the remaining potassium-40 in the ash is therefore a measure of the time that has elapsed since the rock cooled (Klein, 1999). A host of other radiometric dating methods based on radioactive active isotopes and applicable to tuffs of volcanic ash have been developed (Ludwig & Renne, 2000).

Volcaniclastics expelled during an episode of explosive eruption carry a distinctive and unique chemical composition or chemical signature. Each eruption event, even from the same volcano, produces tephra that is chemically unique. As described above this tephra enters a depositional basin by air fall or fluvial transport and forms layers of tuff (deposit consisting of more than 50% volcanic ash) each of which can be specifically identified by a unique chemical signature. This property makes it possible to

identify the sequence and source of the ash produced, but more importantly it allows for the correlation of widespread intra-basin and inter-basin sediment exposures (Feibel, 1999a).

It is these sediment exposures that interest the paleoanthropologist. They contain the preserved remains of hominin behavior and clues to the paleoenvironmental and paleoecological context of that behavior. The evidence is exposed as the geological processes that preserved it are reversed and once again tectonic and environmental factors drive those processes. Buried sediments are directly exposed as the result of faulting. Uplift, faulting, and volcanic activity can all alter the base level of a sedimentary basin resulting in erosion instead of deposition (Prothero & Schwab, 1996). The tectonic dynamics of the East African Rift System are largely responsible for the cycle of preservation and exposure that ultimately created the eroded sediments containing the fossil record of hominin evolution.

Fossil Evidence & Turkana Basin Exposures

The sediments of the Turkana Basin are the source of much of what is understood about hominin evolution. The individual sedimentary formations (Figure 2-6) capture different time slices of the basin history. The Mio-Pliocene Group shown represents those isolated local depocenters that were active sediment sinks during the time when the river system that flowed through the region was generally erosional in character. The Omo Group deposits accumulated after the topography of the basin changed to support deposition. All of the formations in the basin are linked by tuffs that originated from a
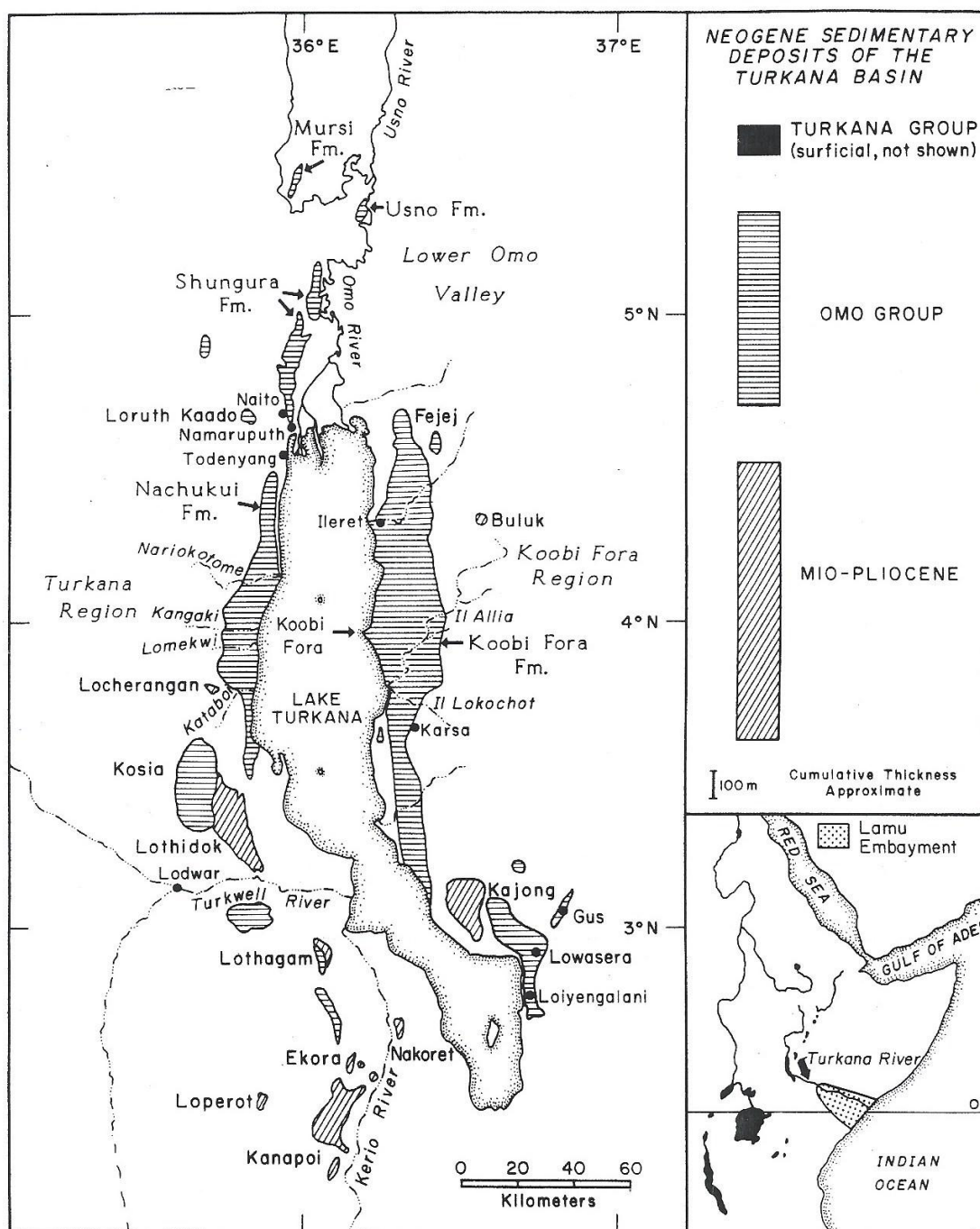
Figure 2-6: **Turkana Basin Map - Major Locations and Sediment Exposures (Brown & Feibel, 1991; Burggraf *et al.*, 1981; White *et al.*, 1981).** **(from Feibel, 1999)**

common source in the Ethiopian Highlands and can be correlated by the tephrostratigraphic signature (Feibel, 1999a) unique to each tuff (Figure 2-7). Hominin fossil traces have been uncovered from virtually all of these formations and, when considered from a basin-wide perspective, they provide a picture of the Plio-Pleistocene hominin adaptative radiation.

Lothagam & Kanapoi: These sediments are among the oldest in the basin (5.6-4.2 million years). They represent local depocenters that existed when the dominant fluvial system in the basin was primarily an erosional system. At Lothagam, a mandible fragment and teeth of *Australopithecus afarensis* or *Ardipithecus ramidus* dated at 5.6 million year have been uncovered. Sediments at Kanapoi, yielded 4.2 million year old teeth and a distal humerus of *Australopithecus anamensis*.

Lower Omo Group: These sediments include the Mursi (4.1), Nkalabong (3.95), Unso (4.1-2.97), and Shungura (3.6-0.8) formations that together span the time interval from 4.1 to 0.8 million years ago. The Shungura Formation contains a very rich fossil record that was utilized to develop the standard biostratigraphic reference for East African fauna. Most of the hominin fossils (teeth) are dated between 3.0 and 2.0 million years old and come from the Shungura and Unso formations. Oldowan stone tools dated at 2.3-2.4 million years have also been uncovered. The following hominin species are represented: *A. afarensis, A. aethiopicus, A. boisei, and Homo habilis*.

West Turkana: The sediments on the west side of Lake Turkana form the Nachukui Formation. Because of the high relief from the lake margin to the basin margin, the lateral extent of the exposures is far less than on the east side of the lake.

Figure 2-7: **Tephrastratigraphic Correlation of Turkana Basin Sediments .**   **(from Feibel, 1999)**

However, the Nachukui Formation does contain an almost continuous sedimentary record that extends from 4.3 to 0.7 million years ago. The best fossil-bearing sediments are between 3.0 and 1.6 million years old. The Nachukui Formation has yielded many hominin fossils (e.g. *A. afarensis, A. boisei*) including the famous black skull (*A. aethiopicus* dated at 2.4 million years old) and the remarkably complete skeleton of the Nariokotome Boy (*H. ergaster*) (Walker & Shipman, 1996). Stone tools dated at 2.35 million years were excavated at Lokalalei (Kibunjia 1994).

East Turkana: The sediments on the east side of Lake Turkana make up the Koobi Fora Formation. The lateral extent of the exposures is vast because of the relatively low relief between the bottom of the basin and the basin margin that existed in the Plio-Pleistocene as a result of the hinged grabens that created the basin. Uplift in the east and northeast has greatly increased the degree of relief since the Plio-Pleistocene and has promoted erosion leading to the extensive exposures. Fossil-bearing deposits date back more than 4.1 million years but virtually all the hominin fossil come from deposits dated 2.1 to 1.3 million years (Feibel *et al*., 1989). *A. boisei, H. habilis, H. rudolfenses, H. ergaster, and H. sapiens* are all represented in the Koobi Fora Formation. Until this research, stone tools did not predate 1.89 million years.

The sediments of the Turkana Basin provide a unique opportunity to explore the impact of tectonic rifting on local climates, environments, and hominin evolution. The detritalclastic and volcaniclastic sediments that fill the basin all have a single source in the Ethiopian Highlands allowing archaeological and fossil evidence from the far reaches of the basin to be compared and contrasted; for example intra-basin differences in the archaeological evidence such as the appearance stone tools at West Turkana by 2.35

million years ago but not until much later in East Turkana. These same sediments also entered the northern and eastern drainages (ancestral Awash River) of the Ethiopian Highlands and therefore deposits from Lower Awash and Hadar contain fossils that are contemporary with those in the Turkana Basin. This enables far a broader regional view of the impact of rifting in East Africa.

Turkana Basin Evolution

The Turkana Basin is probably the best known and most extensively studied depositional basin in the Great Rift Valley. It has yielded many important hominin fossils and is the site of continuing paleoanthropological and paleoecological research. It is an excellent example of the sedimentary processes at work in rift valley depositional basins and how they change over time. The Turkana Basin is composed of a combination of separate structural entities; Turkana Rift, Kibish Rift, Omo Rift and Usno Rift (Figure 2-8). These features, formed by complex hinge-faulting and intrabasin uplift (Sibiloi & Kokoi horst) produced a series of alternating half-grabens (Feibel, 1988). Most of the faults track north-south with steep to vertical dip. The main segment of the rift system goes through Lake Chew Bahir and proceeds east of the basin before passing through the south end of Lake Turkana (Behrensmeyer, 1975). The basic structure of the basin was largely formed before 4 million years ago. For the last 100,000 years it has been a closed alkaline-lake basin with no outflow. The Omo River to the north contributes about 90% of the annual water input with the Turkwell River and Kerio River to the southwest contributing the balance (Feibel, 1999, 1988).
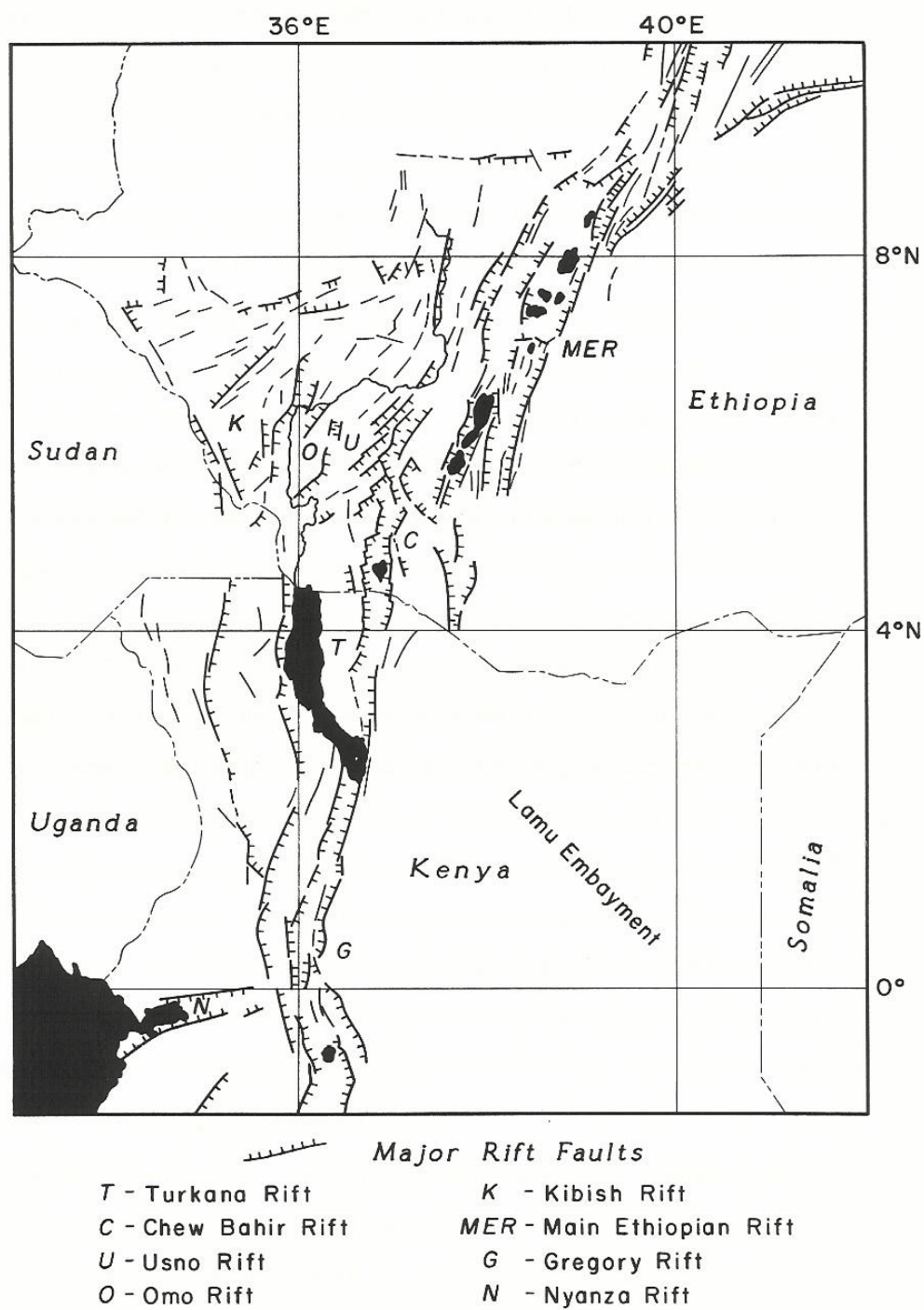
Figure 2-8: **East African Rift Complex.** **(from Feibel, 1988)**

The Precambrian metamorphic basement rock is only exposed in the north and east at the basin margin. Most of the basin is blanketed by thick layers of sediment consisting of detrital clastics, bioclastics and volcaniclastics. The detrital clastics make up the bulk of the deposits. The source of this sediment is erosion of the metamorphic and volcanic source terranes to the north and northeast, and Miocene and Pliocene volcanics (Gombe Group lavas and fissure-erupted basalts and ignimbrites) (Feibel, 1999). The erosional products were transported into the basin by major and minor fluvial systems; both perennial and ephemeral. The volcaniclastics consist of tuff composed of tephra from volcanic sources in the Ethiopian Highlands transported mostly by fluvial systems but also to some extent through the air. These volcanic sources have produced approximately 130 tuffs that can be used as isochronous markers and as geochemical correlates across the basin. The bioclastics are *in situ* accumulations of biogenic material, mostly $CaCO_3$ or SiO_2, produced by diatomites, cryptalgal biolithites, ostracods and mollusks in the lakes or streams. There are also accumulations of chemogenic and pedogenic precipitates (mostly $CaCO_3$) in the sediments. The entire stratigraphic sequence is 560 meters thick in East Turkana (Figure 2-9) but is not exposed as a single sequence anywhere in the basin (Feibel, 1988).   From the late Miocene to the early Pliocene there was no large depositional basin. The ancestral Omo River flowed into the evolving basin and exited the region via the "Turkana River" to the east, draining into the Indian Ocean (Feibel, 1999, 1988). There is no evidence of extensive sedimentation except for a few local depocenters at Buluk, Lothagam and Kajong. It is likely that the ancestral Omo River was an erosional system in the young basin at that
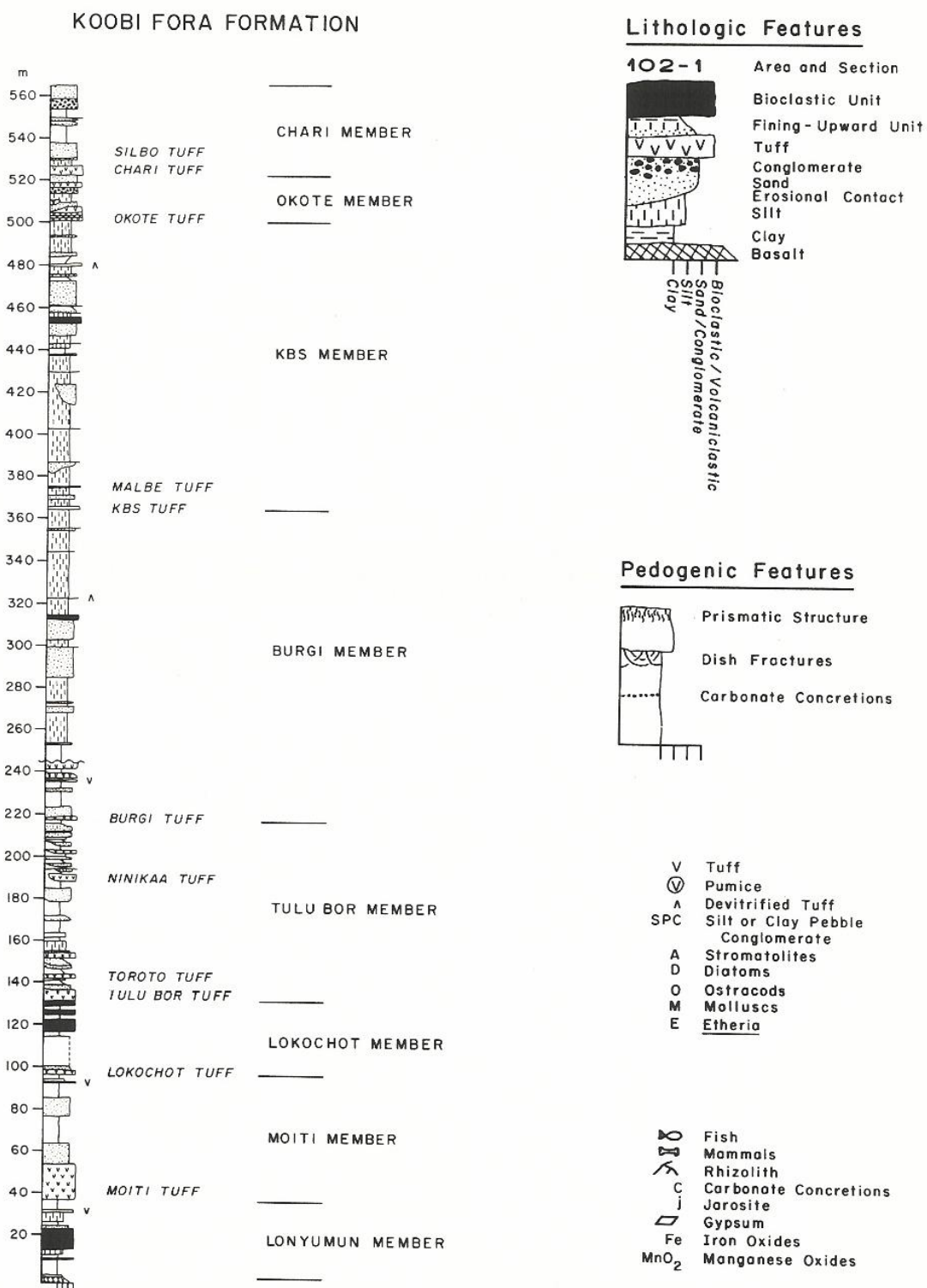
Figure 2-9: **Koobi Fora Formation**   (from Feibel, 1988)

time. From the mid-Pliocene to the mid-Pleistocene an integrated depositional fluvial

system dominated the basin. Regional volcanic activity at about 4.2 million years ago in

the southern basin suggests that a lava flow dammed the Turkana River and caused the

huge Lonyumun Lake to form. Evidence suggests the slow formation of a stable fresh

water lake where evaporation and not outflow accounted for the stability in lake level

(Figure 2-10).

The nature of the basin changed with the creation of the Lonyumun Lake as

subsidence increased during the lake phase and the basin character changed from

erosional to depositional. The lake phase only lasted about 100,000 – 200,000 years and

was superseded by a large meandering river system after the lake filled with sediment

(Figure 2-11). Because of the resultant changes in basin topography, the fluvial system

was depositional also.

A period of relative tectonic stability followed and the basin continued to be

dominated by the ancestral Omo River. The basin's depositional topography changed as

a function of the water and sediment load that flowed out of the Ethiopian Highlands;

alternating between braided stream, large meandering river and lacustrine phases.

Around 2.3 million years ago an increase in regional tectonic activity caused the eruption

of Mount Kulal and produced significant uplift northeast of the basin. This again

changed the depositional nature of the basin. Ancestral Omo sediments continued to

accumulate on the west side of the basin but much of the east side of the basin

experienced erosion; perhaps as the Lake Chew Bahir Basin drained to the south and west

following the uplift (Figure 2-12).   This caused the unconformity in Burgi sediments in

the eastern basin sedimentary record. A large lake phase followed (Lorenyang Lake)

~ 4.2 Ma

Lake
Margin

Fluvial
Channel

Alluvial
Fan

Highland
Boundary

0   20   40   60
Kilometers
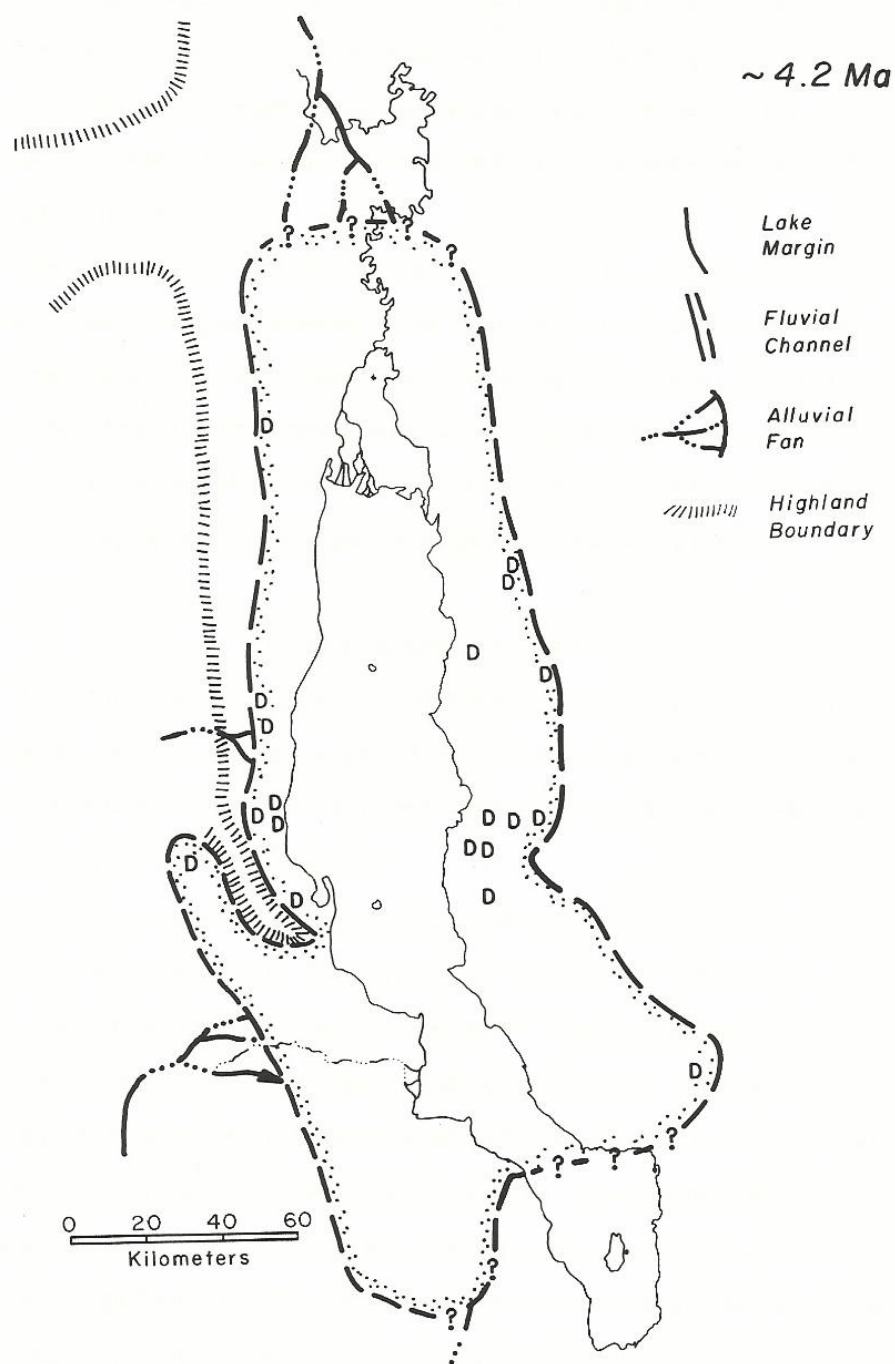
Figure 2-10: **Dominant Depositional Environment During Lonyumun Member Times (Modern Lake Turkana Shown for Reference).**

(from Feibel, 1988)

3.9 Ma

0   20   40   60
Kilometers
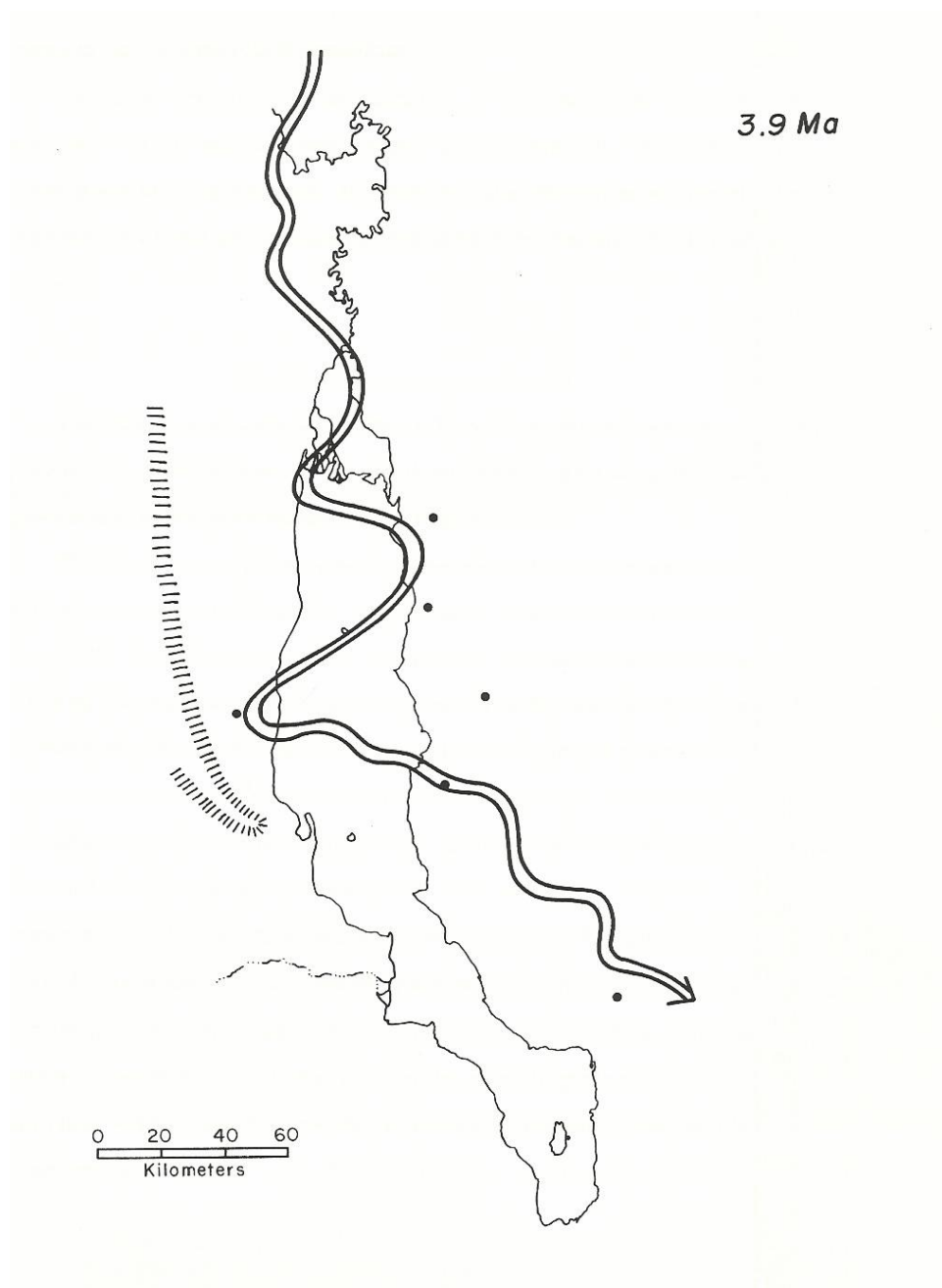
Figure 2-11: Dominant Depositional Environment Following the Infilling of the Lonyumun Lake (Modern Lake Turkana Shown for Reference).   (from Feibel, 1988)

2.3-2.4 Ma

NO
DEPOSITION

0   20   40   60
Kilometers
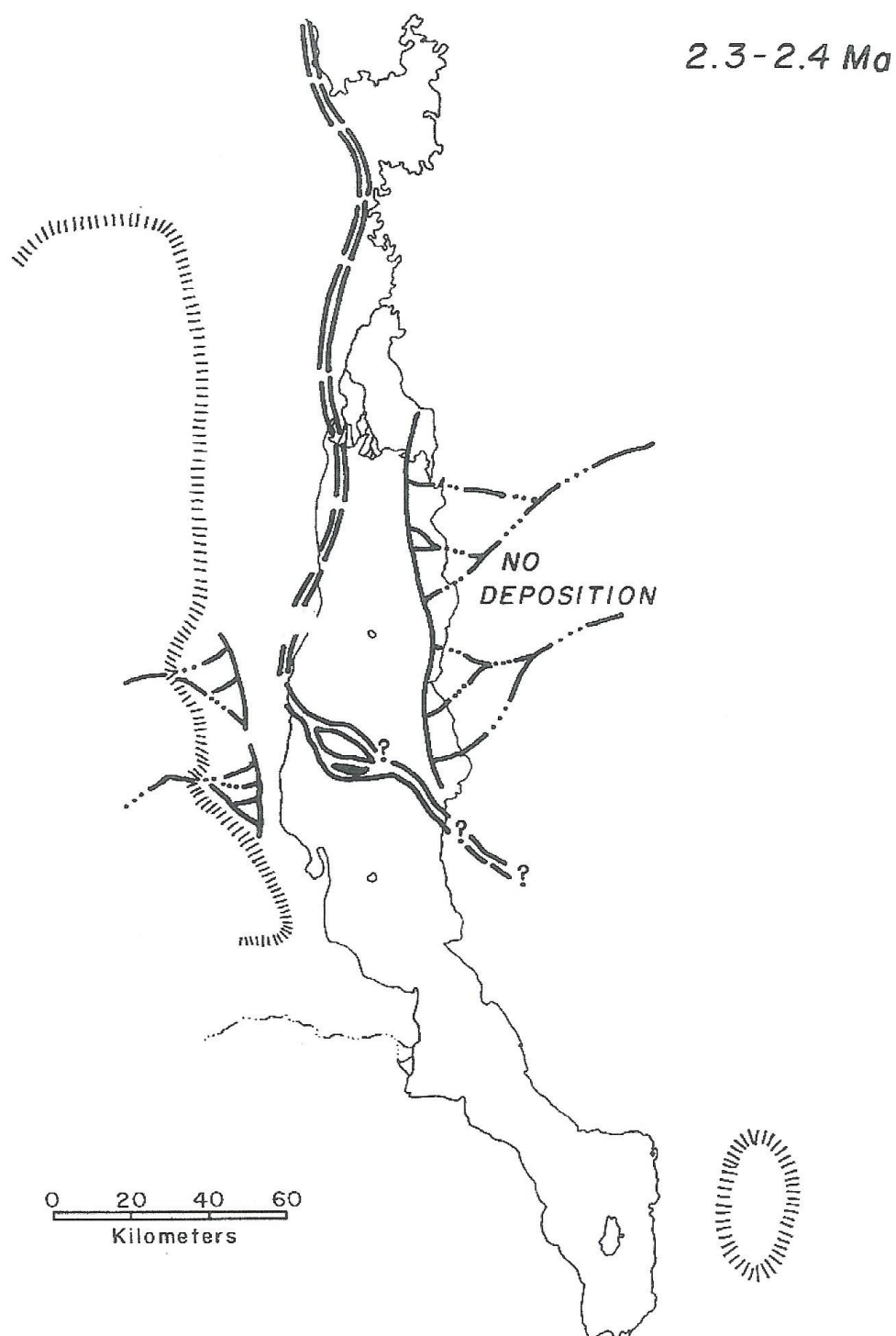
Figure 2-12: **Erosional Environment in East Turkana During the**
Burgi Member Times (Modern Lake Turkana Shown for Reference)
(adapted From Feibel, 1988)

and extensive deposits, representing lake transgressions and prograding delta episodes due to lake instability, were deposited in the eastern basin. (Figure 2-13). This is the time period, Upper Burgi Member (2.3-1.88 million years ago), of interest to this research.

Sometime after 1.88 million years ago perennial flow of the Turkana River, which had drained the basin to the Indian Ocean ceased likely due to volcanic activity in the southern end of the basin. Since there is no indication that the flow of the ancestral Omo was diminished during this period, it is hypothesized that a significant portion of the Omo water and sediment was diverted into a different drainage (possibly the Nile drainage) before it reached the Turkana Basin. (Figure 2-14) High levels of volcanic activity in the Ethiopian Highlands between 1.65 and 1.39 million years ago dumped huge quantities of tephra into the Omo catchments and the fluvial system in the Turkana Basin was overwhelmed by this tephra. The meandering fluvial system was transformed into a complex of braided channels and the lake margin became an area of shifting marshlands. The nature of the basin is uncertain after this period. There are isolated indications that a significant fluvial system flowed through the basin, at least periodically. Sedimentation in the basin stopped sometime after 700,000 year ago and did not commence again until the beginning of the present Lake Turkana phase about 200,000 years ago. After 10,000 years ago a major transgression commenced, resulting in a lake that was 80 meters above the present lake surface. The Holocene Galana Boi Formation resulted from this lacustrine phase (Feibel, 1999, 1988; Behrensmeyer, 1975).

I.89 Ma
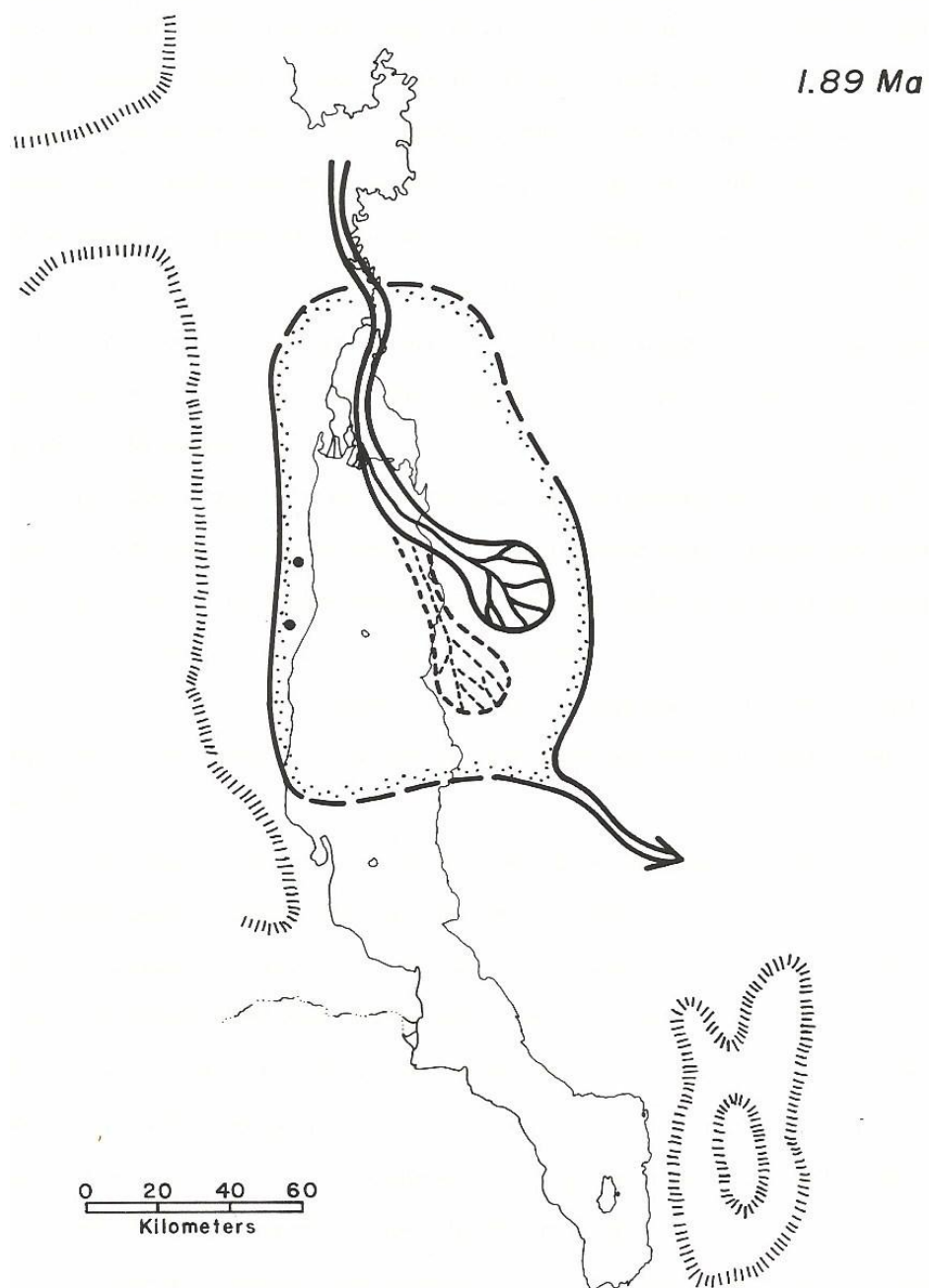
Figure 2-13: **Dominant Depositional Environment During Upper Burgi Member Times (Modern Lake Turkana Shown for Reference).**
(from Feibel, 1988)
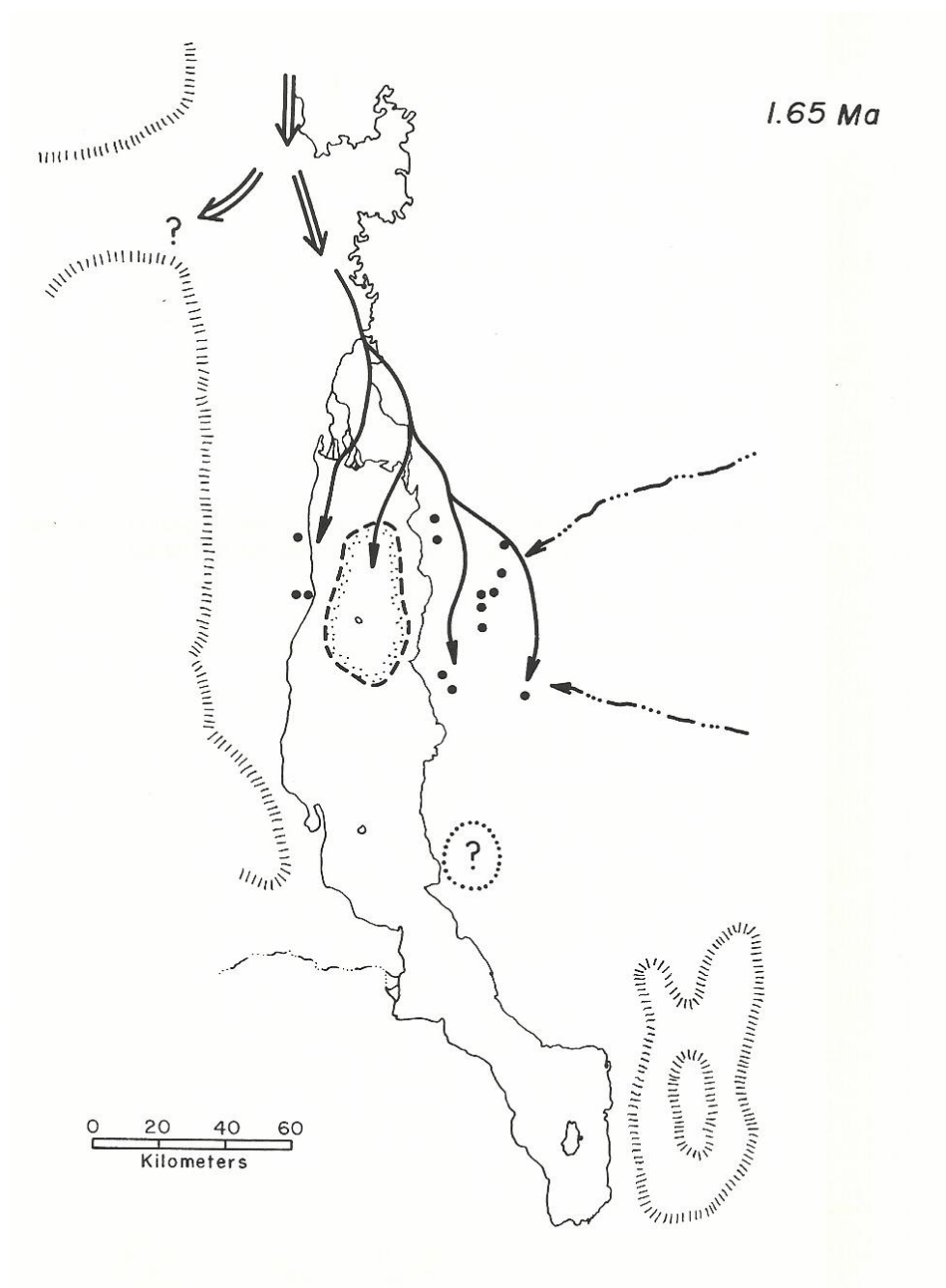
Figure 2-14: **Dominant Depositional Environment Post-Upper Burgi Member Times (Modern Lake Turkana Shown for Reference).**

(from Feibel, 1988)

Chapter Three will provide a brief history of exploration and research in the East Turkana

Basin. The modern geographic setting along with the rationale for the selection of each

research location is explained. The field research methodology is defined and a summary

of the fossil evidence collected is provided.

Chapter 3: Research Area and Methodologies

Introduction

This research was conducted at Koobi Fora located on the eastern shore of Lake Turkana in Northern Kenya (Figure 3-1). Lake Turkana was introduced to the western world by a Hungarian aristocrat, Count Samuel Teleki and his fellow adventurer, an Austrian naval officer, Lt. Ludwig von Hohnel in 1888. Their historic expedition began in Zanzibar in October of 1886 and concluded in Mombassa in August 1888. It included efforts to climb both Mount Kilimanjaro and Mount Kenya, but its most significant accomplishment was the "discovery" of Lake Rudolf and Lake Stefanie (named after the crown prince of Austria and his wife but later changed to Lake Turkana and Chew Bahir respectively). While this was largely an expedition of adventure and exploration, Count Teleki's report of his travels in East Africa included observations of geology, sedimentology, and fossil fauna along with valuable ethnographic information about the native tribes of the Turkana region (Brown, 1989; Harris, 1978). Perhaps most significantly, Telecki's expedition spawned additional European ventures into this remote area of northern Kenya. However, it was not until the 1930's that serious scientific exploration commenced in earnest. Detailed paleontological research was conducted in the lower Omo Valley in Ethiopia and in the northern Turkana district of Kenya by a French team headed by C. Arambourg in 1932-33. A British expedition to the southern Turkana Basin in 1934 conducted geological research under the direction of Worthington and the first artifacts from the basin were recovered by V. E. Fuchs during this

Figure 3-1: Kenya and Koobi Fora Research Area

(adapted from SAS. UPENN.edu Image)

 expedition. Upon reviewing reports of this field research, L.S.B. Leakey recognized a similarity between the fauna and artifacts recovered from the Turkana region and Plio-Pleistocene material he had collected at Olduvai Gorge in Tanzania. This sparked interest in the region as a possible source of new evidence of human evolution.

The first detailed archaeological investigation in the basin was conducted by L. H. Robbins in 1965-66 at a Late Stone Age (LSA) site at Lothagam (Figure 2-5). A team from Harvard University returned to the Lothagam site in 1967-68 and discovered promising deposits of late Mio-Pliocene sediments that yielded the first hominin fossil from the basin, a mandible initially attributed to *Australopithecus africanus* (Harris 1978). In 1967, F. C. Howell, C. Arambourg, and L. S. B. Leakey organized the first large multi-national and multi-discipline paleoanthropological expedition into the Lower Omo Valley in southern Ethiopia.

A very young Richard Leakey, who managed the logistics for the Kenyan team (which was part of this multi-national expedition), noticed vast areas of exposed sediments that appeared to be very old along the eastern shore of Lake Turkana during one of his flights between Nairobi and Ethiopia.   He borrowed a helicopter from the American team for a return reconnaissance trip and discovered that the extensive exposures were fossil bearing and did indeed date back to the Pliocene. Before the end of 1968 he had obtained funding and embarked upon his first detailed survey of the exposed sediments in this area. In less than ten years, the region known as Koobi Fora to the local people, produced over 300 bones from more than 180 hominin individuals (Leakey & Lewin 1978).

Today, Koobi Fora has been incorporated into Sibiloi National Park which is administered by the Kenyan Wildlife Service and has been designated as a World Heritage Site. The Koobi Fora base camp (the location of Richard Leakey's initial research camp) is situated at the base of the Koobi Fora ridge on a spit of sand that extends out into the lake and is maintained by the National Museums of Kenya as a center for paleoanthropological research in the East Turkana Basin (Figure 3-2).

This dissertation field research was conducted in the sediments of the Koobi Fora Formation (Figure 3-3) and limited to the interval represented by the Burgi Member of that formation. The base of the Burgi Member is defined by the Burgi Tuff dated at 2.6 million years old and capped by the KBS Tuff dated at 1.869 +/- 0.021 million years old (McDougall & Brown 2006). In East Turkana this member is divided into two distinct time intervals separated by an erosional unconformity; the result of tectonic uplift in the Chew Bahir Basin to the northeast. The lower Burgi sediments represent a depositional interval from 2.6 to about 2.4 million years ago while the upper Burgi time interval consists of sediments deposited on top of the unconformity between about 2.2 and 1.87 million years ago (Brown & Feibel 1986) (Figure 3-4). Lower Burgi sediments generally outcrop in the basin to the south of the Koobi Fora base camp (fossil collection areas 200, 202, 204, 207, 209) and the upper Burgi sediments generally outcrop to the north of the base camp (fossil collection areas 10, 12, 14, 15, 41, 100, 102, 103, 104, , 105, 106, 107, 109, 110, 115, 116, 117, 123, 125, 127, 129, 130, 131, 210 (Feibel 1988) (Figure 3-5). upper Burgi deposits exhibit isolated sequences of alternating strata of bioclastic sediments interfingered with strata consisting of detrital
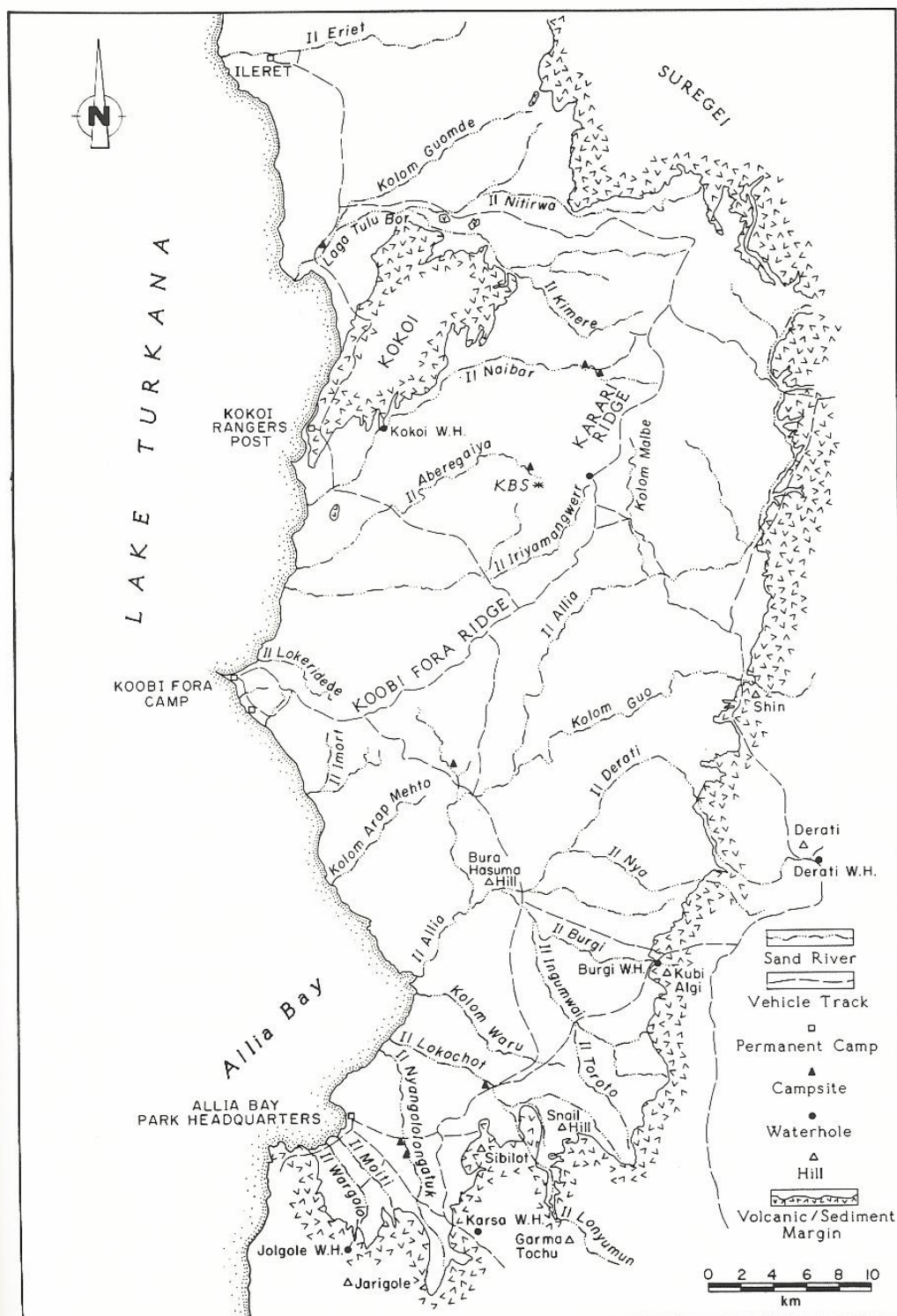
Figure 3-2: **Koobi Fora Landmarks, Drainages, and Roads**
(from Feibel, 1988)
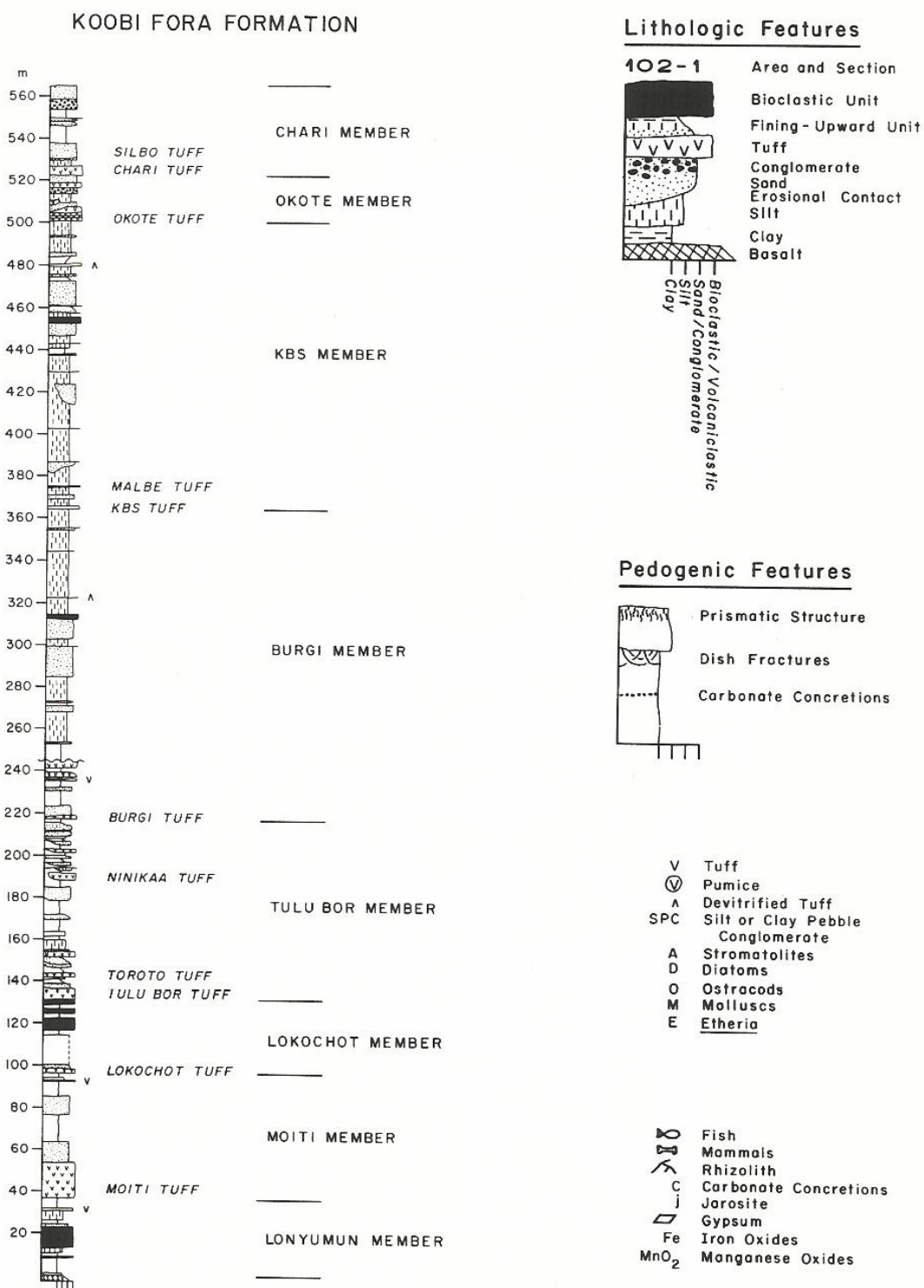
Figure 3-3: Composite Section of the Koobi Fora Formation
(from Feibel 1988)

Figure 3-4: Upper Burgi Member Sections in the Ileret Region
(from Gathogo and Brown, 2006)
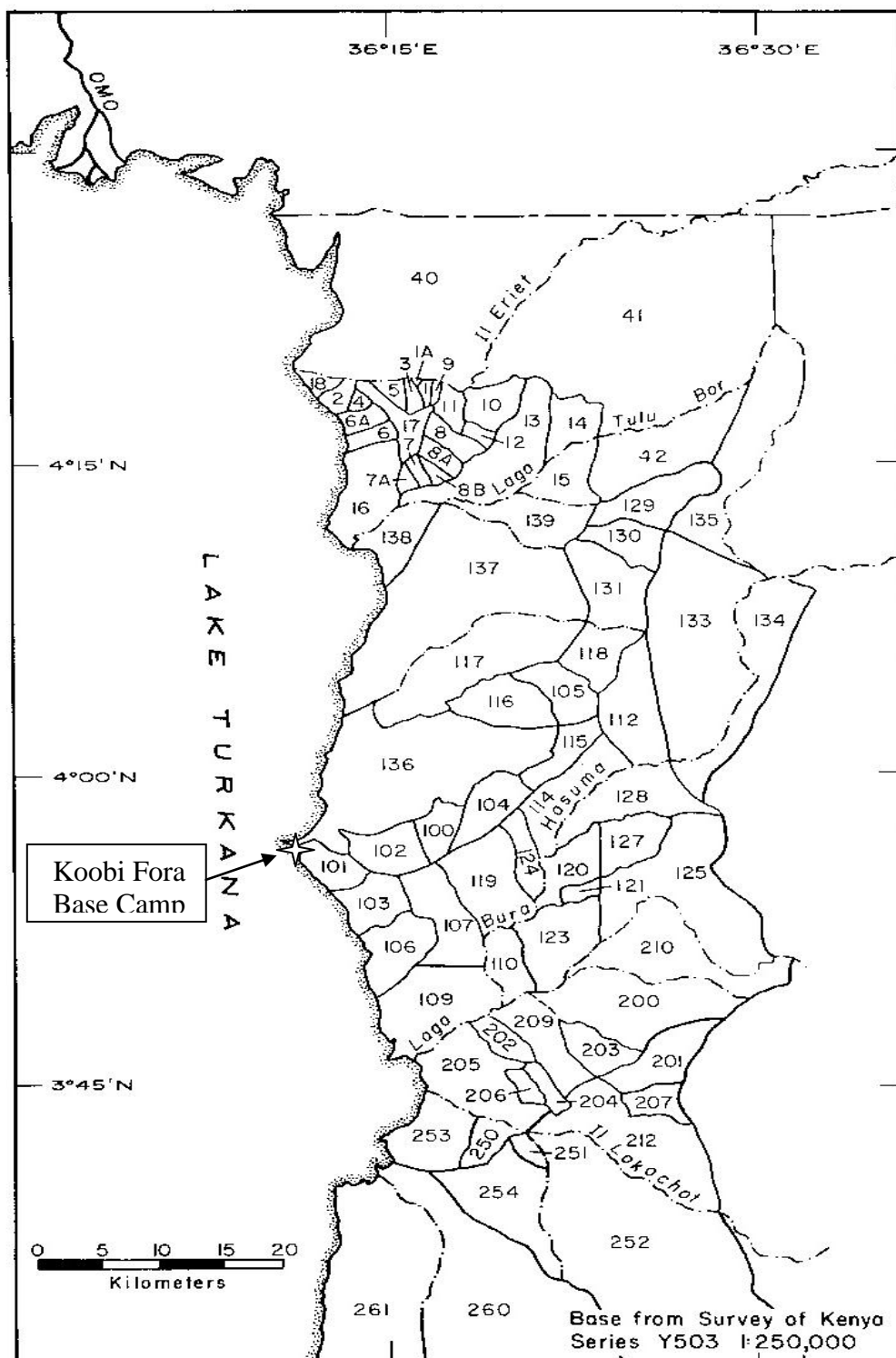
Figure 3-5: **Fossil Collection Areas in Koobi Fora**
(adapted from Feibel 1988)

clastics and volcanic clastics. This sedimentary structure is associated with fluvial activity interacting with fluctuating lake levels, resulting in deltaic infilling (Brown & Feibel 1991). Upper Burgi exposures were targeted for this research because they are laterally extensive at Koobi Fora and are rich in terrestrial vertebrate fossils in many locations. The specific research locations within these areas were initially identified based upon personal conversations with Dr. J.W.K. Harris and Dr. Craig Feibel; and also during preliminary field survey conducted in 2001. The hominin lineage was experiencing dramatic evolutionary changes during this time; including the first appearance of the genus *Homo* and upper Burgi exposures have produced over three dozen hominin body fossils. Ewxcept for one small surface scatter of artifacts in Area 105 (Isaac *et.al* 1976), virtually no archaeological evidence has been reported from these deposits. Therefore it is hypothesized that upper Burgi Member exposures may contain a wealth of previously untapped archaeological evidence (in the form of hominin modified bone) of habitat, ecology, changing diet, and movement across the ancient landscape during this critical period of hominin evolution.

Physical Evidence

Physical evidence for this research exists on multiple levels. Traces of hominin presence on this ancient (2.2-1.87 million year old) Koobi Fora landscape consist of stone tools and/or hominin modified bone identified during surface survey. Surface transects are a valuable tool necessary to systematically identify this evidence but issues concerning the original context of the surface material may be encountered. Bunn (1994) defined several possible sources of isolated surface finds that need to be considered when making behavioral inferences. These surface accumulations could represent: 1.)

undisturbed remains of an individual hominin action, 2.) portion of a larger accumulation that has been transported by fluvial action, 3.) The eroding margin of a larger accumulation. Most of these source issues can be resolved by excavation and fortunately where excavation is not practical careful examination of the depositional environments surrounding the surface finds enables many individual surface finds to be assigned to "…an approximate stratigraphic provenance and microhabitat" (Bunn, 1994, p252). This archaeological evidence is thus valuable in that it not only pinpoints hominin presence on this landscape but also provides clues of habitat utilization. In order to build new models of hominin behavior it is necessary to put the evidence of their presence into an ecological and paleolandscape context. The upper Burgi exposures deemed appropriate for this field research represent distinct and laterally distant geographic locations on the modern landscape. Targeted for systematic detailed surface survey and limited excavation were fossil bearing sediment exposures in fossil collection areas 102, 105, 130, 131, and 41 (Figure 3-5) which had been previously identified during preliminary field research and were already defined by UTM coordinates during that 2001 fieldwork. This dissertation field research entailed the collection of fossilized bone from each survey area and excavation, along with the characterization of each individual element of fossilized bone found as to taxon, element, side, size, portion, surface condition, perimortem/postmortem biotic modification, and changes due to diagenesis. The character of the exposed sediments in each excavation and survey area was described in order to define the ancient geographical context of the fossil evidence, i.e. lakeshore, river, floodplain, etc. The lateral extent of each fossil bearing area to be investigated was identified and sedimentary sequences were developed in order to determine the

heterogeneity/homogeneity of the paleolandscape. These sedimentary sequences were correlated with regional marker beds and major lithofacies and were integrated into an ecological context for habitat definition. In all of the proposed research areas, the upper Burgi Member sediments are bounded on top by well defined outcrops of the KBS Tuff. Survey was confined to the variable sedimentary sequences below the KBS Tuff and above the fully lacustrine sequence at the base of the upper Burgi Member. Pockets of terrestrial vertebrate fossils in prograding deltaic lobe sequences within the upper Burgi lacustrine sequence were also surveyed. Analysis of the faunal assemblage allows for the reconstruction of ancient animal communities and when combined with data on sedimentation and paleobotany it is possible to construct meaningful inferences about paleoenvironments and hominin habitats. The individual locations selected for investigation trace along a 50 kilometer arc that runs from the vicinity of the modern lakeshore near the Koobi Fora base camp all the way to the edge of the basin margin. The research objectives were the same for each individual location but every location presented unique idiosyncrasies that required some modification of the methodology employed in the field. Locations that were geographically widely spaced were selected in order to reconstruct an isochronous picture of hominin presence and habitat utilization across large portions of the ancient landscape.

This chapter is divided into three sections that describe the research methodology starting from the site most proximate to the basin margin (Area 41) and proceeding along an arc southwest towards the modern lakeshore (Area 102). Each section contains a description of the modern geographical, geological, and sedimentary context of the

research location, the reason it was selected for investigation, details of specific

methodologies, and a summary of data collected.

Sub-section 1.)   Ileret: Area 41 (site designation: FwJj 20)

Survey 2004:	Jack McCoy
Survey 2005-2007	Jack McCoy
Excavation 2004:	J.W.K. Harris / D. Braun
Excavation 2005:	J.W.K. Harris / D. Braun / J. McCoy
Excavation 2006:	D. Braun
Geology/Paleomag 2007:	N. Levin / D. Braun

Research Location Selection Rational

In 2004 this field research was commenced in fossil collection Area 41 under the

direction of Dr. J.W.K. Harris. Previously in 2002 and 2003 the Koobi Fora Field

School, also led by Dr. Harris, had conducted exploratory survey in the area. The survey

yielded one very promising but isolated location with a differentially dense concentration

of terrestrial vertebrate fossils scattered across the surface. Area 41 is a large and, due to

the topography and lack of roads, difficult area in which to work. However, because of

the unique nature and richness of the surface material, this location was selected for

intensive surface survey. It is possible that additional locations of interest will be

discovered in the future from this area but extensive survey during the last four years of

field work has failed to locate them.

Modern Geographic Context

Area 41 is situated along the western flanks of the Suregei volcanic plateau in a

region known locally as the Il Dura. It is bounded on the north by the ephemeral Il Eriet

River and the Ethiopian border, and on the south by the ephemeral Tulu Bor River. The

Il Dura sub-region also encompasses fossil collection Areas 14, 15, and 42. Travel to this

extremely remote part of Kenya is both difficult and sometimes dangerous and therefore

very little comprehensive paleoanthropological research has been conducted this close to

the Ethiopian/ Kenyan border. The site of the field research is about 15 kilometers east

of the modern village of Ileret and less than 2 kilometers west of the basin margin

volcanics. Classic undulating eroded sediment badland topography is dominant with

areas of significant relief present where eroding sediments are capped by more resistant

deposits. Eroded sediments are exposed on the western face of a prominent ridge that

runs north/south and the research site is located in a natural "amphitheater" that had

formed on the southern portion of that ridge (Figure 3-6). Total relief from the top of the

ridge to the bottom of the local drainage is approximately 30 meters. The KBS Tuff

(Appendix 3-1), a grayish white tuffaceous layer, is discontinuously exposed about 7

meters from the top of the ridge and the stone tools and fossil bones are located about 14

meters below this tuff horizon (Photograph 3-1).

Specific methodologies

Once the lateral extent of the fossil bearing exposures was determined, a datum

was established and a survey grid (100 meters by 110 meters) was created (Figure 3-7).

The corners of each grid square were "shot in" using a laser theodolite. Fifteen squares
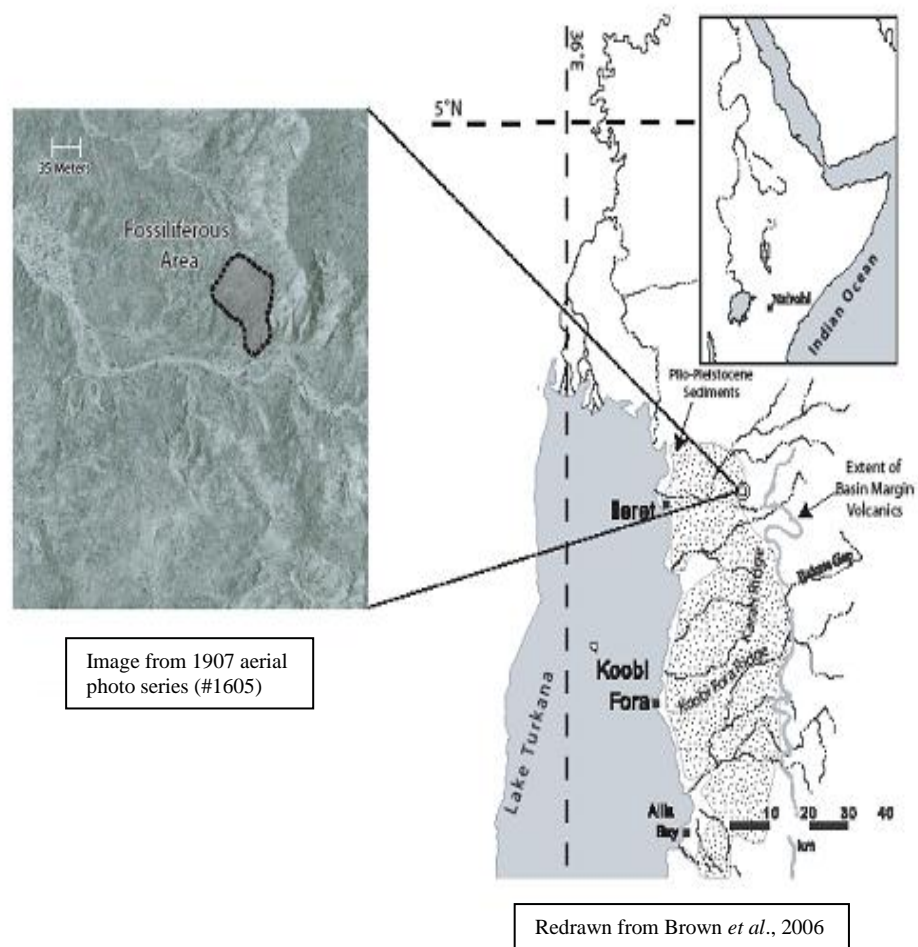
Figure 3-6: **Geographic location of fossil bearing upper Burgi sediment exposures in Area 41 and the location of archaeological site FwJj 20.** (from Braun *et al*., in press)
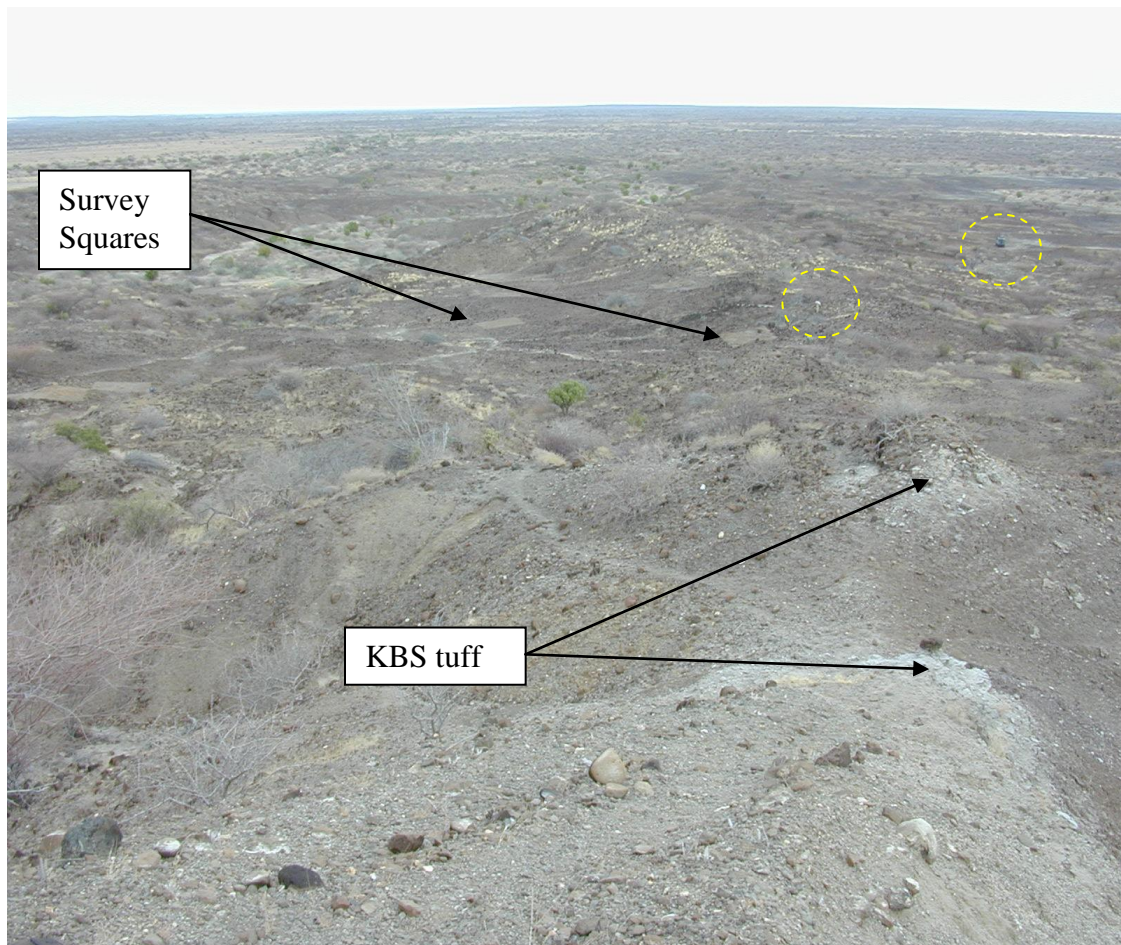
Photograph 3-1: **Natural Amphitheater that is the site of the Area 41 Research: taken from above the KBS Tuff (visible in the right foreground) looking west and encompassing most of the survey area. Landrover and person shown in distance on the right (circles).**
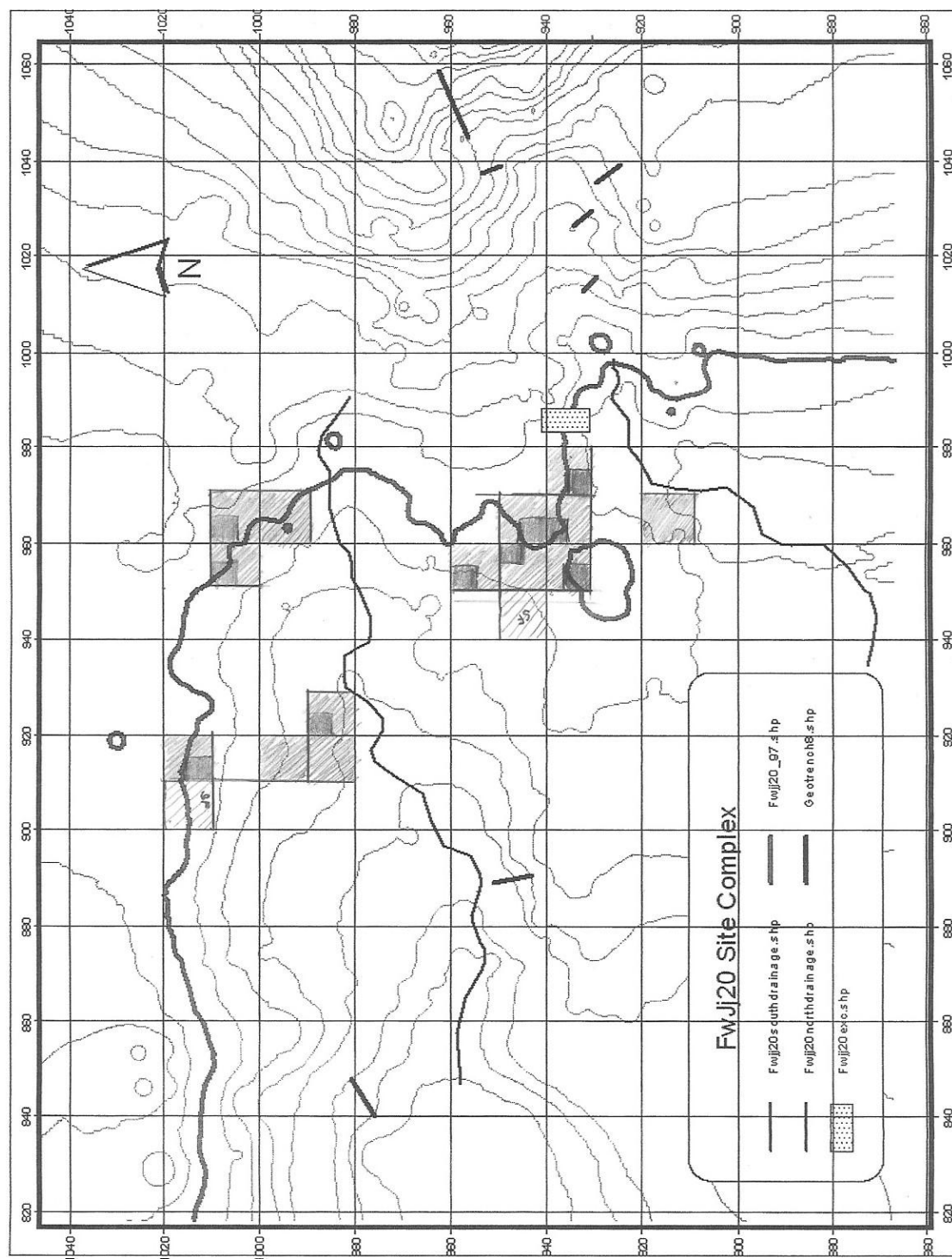
Figure 3-7: **Area 41 Site Grid Showing Survey Squares, 2004 Excavation, and 2005 Geo-Trenches**
(Adapted from Braun 2005 Personal Communication)

(10 meters by 10 meters) were chosen for detailed survey based upon the density of the surface fossils present. As a control, a subset of nine additional squares was randomly selected from the remaining 117 grid squares and these squares were subjected to the same survey protocol. All squares were delineated on the surface by nylon cord (Photograph 3-2) and for each square surveyed six people were aligned along one boundary of the square on hands and knees. In line they crawled across the square identifying, by flag, any fossil bone or tooth encountered (Photograph 3-3). Each fossil that had been flagged was evaluated by the principal investigator and collected if it was identifiable to the taxonomic family level or if any surface modification was likely to be present. Each fossil was marked with a field specimen number (prefixed with the letter "A") and data as to length, width, taxon, size, element, portion, side, spatial orientation, surface condition, and modification marks were recorded on every terrestrial vertebrate fossil tooth or bone collected (Figure 3-8). An additional control was implemented in order to evaluate the effectiveness of the survey methodology. Once the initial survey was completed, the square was divided into quarters and one randomly selected quarter was subjected to a "surface pick" followed by a "surface scrape" with the sediments collected being passed through a ¼ inch screen. This procedure was followed for the first 10 squares surveyed but was suspended thereafter because it was apparent that virtually all the fossils of interest to this research were properly identified by the original methodology. GPS coordinates and the elevations of the datum and corner points on most of the survey squares as well as center points of squares selected for surface scrape were recorded using a Garmin etrex Vista. The accuracy of this device is specified by the manufacturer at "less than 15 meters" but experience with this GPS

Photograph 3-2: Grid Layout in Area 41 Survey Area

Photograph 3-3:   Surface Survey Methodology

Faunal Data Collection Form

GPS (nw corner of survey square):   Sheet #:

Collection Area: Date:

Time:

Photographs: Investigator:

Weather:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ID#	Length (mm)	Breadth (mm)	Skel. Part	Port.	Seg.	Circum.	Side	Size	Taxon	Surface Cond.	Recent Break	Weather Stage	Age Modification	Comments

Figure 3-8: Survey Data Collection Log Sheet

at Koobi Fora over the past 9 years has yielded an actual accuracy of less than 2 meters. Some terrestrial vertebrate fossils of interest were located outside the survey grid. The locations of these fossils were recorded using the GPS.

During exploratory transects across the site in 2004, a number of simple Oldowan stone tools were discovered interspersed among the fossils on the surface in the southeast corner of the survey grid. Because of the number of stone tools and their fresh unweathered condition the decision was made to conduct a small excavation (1 meter by 5 meters) where the stone tools were most abundant on the surface. The excavation was conducted under the direction of Dr. Harris and his graduate student, David Braun. The goals of the excavation were to find the source stratum of the stone tools, see if the fossils were also coming from the same stratum, and determine if there was any *in situ* association between the two. The surface survey coupled with the excavation produced such a wealth of data that two additional field seasons were spawned, the first in February/March 2005 and the second in October/November 2007, where the excavation was significantly expanded. Geological trenching was conducted during all three field seasons in order to characterize the sedimentary history of the location. Geological trenches were positioned vertically across the exposures to insure that there was an overlap of strata in adjacent trenches enabling lateral stratigraphic correlation across the site and the construction of a composite geological section . In December 2007, samples of consolidated sediment were collected from several of the geological trenches and sent to the University of Liverpool, U.K. for magnetostratigraphic analysis (Figure 3-9).
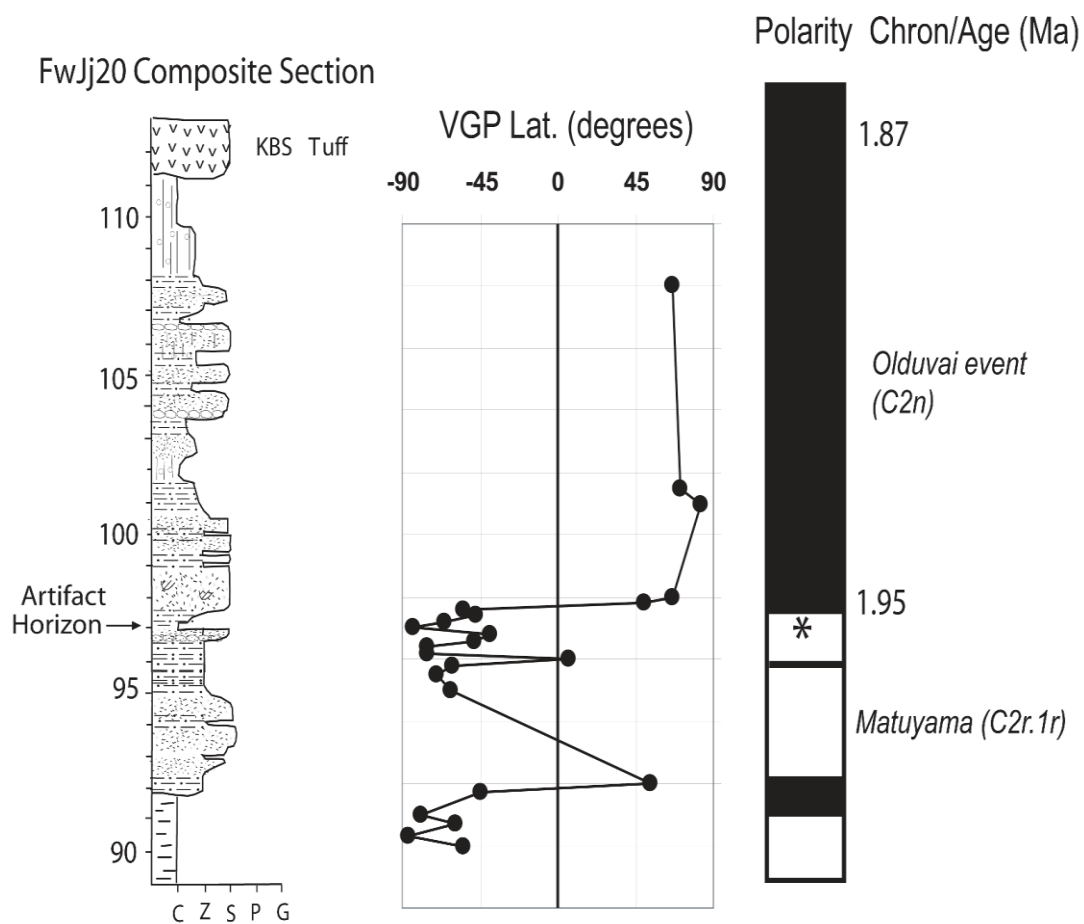
Figure 3-9: **Results of magnetostratigraphic analysis from FwJj 20 and associated geological trenches in Area 41.** (adapted from Braun *et. al* 2008)

Geological & Sedimentary context

For at least 4 million years the depositional topography of the Turkana Basin has fluctuated as a function of tectonic activity due to rifting coupled with the water and sediment load flowing out of the Ethiopian highlands. The basin has alternated between braided stream, large meandering river and lacustrine phases and was dominated during Burgi Member times by a large stable fresh water lake (Lorenyang Lake). However, tectonic uplift in northeast sometime after 2.3 million years ago changed the nature of the basin from depositional to erosional and there is a gap (unconformity) in the sediments of the eastern basin of at least 500,000 years. Around 2.2 million years ago the Lorenyang Lake became unstable as the depositional nature of the basin gradually transitioned from lacustrine to fluvial and the eastern basin again became a destination for sediments from the Ethiopian highlands (Feibel 1988). The sedimentary history of upper Burgi Member times in the Il Dura region reflects this change with large deposits of sediment representing alternating periods of lake transgression and regression with associated episodes of delta progradation of the Proto-Omo River along the northeastern shore of the Lorenyang Lake (Figure 2-12).

The artifacts and most of the fossils were eroding out of strata consisting of a 6 centimeter thick clay deposit that was cut by coarse sand lenses and overlaid by approximately 3 meters of medium grain sand that is also fossil bearing and exhibits horizontal laminated and ripple marked units along with 10-15 centimeter high trough cross sets. The artifact/fossil bearing layer sits atop about 2 meters of planar laminated silty clays characteristic of prodeltaic deposition and below these sediments is at least 3.5

meters of mostly massive clays and silts characteristic of deep lacustrine deposition. The

sediments above the medium grain sand unit consists of a series of fining upwards

sequences and paleosols that are capped by the KBS Tuff about 14 meters above the site

(Figure 3-9) (N. Levin, 2007 Personal Communication; R.L. Quinn & C.J. Lepre, 2006

Personal Communication).

The artifact and bone bearing clay horizon likely represents a flood deposit on a

fluvial (deltaic) bar. This was a subaerial surface upon which the bones and artifacts

were deposited before being covered by coarse sands and silts as the fluvial bar continued

to develop (Levin, 2007 personal communication). The site shows no indications of

significant fluvial transport. Small and large fossil bones and artifacts are found in close

association indicating absence of winnowing. Large linear bones show no preferred

orientation and the artifacts maintain fresh sharp edges with no evidence of rounding.

Also, no unmodified stone clasts of sizes similar to the fossil bones and artifacts were

present at the site or anywhere else in the sand unit which is exposed both at and laterally

away from the site. Magnetostratigraphic analysis of samples of consolidated sediment

taken from the geologic section above the artifact/fossil horizon exhibits a stable normal

magnetic polarity. The sediments at the site horizon exhibit reversed magnetic polarity.

Below the site horizon, mixed but predominantly reversed magnetic polarity prevails.

Therefore the site horizon is interpreted as being older than the beginning of the Olduvai

Subchron which occurred at 1.945 million years ago and younger than the interface that

defines the Burgi Member unconformity (estimated to be about 2.0 million years old)

since all other securely dated geomagnetic reversal events predate 2.0 million years ago.

The site horizon is situated about one meter below the base of the Olduvai Subchron and

about 40 meters above the Burgi Member unconformity and the age of the site is

estimated at 1500 to 5000 years before 1.945 million years ago (Braun *et al*., In Press)

	E900-910	910-920	920-930	930-940	940-950	950-960	960-970	970-980	980-990	990-1000
N1020-1010	13/2 (1)	46/62 (2)								
N1010-1000		0/1 (0)	0/1 (0)		0/1 (0)	27/16 (2)	24/10 (1)			
N1000-990		24/28 (1)					17/5 (2)			
N990-980		23/21 (0)	41/45 (0)				1/1 (1)			
N980-970										
N970-960										
N960-950		1/0 (1)		0/1 (0)		16/7 (0)				
N950-940					2/0 (0)	26/19 (1)	32/24 (0)			
N940-930						23/10 (2)	74/52 (4)	27/46 (2)		
N930-920										
N920-910							8/8 (1)			
N910-900										
N900-890										

Area 41 Survey Grid 2004

Data Summary: **Area 41**
Specimens collected per survey square: {bones/teeth, (hominin modified)}

Additional bones and teeth collected during subsequent field seasons.
Loci identified by GPS points:

Bones: 21   Teeth: 16   Modified: 5

Sub-section 2.)   **Karari Escarpment and Aberegaya Ridge : Area 130/131/105**

> 2001 Survey: Jack McCoy
> 2004 Survey and Excavation: Jack McCoy
> 2005-2007 Survey: Jack McCoy

Research Location Selection Rational

The Karari Escarpment has been the site of extensive paleoanthropological investigation for more than three decades. Hominin fossils from Burgi, KBS, Okote, and Chari Member sediments on the escarpment are the source of much of what we understand about the basic trajectory of hominin evolution in East Africa during the Plio-Pleistocene. Archaeological traces from KBS, Okote, and Chari Members are the basis of testable models of emerging human behavior.   However, archaeological traces of that behavior extending back into the late Pliocene have yet to be identified despite decades of survey and excavation in the Pliocene sediments of the upper Burgi Member at Koobi Fora. These sediments are extensively exposed on the western slopes of the Karari Escarpment and were the focus of preliminary research conducted in 2001. Like the Karari Escarpment, the Aberegaya Ridge has witnessed a great deal of paleontological research during the past 30 years and has yielded numerous hominin fossils as well as important KBS Member archaeological sites such as FxJj 1 and FxJj 3. During field survey in 2001, fossil bearing exposures of upper Burgi sediments were identified on the ridge and surrounding valleys that also warranted additional investigation. These concentrations of terrestrial vertebrate fossils that could possibly include hominin modified bone, were targeted for this research.

Modern Geographic Context

Fossil collection Areas 130 and 131 are situated along the Karari Escarpment approximately 16 kilometers south-southeast of FwJj 20 in Area 41 and about 20-25 kilometers east of modern Lake Turkana (Figure 3-10). Headwater erosion of ancient basin sediments by the Il Naibar and Laga Tulu Bor ephemeral rivers is responsible for the topography of the escarpment in its present form. This feature emerges from the base of the Suregei Hills at the basin margin in the northeast and extends southwest for about 20 kilometers where it merges with the rolling mounds of the Aberegaya Ridge and the headland of the Koobi Fora Ridge. The escarpment encompasses fossil collection Areas 129, 130, 131, and 118. Areas 130 and 131 are at the central point and most prominent part of the escarpment where the outcrop slopes steeply off the headlands to the west and merges with the extensive Lorenyang Lake lacustrine sediments which form the basal upper Burgi exposures. The exposed sediments consist mostly of Okote Member outcrops overlying KBS and Burgi Member sediments (Figure 3-11). There are prominent outcrops of the KBS Tuff across the northern and western faces of the escarpment. An area called the "back slope" descends to the east with a low gradient and eventually merges with basin margin volcanics near the Ol Bakate Gap. Both collection areas (130 & 131) are accessible by road but the individual research locations can only be reached by hiking for 20-40 minutes over rough eroded undulating terrain.

The Aberegaya Ridge in Area 105 abuts the southern end of the Karari Escarpment and runs roughly east/west. The ridge sits between two valleys, Bogi
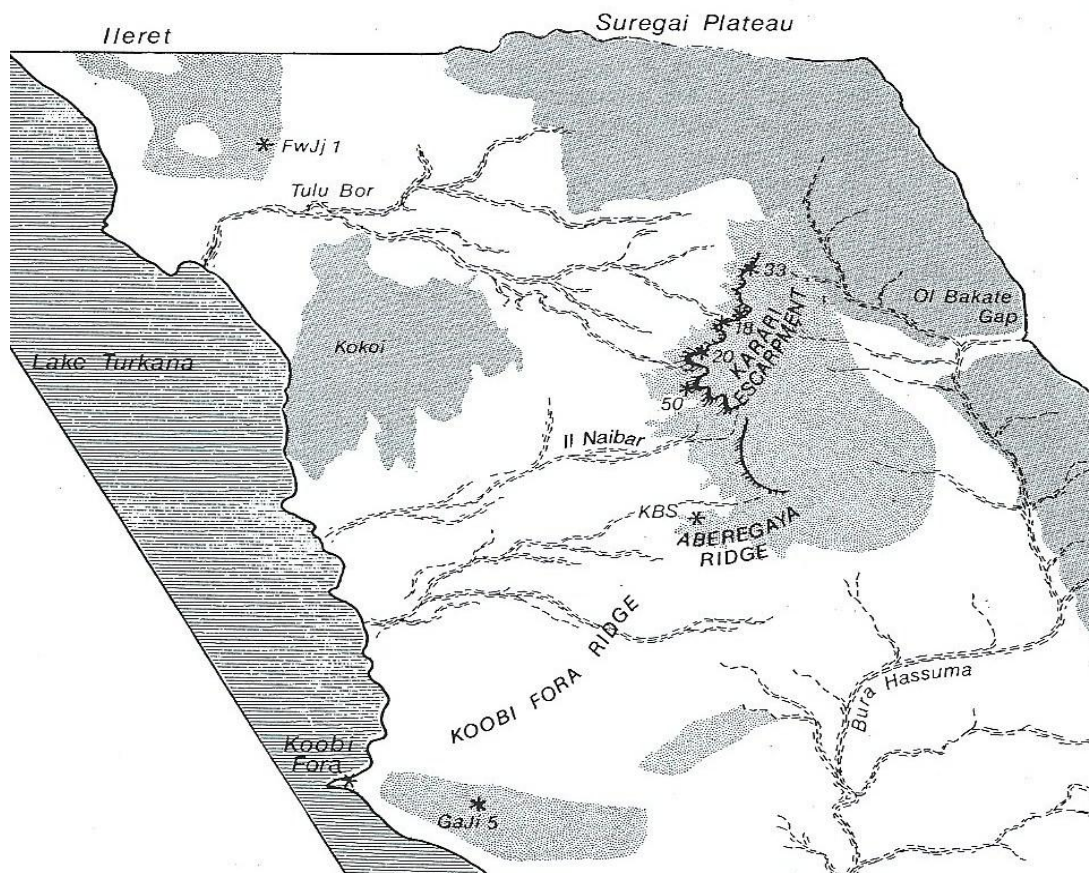
Figure 3-10: **Modern geographic location of the Karari Escarpment and the Aberegaya Ridge.** **(adapted from Isaac & Behrensmeyer 1997)**
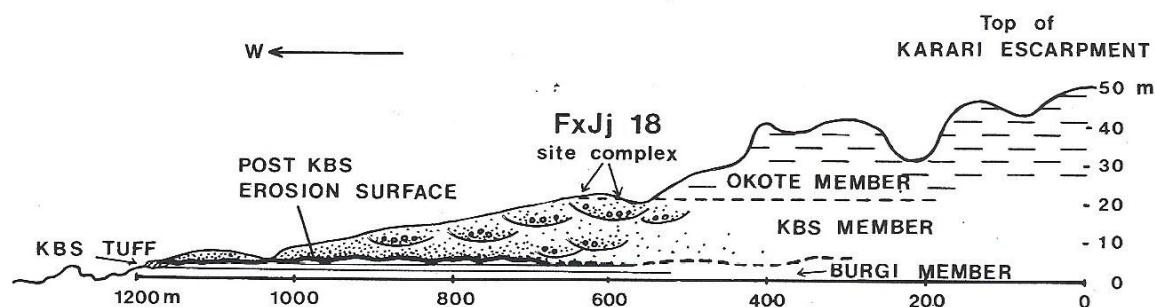
Figure 3-11: Representation of the general sedimentary character of the Karari Escarpment. **(adapted from Isaac & Behrensmeyer 1997)**

Karuma in the south and Aberegaya in the north and the modern topography is the result of cut-back erosion from the ridge into the valleys. The ridge is primarily composed of lacustrine sediments deposited during the Lorenyang Lake phase of upper Burgi Member times. However, fluvial and deltaic sediments deposited as the lake level fluctuated are common in Area 105. The KBS Tuff is not ubiquitous in Area 105 but is prominent in fluvial channels that were incised into the upper Burgi sediments during KBS Member times and choked by KBS tephra from the Ethiopian highlands. Many of the KBS Member archaeological sites in Area 105 are closely associated with the tuff in these channels. Most locations identified during this research were situated in low relief deltaic/lake margin sedimentary environments. Like the Karari Escarpment there are established gravel roads nearby but the individual research locations can only be reached, cross-country, by foot.

Specific methodologies

Surface survey methodologies were consistent with those used in Area 41 described in the previous sub-section with a few exceptions. No laser theodolite was available for this part of the field work. Extensive areas were surveyed and the fossil sites discovered are widespread. In all cases survey was conducted well below and down section (west and south) from the prominent KBS Tuff outcrops along the northern and western faces of the escarpment. Where differentially dense concentrations of terrestrial vertebrate fossils were noted on the surface, an arbitrary datum was positioned (GPS coordinates recorded) to the north and west of the surface patch and a north/south, east/west grid of 10 meter by 10 meter squares was constructed using nylon cord. None

of the fossil sites described above were as latterly extensive as the location explored in Area 41.

In addition, several lower density patches (but still exhibiting differentially and significantly higher surface fossil density than the surrounding low density scatter) were located and systematically surveyed using a different methodology. It quickly became apparent that a grid of squares (10 meters x 10 meters) would not be a practical or efficient method to explore these patches because of the large area and lower density of fossils. The overall boundaries of the patch were defined and the patch was subjected to the same detailed surface survey methodology by the field team, but no survey grid was employed. Each fossil of interest to this study was marked by a flag. The principal investigator evaluated each flagged fossil, and appropriate fossils were measured, collected and the GPS coordinates were recorded along with all the other pertinent data (see figure 3-8).

Geological & Sedimentary context: Area 130

Extensive surface survey in Area 130 yielded five distinct areas of upper Burgi Member exposures yielding terrestrial vertebrate fossils. In the order which the specific sites were identified, each research location was assigned a distinct field site number; 130A, 130B, 130C, 130D, and 130E respectively (Figures 3-12 & 3-13 & 3-14). There was considerable variation among the individual sites in terms of surface fossil density and lateral area involved and therefore the research methodology was adjusted, appropriate to these circumstances.

Site 130A is located at the base of a large sand body about 6 meters below an exposed outcrop of the KBS Tuff capping a finger of sediment along the eroding high

Area 130 sites
See Figure 3-13

Area 131 Sites
See Figure 3-16

(from Vondra, Burggraf and White, 1978)

(from Bainbridge 1976)

Figure 3-12:
Area 130 and 131
Research Areas
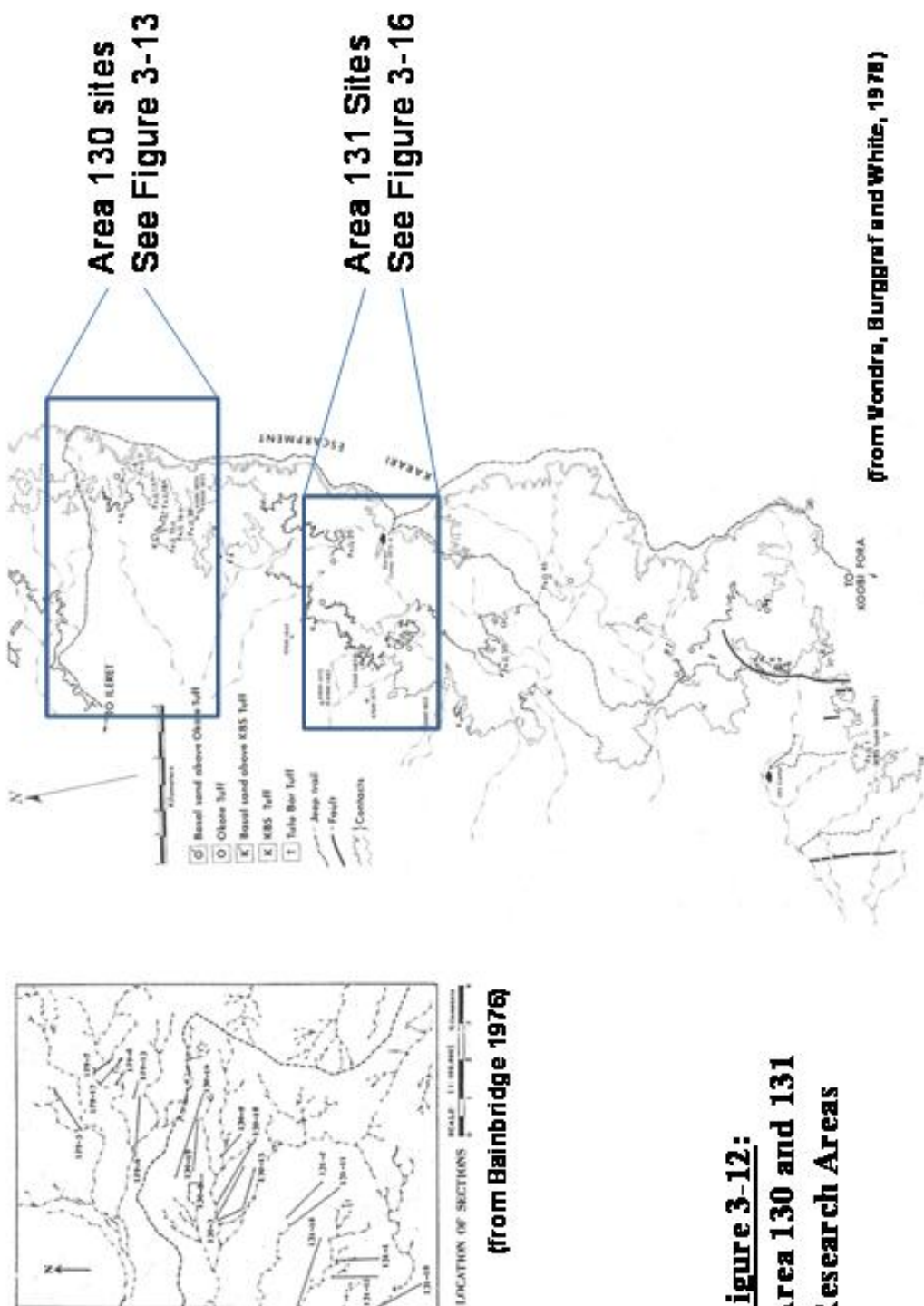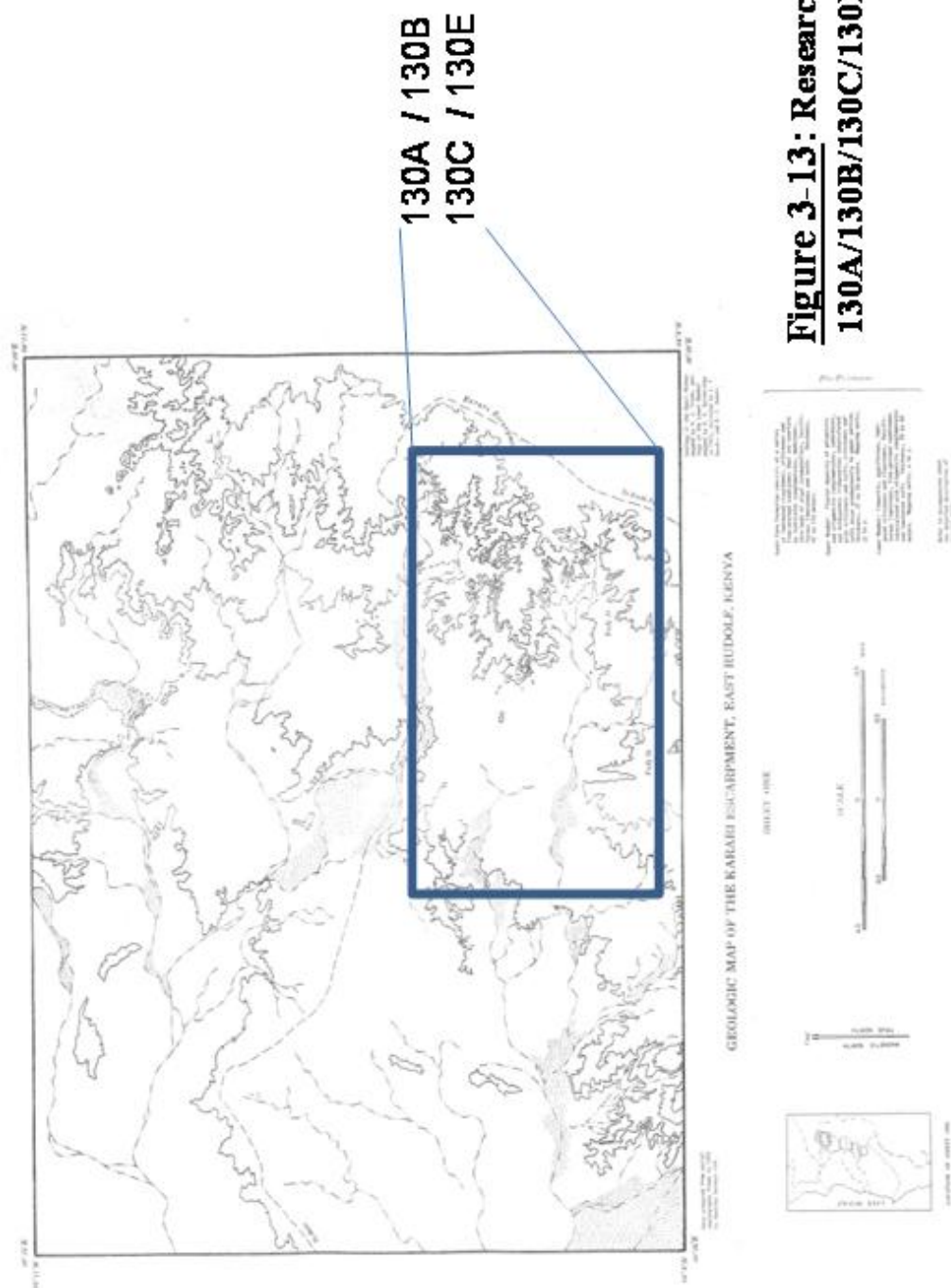
130A / 130B
130C / 130E

**Figure 3-13: Research Areas
130A/130B/130C/130E**
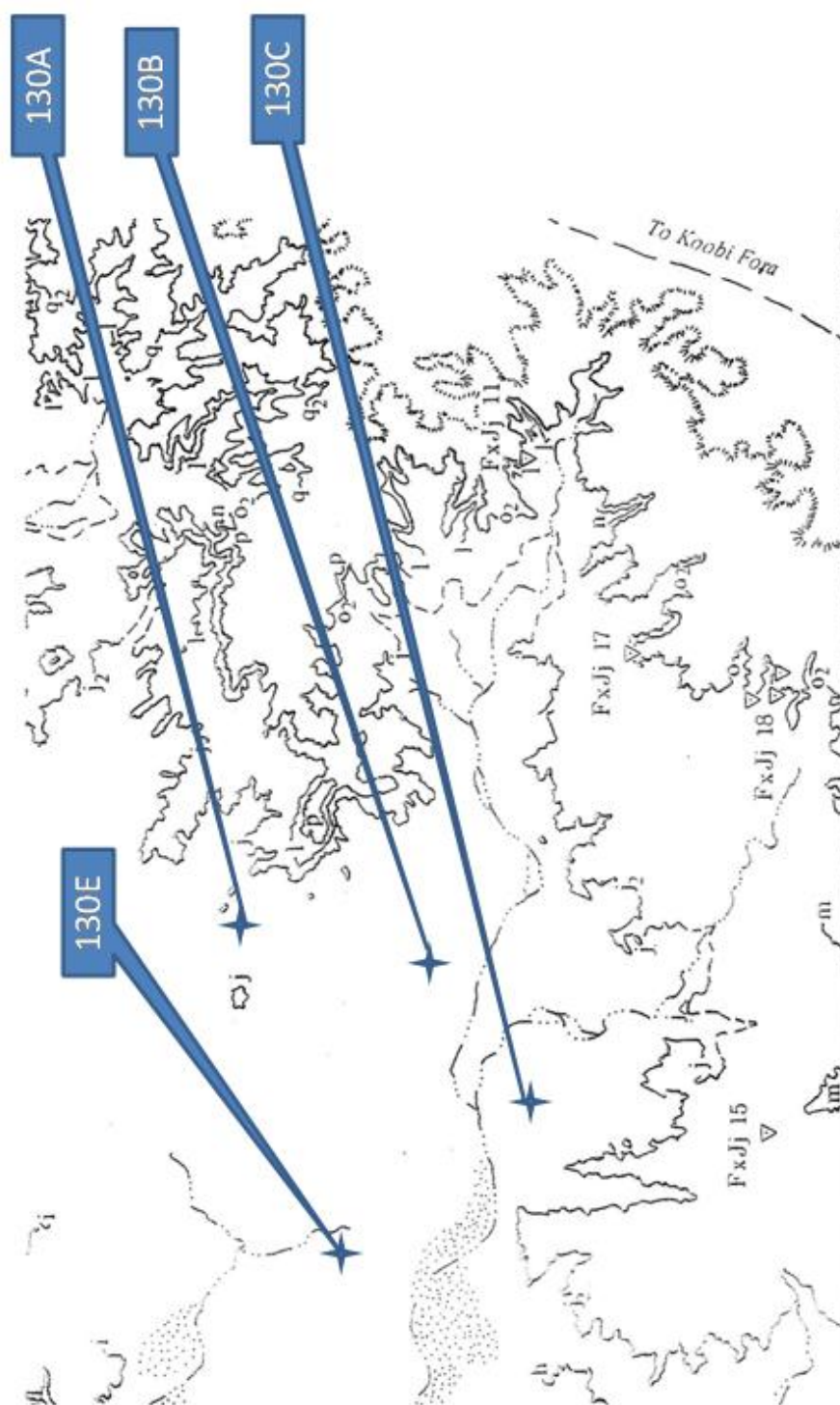
Figure 3-14: Area 130 Research Locations

relief northern and western faces of the Karari Escarpment (Figure 3-14 and 3-15). Two squares (10 meters by 10 meters) were established encompassing a surface patch of terrestrial vertebrate fossils and detailed surface survey was conducted employing the previously described protocol; including a surface pick and scrape of a randomly selected corner area (5 meters by 5 meters)from each of these squares. The survey squares extended part way up the outcrop but most of the fossils were found on a silty-sandy-clay surface at the base of the outcrop. It is possible that some had eroded from the sand body which is exposed directly above the surface. A few very well preserved bones and teeth were extracted from this loose sand during the surface scrape. The series of silty-sandy-clay surfaces at the base of the outcrop are interpreted as a delta front at the base of a sand body that was likely a deltaic channel sand or reworked beach (Feibel 2007, personal conversation). Additional identifiable terrestrial vertebrate fossils were discovered to the north and east of the survey squares. The GPS was used to record the positions of the fossils that were collected for later laboratory analysis.

     Site 130B represents a small patch of fossils located about 300 meters south southeast of 130A and at the same base stratigraphic level on a low relief surface of silty-sandy-clay (Figure 3-14 and 3-15). At this location, the sand body observed at Area 130A had been completely eroded. However, evidence of that sand body is still visible in exposures about 17 meters to the east. Two squares (10 meters by 10 meters), were established on an east/west/north/south grid. Of specific interest was a midshaft fragment with obvious evidence of fresh green fracture. However, no additional modified bones were identified at this site.

**Figure 3-15: Stratigraphic Position of Research
Areas 130 A / 130 B / 130C**
(from Bainbridge 1976)
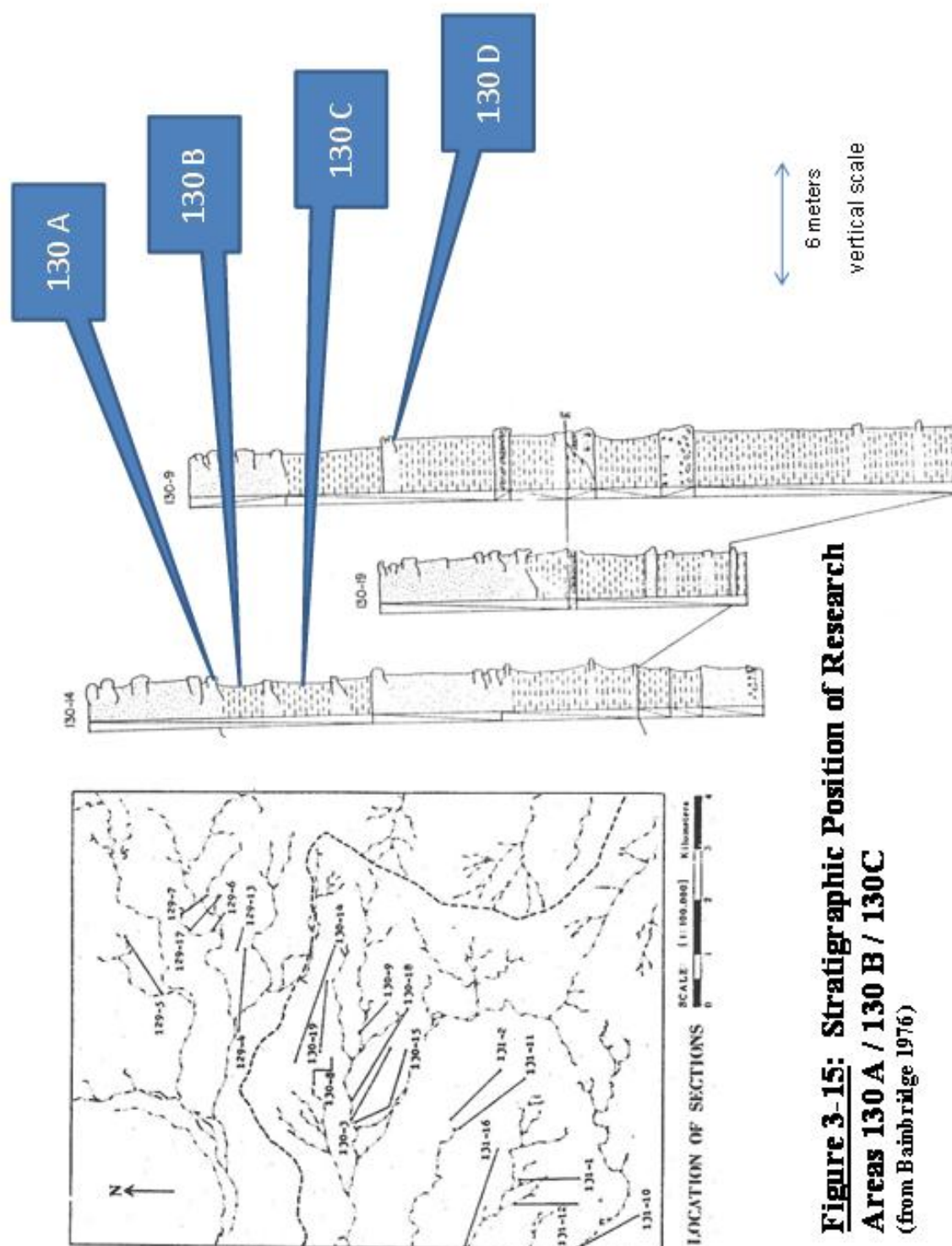
Investigation at **Site 130C** was initiated for two reasons. The fossil bearing deposits were identified during preliminary research in 2001 and this location was also suggested by Kamoya Kimeu and Dr. Craig Feibel (and identified by GPS coordinates) as a possibly productive location for this research. The topography at this location consists of a series of eroding mounds between two sand filled drainages running roughly northeast to southwest. Two overlapping geological trenches were dug into the side of the northern-most mound to establish the microstratigraphy of the site. The geological section (Figure 3-16) shows alternating deposition layers of sand and silty-clay indicative of delta channel lateral movement or lake transgression/regression cycles. Some of the fossils discovered on the surface were likely transported by a channel (represented by the sand body near the top of the section) and deposited on the silty-clay base as the channel sand eroded away; creating the possibility that some of the fossils are in secondary context. Both surface fossils and *in situ* fossils were present (exhibiting little surface erosion) and some of the *in situ* fossil bones retained their original articulated associations. Therefore, if transport did occur it is likely that the distance transported was minimal. The fossils are on, and incorporated into, a poorly formed paleosol indicating possible extended sub-aerial exposure during site formation (Feibel 2007, personal conversation). The relatively dense surface patch of fossils covered an area of approximately 50 meters by 100 meters. A survey grid consisting of 12 squares (10 meters by 10 meters) was established conforming to the existing topography. Surface survey was conducted according to the established protocol and also additional fossils of interest to the research that were located outside the survey grid were collected after their position on the surface was recorded using GPS coordinates.
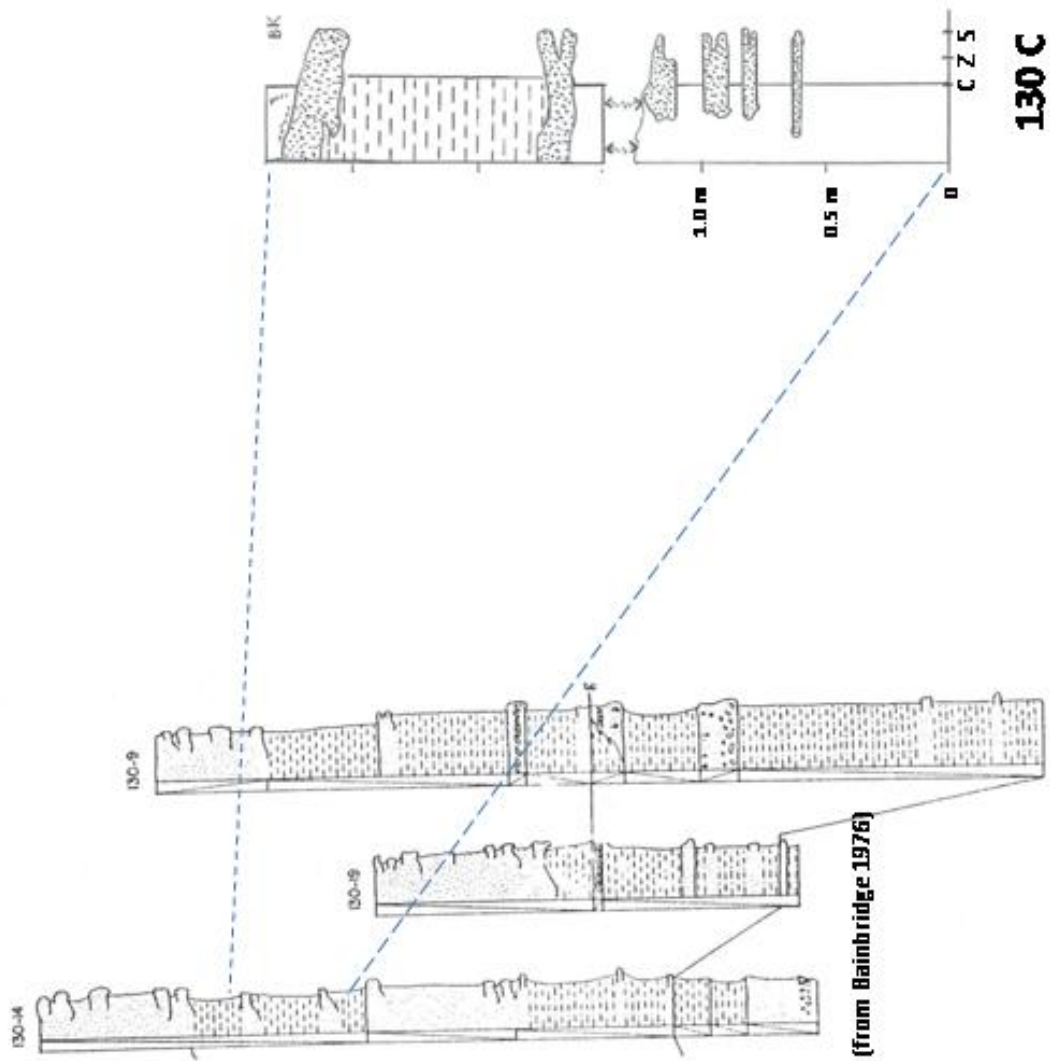
Figure 3-16: Stratigraphic Section from Research Area 130 C

Work at **Site 130D** was conducted adjacent to archaeological site FxJj 83 excavated by the Koobi Fora Field School during field seasons in 2003 and 2004. During survey at that site in 2003, a differentially dense patch of fossils (including a partial skeleton of a *Theropithecus* exhibiting possible cut marks) was identified eroding out of high relief exposures about 15 meters north of FxJj 83. Two squares (10 meters by 10 meters) were established congruent with the grid developed for the FxJj 83 excavation and surface survey and surface scrape were conducted according to the standard protocol established in Area 41. Site 130D is situated lower in the stratigraphic section than 130A, 130B, and 130C but the sediments describe a very similar depositional context (Figure 3-15). As in the other Area 130 sites, the fossils were found on a silty-clay surface at the base of a sand body.

Site **130E** was selected for investigation when a scatter of extremely well preserved surface fossils was discovered during general exploratory survey. One nearly complete bovid tibia with excellent surface preservation and significant evidence of carnivore and possible hominin modification was discovered by Hillary Sale, a Dassenetch tribesman who was part of the field team. The tibia was still partially embedded in a sand stratum at the base of several small mounds. The proximal articulation of the tibia, also in excellent condition, was detached and located only a few centimeters to the north indicating that the tibia was only recently uncovered by erosion. Based on this remarkable fossil and the excellent surface preservation of the fossils proximate to it, a small (2 x 2 meters) excavation was conducted to determine if additional modified bones might also be preserved in this sand. The excavation yielded no additional fossils. The surface fossils that defined this patch were collected and

surface positions were identified by GPS coordinates as defined above. A geological

trench was dug adjacent to the excavation (Figure 3-17). The geological section shows

that the bones were preserved in a sand body that formed at the terminal end of a delta

channel. The sand bodies in the section are depositionally inclined (dip) which indicates

that the sand bodies represent a subaqueous delta front (Figure 3-18). That makes it

likely that the bones were transported and are in a secondary context. The excellent

surface preservation of the fossils also implies that the time and distance of the transport

was minimal. The section also shows that the channel sands were later covered by

lacustrine silts and clays as the lake transgressed. Lake regression followed and a

significant vertisol formed over the sand body. This cycle of lake transgression and

regression is very characteristic of the upper Burgi deposition history in the eastern

Turkana Basin.

Data summary: Area 130

Specimens collected per survey square: {bones/teeth, (hominin modified)}

Area 130 A Survey Grid (2004)

	E1000-990
N1000-990	**5/2 (0)**
N990-980	**6/8 (0)**

**Additional bones and teeth collected outside the survey grid.
Loci identified by GPS points:**

Bones: 25   Teeth: 11   Modified: 3

Area 130 B Survey Grid (2004)

	E1000-990
N1000-990	**14/7** **(3)**

Area 130 C Survey Grid (2004)

	E980-990	E990-1000
N1000-990	**2/2** **(0)**	**10/9** **(0)**
N990-980	**2/3** **(0)**	**1/0** **(0)**
N980-970		**1/3** **(0)**

Additional long bone shaft fragments collected outside the survey grid.
Loci identified by GPS points:

Bones: 4   Teeth: 0   Modified: 0

Area 130 D Survey Grid (2004)

130 D Square 1	**10/2/coprolite** **(0)**
130 D Square 2	**17/3** **(1)**

Area 130 E Survey Grid (2004)

	E980-990	E990-1000
N1000-990	**4/1** **(1)**	**6/4** **(0)**
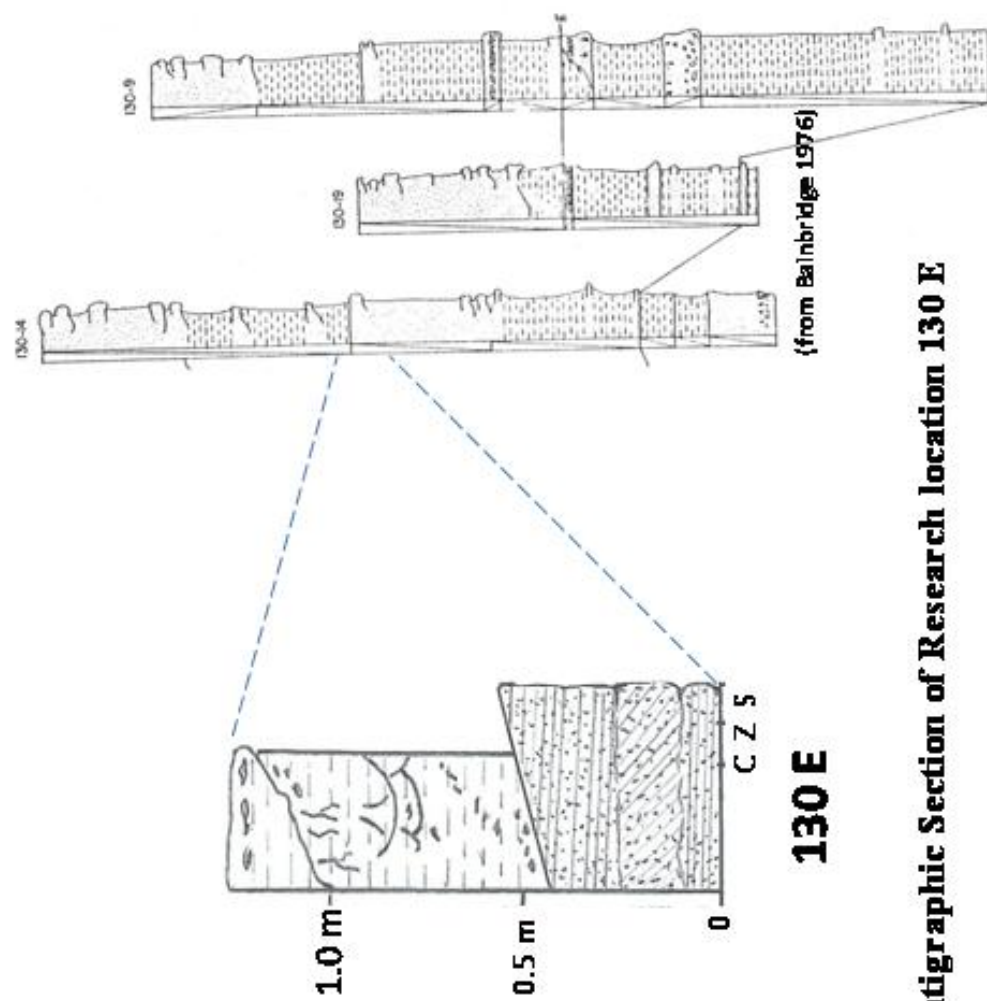
Figure 3-17: Stratigraphic Section of Research location 130 E
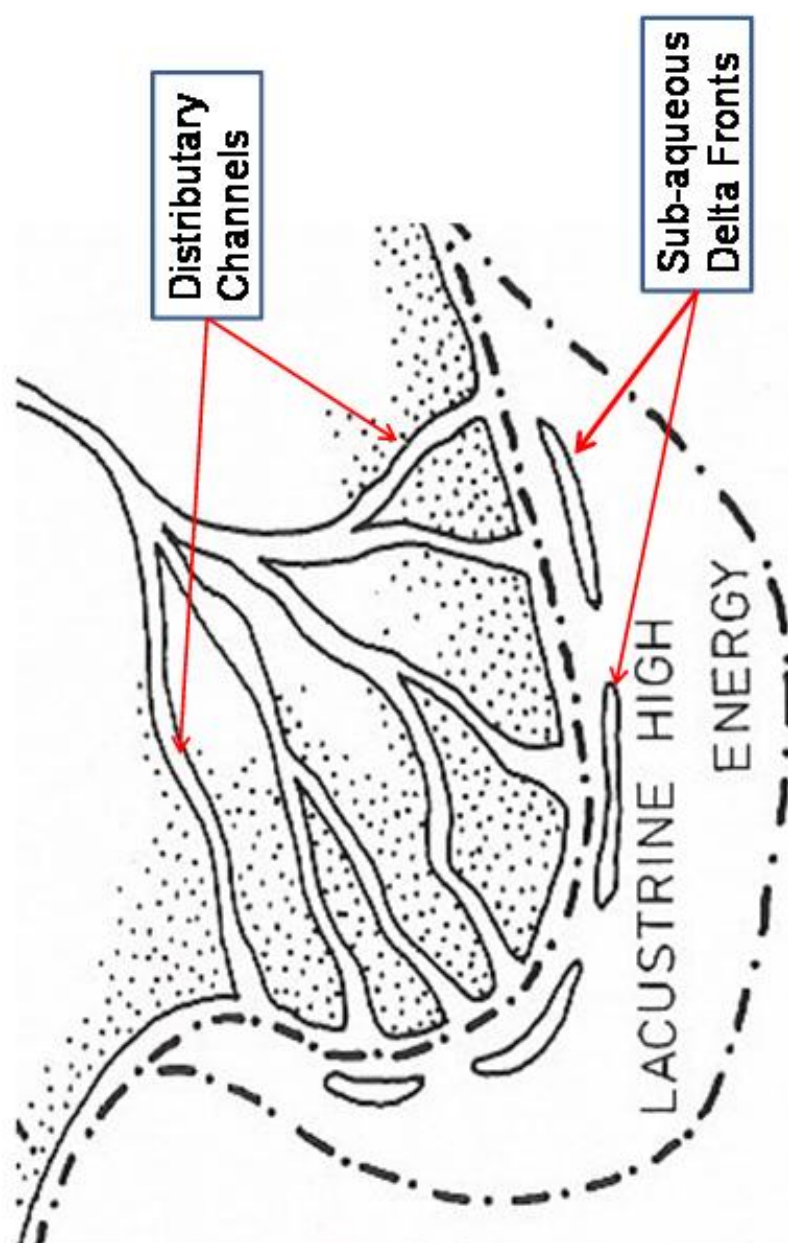
Figure 3-18: Lorenyang Lake Delta Formation

(adapted from Findlater 1978)

Geological & Sedimentary context: Area 131

Extensive surface survey was conducted in Area 131 in 2001. Much of the exposed sediments surveyed in this area consist of massive silts and clays characteristic of lacustrine deposition and largely devoid of any terrestrial vertebrate fossils. However, two very promising areas, both proximate to the site where the *Homo rudolfensis* (KNM-ER-1470) skull was found (Area 131A: 115 meters west northwest of 1470 and Area 131B: 113 meters north of 1470), were selected for further investigation (Figures 3-19 and 3-20). The depositional environment for these fossil patches is similar to that of KNM-ER-1470 (Figure 3-21). The laterally extensive sandstone that represents a beach caps a series of silty-clays exposed in this region of Area 131. Below this is a large sand body that was formed in a deltaic channel and subsequently reworked as a beach and, moving further down section there are a series of silty-clays representing a delta front. KNM-ER-1470, Area131A, and Area131B are found in these sediments. The fossils are interpreted as eroding from delta margin sediments that were deposited in the upper part of a distributary channel (Feibel 2007, personal conversation; Leakey & Leakey 1978) (Figure 3-18).

Figure 3-19: Research
Areas 130E/131A/131B
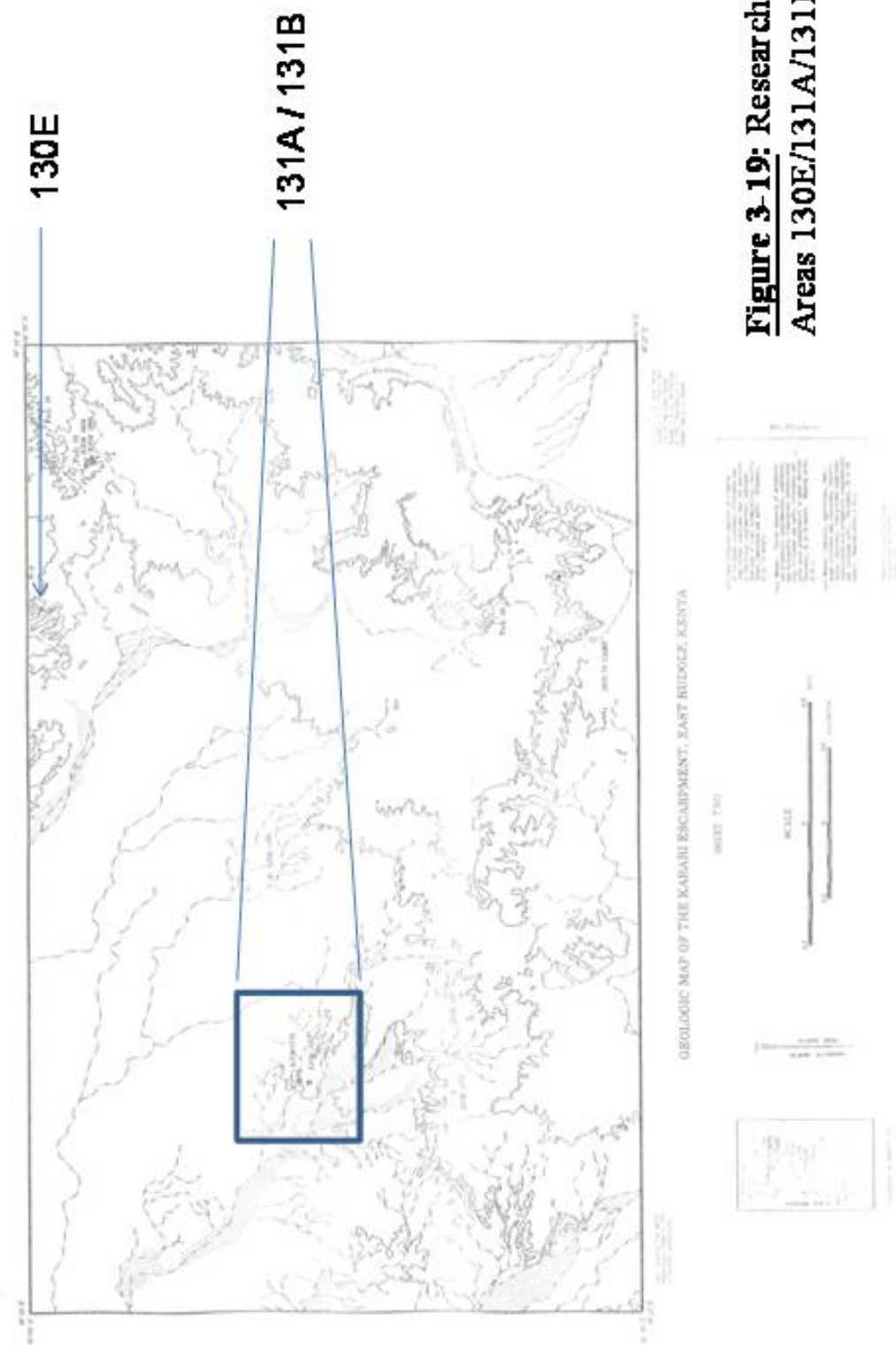
Figure 3-20: Area 131 Research Locations
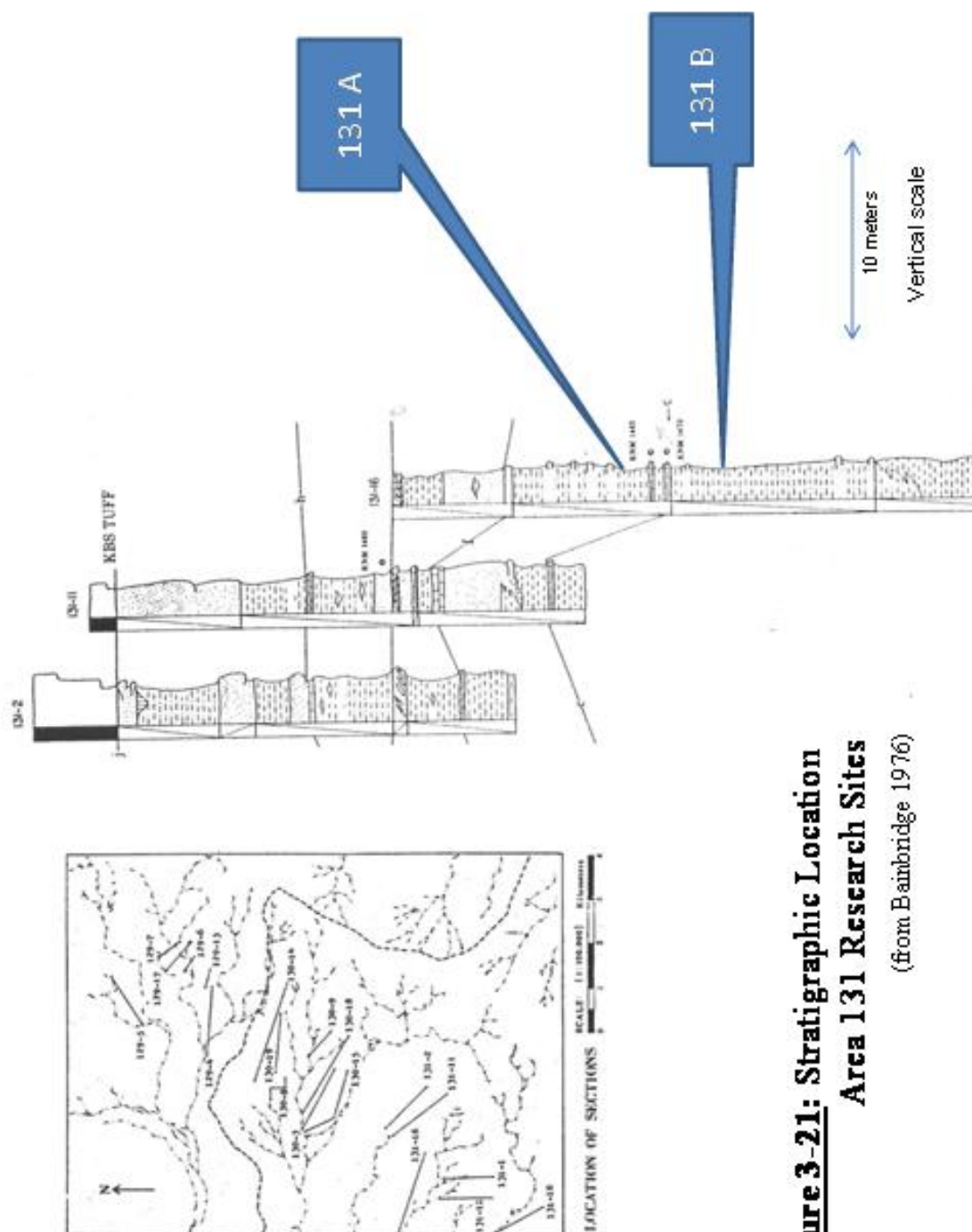
Figure 3-21: Stratigraphic Location Area 131 Research Sites

(from Bainbridge 1976)

Data summary: Area 131

Specimens collected per survey square: {bones/teeth, (hominin modified)}

Area 131 A Survey Grid (2004)

	E960-970	E970-980	E980-990	E990-1000
N1000-990			**13/1 (0)**	**12/1 (0)**
N990-980	**18/1 (0)**	**5/0 (0)**	**8/1 (0)**	**7/2 (0)**
N980-970				**3/1 (0)**
N970-960				**0/1 (0)**
N960-950		**21/1 (0)**		

Area 131 B Survey Grid (2004)

	E980-990	E990-1000
N1010-1000		**6/0 (1)**
N1000-990	**13/0 (0)**	**16/1 (0)**

Geological & Sedimentary Context: Area 105

Three locations in Area 105, south and east of archaeological site FxJj 3, were

identified for future intensive field survey during preliminary research in 2001. A fourth

location, northwest of archaeological site FxJj 1, was identified during the 2004 field

season. Most of the exposed sediments in Area 105 consist of massive lacustrine clays and silts. There are also isolated areas of sandy clays and sandy-silty-clays inter-fingered with sand lenses which represent fluvial/deltaic floodplain facies; and areas exhibiting alternating layers of sand and silt that represent delta or delta channel floodplain facies (Brown & Feibel 1991). Virtually all of the terrestrial vertebrate fossils are located in these isolated sedimentary facies. Surface fossil patch densities are low relative to the previously described locations and therefore all surface survey and collection in Area 105 was conducted by the alternate survey methodology using the GPS coordinates to record the relative surface position of the fossils.

The **"Valley of the Giants"** site is a low relief valley located 490 meters northwest and down section of archaeological site FxJj 1 with eroding mounds of fluvial/deltaic floodplain sediments yielding both aquatic and terrestrial vertebrate fossils (Figures 3-22, 3-23, 3-24). The bones of size Class 2 and 3 are present but fossil bones of size Class 5 and 6 animals dominate the surface fossil assemblage, hence the working field name of this unique assemblage.

Working south from archaeological site FxJj 3, and down section from the KBS Tuff outcrop, several patches of terrestrial vertebrate fossils were identified. A patch of fossils designated as **"SE of FxJj 3"** was located about 330 meters southeast of FxJj 3 (Figures 3-25 and 3-26). The topography and sedimentary environment was similar to that of the "Valley of Giants" but this fossil assemblage was dominated by size Class 2 and 3 animals (Figure 3-27). The patch of fossils designated as **"FxJj 13 Location"** was located about 1.7 kilometers southeast of FxJj 3 (Figures 3-28 and 3-29). FxJj 13, a

See Figure 3-23

SHEET 4 OF 4

GEOLOGIC MAP OF THE SOUTHERN KARARI ESCARPMENT
EAST TURKANA, KENYA

Figure 3-22:
Research Area 105
Valley of the Giants Site
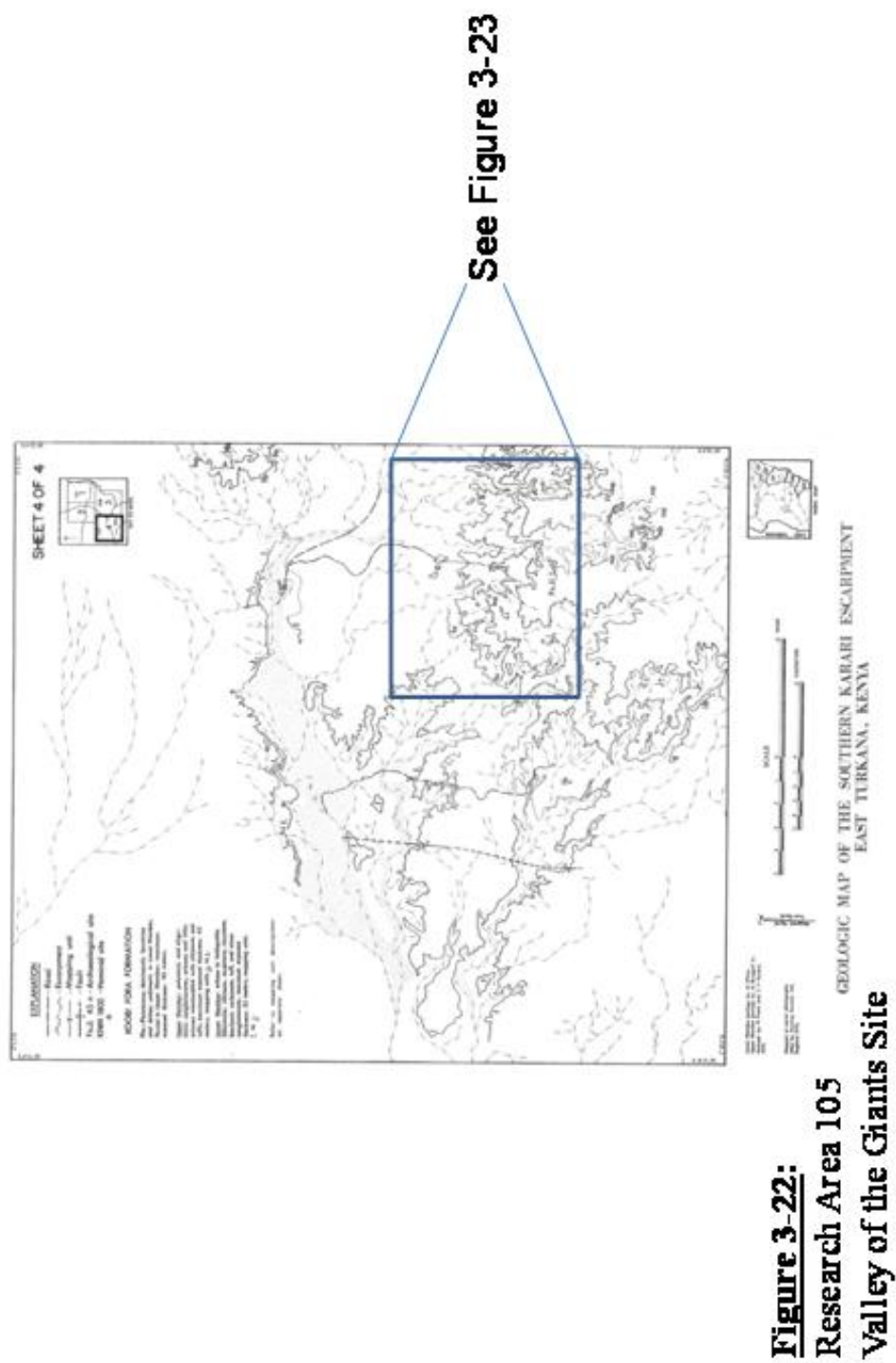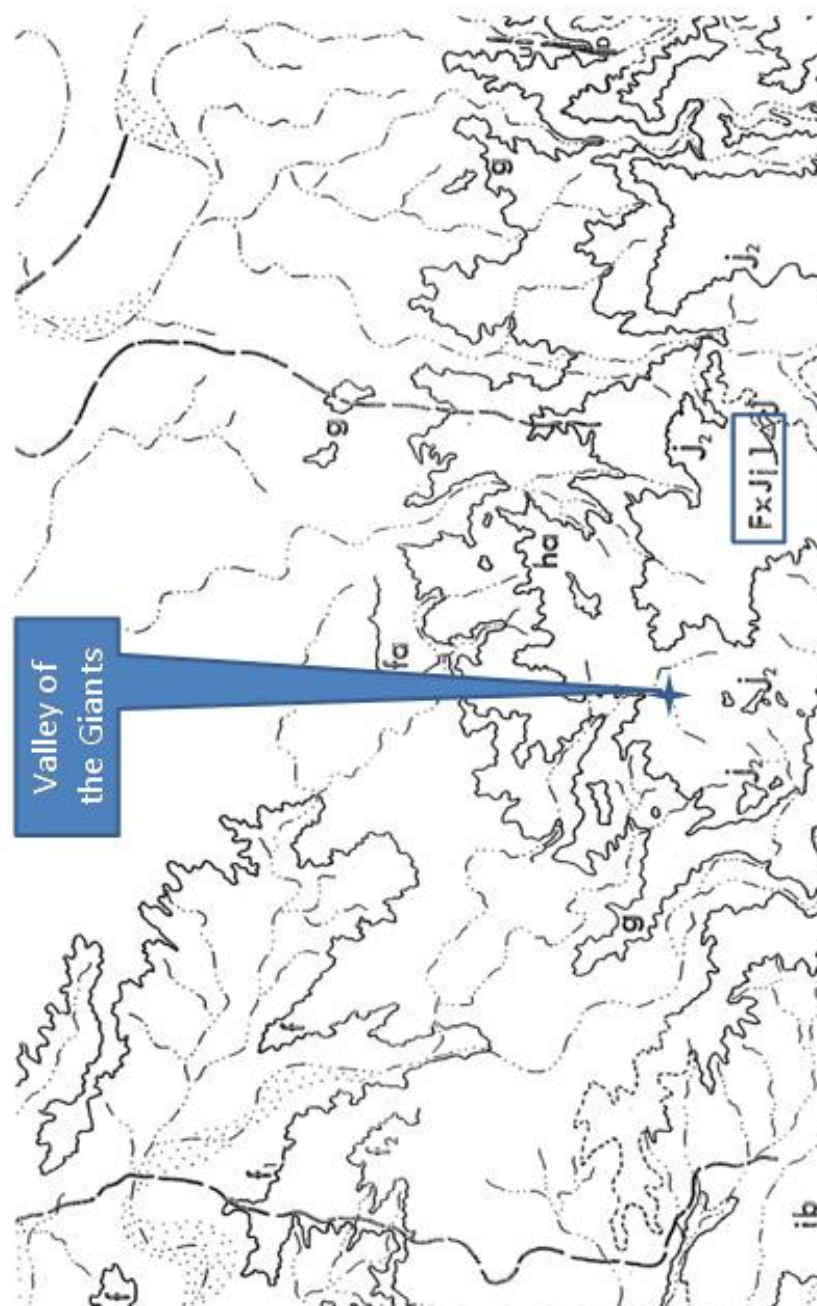
Figure 3-23: Area 105
Valley of the Giants Site
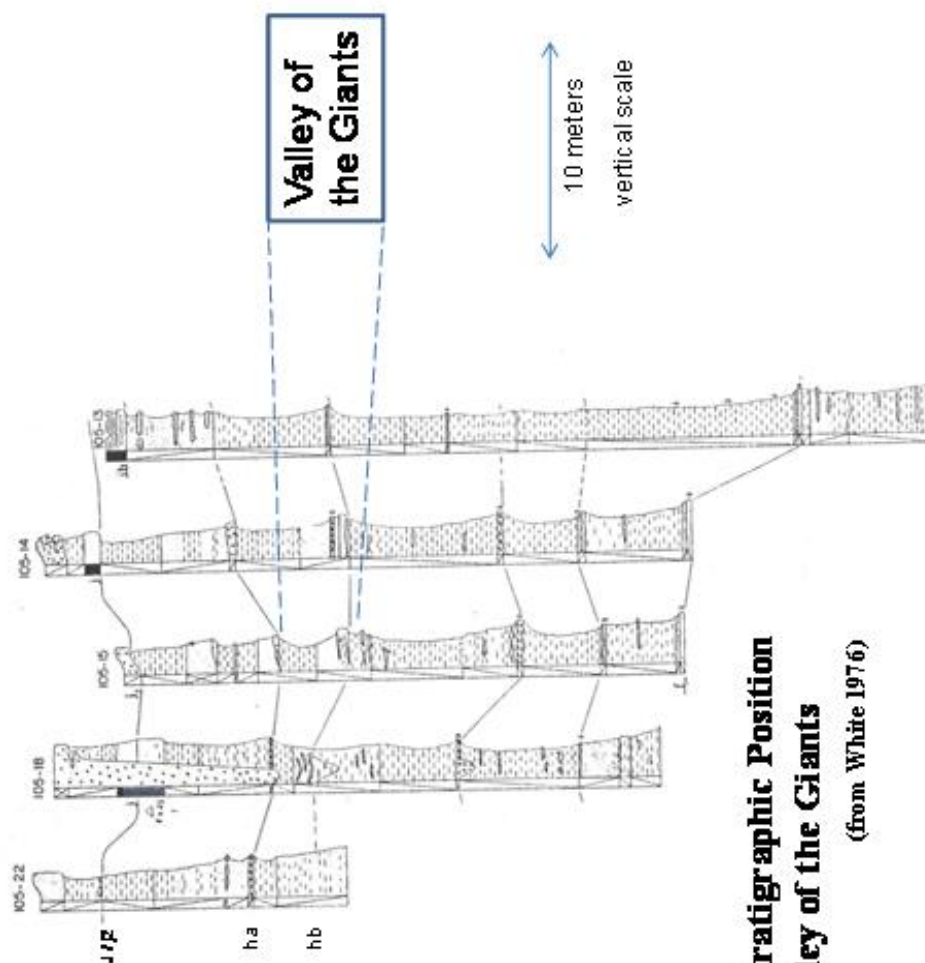
Figure 3-24: Stratigraphic Position
Valley of the Giants
(from White 1976)

See Figure 3-26

SHEET 3 OF 3

EXPLANATION

KOOBI FORA FORMATION

GEOLOGIC MAP OF THE EASTERN KOOBI FORA RIDGE,
EAST TURKANA, KENYA

Figure 3-25:
Area 105
SE of FxJj 3

Figure 3-26:
Area 105
SE of FxJj 3

KWT 105-7

Figure 3-27: Stratigraphic Position
SE of FxJj 3 Locations
(from Tindall 1985)

See Figure 3-29

GEOLOGIC MAP OF THE EASTERN KOOBI FORA RIDGE, EAST TURKANA, KENYA

Figure 3-28:
Area 105
FxJj 3 Location
Water Tank Sites

EXPLANATION

S1 ········· — Mapping horizon

ᵤ ───── — Fault

────── — Road

········· — Ephemeral stream

KNM—ER 804 ⊙ — Hominid site

FxJj 3 △ — Archaeological site

KOOBI FORA FORMATION

Plio-Pleistocene; lacustrine, beach, deltaic, and fluvial sediments; maximum exposed thickness 66 m in area 105 and 150 m in area 10A;carbonaceous to feldspathic litharenite, intraformational conglomerate, siltstone, mudstone, claystone, biocimatic carbonate, and tuff.

Refer to mapping horizon descriptions on the opposite sheet.

SE of FxJj 3
Location

Water Tank
Sites

Figure 3-29:
Area 105
Water Tank Sites

small surface scatter of artifacts, is the only published archaeological site from the upper

Burgi Member (Isaac *et al.* 1976). During survey in 2004, evidence of the original

excavation at this site was found. A few additional artifacts had eroded out of the

excavation walls along with several fossil bones. These were collected and their position

on the surface recorded by GPS coordinates. The sedimentary context for this location is

similar to that of FxJj 13. About 2.5 kilometers southeast of FxJj 3 several small patches

of terrestrial vertebrate fossils were investigated. These patches were designated as the

"Water Tank" locations because the best access to these sites was from a parking area

adjacent to an old water storage tank (Figure 3-29). Fossils were found eroding from

small mounds in a large low relief area that was down section from small discontinuous

outcrops of the Malbe Tuff (a tuff identified in this location that is stratigraphically found

above the KBS Tuff) (Feibel 2007, personal conversation) (Figure 3-30).

Data summary: Area 105

Area 105 Survey Area designated as: **"Valley of the Giants" (GPS-Y)**

Bones: 22 **Teeth: 1** **Modified:** **5**

Area 105 Survey Area designated as: **"South of FxJj 3" (GPS- Z)**

Bones: 44 **Teeth: 8** **Modified:** **5**

Area 105 Survey Area designated as: **"FxJj 13 Location"**

Bones: 6 **Teeth: 0** **Modified:** **1**

Area 105 Survey Area designated as: **"Water Tank" (GPS-X)**

Bones: 36 **Teeth: 7** **Modified:** **0**

KWT 105-3

Mallee Tuff (above KBS Tuff)

Water Tank Locations

10 meters
Vertical scale

Figure 3-30: Stratigraphic Position
Water Tank Locations

(from Tindall 1985)
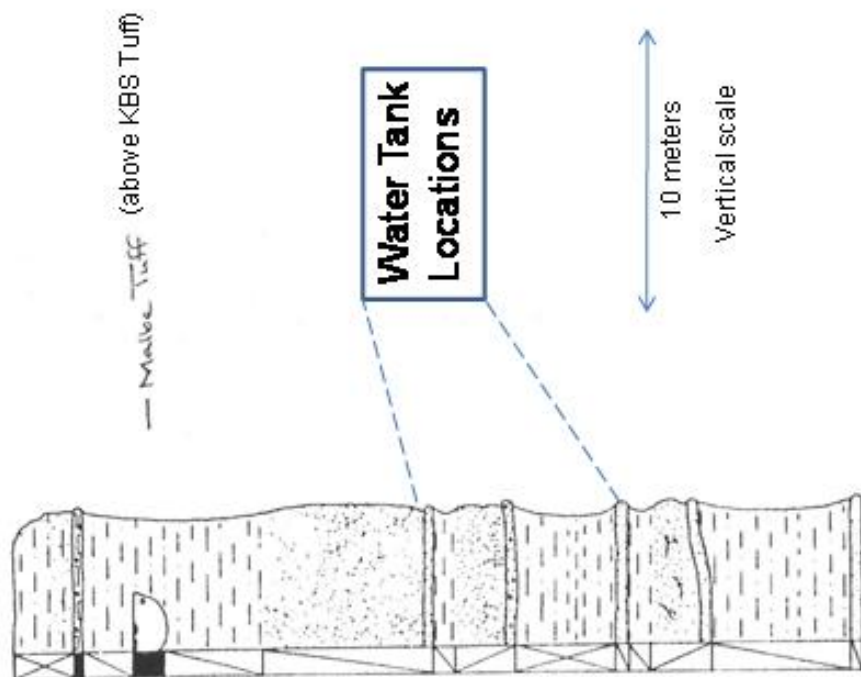
Sub-section 3.)   **Koobi Fora Ridge: Area 102**

2001, 2004, 2007 Survey: Jack McCoy

Research Location and Modern Geographical Context

Area 102 is located at the western end of the Koobi Fora Ridge near the shores of modern Lake Turkana. The stratigraphy is very complex but the KBS Tuff does outcrop in Area 102 and upper Burgi exposures are present. Surface survey in the western portion of the area was conducted in 2001 but outcrops of the KBS Tuff were not located and it was not possible to identify patches of terrestrial vertebrate fossils from the upper Burgi Member. In 2004 additional survey was conducted based on GPS coordinates provided by Dr. Craig Feibel for an upper Burgi hominin fossil site (KNM-ER-3228). This site was located but extensive survey of the exposures surrounding this site yielded no terrestrial vertebrate fossils. In the last two days of the 2007 field season, an outcrop of the KBS Tuff was positively identified in the western part of Area 102 and terrestrial vertebrate fossils were eroding from the sediments below the tuff. A few fossils were collected during the limited time available and their position on the surface marked with GPS coordinates. Additional research in this area is necessary.

Data summary

Area 102 Survey Area

| **Bones:** | 7 | **Teeth:** | 5 | **Modified:** | 0 |

In Chapter Four the fossil faunal evidence described in this chapter is analyzed. The ancient animal communities are reconstructed and the implications for hominin paleoecology and habitat utilization are discussed.

Chapter 4: Faunal Analysis: Implications for Paleoecology and Habitat Reconstruction

Introduction

Evidence of hominin presence on the landscape from stone tools or modified bone must be placed in an environmental and ecological context in order to construct meaningful hypotheses about hominin habitat and changing foraging behaviors.   In this chapter the faunal and floral evidence collected during the field research is analyzed in order to describe Upper Burgi Member ecology and, together with complementary evidence of the environments of deposition developed in Chapter Three, reconstruct the paleoenvironment of the research locations based on geological and ecological analogs developed from the modern African landscape. Ideally the fossils from each research location would be an accurate representation of the composition of the ancient animal community (life assemblage or biocoenose); unfortunately that is usually not the case. If the assemblage of bone on the surface is accumulated over long periods of time (time averaged), it is possible that another, and perhaps different, biocoenose could be introduced prior burial. Animal carcasses concentrated in any one area (death assemblage or thanatocoenose) represent only a subset of the biocoenose. Taphonomic processes can add or subtract specimens as the bones and teeth are buried, fossilized, and eventually uncovered and collected creating a different subset (taphocoenose). The fossils ultimately analyzed (identified assemblage) therefore represent a modified and perhaps even smaller subset of the original bioconose (Lyman 2008) (Figure 4-1).
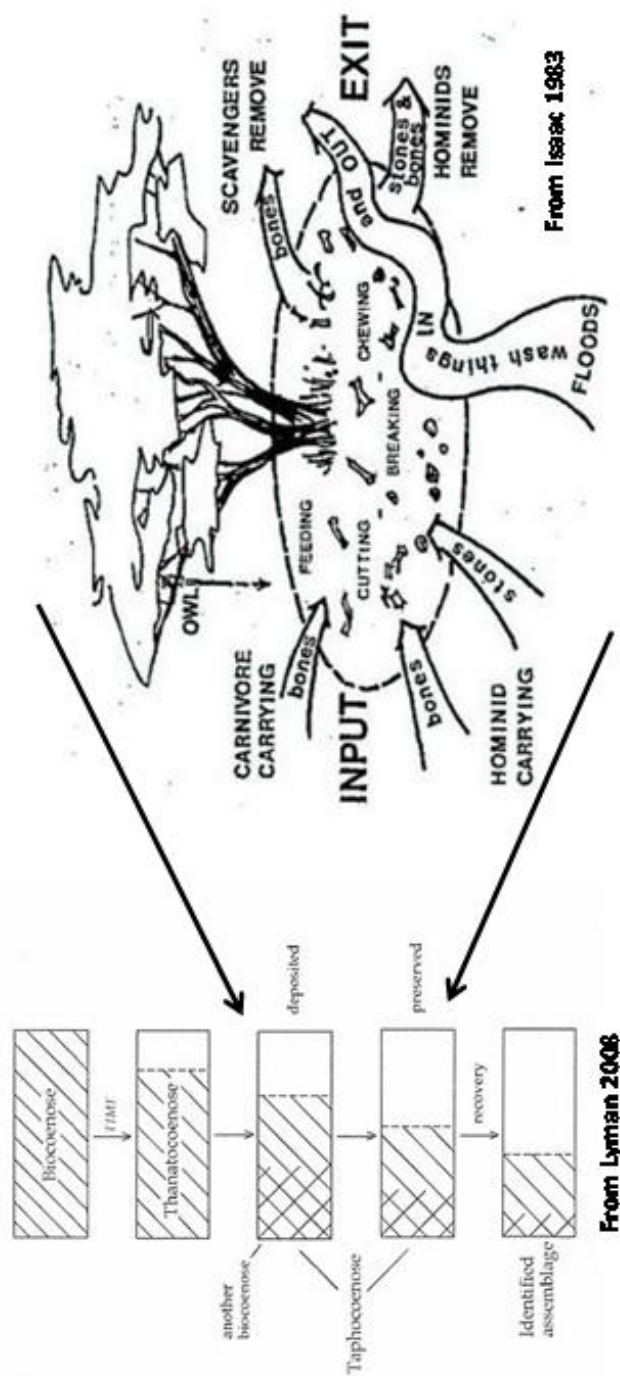
Figure 4-1: Site formation processes showing factors that potentially impact the probability that the identified assemblage is representative of the biocoenose. (adapted from Lyman 2006 & Isaac 1976)

Taphonomic processes that help to create the taphocoenose also produce an imprint that reflects the taphonomic history of the final assemblage. Carnivores are major taphonomic agents. As carnivore activity increases the number of complete skeletal elements in an assemblage decreases and the specimens that do remain in the thanatocoenose along with the damage (modification) inflicted on those fossil bones reflects levels of carnivore involvement and competition. Moving water is also a significant taphonomic agent. Skeletal elements and specimens in the thanatocoenose are transported into or away from a site as a function of water velocity, individual bone density, and bone surface area. The specimens that remain to be buried and fossilized provide evidence of the ancient depositional environment of the location as well as an indication about the autochthonous or allochthonous nature of the assemblage. Building on laboratory water flume experiments by Voorhies (1969), Behrensmeyer (1975) expanded the experimental criteria to include wild African fauna in order to make paleogeographical and faunal habitat inferences from Plio-Pleistocene fossil assemblages at Koobi Fora. Whole or almost whole individual skeletal elements or specimens are assigned to groups that reflect their tendency to be transported by moving water (Appendix 4-1) and therefore the presence or absence of specific skeletal elements or specimens in the final assemblage can be indicative of site formation processes, paleoenvironments, and relative site integrity. The speed of burial, the composition of the sediment, and the chemistry of the groundwater (alkaline conditions and the presence of $CaCO_3$) determine if the bones will be preserved at all.

Quantifying the Faunal Evidence

Zooarchaeologists and paleontologists have devised many schemes to describe an identified assemblage in order to make inferences about the biocoenose it may represent. Unfortunately there has not been a great deal of consistency in terminology utilized in the application of these schemes and therefore it is difficult (sometimes impossible) to compare and/or contrast identified assemblages from different contexts. For consistency, this analysis employs the following definitions as suggested by Lyman (2008):

Skeletal element: "complete discrete anatomical unit (e.g. bone, tooth, shell)".
Specimen: "bone, tooth, shell or fragment thereof (skeletal part or portion)".
Assemblage/Collection: "aggregate of faunal remains whose "setness" has been defined archaeologically".
Identified Assemblage: "set of remains from which measures of taxonomic abundance are derived".

Before it is possible to quantify the assemblage, it is necessary to accurately identify the fossil specimens collected. For this research all specimens were identified to skeletal element and the minimum taxonomic level of "family" (although it was possible to identify some of the specimens to genus or species). The accuracy (nearness of the measurement to the actual variable being measured) and precision or reliability (replicability) of this process is a function of the experience of the investigator and the availability of comprehensive reference collections for comparison. The identifications of specimens collected during field survey and excavation from this research were all performed by the principal investigator in the osteology, archaeology, and paleontology laboratories at the National Museums of Kenya in Nairobi. The National Museum houses osteological collections of modern African animals and fossil collections from Africa (including hominin fossils) that extend well back into the Miocene, and are recognized as

among the best and most extensive collections of this type in the world. The museum

staff (specifically Paul Watene and Mary Mungo) was available to assist with

identifications and scheduled consultations with paleontologists who possess specific

expertise were also utilized. Dr. Laura Bishop provided valuable help with suid

identifications; Dr. Rene Bobe provided guidance on bovid, equid and primate

identifications; and Dr. Brian Richmond performed a detailed metric analysis of a partial

primate humerus, confirming the presence of *Rhinocolobus*.

One way to describe a final assemblage is to construct a list of all the different

taxa present. This nominal scale of measurement only provides an *inventory* of the

specific animals identified in the final assemblage. However, it is a gross approximation

of the taxonomic diversity present at each research location. A *census* of the individuals

that make up the final assemblage (measure of taxonomic abundance both inter-

taxonomic and intra-taxonomic) is a more useful measure if meaningful inferences about

the biocoenose are to be made. The census for this research was created using the

number of identified specimens (NISP). NISP is a directly observed measure that is

fundamental and not derived. It also has the advantage that is cumulative across the

entire assemblage (Lyman, 2008). NISP is a much utilized measure in zooarchaeological

research but unfortunately is defined in several different ways. For this research,

Lyman's definition of specimen (referenced above) is used. "Identified" is defined here

as: taxonomic identity to family level or better. NISP is a measured quantitative variable

that enables inferences about relative taxonomic abundances and ecological diversity in

the biocoenose to be delineated.

Another analytic method that has been employed to estimate taxonomic abundance is the minimum number of individual (MNI) animals that would account for the identified specimens in the final assemblage. MNI is a measure that is derived from NISP values. MNI is widely used in zooarchaeological research but also suffers from a variety of different interpretations. For this research, MNI is derived using a tally of the most common specimen identified to skeletal element for each taxon. Additional factors of animal size class and side of bilaterally symmetric elements were also considered. Taxon lists, NISP, and MNI were calculated for each research location. Taxon lists and a summary of NISP and MNI values are shown in Tables 4-1 through 4-10.

The target variable of interest to this research is a measure of the relative taxonomic diversity in the biocoenose (inventory and census) as represented by the identified faunal assemblage from each research location. For this research, NISP is the most appropriate metric and will be utilized in the analysis. When compared to MNI, NISP is always an ordinal scale of measurement (and with some assumptions can be considered a ratio scale), it requires fewer steps and assumptions to compile, relies less on individual interpretation, and usually produces the same information ("statistically indistinguishable") about taxonic abundance (Lyman 2008). The biggest problems associated with NISP are the issues of interdependence (the possibility that specimens from one animal may be present in more than one assemblage or multiple specimens of the same animal present in one assemblage), interspecies variation in the different number of skeletal elements present in different taxonomic families, and differential fragmentation across taxa; any of which could impact faunal inventory and census. Interdependence is addressed by the way that each assemblage is defined; and the

reasonable assumption (based upon the research focus on mammalian terrestrial vertebrates only) that interdependence is randomly distributed across all taxa and all assemblages. In this analysis interspecies variation is not a factor as it doesn't significantly impact relative comparisons of taxonomic family level frequencies (Lyman, 2008).

The research locations are identified by the fossil collection areas (41, 130, 131, 105, 102) traditionally utilized by paleontological and archaeological researchers at Koobi Fora (Figure 3-5). The issue of designating each research location as an "assemblage" (as defined above) could be problematic and is discussed below for each research location.

Area 41

Of the five locations explored during this research, Area 41 is the most unique. It is situated in a very remote part of East Turkana that was virtually undisturbed by visitors or previous research. The surface fossils were restricted to a small area (making the designation, "assemblage", straightforward) and the surface density of fossils was high. Additionally, well preserved stone tools were observed on the exposed surface. The initial field season in 2004 was so productive that it led to two extended excavation field seasons as well as annual visits by the Koobi Fora Field School where additional survey was conducted. Hominin presence at this location during the late Pliocene was confirmed by the discovery of both modified bone and stone tools on the surface and *in situ*. Interest in the potential value of this site attracted scientists from other disciplines who conducted a variety of complementary studies adding context and validity to this

research. Considerably more data was collected from area 41 (a far larger sample) than all the other locations and these data serve as the baseline for interpretation of habitat and paleoecology for the balance of this research.

Faunal Data

The surface survey at Area 41 yielded over 875 terrestrial vertebrate specimens, (614 identifiable to taxon) and the excavation produced over 3000 specimens of bones and teeth (347 identifiable to terrestrial vertebrate taxon). The excavated materials were concentrated within about 20 vertical centimeters of an arbitrary 97 meter excavation horizon (Photograph 4-1). Analysis of the sediments lateral to, and above and below, the level of the archaeological site confirmed the strong association of the surface and *in situ* material. The exposures surrounding the roughly 13,000 square meters that delineates the research location were virtually devoid of surface fossils. An analysis of the faunal material from geological trenches proximate to the extensive excavation describes a very different depositional and preservational environment. The faunal assemblage from these peripheral trenches is dominated by aquatic species (fish, hippopotamus, and crocodile) whereas the excavated material is dominated by terrestrial vertebrates (Levin, personal correspondence) [(Figure 4-2)]. Contamination by younger fossil material from higher in the outcrop is also extremely unlikely. While the outcrop above the research location exhibits relatively high relief, extensive survey and geological trenching of the fifteen vertical meters of exposed sediments between the research area and the exposed KBS Tuff yielded neither aquatic nor terrestrial fossils. Survey of the approximately 10 vertical meters from the KBS Tuff to the top of the outcrop produced exactly the same
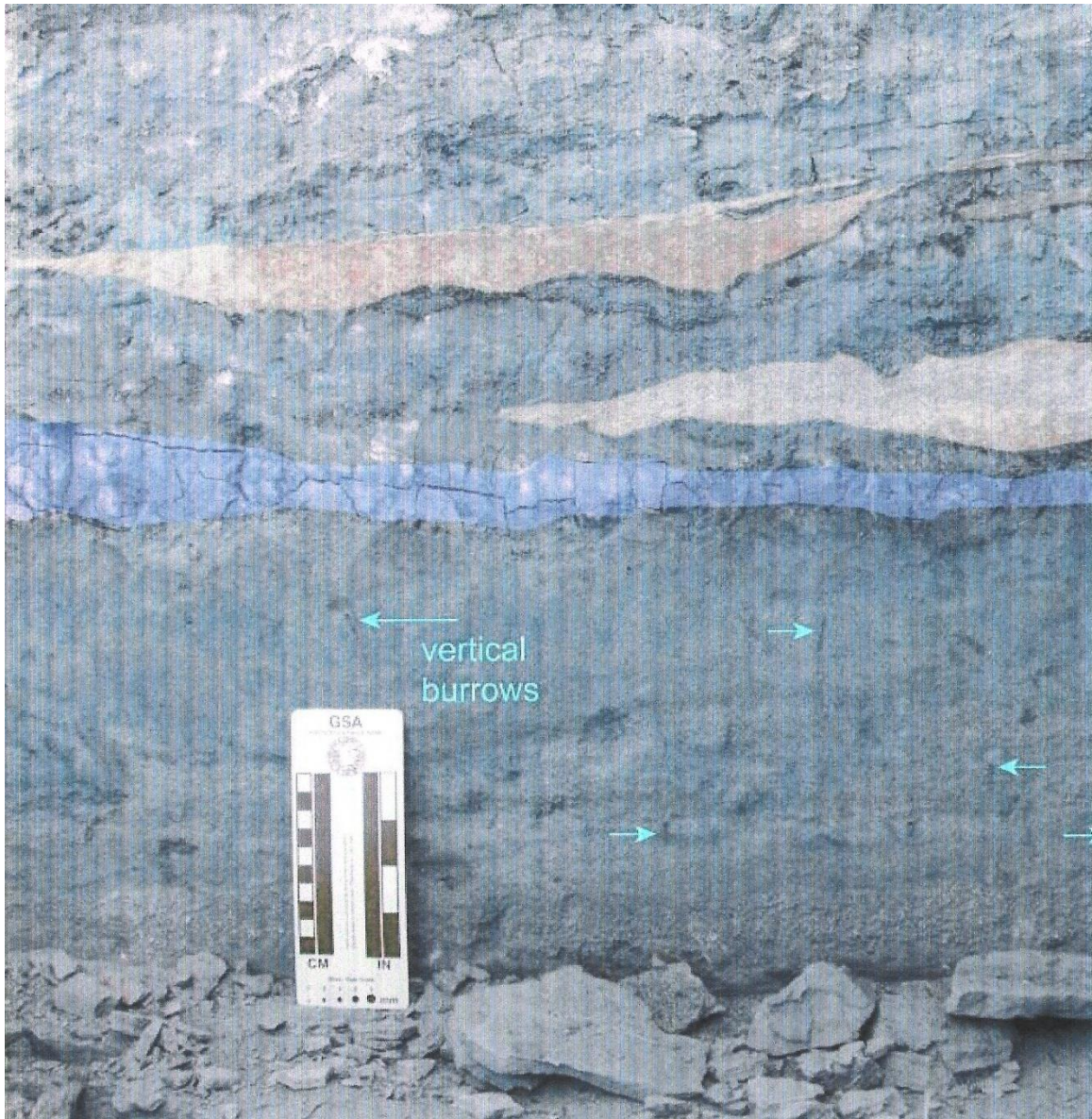
Photograph 4-1: Photograph of section from Area 41 site showing 6 cm fossil and artifact bearing clay horizon (highlighted in blue). Sand lenses above this horizon are highlighted in red. (Levin 2007, Personal Communication)
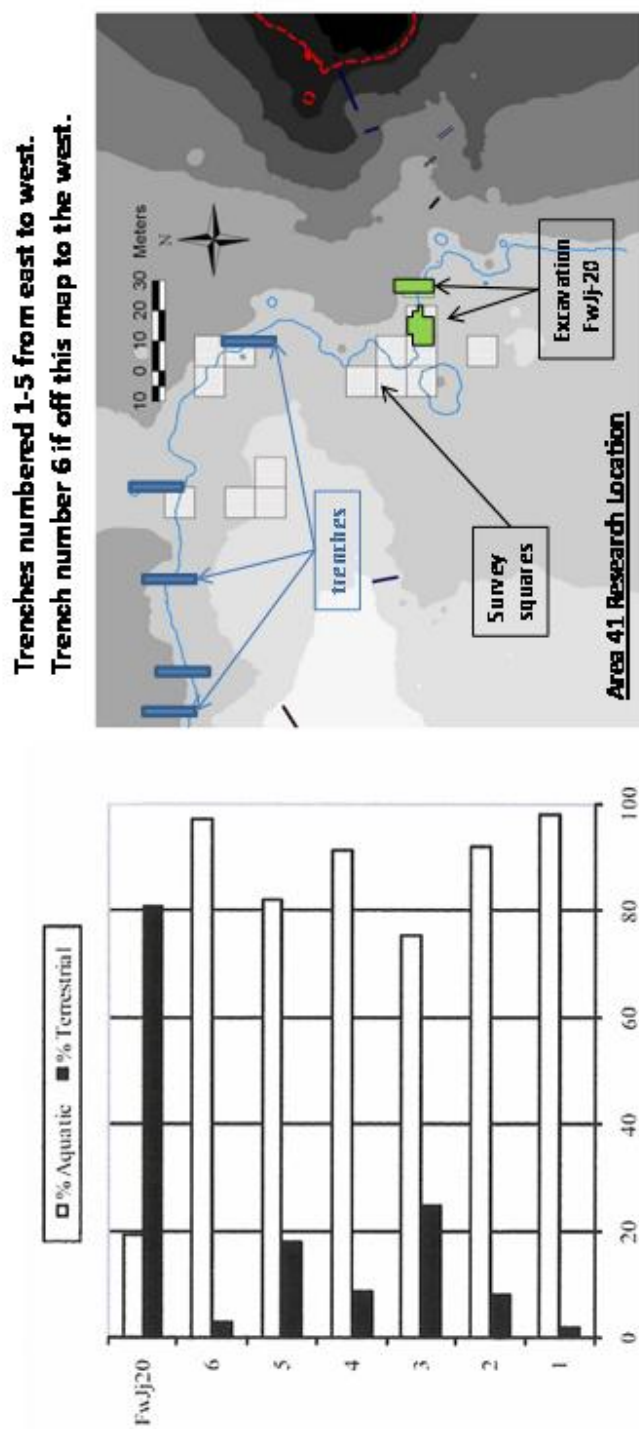
Figure 4-2: Geological trenches dug proximate to the FwJj-20 excavation in order to confirm that the fossil/artifact horizon at FwJj-20 represents a single vertical, and laterally constrained unique fossil accumulation.

(adapted from Braun et al., in press)

result. Additional geological trenches dug "up-section" and well "down-section" from the artifact/terrestrial vertebrate fossil horizon were likewise devoid of fossils. Tables 4-1 and 4-2 show summaries of the area 41 faunal data for the survey, excavation, and a composite of the two. Because all of the surrounding contextual evidence indicates that virtually all the terrestrial vertebrate fossils (surface and *in situ*) derive from a single and laterally limited sedimentary horizon, the survey and excavation data is combined for this faunal analysis. While the survey and excavation data exhibit strong correlation with regard to ordinal taxonomic frequency, statistical examination of the taxonomic composition of the survey and excavation evidence indicates that the surface material is not simply a reflection of the remaining *in situ* material (chi squared = 59.56, df = 4, p < 000.1, Cramer's V= 0.249) but rather a distinct and different subset of the assemblage. Therefore the survey and excavated material combined provide the best representation of the taphocoenose and hence identified assemblage for this research location.

Area 41 taxonomic families; Bovidae (57%), Suidae (17%), Equidae (12%), Primates (7%), and Proboscidea (4%) account for 97% of the total terrestrial vertebrate assemblage (Figure 4-3) and this ranking generally agrees with Behrensmeyer's large terrestrial vertebrate rank order (1.bovid, 2. suid, 3. equid, 4. elephant, 5. primate) for similar Upper Burgi sedimentary environments in areas 105 and 130 at Koobi Fora (Isaac and Behrensmeyer, 1997).

Like most East African Plio-Pleistocene fossil fauna assemblages, bovids are most abundant and in this assemblage two bovid tribes dominate. Reduncines (grazers in wet grasslands and woodlands in riparian habitats) and Tragelaphines (browsers in bush and forest) [(Isaac & Behrensmeyer, 1997; Feibel *et al*., 1991; Schrenk *et al*., 1995;

Class	Order	Family	Tribe	Genus	Species
Aves					
Mammalia	Artiodactyla	Bovidae			
			Aepycerotini		
				cf. *Aepyceros*	
			Alcelaphini		
				cf. *Connochaetes*	sp.
				cf. *Damaliscus*	sp.
			Antilopini		
				Antidorcas	cf. *recki*
				Gazella	sp.
			Hippotragini		
				cf. *Oryx*	sp.
			Reduncini		
				Kobus	kob
				Kobus	sigmoidalis
			Tragelaphini		
				Tragelaphus	sp.
				cf. *Tragelaphus*	strepsiceros
		Giraffidae			
				cf. *Giraffa*	sp.
				Giraffa	pygmaeus
		Hippopotomidae			
				Hippopotamus	gorgops
				Hexaprotodon	sp.
		Suidae			
				cf. *Kolpochoerus*	sp.
				Kolpochoerus	heseloni
				cf. *Metridiochoerus*	sp.
				Metridiochoerus	andrewsi
				cf. *Notochoerus*	sp.
				Notochoerus	scotti
	Carnivora	Felidae			
	Perissodactyla	Equidae			
				Equus	sp.
				Eurygnathohippus	sp.
		Rhinocerotidae			
				Ceratotherium	sp.
				Diceros	sp.
	Primates				
		Cercopithecidae		*Papio*	sp.
				Theropithecus	sp.
				Theropithecus	oswaldi
		Colobinae			
				cf. *Rhinocolobus*	turkanaensis
	Proboscidea				
		Elephantidae			
				Elephas	recki
	Rodentia				
Pisces					
Reptilia	Crocodilia				
		Crocodylidae		*Crocodylus*	niloticus

Table 4-1: Area 41 Taxon List

Area 41   Survey Square [(defined by NE corner of each square (Figure 3-7)] NISP (MNI)

Survey Square	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
N920E970	2 (1)	0	1 (1)	0	6 (1)	0	0	1 (1)
N940E960	18 (4)	0	2 (1)	0	1 (1)	1 (1)	0	1 (1)
N940E970	68 (7)	2 (1)	6 (1)	1 (1)	2 (1)	0	0	11 (3)
N940E980	43 (5)	0	5 (1)	0	2 (1)	8 (2)	0	10 (3)
N950E960	25 (5)	1 (1)	2 (1)	0	2 (1)	0	0	5 (2)
N950E970	27 (3)	1 (1)	5 (2)	1 (1)	1 (1)	0	0	5 (2)
N960E940	0	0	0	0	1 (1)	0	0	0
N960E960	10 (3)	0	1 (1)	0	1(1)	0	0	5 (1)
N990E920	23 (3)	0	7 (1)	0	0	0	0	6 (2)
N990E930	49 (5)	0	8 (2)	1 (1)	1 (1)	0	0	14 (3)
N990E970	0	0	0	0	1 (1)	0	0	1 (1)
N1000E920	26 (3)	0	8 (1)	0	0	0	0	6 (2)
N1000E970	7 (3)	0	1 (1)	0	3 (1)	0	0	1 (1)
N1010E920	0	0	0	0	1 (1)	0	0	0
N1010E930	0	0	0	0	0	0	1 (1)	0
N1010E950	0	0	0	0	1 (1)	0	0	0
N1010E960	23 (5)	1 (1)	0	0	7 (1)	0	0	1 (1)
N1010E970	13 (4)	0	0	1 (1)	7 (1)	0	0	2 (1)
N1020E890	0	1 (1)	0	0	1 (1)	0	0	0
N1020E910	2 (1)	0	0	0	2 (1)	0	0	0
N1020E920	45 (5)	0	14 (1)	0	5 (2)	2 (1)	0	6 (2)
Gps	10 (3)	2 (1)	4 (1)	0	5 (1)	0	0	9 (2)

Area 41 Survey NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 41 Survey	391(18) 63.7%	8(3) 1.3%	63(4) 10.3%	4(2) 0.7%	52(4) 8.5%	11(2) 1.8%	1(1) 0.2%	84(9) 13.7%

Area 41 Excavation (2005 & 2006) NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 41 Excavations	154 (16) 44.4%	6 (2) 1.7%	51 (2) 14.7%	10 (2) 2.9%	17 (2) 4.9%	23 (1) 6.6%	7 (2) 2.0%	79 (6) 22.8%

Table 4-2: Area 41 NISP (MNI)- [Page 1]

Area 41 Survey and Excavation – NISP(MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 41	545(24)	14(3)	114(5)	14(2)	69(6)	34(2)	8(2)	163(21)
Composite	56.7%	1.5%	11.9%	1.5%	7.2%	3.5%	0.8%	17%

Area 41 Bovids (excavation) – NISP and percentage of NISP identifiable to tribe

	Reduncini	Tragelaphini	Alcelaphini	Antilopini	Aepycerotini	Hippotragini
Area 41 Bovids	21 34%	5 8%	28 45%	5 8%	2 3%	1 2%

Area 41 Bovids (survey) – NISP and percentage of NISP identifiable to tribe

	Reduncini	Tragelaphini	Alcelaphini	Antilopini	Aepycerotini	Hippotragini
Area 41 Bovids	35 36%	31 32%	13 13%	15 15%	3 3%	0

Area 41 Bovids (combined) – NISP and percentage of NISP identifiable to tribe

	Reduncini	Tragelaphini	Alcelaphini	Antilopini	Aepycerotini	Hippotragini
Area 41 Bovids	56 35%	36 23%	41 26%	20 13%	5 3%	1 1%

Area 41 Suid (composite) NISP (MNI) and percentage of NISP identifiable to genus

	Kolpochoerus sp.	*Metridiochoerus* sp.	*Notochoerus* sp.
Area 41 Suids	38 (5) 53.5%	14 (3) 19.7%	19 (3) 26.8%

Table 4-2: Area 41 NISP (MNI) - [Page 2]

Figure 4-3: Area 41 (% NISP)

Figure 4-4: Area 41 Bovid Tribes (% NISP)
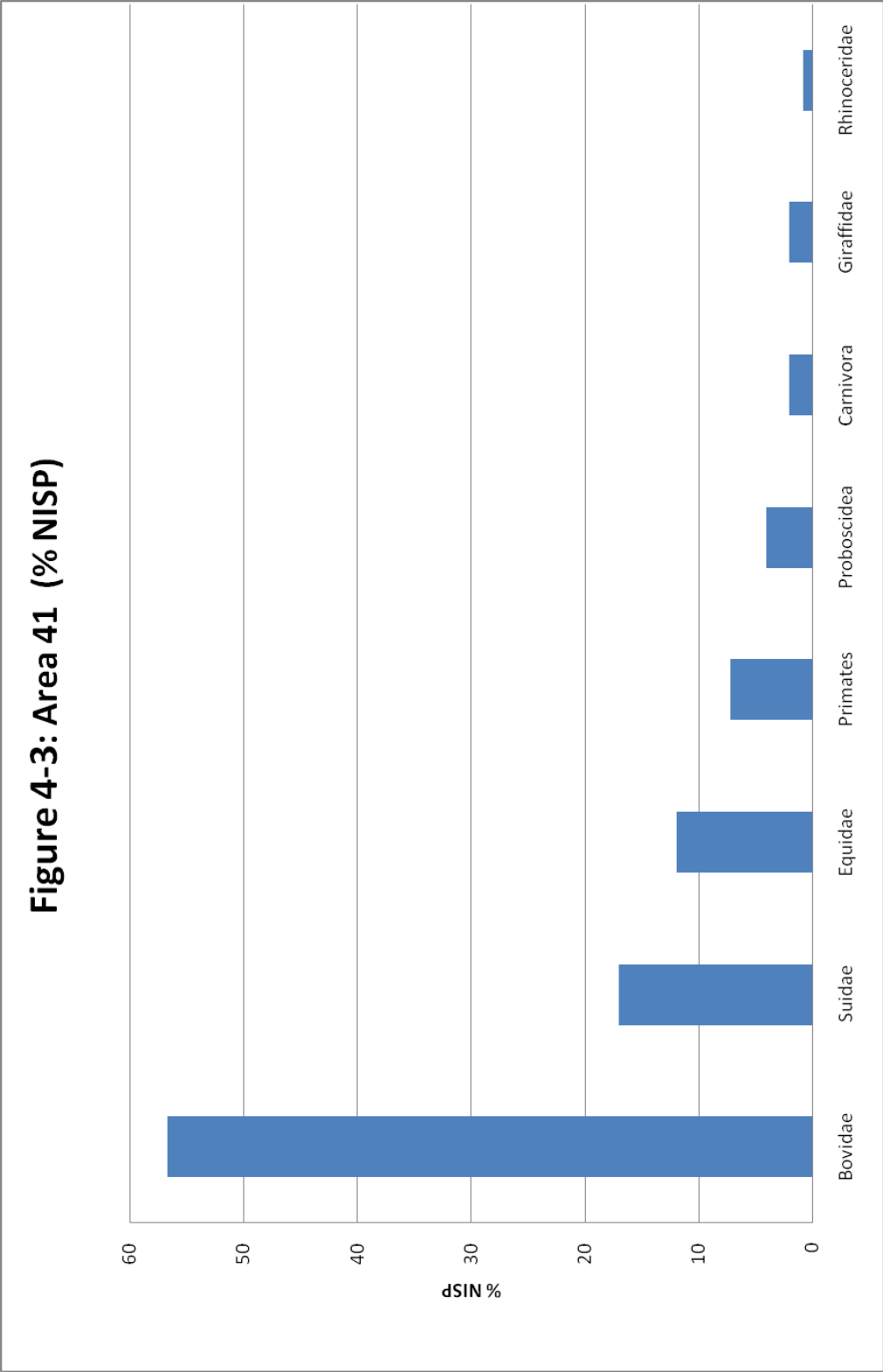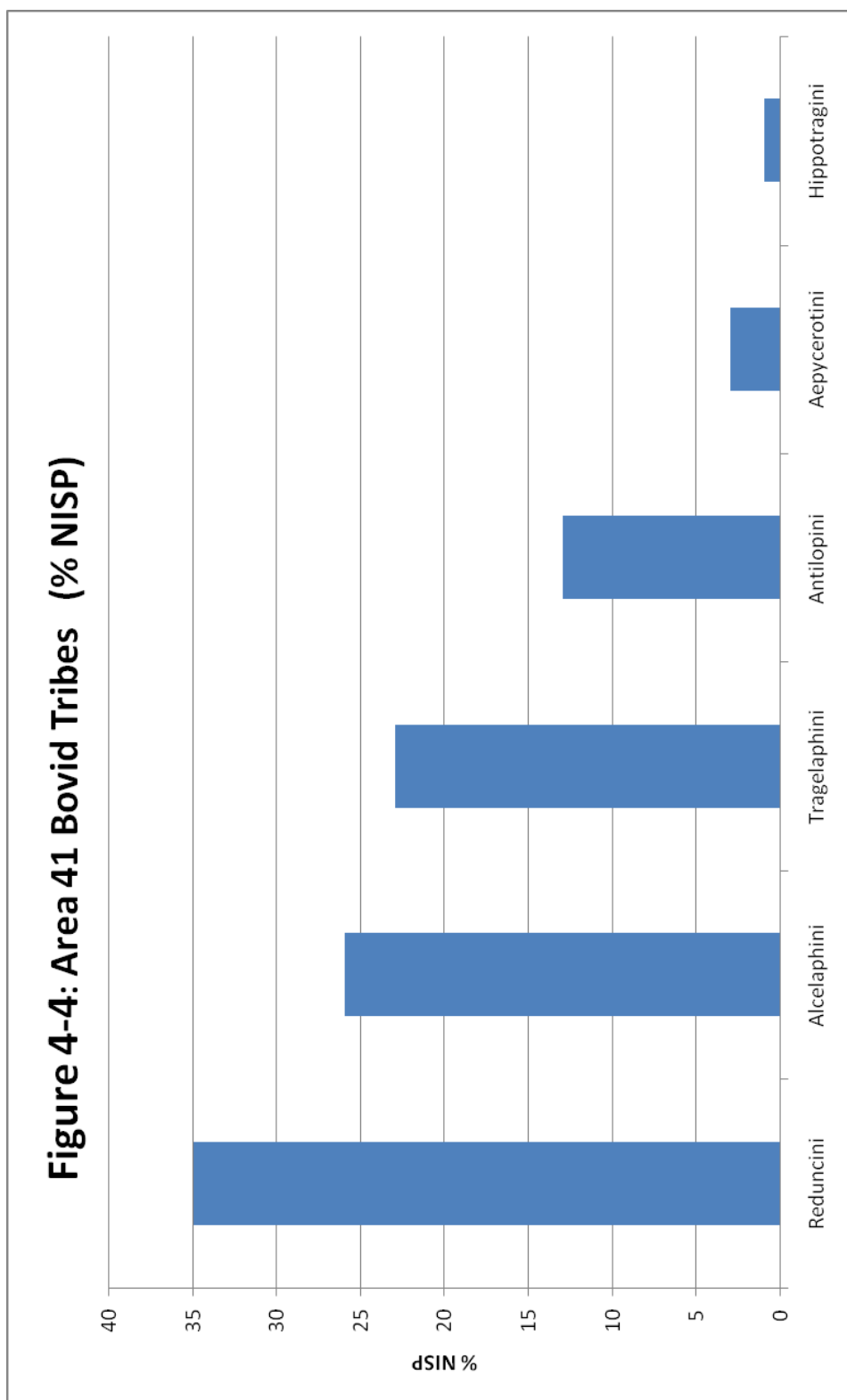
Gentry, 1976)] comprise 58% of the bovid NISP (Figure 4-4). Of the suids, *Notochoerus*

and *Metridiochoerus* are present but *Kolpochoerus* is the most abundant genus and is

interpreted as being a less hypsodont mixed feeder or browser (Feibel *et al*., 1991; Harris

& White, 1979) [Table 4-2]. **"*Kolpochoerus*, reduncines and tragelaphines represent**

closed habitat fauna" (Behrensmeyer 1975, p. 557). *Diceros* [a solitary browser (Feibel

et al., 1991)], *Eurygnathohippus* [less dry, less open-vegetation habitat than *Equus*, a

mixed feeder (Feibel *et al*., 1991)], *Giraffidae* [a forest/savannah woodland browser

(Feibel *et al*., 1991)] and *Rhinocolobus* [a large arboreal folivore (Fleagle, 1988)] are all

present. Behrensmeyer (1997) found that the percentage of primate fossils is usually

comparable to those of rhinos and giraffes at most East African Plio-Pleistocene

locations. However, at area 41 the percentage of primate fossils is seven times that of the

rhinos and giraffes. The most abundant primate genus in this assemblage is

Theropithecus. *Theropithecus* is interpreted as an open savanna grazer based on the close

evolutionary relationship with modern *Papio* and the emergence and expansion of the

species at a time in East Africa when there was a major shift from C3 to C4 vegetation

(Bobe, 2006; Bobe & Behrensmeyer, 2004). Modern baboon troops often seek the

shelter and protection of large trees or rock formations associated with riverine gallery

forests each night in order to avoid predators (Boinski *et al*., 2000), and it is likely that

this modern behavior is a reasonable analog for Plio-Pleistocene *Theropithecus* that could

explain the high percentage of primate fossils at area 41. Fossils of several species of

fish as well as water dependent vertebrate species (*Hippopotamus*, *Hexaprotodon*, and

Crocodylus) were ubiquitous both on the surface and in the excavation indicating that the

site was proximate to the ancient Loryenyang Lake, a perennial/ephemeral fluvial system,

or perhaps both (Feibel, 1988). This is consistent with the signal of a well-watered riparian forest/woodland habitat indicated by the terrestrial vertebrate assemblage described above. Dry, open habitat (grassland grazers) terrestrial vertebrates are also present, but they are in the minority. The alcelaphines (26% of bovids identified to tribe) are interpreted as open savanna grazers but many are also obligate drinkers (Gentry, 1978 & 1976; Feibel *et al*., 1991) and would be expected to be present in lakeshore or riverine environments.

Fossil Wood

Fossil wood is an often neglected but potentially rich source of information about paleoenvironment. The "wood" portion of trees, shrubs, and bushes provides form and strength to the plant and facilitates the uptake of water and minerals from the soil. Wood anatomy tends to be evolutionarily more conservative than other plant parts, exhibiting little change over extended periods of time, and therefore the micro-structures of ancient woods are very similar to extant genera. Communities of modern trees, shrubs, and bushes are often restricted to very specific environments (e.g. soil, rainfall, temperature range, altitude, etc.). Because of this, an assemblage of fossil wood specimens can be employed to make meaningful inferences about paleoenvironments based upon analogs observed in the environments exploited by modern plant communities (Bamford, 2005 personal communication).

During the 2005 field season, paleobotanist Dr. Marion Bamford collected more than one hundred pieces of silicified wood from the Upper Burgi sediments within a three kilometer radius of the excavation at FwJj20 in area 41. Preparation and thin section

analysis of these specimens was conducted at the Bernard Price Institute for

Paleontological Research in South Africa. Most of the fossil wood from area 41 belongs

to the genus *Drypetes* which today is usually found in low altitude riverine forests. Also

present was *Funtumia africana, Chytranthus, Pancovia, Erythrophleum,* and *Schotia*.

This floral assemblage is characteristic of mostly low altitude, generally moist riverine or

swamp forests consistent with the perimeters of lakes, rivers, and delta distributary

channels. In such environments that are well watered and where extended periods of

water stress are limited (e.g. lakeshore, delta, perennial river), tree microstructure is

dominated by large diameter vessels for water transport. The fossil microstructure of the

area 41 fossil wood specimens (Figure 4-5) generally exhibits these large diameter

vessels (Bamford *et al*., 2008 in press). As with the fossil bones and teeth, the fossil

wood found at this research location is likely autochthonous. The surfaces retain small

morphological features and exhibit little evidence of pre or post fossilization abrasion as

a result of extended fluvial transport. This is true of not only fossil hardwoods but also of

large trunk sections of soft palm-like trees (Braun *et al*., 2008 in press).

Stable Isotope Analysis

Carbon (^{13}C)

The relative concentration of stable isotopes of oxygen and carbon present in the

tooth enamel of the vertebrates at area 41 was analyzed by Dr. Naomi Levin of the

University of Utah. Plants absorb carbon from the atmosphere in the form of CO_2 and

incorporate the carbon from this compound into the sugars and starches produced via

photosynthesis. The naturally occurring isotope of carbon (^{13}C) is differentially

Figure 4-5: **Transverse thin section of fossil wood (*Funtumia afraica*) from area 41. The large vessels are a characteristic of plant genera that prefer well watered environments and are intolerant of protracted water stress.** (adapted from Braun *et al*., 2008 in press; photo compliments of Dr. Marion Bamford)

metabolized by various plant types using different photosynthetic pathways. Trees, shrubs, forbs, and tubers employ the C3 pathway which differentially incorporates a greater proportion of the available ^{13}C isotope. Grasses employ a C4 pathway which selects less of the ^{13}C isotope. Cacti and succulents employ a CAM (crassulacean acid metabolism) pathway where ^{13}C concentration is intermediate between C3 and C4 pathways. The chemical composition of tooth enamel is a function of diet and therefore the ratio of $^{13}C/^{12}C$ in herbivore tooth enamel is a reflection of what types of plants the animal consumed when the teeth were being formed. The tooth enamel of animals that predominately eat grasses (C4 diet-grazers) will be enriched in ^{13}C whereas the tooth enamel of animals that consume the leaves of trees, shrubs, forbs, and tubers (C3 diet-browsers) will be relatively depleted in ^{13}C. In East Africa, the CAM pathway is generally not a significant factor in most large herbivore diets (Cerling *et al*., 2003). Stable carbon isotopes ratios are measured in relation to an accepted standard and reported as delta $^{13}C_{enamel}$ values. Appendix 4-2 contains the delta $^{13}C_{enamel}$ values for dental enamel derived from fossil teeth recovered from the excavation at area 41 (FwJj20).

Delta $^{13}C_{enamel}$ values of all the taxa analyzed, with the exception of the giraffes, show diets that are dominated by grasses (C4 pathway). The data indicates that bovid tribes, Reduncini and Alcelaphini can be characterized as strict C4 grazers while the Aepycerotini tribe shows a more varied diet. These characterizations are consistent with the dietary behavior of the extant bovids from the modern African analogs, strengthening the validity of the faunal analysis. The delta $^{13}C_{enamel}$ values for the other herbivores are also consistent with extant East African herbivore families. Suid, elephant, and

rhinoceros ^{13}C enriched tooth enamel values suggest a diet dominated by C4 vegetation. Delta ^{13}C$_{enamel}$ values for hippopotamus suggest a C4 diet supplemented by C3 plants such as tubers. The delta ^{13}C$_{enamel}$ values for the suids indicate a diet dominated by grazing but the marginally depleted ^{13}C values in comparison to the bovids may be due to a slightly different metabolic process for this family (Cerling *et al*., 2003). Bunodont dental morphology of *Kolpochoerus* would suggest a greater percentage of browse or consumption of tubers in the diet and this may be the reason for the slightly more depleted ^{13}C values when compared to *Metridochoerus* and *Notochoerus.*

Oxygen (^{18}O)

Variations in global climate are well established and documented but it is less clear just how much effect these global changes in climate actually had on the local environments of low-latitude Africa. In a region of extreme tectonic activity, such as East Africa, rapid changes in topography due to volcanism and rifting were common and probably had a more significant impact on local and regional environments than global events. Regional and local tectonic based events can mask or completely overwhelm any evidence of global climate variations in the geological record. For example, explosive volcanism can transform an entire regional landscape in such a way that the geological and fossil record reflects a shift in climate (mock aridity) where none actually existed (Harris & Van Couvering, 1995). Studies of micro-mammal fossils in the Omo Valley have been used as evidence of global climate trends. The fossils indicated a distinct shift from primarily mesic types of rodents (require moderate amounts of water) to primarily xeric types (low water need). This data could be interpreted as evidence of a shift in

climate but the turnover in fauna could just as easily be explained by local volcanic activity (Feibel, 1997). It is becoming increasingly clear that no universal global climate-based hypothesis can fully explain local environments. Local changes in faunal communities, not driven by global climate factors but rather the result of geological and environmental changes brought about by rifting have been detected in the fossil record of sub-Saharan Africa from the Plio-Pleistocene. These tectonic factors "may be of equal or greater importance to our understanding of the patterns of faunal change through time and may have an influence on speciation itself." (Hill, 1987, p. 592).

There are several indications that much of East Africa experienced increasing aridity throughout the Plio-Pleistocene. This trend has been suggested for the Turkana Basin also but the evidence is not conclusive. Precipitation rates along with water inflow and retention in the basin are the factors that affect the local vegetation which is often used as a proxy for indications of aridity in the paleoclimate (Feibel, 1988). Not much is known about the Plio-Pleistocene precipitation, but from the description in Chapter Two it is clear that the Turkana Basin existed as a mostly fluvial dominated rift system throughout that time period. Tectonic activity or short intervals when subsidence was greater than sediment supply would cause major rift-lakes to form (Withjack *et al.*, 2002). The dynamics of the river/lake system and the amount of water retained in the basin by the fluvial system greatly influenced the local climate and created a variety of habitats at any given time period. Piracy of the Omo's water to the Nile drainage would have left misleading evidence of increasing aridity in the sedimentary record and there is no independent evidence of a general trend to increasing aridity in the basin during the Plio-Pleistocene (Feibel, 1999).

In fact, the analysis of stable oxygen isotopes in herbivore tooth enamel points to the opposite conclusion. The primary source of the tooth enamel oxygen is the environmental water that the animal ingests while eating, drinking, and breathing. Like carbon, there is a small but measurable percentage of a naturally occurring stable isotope of oxygen (^{18}O) present in the environmental water. Since the ^{18}O isotope is heavier than ^{16}O, it is less susceptible to evaporation. Fractional evaporation (a function of temperature and relative humidity) of water molecules (H_2O) containing both the ^{18}O and ^{16}O atoms will result in an "evaporative enrichment" of ^{18}O atoms in the remaining liquid H_2O. Some herbivores [obligate drinkers, aquatic vertebrates (e.g. hippopotamus)] obtain most of their water from perennial sources (lakes and rivers) that experience very little relative enrichment in ^{18}O due to fractional evaporation. Hence there is almost no measurable variation in ^{18}O concentration in the tooth enamel of these animals due to variations in environmental aridity. The animals that obtain water in this manner are referred to as "evaporation insensitive" (EI). Other herbivores obtain their water from leaf moisture (dew and rain) and the vegetation they ingest (e.g. giraffes). This water source is very susceptible to fractional evaporation of ^{16}O. The concentration of ^{18}O remaining in this source of water will increase due to increases in environmental aridity; resulting in changes in the chemical composition of tooth enamel. Animals that utilize this source of water are referred to as "evaporation sensitive" (ES). The two different water acquisition strategies will result in significantly different percentages of the ^{18}O isotope incorporated in the dental enamel (Levin *et al*., 2006). For any given assemblage of fossil teeth, the differences between the delta $^{18}O_{enamel}$ values of the EI animals and the ES animals is an indication of the paleoaridity of the site as determined by comparison

with modern East African environments (Bamford *et al*., 2008). The delta $^{18}O_{enamel}$

values (Appendix 4-2) determined from teeth selected from the excavation at FwJj20

show a strong consistency with extant taxa. In modern African ecosystems the ^{18}O

values generally track from low to high by taxonomic family according to the following

order: hippos, elephants, rhinos, suids, equids, bovids, giraffes. The fossil evidence from

area 41 also reflects this pattern and furthermore the isotopic separation between the ES

and EI animals suggests a paleoenvironment that is intermediate to the modern

environment at Tsavo and Mpala in East Africa. This convincing isotopic evidence

signifies an environment during Upper Burgi Member times at Koobi Fora that is

generally far wetter than the modern East Turkana context (Levin personal

communication)

Habitat

The environments of deposition described in Chapter Two indicate that during

late Upper Burgi times the East Turkana Basin was dominated by a large fluctuating lake

(Lorenyang Lake) fed by a perennial meandering river flowing out of the Ethiopian

highlands from the north (Proto-Omo River), and ephemeral rivers periodically flowing

southwest from the basin margin. The ancestral Omo was a large meandering river

during this time period and it would have supported a belt of gallery forest with open

woodland and shrub thickets contiguous to the forest; analogous to the modern Omo

River in Ethiopia (Brown & Feibel, 1991).   The dominant habitat at area 41, away from

the river, would have been valley grassland along the floodplain of the ancestral Omo

River and the ephemeral streams from the eastern basin margin. Varying lake levels

would be associated with lake-margin swamps and marshes and prograding deltas as the

lake regressed. The depositional environments coupled with the taxonomic composition of the fossil fauna discovered (interpreted in conjunction with modern wildlife analogs) basically confirms the interpretation of a fluvial dominated paleoenvirnoment as described above for the Area 41 research location. The complementary studies based on fossil wood and isotopic analysis of herbivore tooth enamel are consistent with this interpretation but additionally point to an even wetter environment with perhaps more extensive riverine woodland and expanded grassland on the surrounding floodplain.

Area 130

Area 130 has been the site of extensive paleoanthropological and paleoecological research since the 1970s. Archaeological field work conducted in the KBS Member (1.88 – 1.65 mya), Okote Member (1.65 – 1.39 mya) and Chari Member (1.39 – 0.7 mya) has produced invaluable insights about hominin biological evolution, as well as evolving behaviors. Older Upper Burgi sediments (2.2 – 1.88 mya) in area 130 have yielded fossils of *Australopithecus* and early *Homo* (Appendix 1-1) but in spite of decades of extensive field research in this area virtually no archaeological evidence (stone tools or modified bone) has been reported. Six days of concentrated survey of Upper Burgi exposures in area 130 during preliminary field research in 2001 identified several locations that exhibited differentially dense concentrations of surface fossils of terrestrial vertebrates; including specimens with hominin modification (Chapter Five). These promising finds led to extended field research in 2004.

It quickly became obvious that some of the surface material at area 130 was not as pristine as the material in area 41, likely due to the relatively greater number of modern

human visitors to the site. In some places on the landscape small piles of fossil bones and teeth, obviously accumulated by modern humans (e.g. tourists, researchers, field school students), were observed and since the context of the fossils was in question, these locations were excluded from consideration. Research location 130C was selected because of the high surface density of terrestrial vertebrate fossils and two such small accumulations were encountered at this location. Although it is likely that the two small accumulations were not transported any great distance, they were excluded from the analysis. Fortunately the amount of remaining undisturbed surface material was so rich that this location was still selected for this research even though the relative NISP is likely to be somewhat under reported.

In spite of the fact that each location represents a distinct and isolated concentration of surface fossils, the five locations selected for survey (130A, 130B, 130C, 130D, 130E) are all constrained within an area of approximately 214 hectares (Figure 3-13), and all share very similar environments of deposition (Chapter Three). Modified bone found in Upper Burgi exposures in this area during this research confirms hominin presence on the ancient landscape (Chapter Five). Leonard and Robertson (2000) using models based on patterns of diet and body mass of modern carnivores, primates (including human hunter-gatherers), and omnivores have estimated the home range ("area traversed during activities associated with feeding, reproduction, rest, seeking shelter") of early *Homo* (*H. habilis*) to be between 54 hectares (ape based model) and 281 hectares (human based model). The size of the region encompassing the area 130 locations is consistent with the home range estimates for *Homo habilis*. Also, the area 130 locations are over 16 kilometers southwest of the area 41 location and more than

4 kilometers distant from the next closest area 131 locations. Therefore there is sufficient justification to designate the fossils from these area 130 locations as a separate and distinct "assemblage" as defined by Lyman.

Faunal Data

Surface survey in area 130 produced 124 fossil specimens identified to taxonomic level of family (NISP). Table 4-3 provides an inventory of the taxonomic diversity that the identified vertebrate fossils represent. Table 4-4 is a taxonomic summary of each individual research location as well a composite census of all the area 130 locations. Frequencies of taxonomic families [Bovidae (54%), Suidae (15%), Equidae (13%), Primates (4%) and Proboscidea (4%) which comprise 90% of the assemblage (Figure 4-6)] closely track those of area 41 and also correspond to the rank order reported by Behrensmeyer (Isaac and Behrensmeyer, 1997). Carnivore (large & small felids and hyenas) fossils (10%) are far more frequent in this assemblage. The difference between area 41 and area 130 with respect to proportions of bovids, suids, equids, and primates is not very significant (chi squared = 1.6, df = 3, p=0.6594, Cramer's V = 0.04). In other words, there is a less than 35% chance that the differences observed between the two identified assemblages actually do represent differences between the "taphocoenose" at the locations rather than just the vagaries of sampling (Drennan, 2004). The bovids dominate this faunal assemblage but hydrophilic (water affinity) tribes, Reduncini and Tragelaphini only account for 52% of the area 130 NISP as compared to 58% in area 41. Bovid tribes usually associated with more xeric environments, Alcelaphini and Antilopini show about the same representation as Area 41. However, Aepycerotini and Hippotragini

bovid tribes that are mixed feeders and exploit a variety of habitats (open and closed) are more frequent (13%) than in area 41 (4%) (Figure 4-7). Again water dependent animals (fish, hippopotamus, and crocodile) are present at each individual location. Two suid genera (*Kolpochoerus* and *Metridochoerus*) are present but the more hypsodont (mega-grazer) *Metridochoerus* is more frequent. Neither giraffe nor rhinoceros fossils were found.

Class	Order	Family	Tribe	Genus	Species
Mammalia	Artiodactyla	Bovidae			
			Aepycerotini		
			Alcelaphini		
				cf. *Damaliscus*	sp.
			Antilopini		
				Gazella	sp.
			Hippotragini		
				cf. *Oryx*	sp.
			Reduncini		
				Kobus	sp.
			Tragelaphini		
				Tragelaphus	sp.
		Hippopotomidae			
		Suidae			
				cf. *Kolpochoerus*	sp.
				Kolpochoerus	*heseloni*
				cf. *Metridiochoerus*	sp.
				Metridiochoerus	*andrewsi*
	Carnivora				
		Felidae		*Dinofelis*	sp.
		Hyaenidae			
	Perissodactyla	Equidae			
				Equus	sp.
				Eurygnathohippus	sp.
	Primates	Cercopithecidae			
				Theropithecus	sp.
		Colobinae			
	Proboscidea	Elephantidae		*Elephas*	sp.
Pisces					
Reptilia	Crocodilia				
		Crocodylidae		*Crocodylus*	*niloticus*

Table 4-3: Area 130 Taxon List

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 130A	27(6) 60%	2 (2) 4%	6 (1) 13%	0	2 (1) 4%	4 (1) 9%	0	4 (2) 9%

Area 130A NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 130B	9(4) 60%	0	5(2) 33%	0	0	0	0	9(1) 7%

Area 130B NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 130C	12 (3) 48%	5 (4) 20%	3 (1) 12%	0	1 (1) 4%	0	0	4 (1) 16%

Area 130C NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 130D	16 (2) 59%	1 (1) 4%	2 (1) 7%	0	0	0	0	8 (3) 30%

Area 130D NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 130E	3 (2) 25%	4 (1) 33%	0	0	2 (1) 17%	1 (1) 8%	0	2 (1) 17%

Area 130E NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 130 Composite	67 (12) 54%	12 (4) 10%	16 (2) 13%	0	5 (2) 4%	5 (1) 4 %	0	19(3) 15%

Area 130 Composite NISP (MNI) and percentage of total NISP

Table 4-4: Area 130 NISP (MNI)

Figure 4-6: Area 41/130 NISP

Figure 4-7: Area 41/130 Bovid Tribes
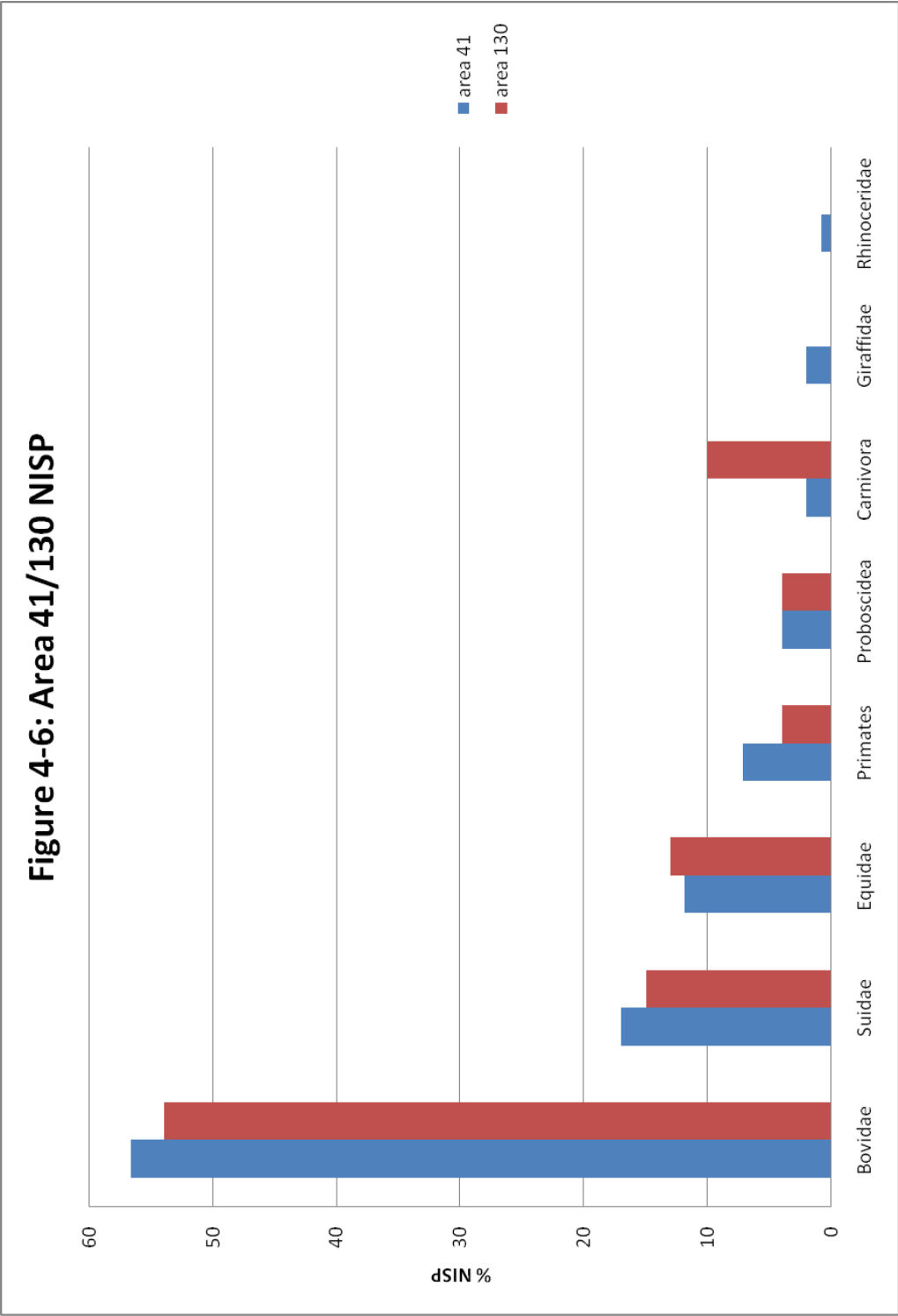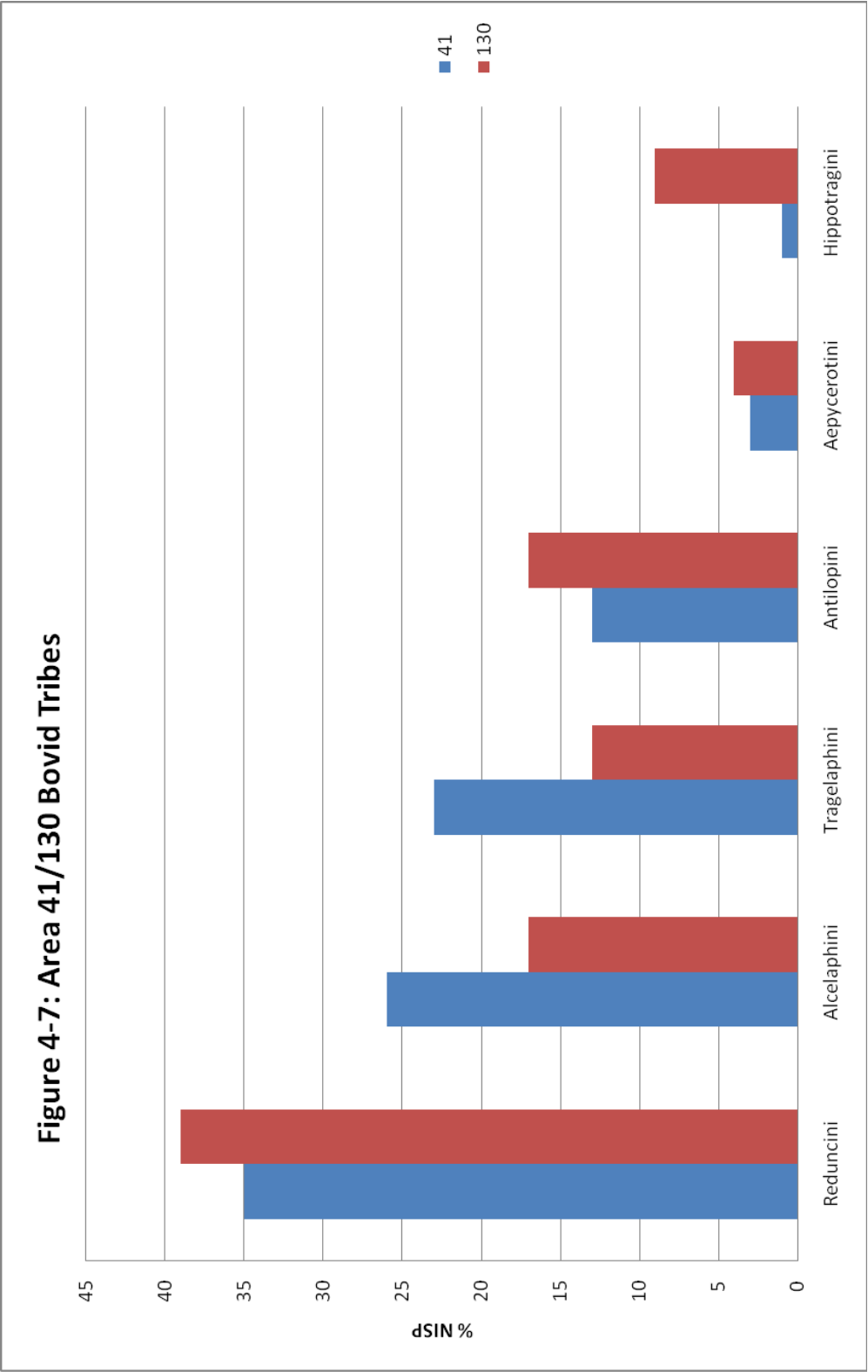
Habitat

The sedimentary environments of the research locations in Area 130 (Chapter Three) are very similar to the research location in area 41. The presence of aquatic and semi-aquatic vertebrates and the high, but lower, percentage of teeth in the NISP (Behrensmeyer, 1975) still signify the proximity to significant fluvial channels but perhaps not as large as in Area 41 (maybe delta distributary channels of the proto-Omo River). Grazing species with C4 dominated diets (bovid, equid, suid) are more prevalent and dedicated browsing genera (*Giraffa, Diceros*) are absent. Open savanna carnivores (hyenas and large felids) are present in relatively greater numbers. The environmental and ecological signal provided by the terrestrial vertebrate fauna therefore indicates a fluvial but perhaps *slightly* more arid and open habitat than that of the Area 41 research location.

Area 131

Area 131 is south of and contiguous to area 130. There are extended continuous and discontinuous outcrops of the KBS Tuff along the high relief western face of the Karari Escarpment in area 131. Six days of extensive field survey in 2001 of the Upper Burgi exposures down-section from the KBS Tuff yielded few locations with dense concentrations of terrestrial vertebrate fossils. Most of the sediments were massive silts and clays indicative of deep lake deposition and were virtually devoid of fossils. However, a few locations representing isolated fluvial sedimentary facies did warrant

additional exploration. The most promising location was the area surrounding the site where a *Homo rudolfensis* cranium (KNM-ER-1470) was discovered. Because of previous comprehensive excavation at the KNM-ER-1470 site, the stratigraphy surrounding that site is well documented (Leakey and Leakey, 1978). Unfortunately the area surrounding the KNM-ER-1470 concrete site marker likely suffers from "human winnowing" similar to sites in area 130C. For the last three decades, researchers, students, and tourists have made the pilgrimage to this famous site and the surface fossils have paid a price. The two locations (131A & 131B), each laterally about 125 meters from the KNM-ER-1470 site marker, were selected for systematic study. These locations are far enough away from the original 1970's excavation to minimize significant human disturbance of newly exposed surface material. One additional location in area 131 with surface terrestrial vertebrate fossil densies sufficient to warrant additional study was discovered near hominin fossil site KNM-ER-1475. Unfortunately only one day of random surface survey was conducted at this location due to time constraints. Therefore the bulk of the fossil material from area 131 was collected from an area of about 8 hectares (the area 130 assemblage is more that 4 kilometers to the north and the area 105 fossil material is more than 10 kilometers to the south). It is therefore reasonable to designate this research area as an "assemblage" as defined above.

Faunal Data

Surface survey in area 131 produced 134 fossil specimens identified to taxonomic level of family (NISP). Table 4-5 provides an inventory of the taxonomic diversity that the identified vertebrate fossils represent. Table 4-6 is a taxonomic summary of each

individual research location as well a composite census of all the area 131 locations. Frequencies of taxonomic families [Bovidae (74%), Suidae (8%), Equidae (3%), Primates (11%), and Proboscidea (1%); comprising 97% of the total assemblage (Figure 4-8)] only loosely track those of area 41 but generally agree with the rank order reported by Behrensmeyer (Isaac and Behrensmeyer, 1997). The major exception is the percentage of primate fossils which is even greater than the relatively high percentage reported for area 41. The difference between area 41 and area 131 with respect to proportions of bovids, suids, equids, and primates is very significant (chi squared = 21.24, df = 3, p<.0001, Cramer's V = 0.1444). In other words, there is a greater than 99.99% chance that the differences observed between the two identified assemblages actually do represent differences between the "taphocoenose" at the locations rather than just the vagaries of sampling (Drennan, 2004).

Unlike area 41 and area 130, this assemblage is dominated by post-cranial skeletal specimens and very few individual teeth were found. In most cases, the identification of the specimens was limited to the taxonomic level of family, thereby reducing the precision of the paleoenvironmental signal produced by the fossil fauna. The bovids dominate this faunal assemblage and tribes that prefer more xeric environments (Antilopini and Aepycerotini) are the only bovids identified (Figure 4-9). Equids (C4) are present but browsing (C3) herbivores such as *Diceros* and *giraffa* are absent.

Class	Order	Family	Tribe	Genus	Species
Mammalia	Artiodactyla	Bovidae			
			Antilopini		
				Gazella	sp.
		Hippopotomidae			
				Hippopotamus	sp.
		Suidae			
				cf. *Kolpochoerus*	sp.
				Kolpochoerus	*heseloni*
				cf. *Notochoerus*	sp.
	Carnivora				
	Perissodactyla	Equidae			
	Primates				
		Cercopithecidae			
				Theropithecus	sp.
				Theropithecus	*brumpti*
		Colobinae			
		Hominidae	*hominini*		
	Proboscidea				
		Elephantidae			
Pisces					
Reptilia	Crocodilia				
		Crocodylidae		*Crocodylus*	*niloticus*

Table 4-5: Area 131 Taxon List

Area 131A NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 131A	74 (5) 80%	2 (1) 2%	3 (1) 3%	0	5 (1) 5%	0	0	9 (2) 10%

Area 131B NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 131B	25 (4) 71%	0	0	0	6 (1) 17%	1 (1) 3%	0	3 (1) 9%

Area 131 Random Survey (131A, 131B, KNM-ER-1475)NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 131 Random	2 (1) 17%	2 (1) 17%	1 (1)	0	0	0	0	7 (2) 58%

Area 131 Composite NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 131 (A&B)	99 (6) 74%	5 (1) 4%	4 (1) 3%	0	14 (3) 11%	1 (1) 1%	0	11 (2) 8%

Table 4-6: Area 131 NISP (MNI)

Figure 4-8: Area 41/131 NISP

Figure 4-9: Area 41/131 Bovid Tribes
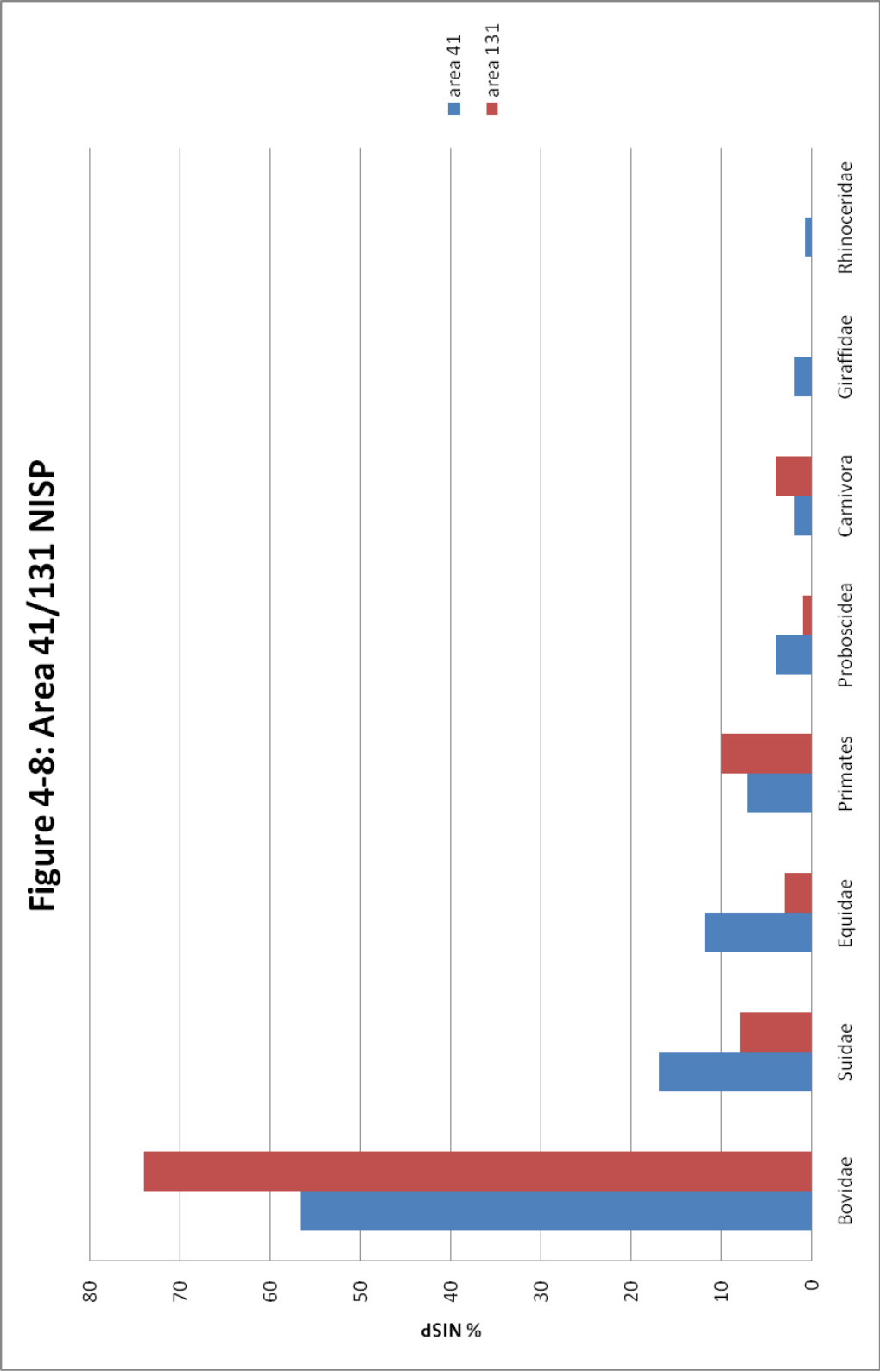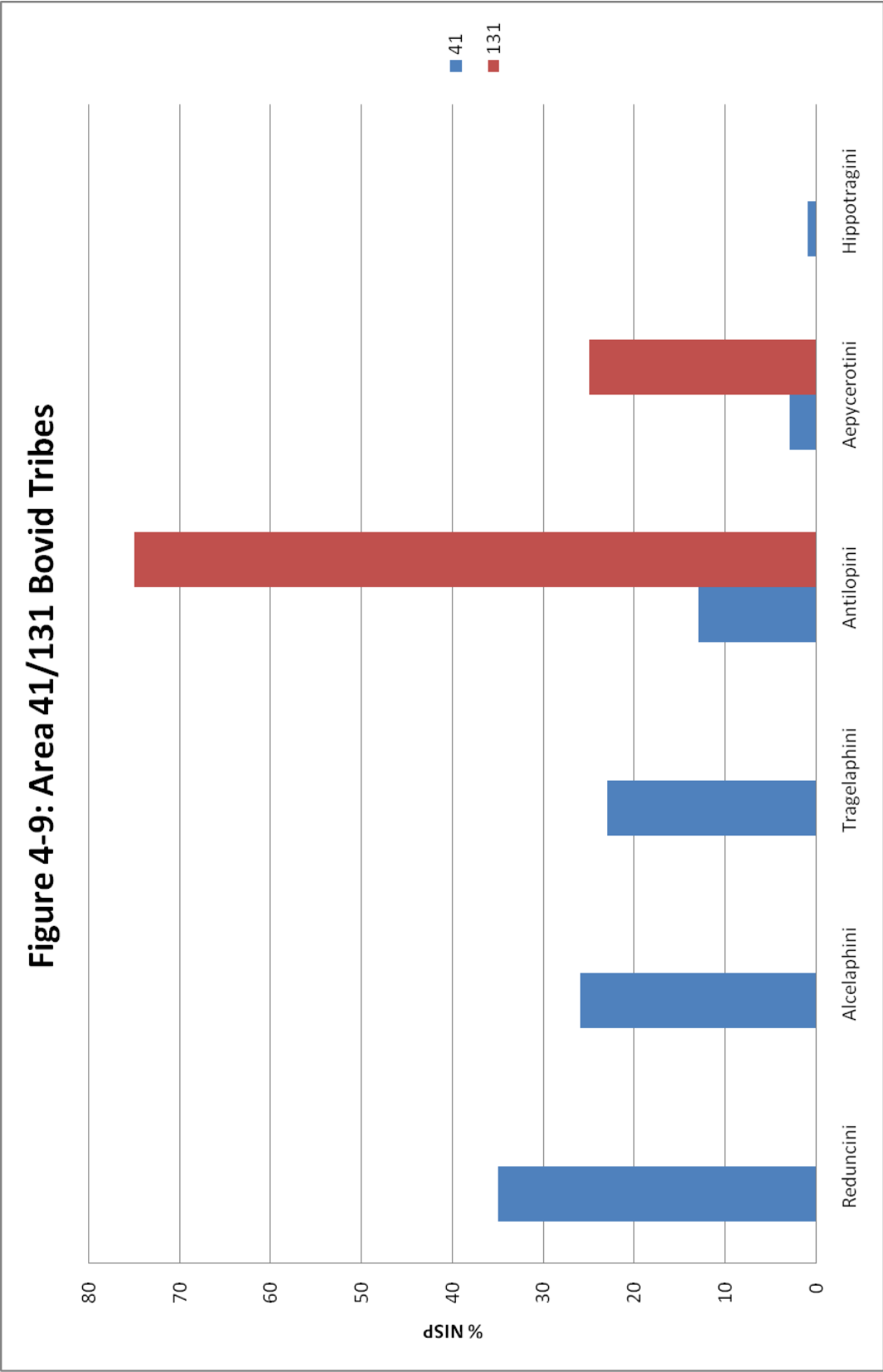
Both hypsodont and brachyodont suids are present but the paucity of teeth in the faunal

assemblage does not allow for meaningful differentiation of the relative abundance of

genera and therefore no environmental inferences can be made based on the suid fossils.

Primates, including both large and small bodied primates and at least one hominin

specimen (Figure 4-10), represent the second most abundant group of taxonomic families

in the assemblage.

Habitats

Sedimentary environments in area 131 are apparently different than area 41. The

fossils appear to derive from silty-clays that are eroding from a delta margin deposited in

the upper part of a distributary channel. No major channel sand bodies were present at

these locations and the small number of teeth in the assemblage tends to corroborate the

delta margin interpretation (Behrensmeyer, 1975). Grazing (C4) herbivores and primates

(*Theropithecus* is the most abundant) dominate the faunal assemblage suggesting a

habitat that is dryer and more open than area 41.

Area 105

Burgi Member sediments in area 105 are largely lacustrine. The KBS Tuff

outcrops along the northern and western faces of the Aberegaya Ridge mostly in channels

incised into the Burgi Member sediments during KBS Member times. The relatively

small surface fossil accumulations were all located in isolated low relief deltaic / lake

margin floodplain facies (Chapter Three) found down-section from the KBS Tuff

Left Distal Fibula (Medial-Posterior View)

45 mm
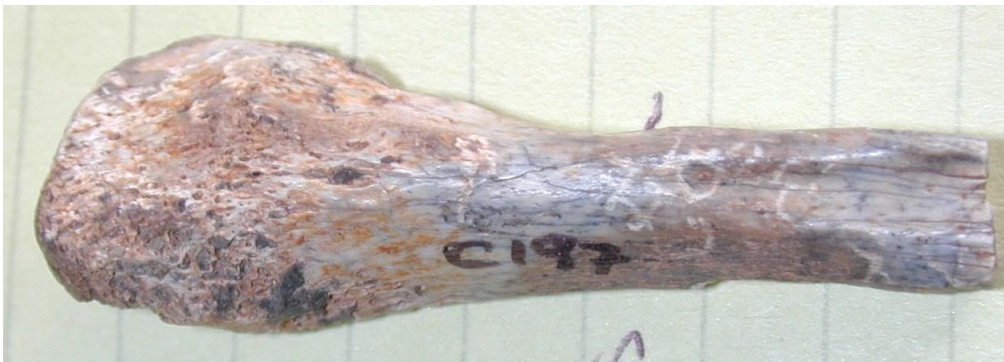
Left Distal Fibula (Lateral View)

Figure 4-10: Possible hominin left distal fibula.

outcrops. The area 105 research locations were more widespread and laterally dispersed than in the other research locations. All of the locations are contained within an area of over 1257 hectares with more than 4 kilometers separating some of the locations in area 105. This extensive area [representing almost 5 times the largest estimated *Homo habilis* home range (Leonard and Robinson, 2000)] would argue against treating all the fossil material as a single "assemblage". The strongest argument in favor of a single "assemblage" is based on the depositional environment which links each individual research location. Curiously, the modern context of each of the area 105 locations was starkly different and likely represents distinct individual taphonomic histories. In spite of these modern contextual differences, all of the locations represent a similar time horizon and all derive from silty-clays that appear to be eroding from a delta margin associated with isolated small delta distributary channels proximate to the fluctuating lake margin.

Faunal Data

Surface survey in area 105 produced 94 fossil specimens identified to taxonomic level of family (NISP). Table 4-7 provides an inventory of the taxonomic diversity that the identified vertebrate fossils represent. Table 4-8 is a taxonomic summary of each individual research location as well a composite census of all the area 105 locations. Frequencies of taxonomic families [Bovidae (48%), Suidae (28%), Equidae (4%), Primates (11%) and Proboscidea (4%) which comprise 95% of the assemblage (Figure 4-11)] roughly track those of area 41 and also generally follow the rank order reported by Behrensmeyer (Isaac and Behrensmeyer, 1997). Like area 131, there is a higher than expected number of primate fossils. The difference between area 41 and area 105

Class	Order	Family	Tribe	Genus	Species
Mammalia	Artiodactyla	Bovidae			
			Alcelaphini		
			Hippotragini		
				cf. *Oryx*	sp.
			Reduncini		
				Kobus	sp.
			Tragelaphini		
				Tragelaphus	sp.
		Hippopotomidae			
				Hippopotamus	*gorgops*
		Suidae			
				cf. *Kolpochoerus*	sp.
				Kolpochoerus	*heseloni*
				cf. *Notochoerus*	sp.
	Carnivora	Felidae		*Dinofelis*	sp.
	Perissodactyla	Equidae			
	Primates				
		Cercopithecidae			
				Theropithecus	cf. *oswaldi*
		Colobinae			
				cf. *Rhinocolobus*	*turkanaensis*
	Proboscidea				
		Elephantidae			
Pisces					
Reptilia	Crocodilia				
		Crocodylidae		*Crocodylus*	*niloticus*

Table 4-7: Area 105 Taxon List

Area 105 GPS-X NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 105 GPS-X	11 (3) 31%	2 (1) 6%	2 (1) 6%	0	9 (2) 26%	0	0	11 (3) 31%

Area 105 GPS-Y NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 105 GPS-Y	7 (3) 41%	2 (1) 12%	0	0	0	3 (1) 18%	0	5 (1) 29%

Area 105 GPS-Z NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 105 GPS-Z	27 (7) 66%	1 (1) 2%	1 (1) 2%	0	1 (1) 2%	1 (1) 2%	0	10 (2) 25%

Area 105 South of FxJj13 NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 105 South of FxJj13	0	0	1 (1) 100%	0	0	0	0	0

Area 105 Composite NISP (MNI) and percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 105 Composite	45 (8) 48%	5 (2) 5%	4 (1) 4%	0	10 (2) 11%	4 (1) 4%	0	26 (4) 28%

Table 4-8:   Area 105 NISP (MNI)
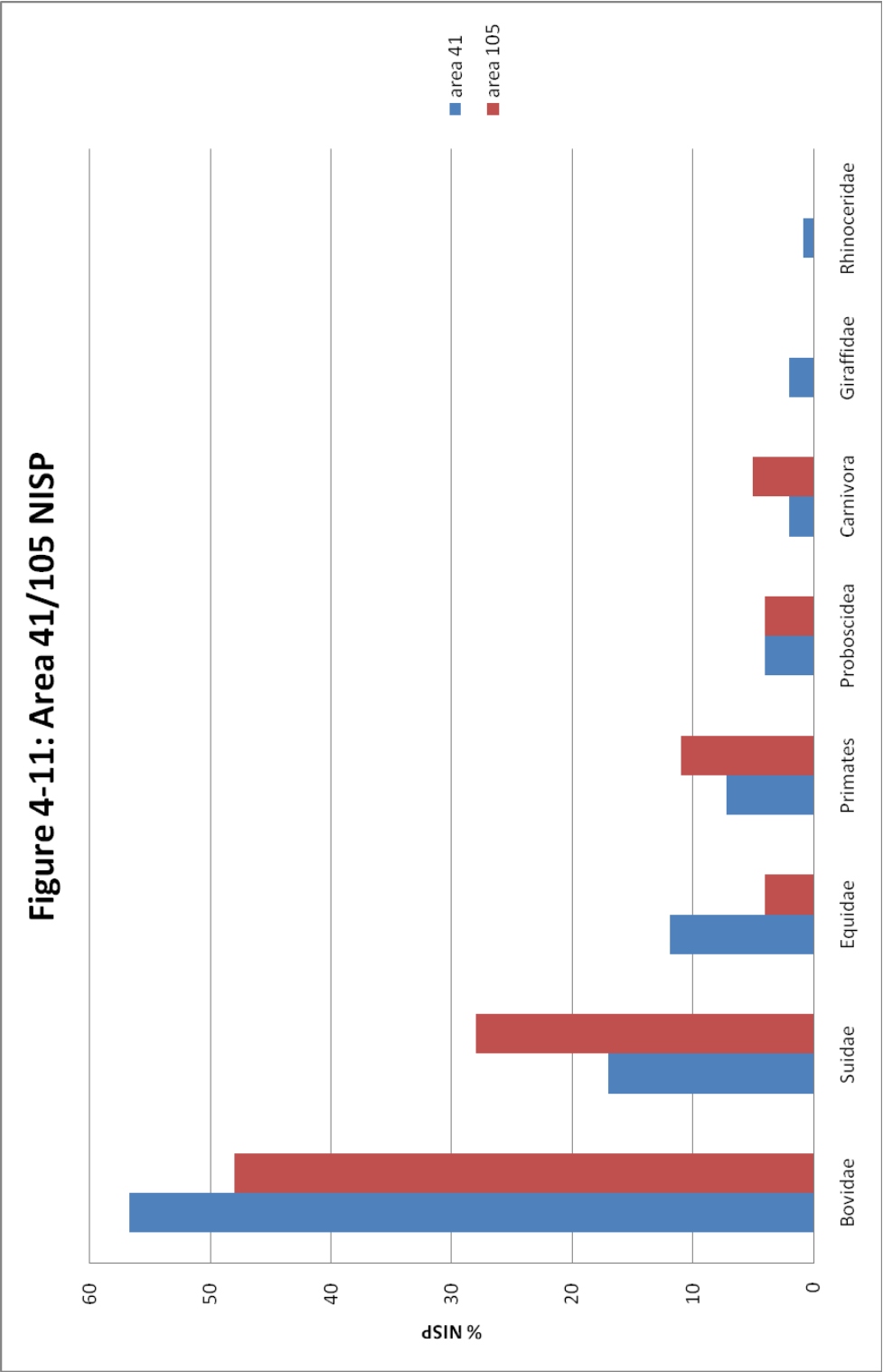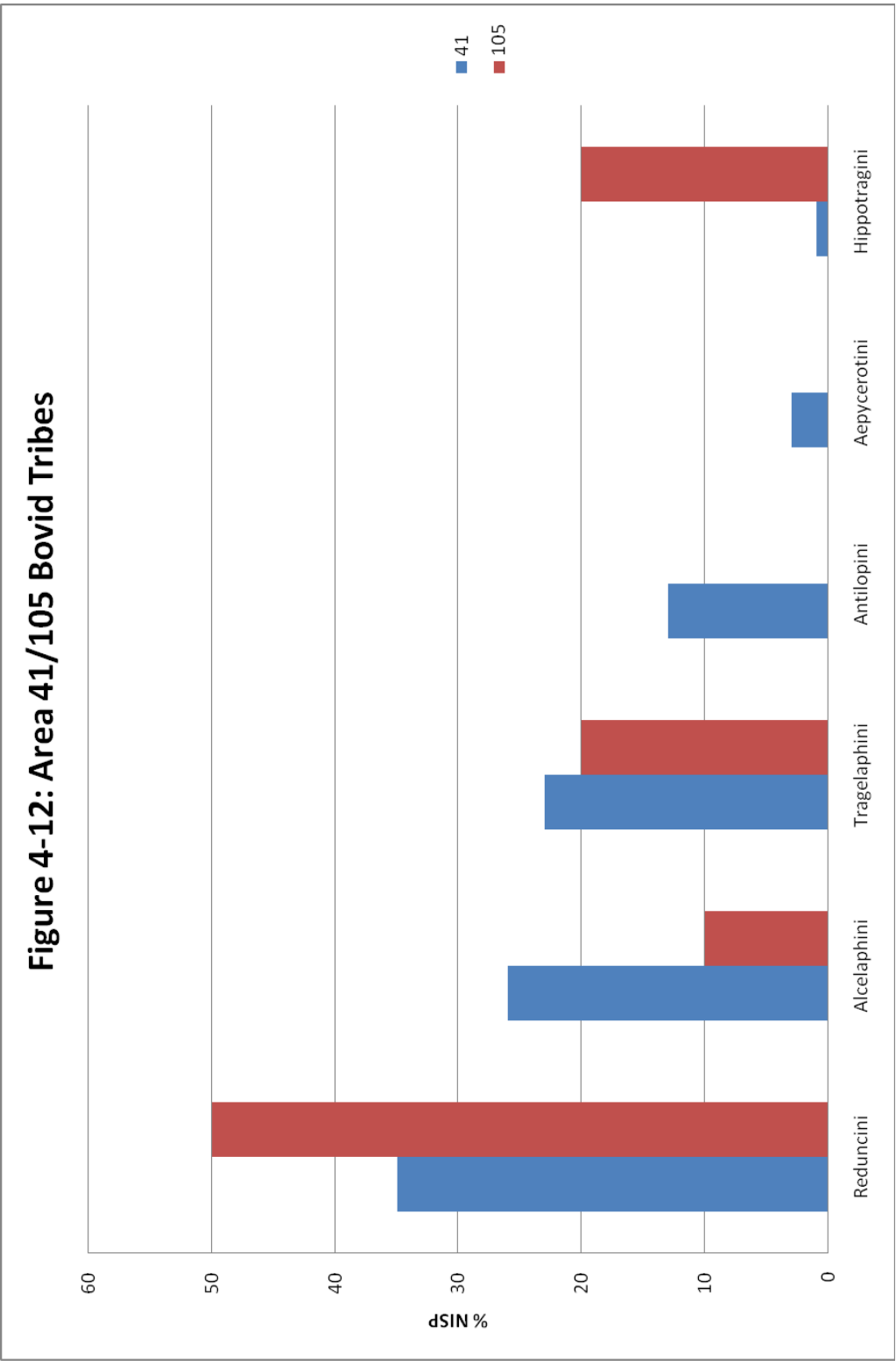
Figure 4-11: Area 41/105 NISP

Figure 4-12: Area 41/105 Bovid Tribes

with respect to proportions of bovids, suids, equids, and primates is very significant (chi squared = 12.67, df = 3, p=0.0054, Cramer's V = 0.1139). In other words, there is a greater than 99.4% chance that the differences observed between the two identified assemblages actually do represent differences between the "taphocoenose" at the locations rather than just the vagaries of sampling (Drennan, 2004). The bovids still dominate this faunal assemblage but they represent less than half of the total NISP with bovid tribes, Reduncini and Tragelaphini accounting for 70% of the bovid NISP (Figure 4-12). Suids and primates are far more prevalent than in area 41 (39% compared to 19%). The suids (brachyodont and hypsodont) are abundant at each location. Unfortunately most of the suid fossils are post-cranial and taxonomic identification is only possible to family level so no meaningful environmental inference is possible. There is a relatively high proportion of suid sub-adult specimens found at locations 105 GPS-Z and 105 GPS-X. Virtually all of the primate fossils (predominately *Theropithecus*) were from location 105 GPS-X.

Habitat

The deposition environment characteristics described in Chapter Three indicate a similar paleoenvironmental context for all the area 105 research locations. The bovid signal (Reduncini and Tragelaphini) coupled with the ubiquitous presence of aquatic and semi-aquatic vertebrates confirm the well watered and more closed habitat reconstruction. Relatively few teeth are present in the composite assemblage which Behrensmeyer (1975) attributes to the absence of flowing water, therefore indicating that the habitat at Area 105 is more likely located at delta margin and not proximate to a

significant fluvial channel. However, both the surface density and the taxonomic

composition of the terrestrial vertebrate fossils at the area 105 research locations vary as

the distance from the basin margin increases and there may be slight, but important,

differences in micro-habitats at the individual locations.

Area 102

As discussed in Chapter Three, the considerable time spent in area 102

performing survey in 2001 and 2004 was totally unproductive. The sediments down-

section from the few outcrops of the KBS Tuff were not fossil bearing. Two days of

survey at the end of the 2007 field season at a KBS Tuff outcrop in area 102 previously

identified by Dr. Craig Feibel did yield terrestrial vertebrate fossils from sediments

positioned stratigraphically below the outcrop. The specimens from this location are all

Voorhies/Behrensmeyer dispersal groups I & II indicating the assemblage is

allochthonous. The small sample size and limited time spent at this location make it

impossible to construct meaningful inferences about the paleohabitat. Tables 4-9 and 4-

10 along with Figures 4-13 and 4-14 summarize the faunal data.

Class	Order	Family	Tribe	Genus	Species
Mammalia	Artiodactyla	Bovidae			
			Alcelaphini		
			Reduncini		
		Hippopotomidae			
		Suidae			
	Proboscidea				
		Elephantidae			
Pisces					
Reptilia	Crocodilia				
		Crocodylidae		*Crocodylus*	*Niloticus*

Table 4-9: Area 102 Taxon List

Area 102 NISP (MNI) – percentage of total NISP

	Bovid	Carnivore	Equid	Giraffe	Primate	Elephant	Rhino	Suid
Area 102	6 (1) 50%	1 (1) 8%	0	0	0	2 (1) 17%	0	3 (1) 25%

Table 4-10: Area 102 NISP (MNI)

Figure 4-13: Area 41/102 NISP

Figure 4-14: Area 41/102 Bovid Tribes
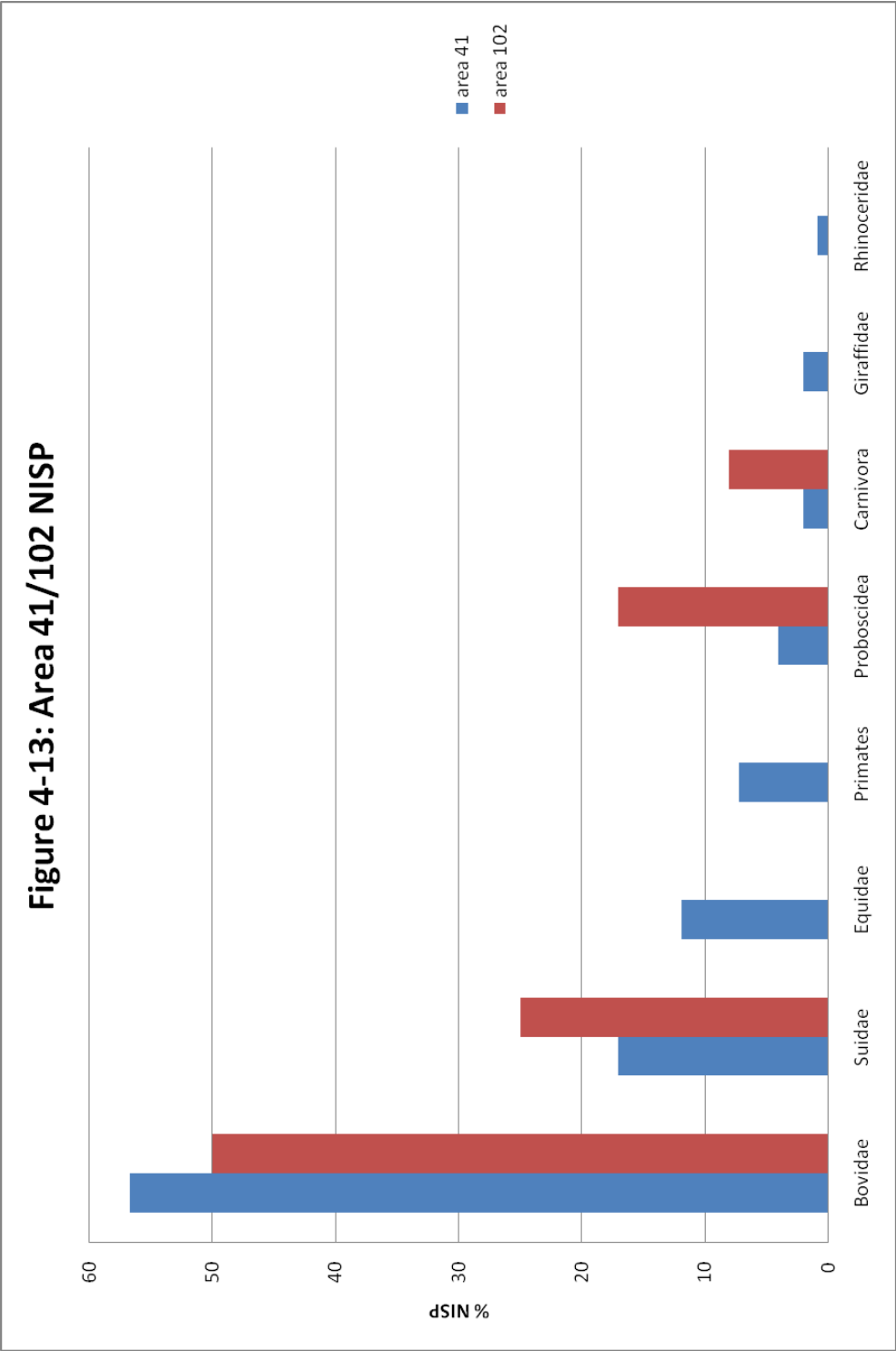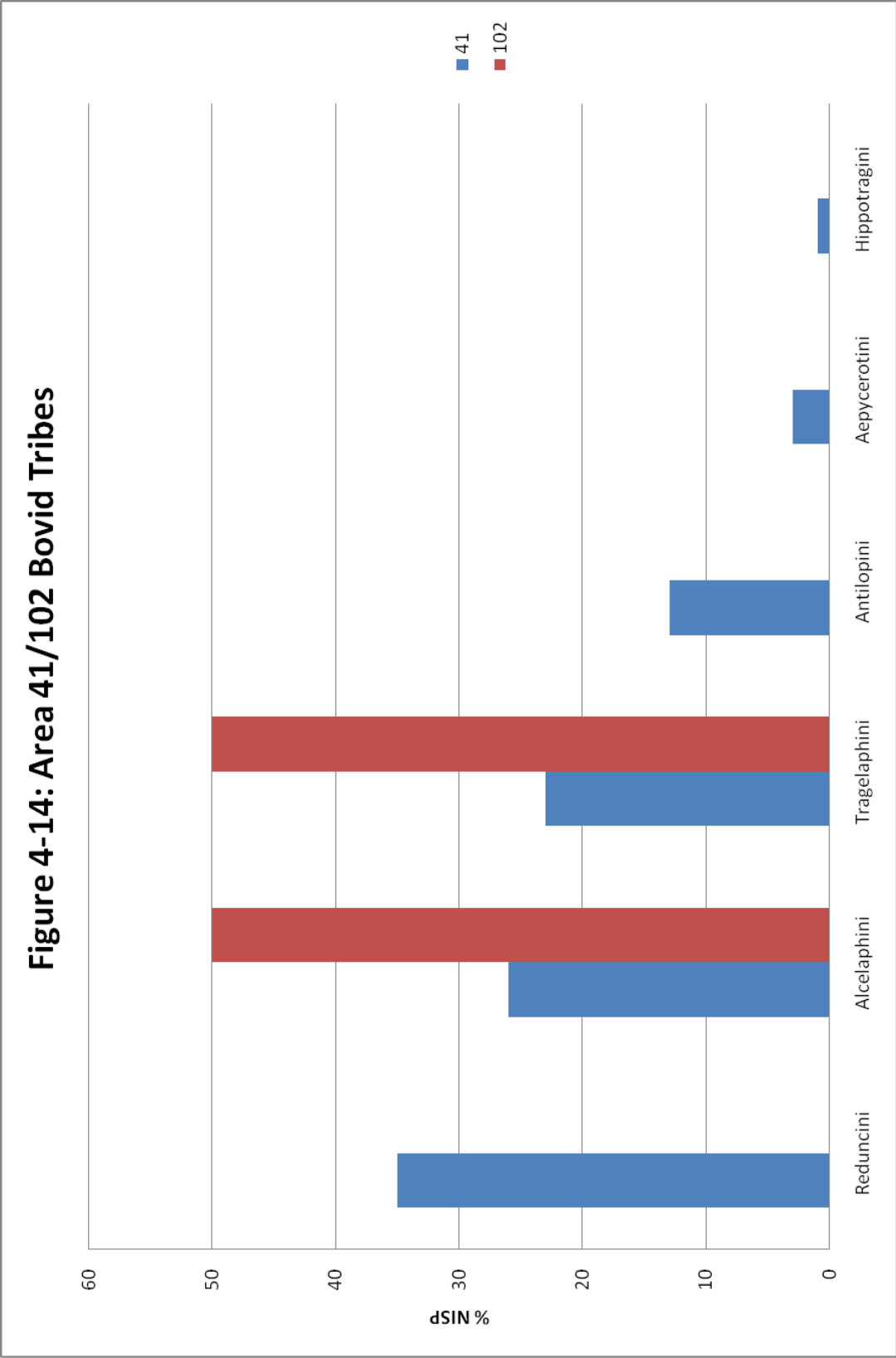
Discussion

The goals of this dissertation research were to identify hominin presence on the
ancient landscape during Upper Burgi Member times through the proxy of modified
bone, say something about hominin behavior during this critical period in human
evolution, and place this behavior in an ecological and environmental context. The issues
of hominin presence and behavior are addressed in Chapter Five. The data presented in
this chapter along with data from Chapter Three address the issues of habitat
(paleoenvironment and paleoecology). Ancient landscapes along with associated animal
and plant communities define hominin habitat and ecological interactions. The locations
utilized in this research were based on assemblages of fossils of terrestrial vertebrates
found on the surface of the modern Koobi Fora landscape. Bones and bone fragments on
the surface that are exposed to the elements will become disarticulated and begin to
weather within months to years depending upon environmental conditions. During this
period, they are subject to a plethora of taphonomic dispersal agents but if the fossil
bones in an assemblage have well preserved and largely unweathered surfaces it is likely
that they were rapidly buried and not widely dispersed (Behrensmeyer, 1975).
"Fragmented bone assemblages can be used with confidence for paleoecological
interpretation if they: a) consist of bones with a wide range of dispersal potentials, b) are
not hydraulically equivalent to associated sediments, and c) retain fresh, unweathered or
unabraded surfaces" (Behrensmeyer, 1975 p. 565). Moreover these assemblages are only
meaningful to this research if they actually represent the animal communities of interest
present at these locations during Upper Burgi Member times (See Figures 4-15 & 4-16
for summary of faunal data). In other words, are the assemblages autochthonous or have

Figure 4-15: Animal Communities in Each Research Location

Figure 4-16: Bovid Tribes in Each Research Location
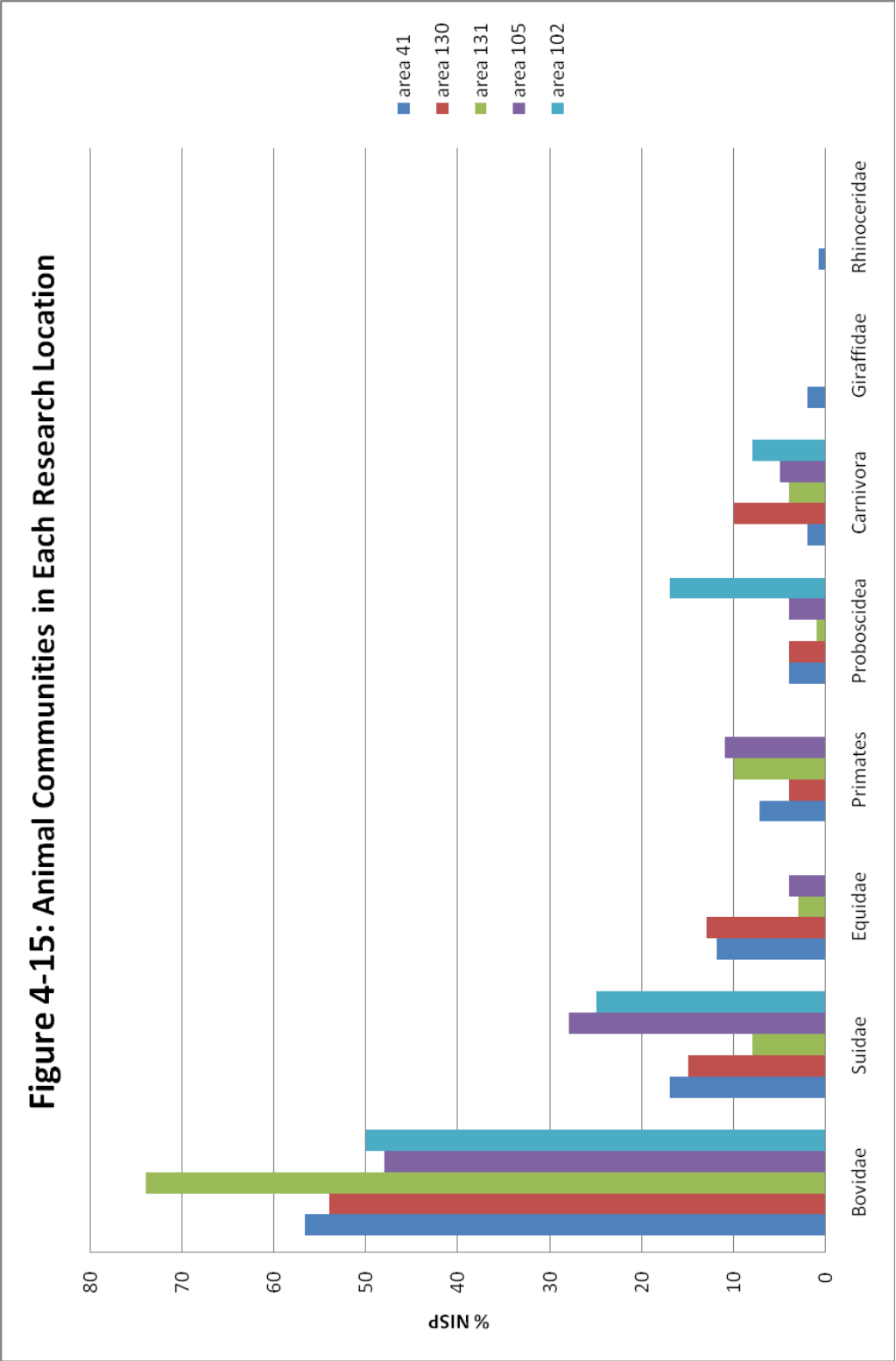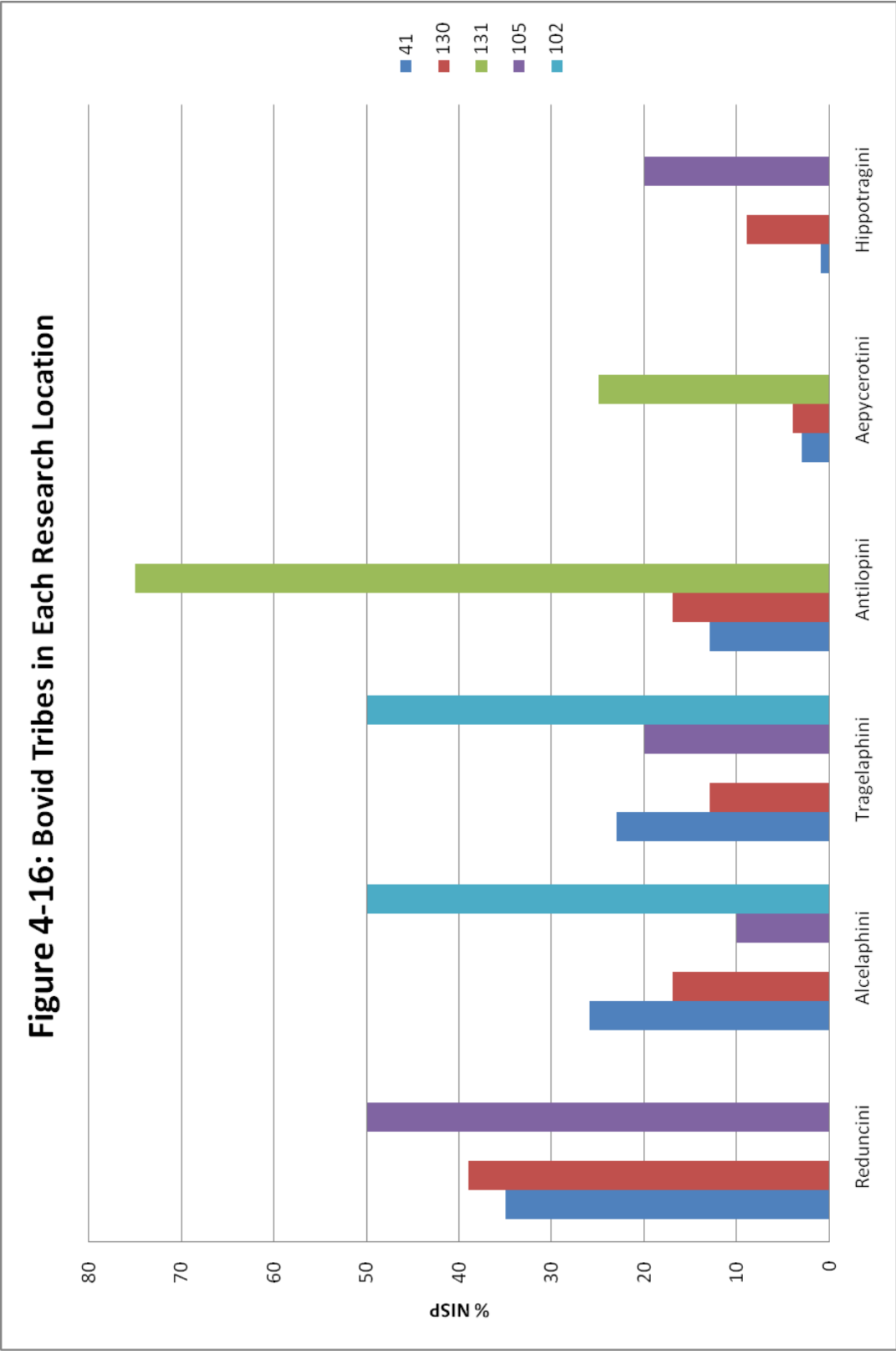
the fossils been transported to these locations from some distant spot on the landscape

representing different environments and habitats (allochthonous)?

Profiles of the skeletal elements in a fossil assemblage can be utilized to answer

this question based on actualistic research conducted by Voorhies (1969) and theoretical

analysis presented by Behrensmeyer (1975). The presence of different specific skeletal

element groups (Appendix 4-1) in a fossil assemblage is a measure of the autochthonous

nature of that assemblage. The composite fossil assemblages from each research location

were sorted and tallied by skeletal element. Because of the definition utilized for NISP

(element identifiable to taxonomic level of family), rib and vertebrate fragments [(with

the exception of the atlas (C1) and axis (C2)] are largely excluded from this research. If

an assemblage is dominated by element groups I & II, it is likely that most of the

specimens were transported into that location (allochthonous). If the assemblage is

composed of significant proportions of all groups (I, II, and III) the assemblage can be

considered autochthonous. In each research location a significant percentage of lag

elements (group III defined by Voorhies & Behrensmeyer) is found in close association

with Behrensmeyer defined group I/II elements thereby providing strong evidence that

the assemblages are likely autochthonous (Appendix 4-3).

Almost all of the individual "sites" within each research location match this

autochthonous pattern of skeletal element representation (Appendix 4-4) with the

exception of 130-E, 131-Random Sample, and area 102. The small number of fossils

from area 130E derives from the secondary context of a relatively high energy fluvial

sand body (delta front) and obviously represents a winnowed assemblage. The bone

surface condition of these fossils is excellent indicating that these lag elements are at

worst very close to the spot where they were originally deposited and therefore likely autochthonous. As discussed earlier, the area "131-Random Sample" (almost exclusively lag elements and likely autochthonous) and "area 102" fossils (all groups I & II and obviously transported) are small sub-assemblages from locations that require additional research.

The specific environmental signal provided by bovids and suids is largely based on tooth morphology that provides the taxonomic precision necessary to identify specimens to tribe (bovids) or genus (suids). The teeth of alcelaphine, reduncine, and tragelaphine bovids are very similar in size and morphology (this is also true of *Kolpochoerus*, *Metridochoerus*, and *Notochoerus*), and therefore not significantly subject to "selected transport sorting". Differences in relative numbers of teeth in an assemblage are thus due to ecological factors and reflect the relative numbers of animals present and perhaps their preferred habitat (Behrensmeyer, 1975).

It is important to remember that, based on stable oxygen isotope (^{18}O) analysis; the East Turkana Basin was significantly wetter during Upper Burgi Member times than it is today. This dissertation research has identified three distinct hominin habitats based upon the environments of deposition (Chapter Three) and faunal evidence. Research locations in area 41 and area 130 represent two very similar paleoenvironments. The depositional environments at area 41 indicate proximity to a significant fluvial channel (similar to the modern Omo River in southern Ethiopia) or perhaps the confluence of an ephemeral river from the basin margin and the ancestral Omo River (Figure 3-8). The faunal signal indicates a well-watered riverine gallery forest bordered by brush-land savanna and surrounding grassland. The depositional environment at area 130 locations

indicates proximity to smaller low energy delta distributary channels (Figures 3-12 to 3-15). The faunal signal, while similar to that of area 41, indicates a less well-watered environment with reduced riverine forest and brush land vegetation but more expansive open grassland environment. Figure 4-17 compares six mammal groups present at both area 41 and area 130, three (brachyodont suids, reduncine and tragelaphine bovids) that are ecologically tied to wetter, more closed habitats and three (hyposdont suids, alcelaphine and antilopine bovids) that are ecologically tied to dryer, more open habitats (Behrensmeyer, 1975). It confirms the similarity in the composition of the animal communities between the two locations and the slight differences in paleoenvironment. The area 131 and area 105 locations are both associated with delta margin depositional environments but not any significant high energy fluvial channel (Figure 3-19 to 3-30). The faunal signal from area131 points to a dryer, more open environment, perhaps on the delta margin located on the upper part of a distributary channel and very different than the area 41 habitat (Figure 4-18). The faunal signal from area 105 points to a wet and well-watered environment, perhaps small delta distributary channels very close to the ancient Lorenyang Lake margin; also quite different than the area 41 habitat (Figure 4-19). Figure 4-20 shows the four research locations and highlights the three distinct habitats described by the faunal evidence (Behrensmeyer, 1975).

In the following chapter, traces of hominin butchery on fossil bones from the research locations and paleo-habitats described above are analyzed. The actualistic studies (published and conducted during this research) that enable the construction of relational analogies (cause and effect) concerning creation of these traces are reviewed and inferences about the behaviors involved are hypothesized.

Figure 4-17: Relative abundance of 6 mammal groups representing open & closed habitats

Figure 4-18: Relative abundance of six terrestrial mammal groups representing open & closed habitats

Figure 4-19: Relative abundance of six mammal groups representing open & closed habitats
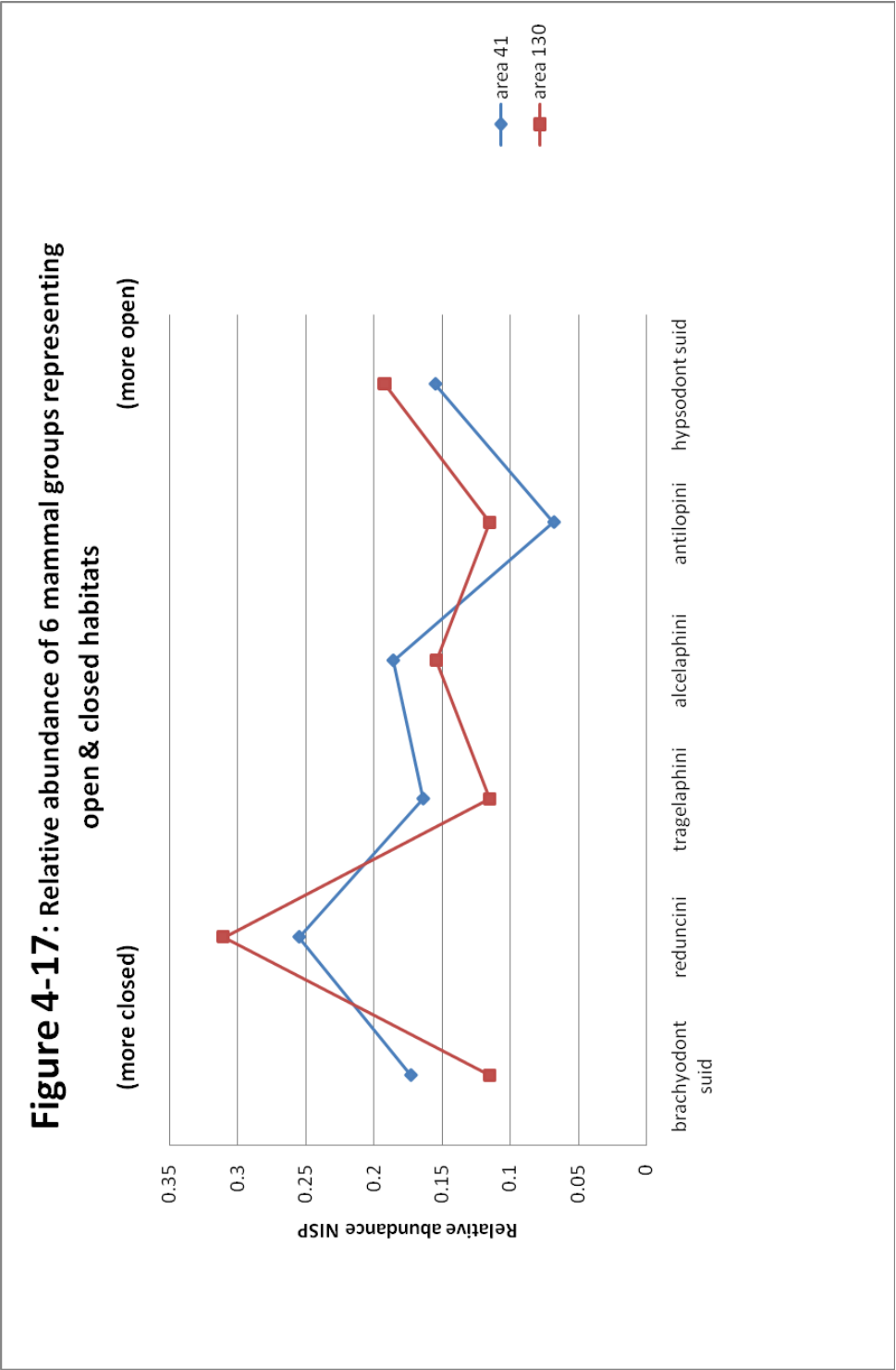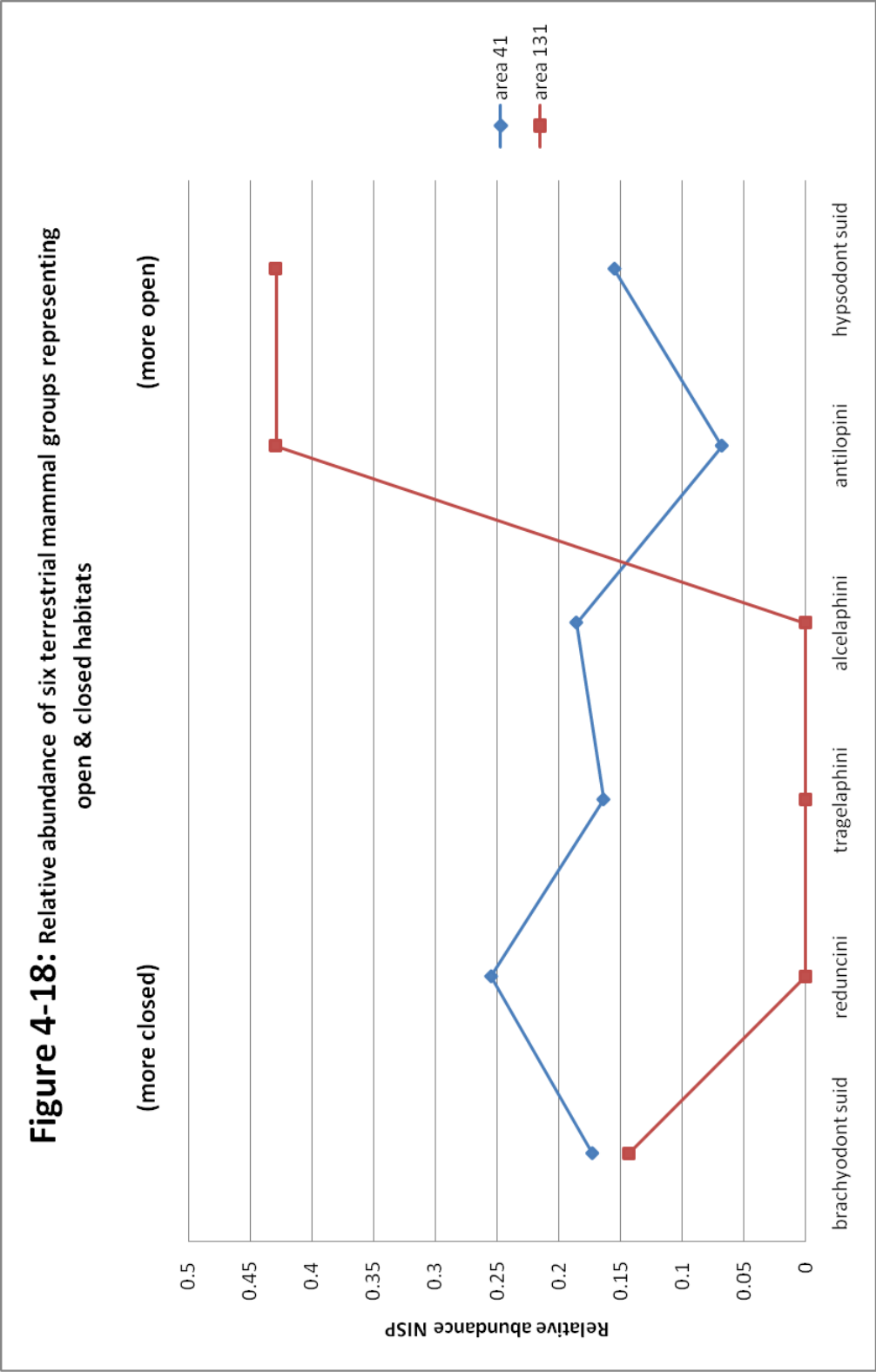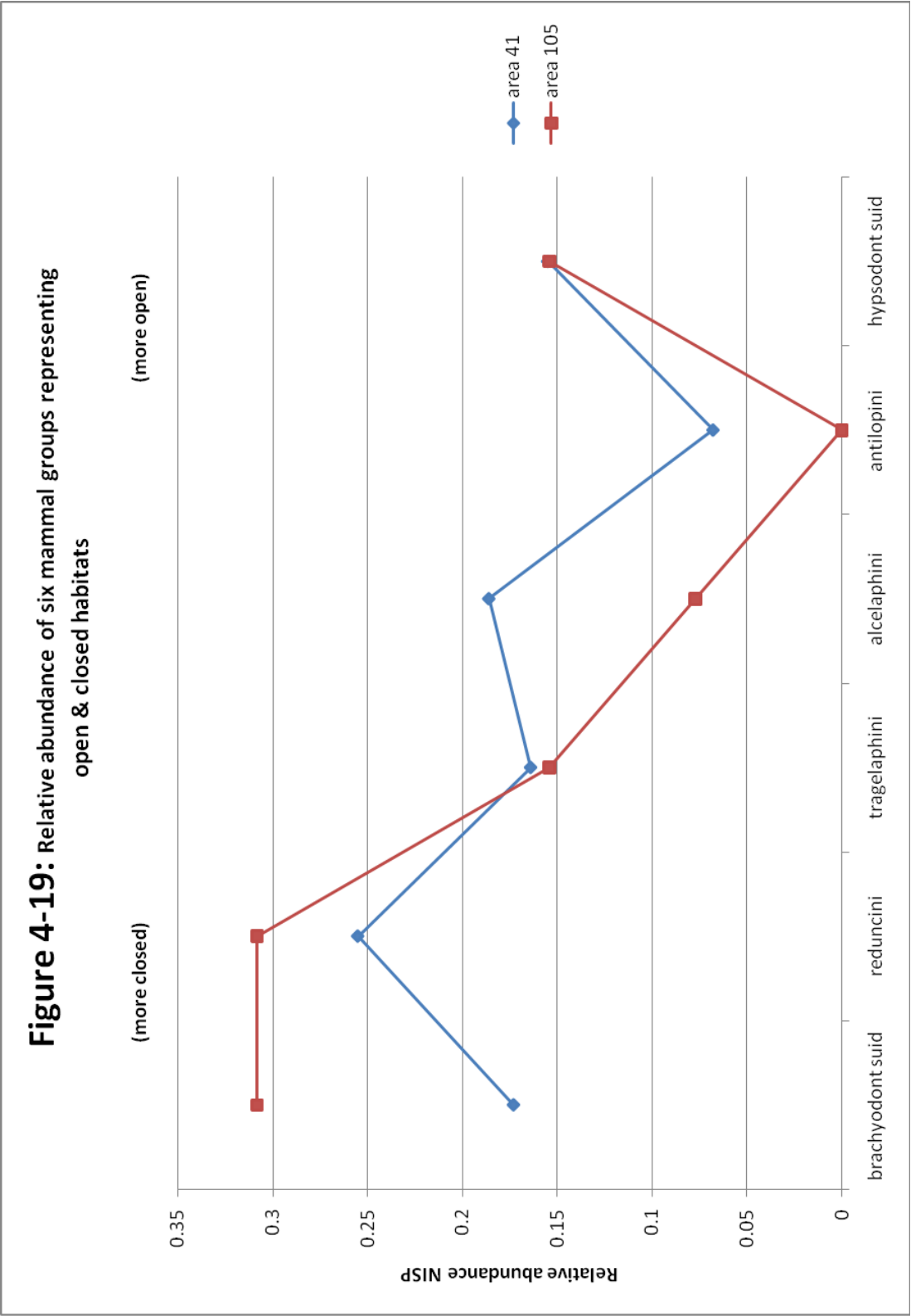
Figure 4-20: Relative % of closed and open habitat terrestrial mammals by research location
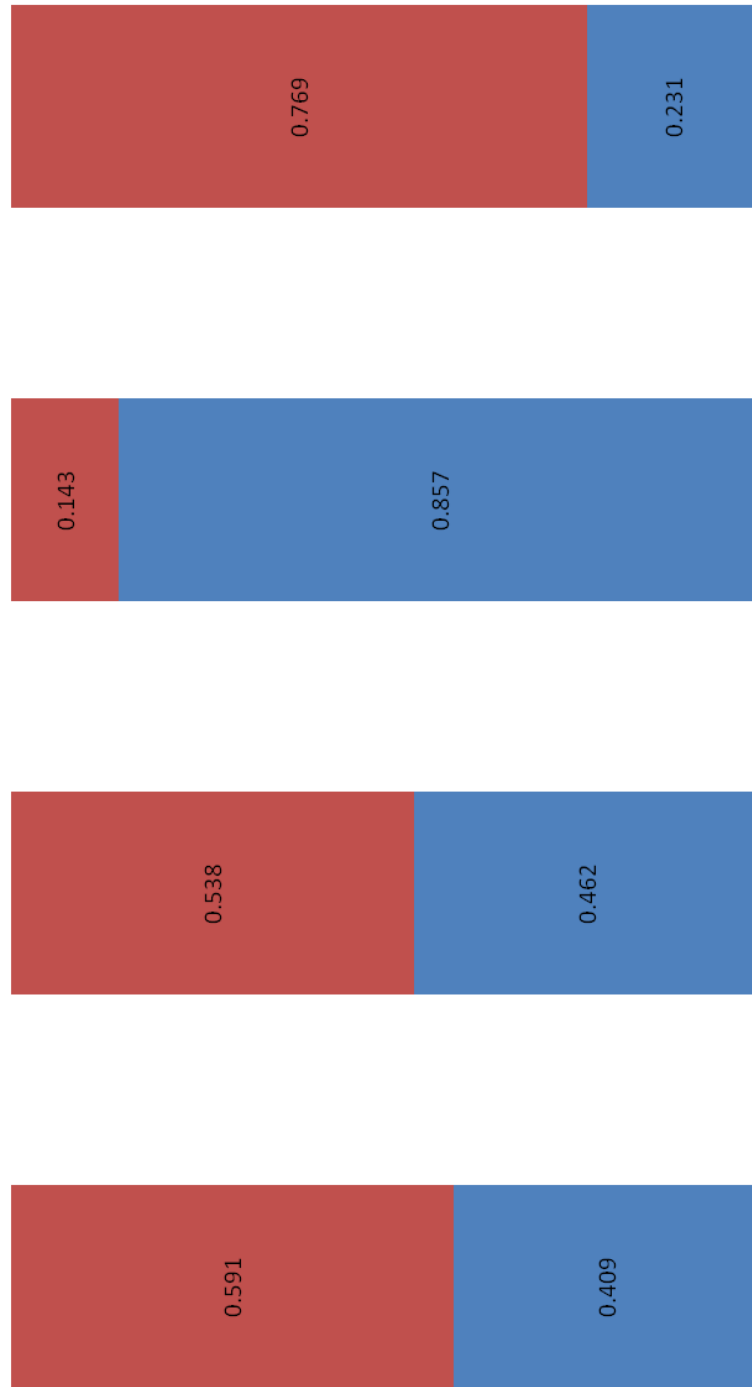
Chapter 5: **Modified Bone**

Introduction

In this chapter the actual traces of hominin butchery behavior (fossilized modified bone) from the research locations and paleo-habitats defined in the previous two chapters are analyzed. Actualistic studies conducted as part of this research along with important middle range studies from the scientific literature are applied in the analysis. Examples of the various unequivocal hominin produced modification marks on bones from each research location are examined in detail and where possible are linked to specific hominin butchery behaviors.

As discussed in Chapter One, the first appearance of the genus *Homo* in the Late Pliocene appears to be coincident with major changes in culture, technology, and diet within the hominin lineage. Certain paleoanthropological milestones mark these changes: stone tools from Gona, Ethiopia (2.5 mya) (Semaw *et al*., 1997) and Lokalalei, Kenya (2.35 mya) (Kibunjia, 1994); modified bone from Gona (2.5 mya) (Dominguez-Rodrigo *et al*., 2005) and Bouri, Ethiopia (2.3 mya) (deHeinzelin et al., 1999); and hominin fossils such as A.L. 666 (2.3 mya) from Hadar, Ethiopia (Kimbel *et al*., 1996). Unfortunately, these few references provide very little evidence of evolving hominin behavior based upon archaeological traces. This dissertation reports on new archaeological discoveries consisting of hominin produced traces on fossil bone from late Pliocene sediments that have already produced a large number of hominin body fossils (Appendix 1-1). These traces can be used as proxies for certain behaviors of the earliest tool making hominins such as foraging, food acquisition, and food preparation prior to

consumption. As discussed in Chapters Three and Chapter Four examination of

depositional environments and a reconstruction of the animal communities present at

each research location was undertaken in order to place the archaeological traces into the

proper environmental and ecological context so that more meaningful analysis of these

issues of changing diet and evolving foraging behaviors could be conducted. The paucity

of traditional archaeological evidence from Koobi Fora in exposures older than the KBS

tuff (1.89 mya) prompted this reinvestigation of Upper Burgi sediments from the

innovative viewpoint of modified bone as a proxy for the absence of traditional evidence

from stone tools. Fossil bones that preserve unequivocal traces of hominin butchery

activities are extremely valuable archaeological evidence that not only pinpoints hominin

presence on the ancient landscape but also enables one to make meaningful inferences

about changing diet and ecological interactions.

From a broader perspective this type of archaeological evidence may open the

door to a better understanding of the origins of habitual hominin carnivory. Extant

chimpanzees are large bodied terrestrial omnivores that occasionally consume some meat

and have been observed to hunt small primates.   This behavior has been hypothesized as

a modern analog for the onset of hominin carnivory but a better interpretation is probably

one of a social bonding vehicle that apparently has little impact on chimpanzee diet

(Stanford, 1999). The onset of hominin carnivory, involving the exploitation of meat and

marrow from size class 1-3 ungulates, represents very different behavior. Early hominins

did not possess the biological apparatus (jaws, teeth, claws) necessary to exploit this food

resource without the assistance of some kind of tools. If indeed culture (evidenced by the

manufacture and use of tools) is something that differentiates us from the

australopithecines, then perhaps the 2.5 million year old Oldowan stone tools do represent a "threshold event" in human behavioral evolution that rapidly appeared and quickly diffused across East Africa and South Africa. The alternative hypothesis, that the appearance of Oldowan stone tools is the end result of a gradual evolution based on ancestral behaviors, predicts that a pre-Oldowan technology should exist. Unfortunately if these early pre-Oldowan tools are present in the sedimentary record they are likely to be archaeologically indistinguishable as such. It is very possible that the only recognizable archaeological evidence of this innovative new behavior is hominin modified fossil bone in the form of percussion marks or notches on long bone shaft fragments (Blumenschine and Selvaggio, 1988). Tool typologies and bone modification patterns specific to this new behavior may or may not be consistent with Pleistocene/Holocene butchery tools and techniques that became established much later in time suggesting that the archaeological remains of this evolving behavior may require investigation based upon an entirely different paradigm. This question is crucial to understanding early hominin behavior and needs to be addressed.

If modern chimpanzee hunting and meat consumption is not a useful analog for the onset of hominin carnivory then other chimpanzee foraging behaviors may be. Chimpanzees do make and use simple tools to extract and consume foods such as nuts and termites. Some populations of West African chimpanzees employ hammer stones and anvils to extract nutritious nutmeat from hard fibrous shells (Boesch, 1991; Boesch & Boesch, 1984). Scavenging defleshed limb bones from carnivore kills and using hammer stones to extract marrow is a foraging activity and an analogous behavior that would demand similar cognitive capacity and require comparable physical skills (Hauser, 2000).

This "marginal scavenging" has been hypothesized to represent a possible first step towards habitual carnivory by hominins (Binford, 1981, 1988). As detailed in chapter one, marrow extraction produces shaft fragments that exhibit characteristic fresh green fracture morphology and percussion damage that in some instances can unequivocally be linked to hominin activity. Flesh scraps often remain on the carcasses of carnivore kills (Photograph 5-1) and could be exploited by a scavenging omnivorous primate employing some form of sharp edged tool. If an artifact is defined as "any object manufactured or modified by human beings" (Fagan, 1987) then traces of carnivory, preserved on the fossil bones, may actually be the earliest artifacts produced by the human lineage.

Actualistic Research

Pre-Oldowan Butchery

Actualistic butchery experiments were conducted in 2001 to test the effectiveness of a hypothesized "pre-Oldowan" tool kit consisting of whole river cobbles, naturallyfractured clasts, and rock fragments produced by throwing a river cobble one time against a large "anvil stone". To simulate a scavenging opportunity, the limbs of size class 2 cervids (*Odocoileus virginianus*) were butchered for meat and marrow utilizing this tool kit (Photograph 5-2 and 5-3). The resultant bones and bone fragments were cleaned and boiled to remove any remaining soft tissues and the butchery marks remaining on the bones were compared to a reference collection of butchery marks produced in a similar manner but utilizing classic Oldowan type tools. The cut marks and percussion damage
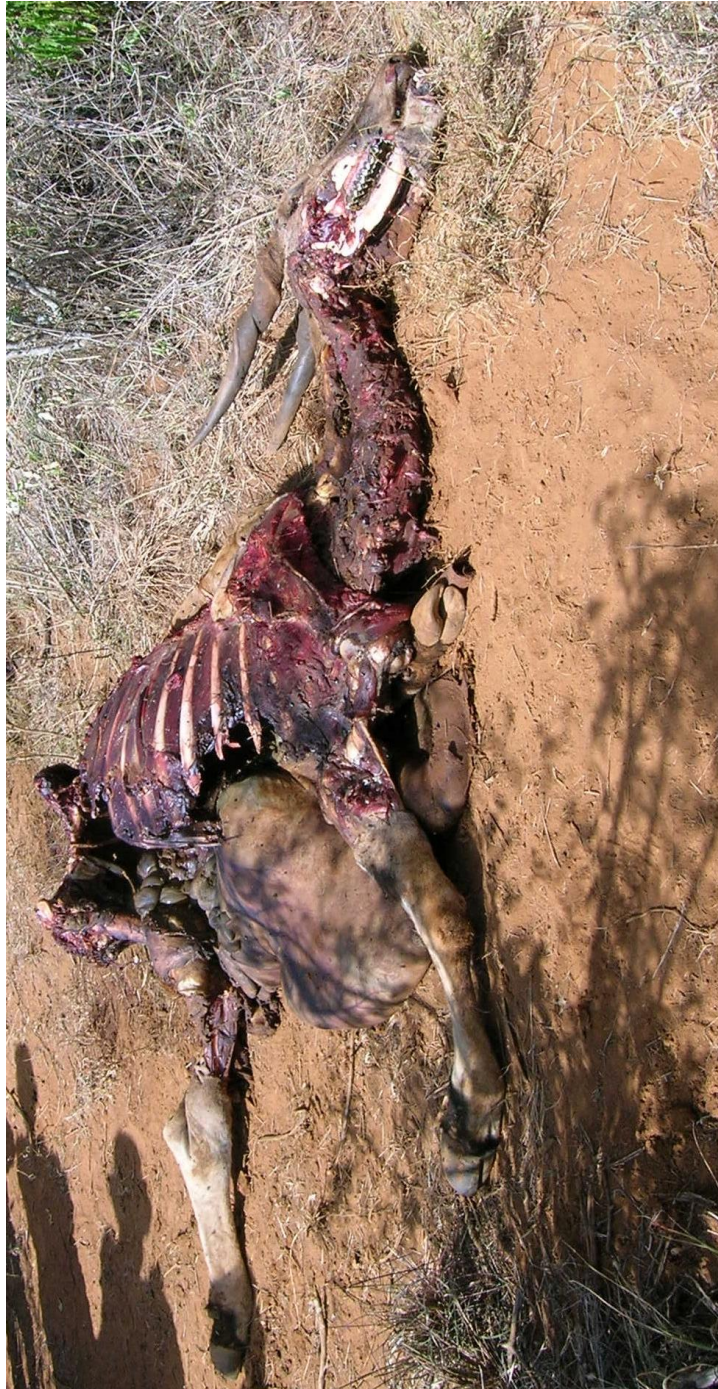
Photograph 5-1: **Eland carcass from lion kill abandoned in heavy brush cover on proximal floodplain ten hours after kill. Location: Sosian Ranch, Kenya - 2006.**

on the two sets of bone fragments were indistinguishable and were unequivocally produced by human actions. However, the "pre-Oldowan" toolkit utilized in this qualitative experiment exhibited none of the stone fracture characteristics that would identify these stones as hominin manufactured butchery tools.

Percussion Fracture (fracture planes)

The fracture mechanics of fresh green cortical bone during the biostratinomic phase of its existence are described in Chapter One. Based on actualistic experimental assemblages, Capaldo and Blumenschine (1994) were able to quantify the different and distinct characteristics of notches on shaft fragments of size class 1 and 2 ungulate limb bones produced by different actors [carnivores (static tooth pressure) and humans (dynamic hammerstone impact)] in terms of specific measurable notch attributes and associated assemblage frequency distributions. Unfortunately many limb bone shaft fragments that may represent the earliest evidence of hominin carnivory do not necessarily exhibit notches. An experimental study of hammerstone broken bones produced 90 percussion notched specimens and 237 non-notched specimens (Blumenschine and Selvaggio, 1988). Pickering *et al*. (2005), building on experimental work by Alcantara Garcia *et al*. (in press), suggested that a "fracture mechanics" approach could be extended beyond notch morphology to fracture plane location and fracture plane angle analysis in order to identify the actor responsible for the production of shaft fragments in a zooarchaeological assemblage. For limb bone shaft fragments, Alcantara Garcia *et al*. (in press) defined three possible fracture planes in relation

Photograph 5-2: Limbs of *Odocoileus virginianus.*

Photograph 5-3: Meat and marrow extracted from forelimb of *Odocoileus virginianus* using Hypothesized "pre-Oldowan"
 toolkit (yellow circle).

to the longitudinal axis of the limb bone: transverse, longitudinal, and oblique (Figure 5-

1). The angle between the outer cortical bone surface and the mid-point face of the

fracture plane of the shaft fragment (Figure 5-2) was measured (by simple handheld

goniometer) for each fracture plane on each fragment and the following conclusions

reported:

1.) Desiccated or mineralized bone tends to fracture either perpendicular or parallel to the
longitudinal axis of a limb bone with a fracture plane angle of approximately 90^0.

2.) Fracture plane angles on shaft fragments produced by carnivores (static tooth
pressure) are usually less than 110^0 or greater than 80^0 but not between 85^0 and 95^0.

3.) Fracture plane angles on shaft fragments produced by humans (dynamic impact
pressure) are usually greater than 110^0 or less than 80^0.

4.) It is statistically possible to differentiate between the actors involved (carnivore
produced static tooth pressure or human dynamic impact via hammerstone) in the
production of an assemblage of fossil shaft fragments for certain fracture planes
(specifically the oblique plane) and exploited animal class sizes.

These conclusions were based on a sample of 14 limb bones fractured by hammerstones

producing 124 shaft fragments (263 fracture planes) and 11 limb bones fractured under

static pressure (some by carnivore action and some simulated using pliers) producing 48

shaft fragments (94 fracture planes). This is an innovative approach that could be useful

in the study of the onset of hominin carnivory but needs to be confirmed by additional

experimental studies.

In 2006 such a study was conducted in accordance with the procedures outlined

by Pickering *et al*. (2005) on an experimentally produced (by Jack McCoy) collection of

percussion fractured deer (*Odocoileus virginianus*) and cow (*Bos taurus*) limb bone shaft

fragments (91 fracture planes) along with experimental assemblages of percussion

From Pickering et al. 2005
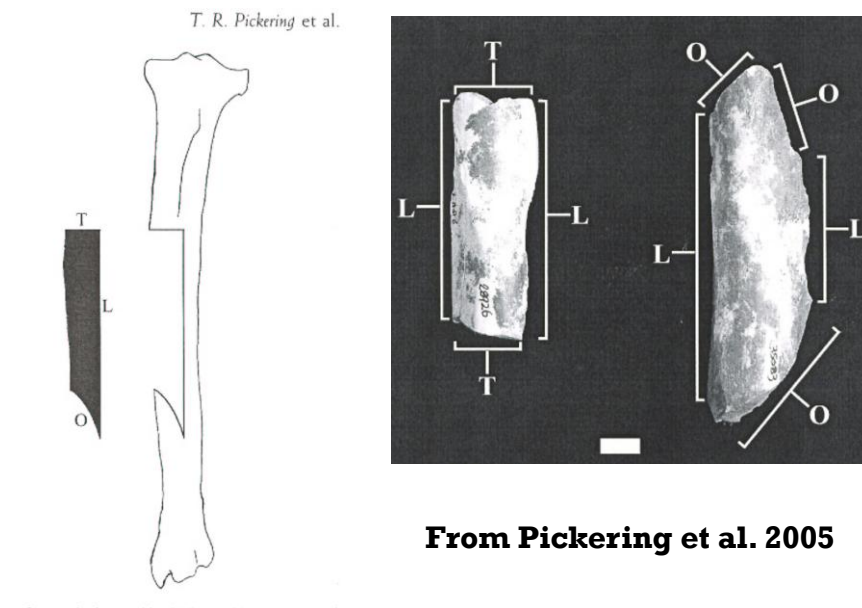
Figure 5-1: Fracture Planes on a Shaft Fragment Defined in Relation to the Longitudinal Axis of the Limb Bone (from Pickering *et al*. 2005)

Hominin (dynamic)
<80 or >110 degrees

Dessicated bone:
90 degrees

Carnivore (static)
80 – 110 degrees

Fracture Plane Angles

Shaft Fragment Cross Section
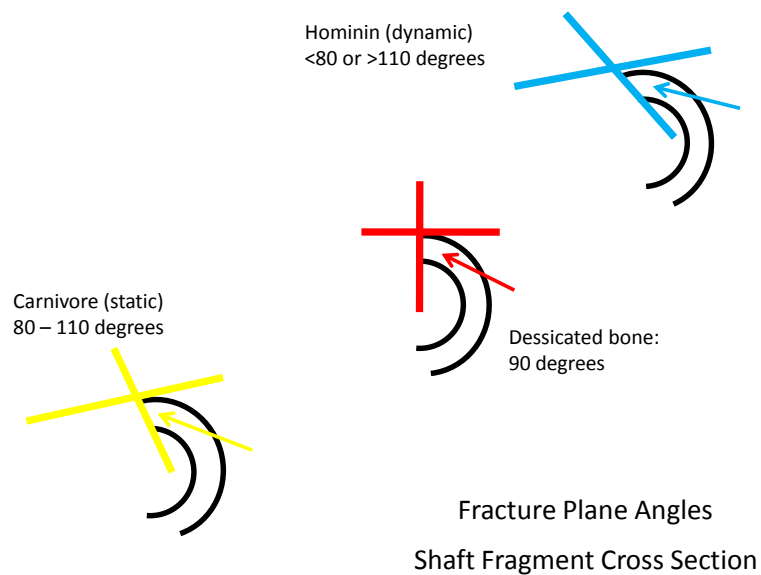
Figure 5-2: Fracture Planes measured in relation to the center of the fracture face and the cortical surface of the bone.

fractured and carnivore produced limb bone shaft fragments (146 fracture planes) of

African ungulates previously compiled by Dr. Robert Blumenschine. The results of this

study reflected a comparable pattern of fracture plane angles produced by different actors

with similar mean values. However, there was significant overlap of the 95% confidence

intervals and thus the statistical significance claimed for the earlier Alcantara Garcia

study could not be replicated. The following problems with the methodology and

assumptions described were also encountered:

1.) Evidence that desiccated or mineralized bone always breaks at a 90^0 fracture angle is largely qualitative or anecdotal. This needs to be confirmed quantitatively.

2.) A more precise method to measure fracture plane angles is needed.

3.) Fracture plane angles often vary across the fracture front and perhaps the angle at the midpoint of the fracture is not the best measure of the fracture angle.

4.) Digital imaging could possibly be employed to address issues 2 & 3.

Nevertheless this approach still holds promise and it has the potential to add context to

the data analysis of this research.

Research Evidence – Hominin Modified Bone

One of the working hypotheses of this research was that the onset of habitual

hominin carnivory would produce relatively dense accumulations of shaft fragments (and

maybe cut marked bone) to be preserved in the fossil record. As described in Chapter

One, there are sound heuristic reasons to expect these assemblages to be present but

unfortunately this working hypothesis was not confirmed in any of the research locations

explored. Bones and bone fragments exhibiting fresh green fracture and/or cut marks

were found, but virtually none of the modified bones discovered were associated with any

dense accumulation of like-modified specimens. Rather they were mostly individual

isolated occurrences.

Specimens of modified bone say little about hominin behavior unless they are

evaluated within the context of the overall fossil assemblage. The measure of the number

of identified specimens (**NISP$_{taxon}$**) developed in Chapter Four to provide a basis from

which to measure relative taxonomic abundance and diversity at each research location is

not appropriate in this case. Fossil teeth and some other skeletal elements are not

necessarily germane to all aspects of the analysis of modified bone and will be excluded

from parts of this analysis. Lyman's (2008) definitions of zooarchaeological terms from

Chapter Four still apply; but the meaning of "identified" varies depending upon the

specific target variables being analyzed. Three subsets of the collected fossil

assemblages from the separate research locations are defined as follows:

NISP$_{bones}$: Number of bone specimens identified as mammalian terrestrial vertebrate.

NISP$_{lbn}$: Number of limb bone specimens (humerus, ulna, radius, femur, tibia, metapodial). This is a subset of **NISP$_{bones}$**.

NISP$_{sf}$: Number of limb bone midshaft fragments and near epiphyseal fragments. This is a subset of **NISP$_{lbn}$**.

A summary of these NISP measures is shown in Table 5-1. Note that the sample size

from area 102 is too small for any measure of NISP to have meaningful significance.

	NISP$_{bones}$	NISP$_{lbn}$	NISP$_{sf}$
Area 41	603	343	219
Area 130	**144**	**102**	**67**
Area 131	**144**	**82**	**16**
Area 105	**122**	**80**	**43**
Area 102	**7**	**0**	**0**

Table 5-1: NISP Measures of Mammalian Bones and Bone Fragments, Limb Bones and Limb Bone Fragments, and Shaft Fragments and Near Epiphyseal Fragments for Each Research Area.

Long Bone Shaft Fragments

The analysis of shaft fragments is a very important part of any zooarchaeological assemblage. Like many aspects of the discipline, the definition of exactly what is being analyzed is not universally agreed upon and it is crucial that the researcher define specific criteria utilized. For this research, shaft fragments were included in the analysis if they exhibited any clear evidence of green fracture (fracture during the biostratinomic phase of their existence) as defined in Chapter One. Some researches exclude shaft fragments if they exhibit as little as 10% post-mineralization fracture but since this research is primarily concerned with the presence or absence evidence of carnivory behavior, no shaft fragments were excluded because they exhibited both green and post- fossilization fracture on the same fragment. Of course only fracture planes that resulted from green fracture were analyzed.

Visible notches were present on a small subset of the shaft fragments collected from areas 41, 130, and 105 (Photographs 5-4 to 5-12). No silicon rubber molds of the shaft fragments were produced so only those notches that could be directly measured
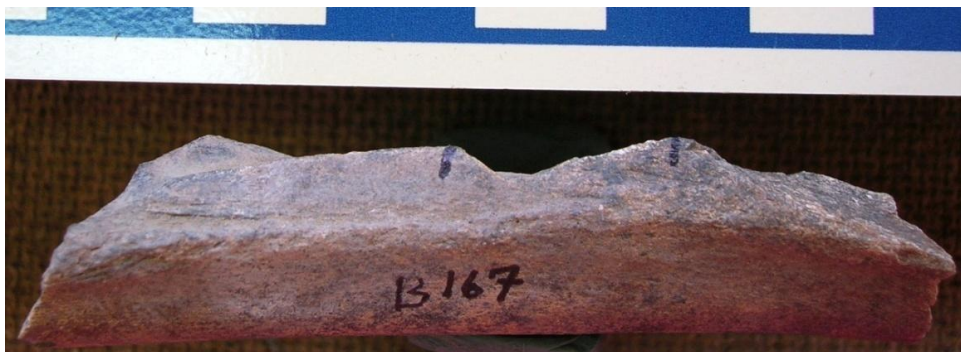
Photograph 5-4: Percussion notch on outer cortical surface of specimen B-167.

Photograph 5-5: Detail of flake scar on inner cortical surface of specimen B-167.
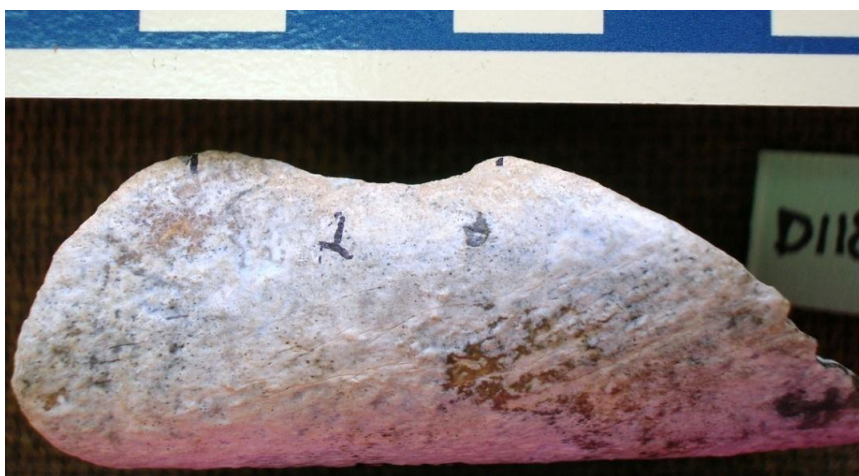
Photograph 5-6: Percussion notch on outer cortical surface of specimen D-118.

Photograph 5-7: Detail of flake scar on inner cortical surface of specimen D144

Photograph 5-8: Percussion mark on outer cortical surface of specimen D-144. Faint striations present radiating out from the percussion mark. Marks are not very distinct and possibly equivocal due to poor surface preservation.

Photograph 5-9: Percussion notch on outer cortical surface of specimen D-151.

Photograph 5-10: Flake scar on the inner cortical surface of specimen D-151.

Photograph 5-11: Carnivore tooth notch on outer cortical surface of specimen A-844.

Photograph 5-12: Detail of flake scar on the inner cortical of specimen A-844.

from the fossil bone were analyzed according to the criteria set forth by Capaldo and

Blumenschine (1994) and only shaft fragments identifiable to size class 1 & 2 ungulates

were considered because the Capaldo and Blumenschine study (1994) found that notch

morphology from that size class sample was most diagnostic of actor involved in the

production of the notch. Notch breadth and notch depth were measured using a Mitutoyo

digital caliper (model # CD-6"CS) and the breadth to depth ratios were calculated

(Appendix 5-1). The results of this analysis are summarized in Table 5-2:

	Ratio of Notch Breadth/Notch Depth	
	Carnivore Mean: 4.13 95% ci: 3.21 – 5.05	**Hammerstone** Mean: 8.19 95% ci: 7.5 – 8.88
Area 41	2	3
Area 130	2	9
Area 105	0	5

Table 5-2: Number of notches attributed to carnivore or hominin activities based on calculated breadth/depth ratios and evaluated in accordance with Capaldo and Blumenschine (1994) criteria for class size 1 & 2 unglates.

While the sample size is relatively small and the specimens collected were not

necessarily found in close physical association, the evidence clearly indicates that both

carnivores and hominins were likely involved in the production of these notches and that

hominins were perhaps the dominant actor.

Areas 41, 105, and 130 yielded enough shaft fragments with **measurable**

fracture plane angles to make analysis worthwhile. A total of 57 shaft fragments from

size class 1 & 2 ungulates yielded 76 measurable fracture fronts (Appendix 5-3). Both

longitudinal and oblique fracture fronts were measured and are summarized in Table 5-3.

The Alcantara Garcia *et al*. (in press), Pickering *et al*. (2005), and the actualistic work

done for this research all agree that the oblique fracture plane is the most likely to provide

a statistically significant indication as to the actor responsible for the production of the

shaft fragment. Although additional actualistic studies need to be conducted in order to

confirm the validity of this approach, the fracture plane analysis does tend to agree with

the notch analysis above. All three locations show both carnivore and hominin

involvement in the assemblage; with hominins again likely the predominant actor.

		Carnivore **fracture angle (fa)** **80<fa<85 or 95<fa<110**	**Hammerstone** **fracture angle(fa)** **fa<80 or fa>110**
Area 41	**Oblique Plane**	3	17
	Longitudinal Plane	4	8
Area 130	**Oblique Plane**	2	13
	Longitudinal Plane	1	2
Area 105	**Oblique Plane**	5	9

Table 5-3: Number of fracture planes attributable to either carnivore feeding activity or hammerstone percussive fracture by hominins from Koobi Fora research assemblages [Based on criteria developed by Alcantara Garcia *et al*. (in press)].

Cut Marked Bone

Cut marked fossil bone has been the traditional evidence that unequivocally links

hominin behavior to a fossil assemblage. Unlike percussion notches or shaft fracture

plane angles, cut marks are strictly a surface trace phenomenon. Taphonomic and

diagenetic processes also create marks on the surfaces of bones in addition to determining

the ultimate condition of the bone surfaces preserved in the fossil record (Hedges, 2002; Lyman, 1994; Johnson, 1985; Behrensmeyer, 1978). One of the most important skills required of the zooarchaeologist is therefore the ability to identify cut marks and differentiate them from other marks on the surfaces of the fossil bones. For four years prior to commencing this field research, actualistic studies and extensive examination of reference collections at Rutgers University and the National Museums of Kenya were conducted. As outlined in Chapter One, there is a broad spectrum of literature, much of it the result of sound actualistic research, describing sets of characteristics that define different types of marks found on bone surfaces. Blumenschine *et al*. (1996) have demonstrated that it is possible to accurately identify these marks based on the sets of characteristics as shown in Appendix 5-3 without the need for expensive sophisticated equipment, provided the investigator has sufficient experience with control collections of modified bones.

Variations in surface preservation may unfortunately introduce ambiguity when working with fossil assemblages. Some surface modification marks are preserved but do not retain all of the diagnostic characteristics described by the actualistic studies. The surface condition of the fossils collected during this field research was far from uniform; varying both within and between assemblages. Marks that were basically linear, v-shaped in cross section, and visibly distinct from other identifiable marks were designated in the field as possibly cut marked (Appendix 5-4 raw list of CM bone). Moreover, all terrestrial vertebrate fossils with surfaces that could potentially preserve modification marks were collected and transported to the laboratory for detailed examination using the characteristics outlined in Appendix 5-3. All specimens collected

were physically examined multiple times employing low incident light and 20x magnification. Molds of possible cut marks from those specimens exhibiting more than one diagnostic cut mark characteristic were produced utilizing a 3M product, ESPE, low viscosity vinyl polysiloxane dental impression material. Cross sections of all of these molds were examined and photographed under a light microscope and some of the complete molds were transported to Rutgers University, United States, and Cape Town University, South Africa for SEM (Scanning Electron Microscope) examination. Traditionally, cut marks are tied to specific butchery tasks such as disarticulation; skin, tendon, or periosteum removal prior to marrow extraction; or muscle removal (filleting). Where applicable these tasks are referenced but how they relate to the actual behavior must be viewed with some skepticism until more data on hominin carnivory in the late Pliocene is compiled. The cut marks are described based on their morphology and were evaluated against generally accepted characteristics. They provide the most convincing faunal evidence for the presence of hominin carnivory behavior at these locations. Stone tools and flakes were only found at the research location in Area 41.

Area 41

In this area extensive surface survey and excavation were conducted and both methodologies produced specimens with surface marks consistent with modification employing sharp edged tools. Multiple taxa and different specific skeletal elements were present, but unfortunately many fragmentary specimens are only identifiable to the generic: "long bone midshaft fragment". Examples of these specimens are described in detail: 5 bovid, 2 equid, 1 suid, and 4 of indeterminate taxon.
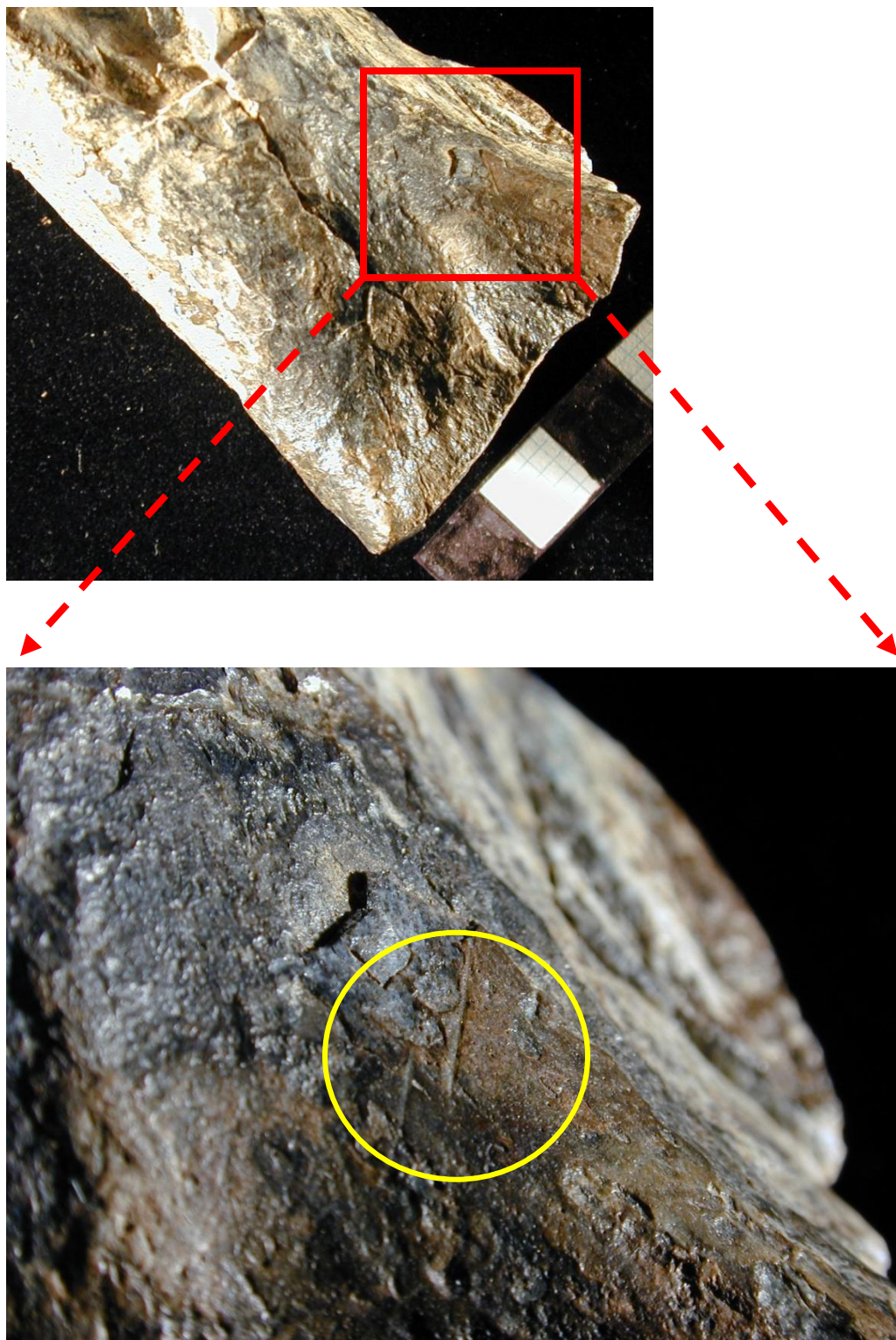
Figure 5-3: Specimen A-365 – Bovid humerus midshaft fragment. Marks are consistent with slicing to remove meat scraps or bulk meat.

Specimens A-365, A-860, and A-668 are all bovid limb bone fragments collected during surface survey. Specimen A-365 is a bovid left distal humerus midshaft fragment (size class 2 or small 3). The proximal end and the distal articular surfaces are absent likely due to post-fossilization break. One tooth pit and two transverse/oblique (7.5mm and 4.3 mm) linear marks, both v-shaped in cross section, are present on the lateral anterior surface (Figure 5-3). Specimen A-860 is a bovid left tibia midshaft fragment (size class 2). Both distal and proximal ends are absent again, likely the result of post-fossilization breakage. Surface preservation is generally good. There is no evidence of carnivore modification but there is one 4.5 mm linear, transverse, v-shaped in cross section mark on the anterior surface of the tibia crest (Figure 5-4). The marks on these bones are consistent with mass muscle or flesh scrap removal from individual limb bones. Specimen A-668 is a bovid right humerus distal medial epiphysis fragment (size class 2). There are two linear marks on this fragment. One distinct mark (5.7 mm in length) that is v-shaped in cross section is located on the distal medial surface just proximal of the articular surface. The other less distinct 5.5 mm linear mark is also located on the lateral surface but is further from the articular surface and transverse to the long axis of the bone (Figure 5-5). Molds of both marks were examined by SEM at Rutgers University. Scanning Electron Microscopes produce images with great depth of focus allowing small micro-features of well preserved cut marks to become visible. Cut mark characteristics such as fine linear striations and shoulder effects (Shipman and Rose, 1983) are visible in the SEM image of the 5.7 mm mark on this specimen (Figure 5-6). Both of these marks are consistent with disarticulation of a bovid forelimb.

Figure 5-4: Specimen A-860 – Bovid tibia midshaft fragment. Slicing mark consistent with flesh scrap removal
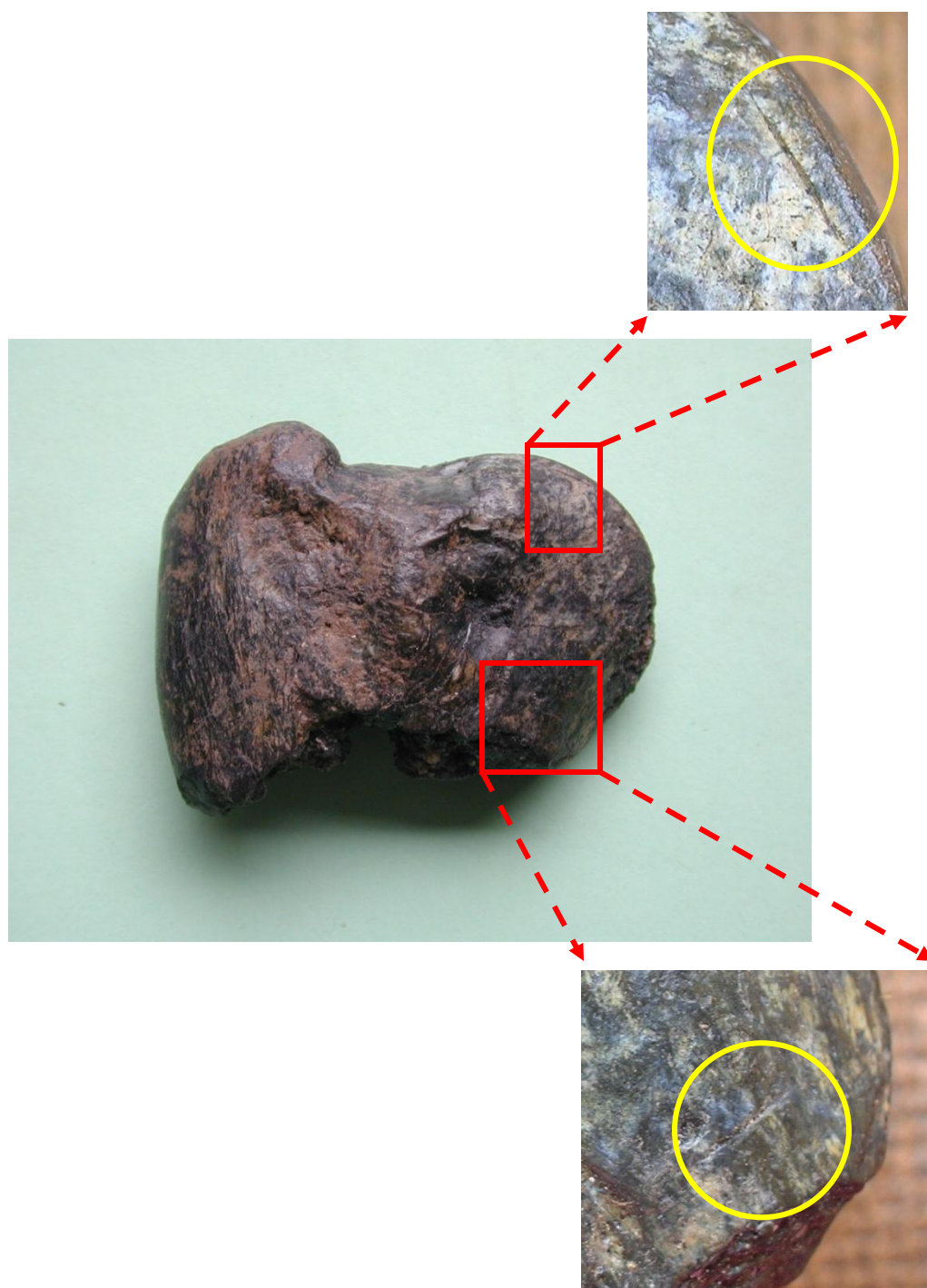
Figure 5-5: Specimen A-668 – Bovid right distal humerus fragment.
Cut marks consistent with disarticulation actions.
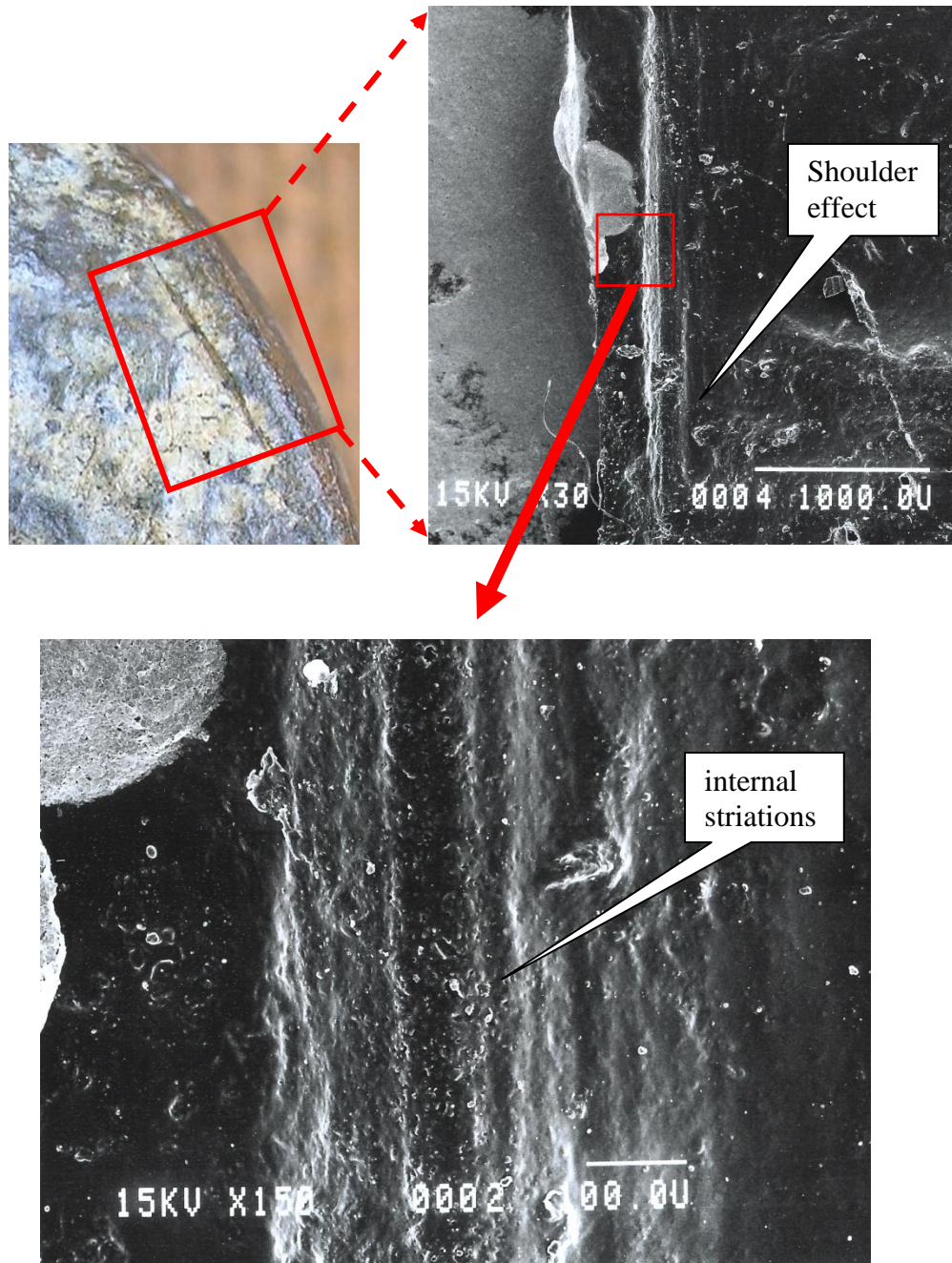
Figure 5-6: Specimen A-668 – Scanning Electron Microscope images showing shoulder effects (X30 magnification) and mark internal striations (X150 magnification). SEM images courtesy of Dr. Lee Simon, Rutgers University.
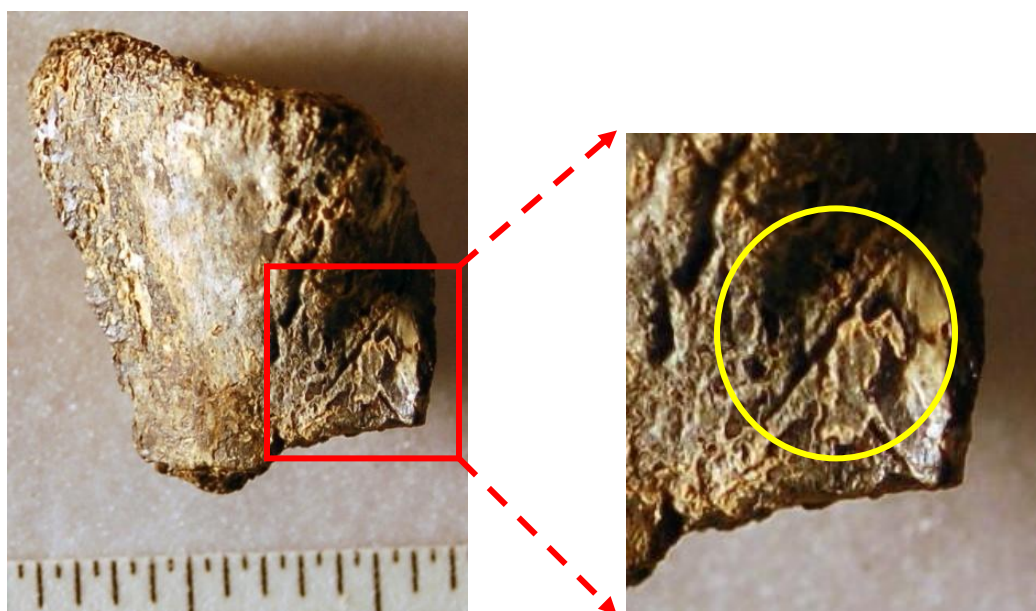
Figure 5-7: Specimen 8602 (top) – Bovid tibia midshaft fragment. Marks consistent with flesh scrap removal.

Specimen 6255 (bottom) – Bovid hemi-mandible fragment. Mark consistent with mandible removal.

Specimens 8602 and 6255 are bovid fossil bone fragments found *in situ* during excavation. Specimen 8602 is a right tibia midshaft missing both distal and proximal ends due to post-fossilization breakage. Much detail of the original surface has been lost, likely due to rolling and polishing during fluvial transport (Figure 5-7). However, two deep parallel linear marks are preserved on the distal anterior surface of the midshaft fragment. The internal morphology of the distinctive marks has also been polished and some of the v-shaped character of the marks has been eroded. These deep chop-like marks could be considered consistent with disarticulation or tendon removal. Specimen 6255 is a bovid right hemi-mandible fragment including part of the ascending ramus and the mandibular condyle. There is one deep linear (v-shaped in cross section) mark on the medial posterior surface of the proximal ascending ramus (Figure 5-7). This mark is consistent with jaw removal to access the tongue or the marrow packet located in the horizontal ramus of the mandible of some bovids. Interestingly, a bovid hemi-mandible was unearthed during excavations with possible evidence of this kind of marrow exploitation (Figure 5-8).

Two equid specimens (A-077 and A-121) were collected during surface survey. Specimen A-077 is the distal end of an equid left metapodial. The surface condition of the specimen is uneven and pitted due to digenetic factors but there is a discernible carnivore tooth pit and also a transverse linear mark preserved on the lateral anterior surface. The mark is not very v-shaped, but it is slightly undercut on the distal side and could be considered consistent with skin or periosteum removal prior to marrow

Specimen 5455 bovid (tragelaphini) right hemi-mandible with evidence of percussion fracture for marrow removal.

Figure 5-8: Specimen 5455 – Hemi-mandible of size class 2 bovid (cf. *Strepsiceros sp*). Fragments of the horizontal and ascending rami surrounding the gonial angle were not found in the excavation. The damage to this area is suggestive of percussion fracture but bone preservation was such that notch dimensions or angles could not be accurately measured. No obvious percussion marks were found on the surface of the bone. No carnivore tooth marks or evidence of gross gnawing was present.
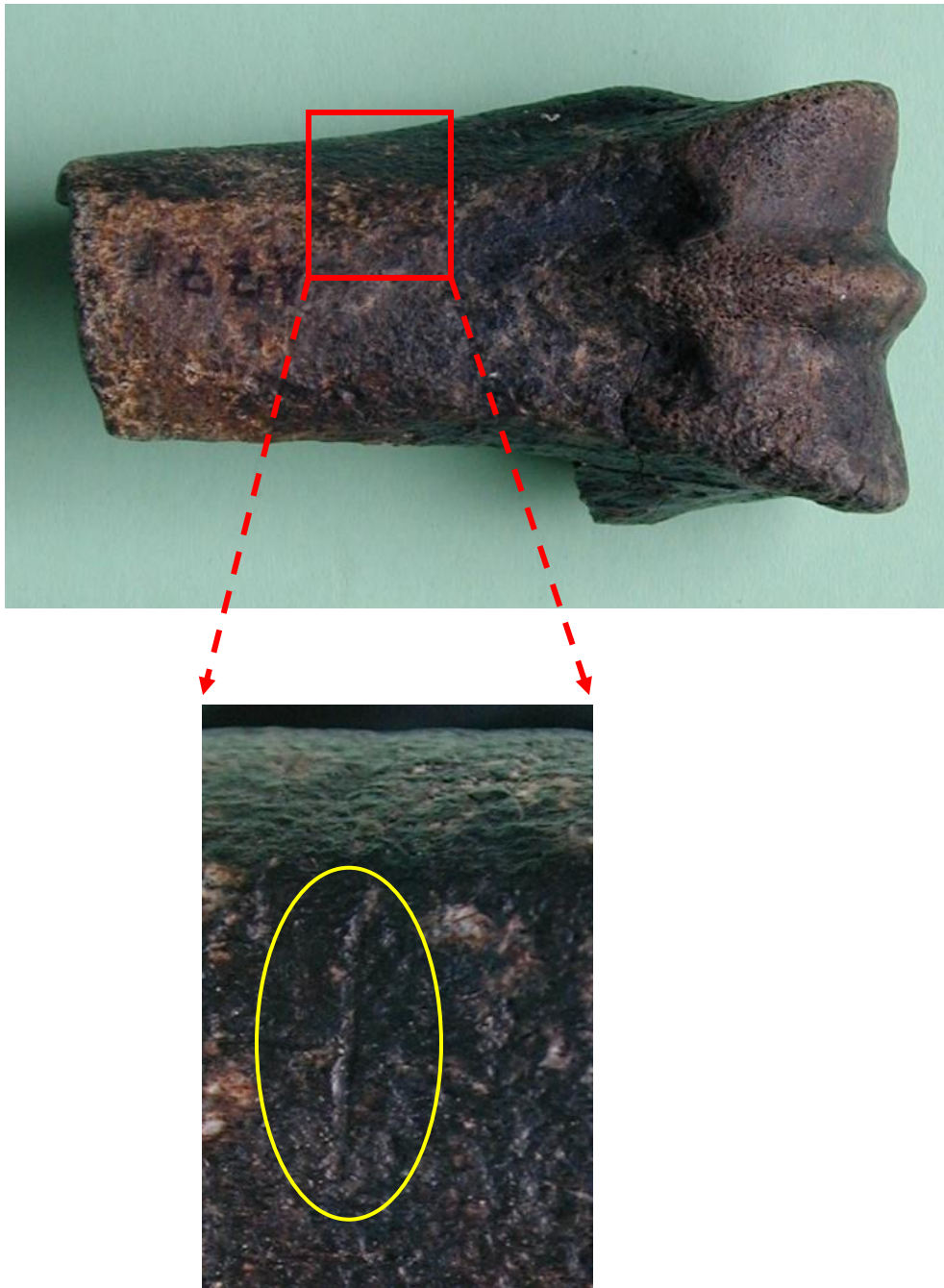
Figure 5-9: Specimen A-077 – Left distal equid metapodial. Note the uneven and pitted surface condition. The transverse mark is slightly undercut on the distal edge. Cut marks consistent with skin or periosteum removal prior to marrow extraction.
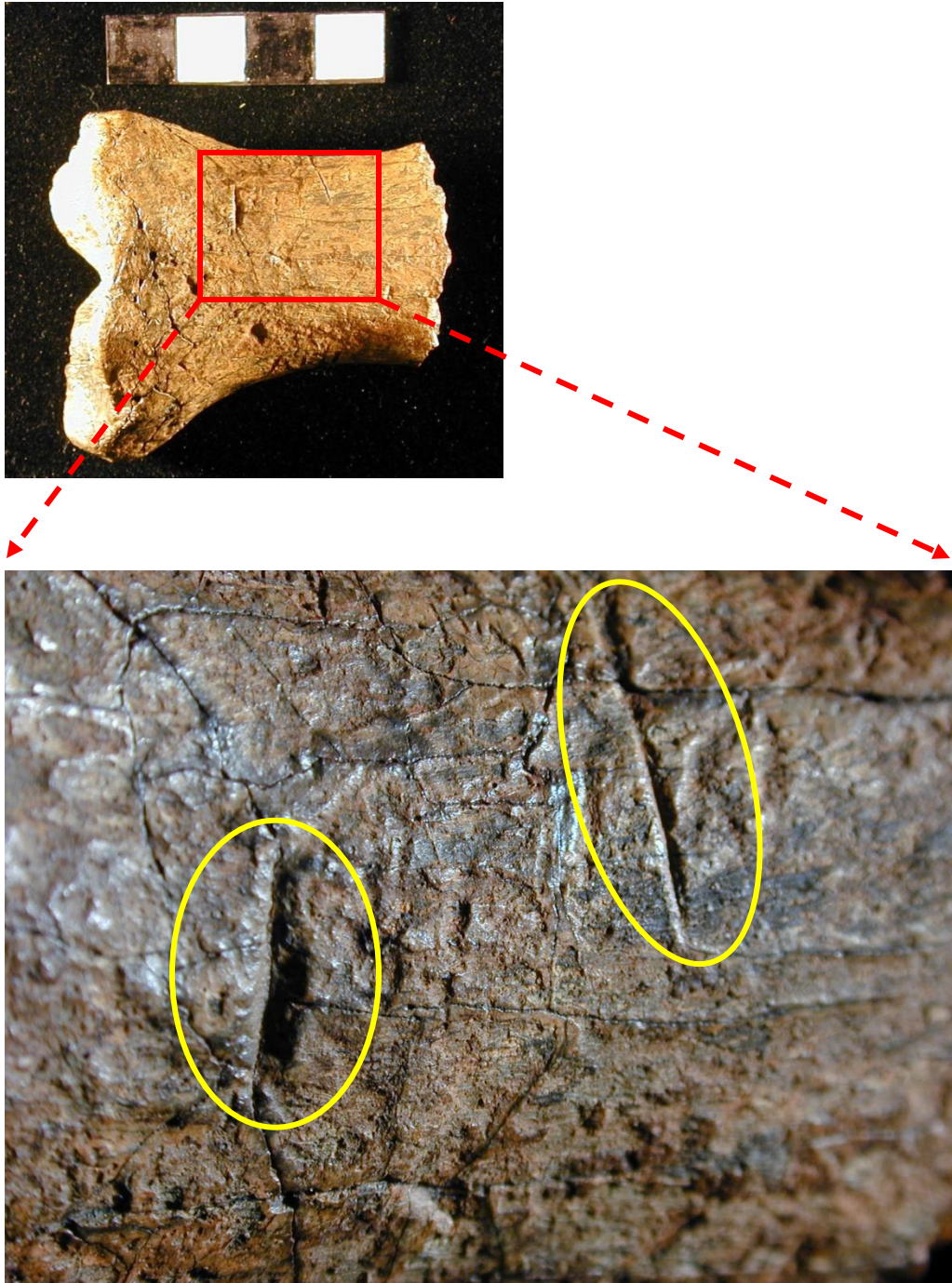
Figure 5-10: Specimen A-121 – Equid right proximal first phalanx.
Cut marks consistent with skin or periosteum removal prior to marrow
extraction.

extraction (Figure 5-9). Specimen A-121 is the proximal end of an equid right first phalanx (Figure 5-10). The surface preservation is uneven but several deep modification marks remain. An obvious carnivore (perhaps crocodile) tooth mark and two linear, transverse, and v-shaped in cross section marks are present. One mark on the anterior lateral surface is shorter (8.8 mm), broader, and deeper; suggesting a possible chopping action. The other mark on the lateral anterior surface is longer (11.4 mm), more narrow, and more shallow; suggesting a possible slicing action. Both marks are consistent with skin or periosteum removal prior to marrow extraction. It was surprising that the only two examples of modified equid bone were distal elements of the manus/pes which would provide only limited food value. This was discussed with two members of the Kenyan field crew: Paul Watene (who lives in rural Machakos) and Hillary Sale (a Dassenetch pastorialist from Ileret Village north of Koobi Fora). Both indicated that particularly in times of food stress, equid manus and pes are routinely butchered in order to extract even small amounts of marrow sometimes available in metapodials and phalanges. While only anecdotal, this information provides context to this evidence.

Only one fossil bone (A-825), with possible hominin modification identifiable to the family Suidae, was collected during surface survey. Specimen A-825 is the proximal end of a suid left radius (Figure 5-11). The surface condition is good and preserves carnivore tooth pits, tooth scores, and two linear, transverse, v-shaped in cross section marks on the anterior medial surface. The long linear transverse mark is superimposed over one of the carnivore tooth scores; the implication being that the sequence of access was carnivore followed by hominin.

Possible cut marks

Carnivore tooth scores
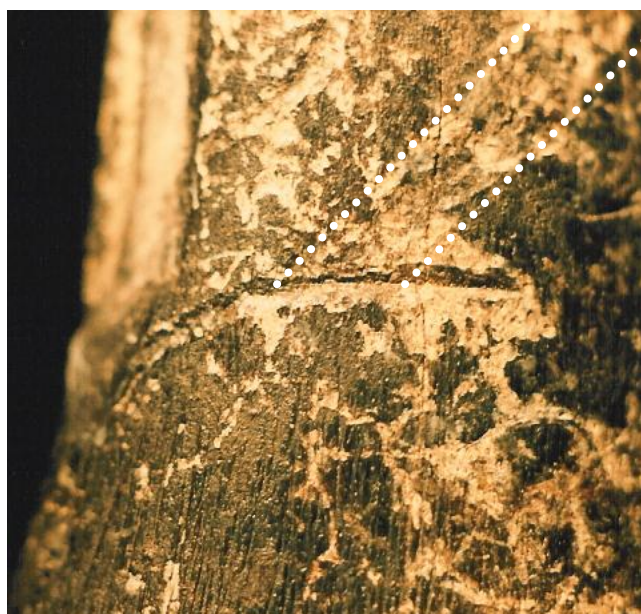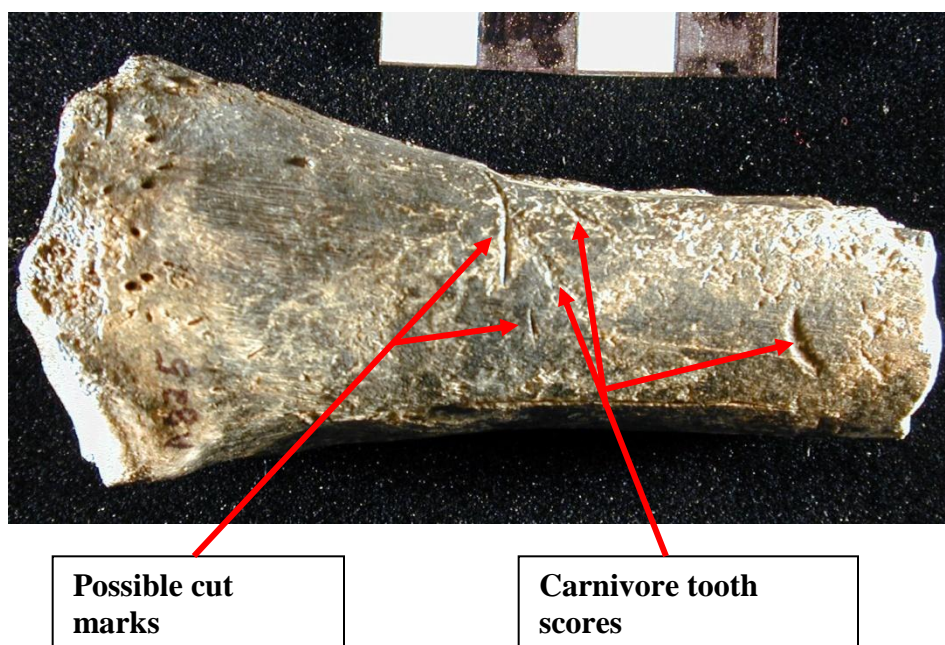
Detail of possible cut mark Superimposed over carnivore tooth score (white dashed line).

Figure 5-11: Specimen A-825 – Suid left proximal radius.

Figure 5-12: **Specimen A-400: Radius midshaft fragment of small size class 2 ungulate.**

Specimens with possible hominin modification but not identifiable to specific taxon were collected from the surface survey (A-400, A-910) and from the excavation (5211, 7808). Specimen A-400 is a radius midshaft fragment with both proximal and distal ends absent (Figure 5-12). The perimeter of the fragment exhibits evidence of fresh green fracture and there is some evidence of percussion marks on the surface although generally much of the surface is not well preserved. Where the original surface is present, its condition is good and a group of short, parallel, linear marks that are v-shaped in cross section are well preserved. These marks are consistent with forelimb flesh removal.

Specimen A-910 is a near-epiphyseal fragment of a limb bone exhibiting a short, linear, deep mark that is v-shaped in cross section. The surface of the fragment is worn and polished, likely due to fluvial transport, and the fine striations characteristically found in a slicing mark have been eroded away. The actualistic work of Shipman and Rose (1983) addressed just this situation. Figure 5-13 compares SEM photographs of the Shipman and Rose experiment with a SEM photograph of A-910.

Specimen 5211 is a complete ungulate rib found *in situ* during the FwJj-20 excavation. The rib has two short, linear, transverse marks; one long linear, transverse/oblique mark; and possibly one long linear longitudinal mark. The transverse and oblique marks are deep and clearly v-shaped in cross section. As shown in Figure 5-14, the rib is generally in excellent condition and shows no signs of fluvial transport but the original surface has been largely degraded during diagenesis and any traces of micro-morphology are gone. Molds of the marks were only useful in confirming the cross section shape of the marks.
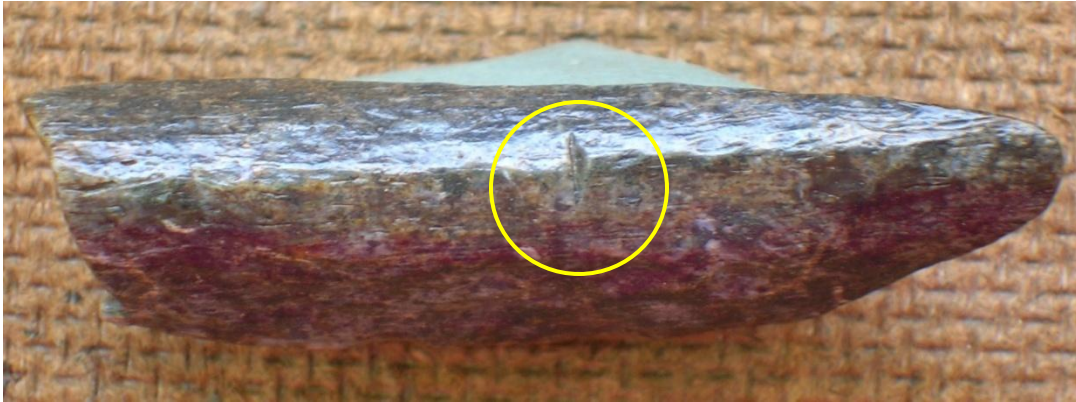
Specimen: A-910
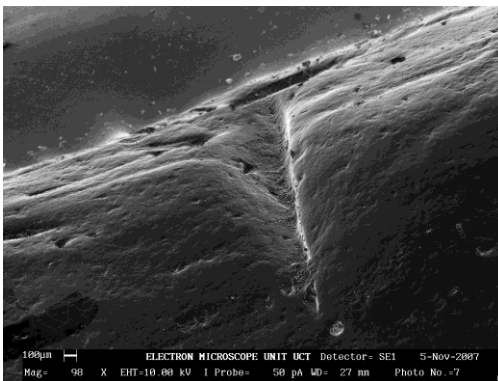
A-910
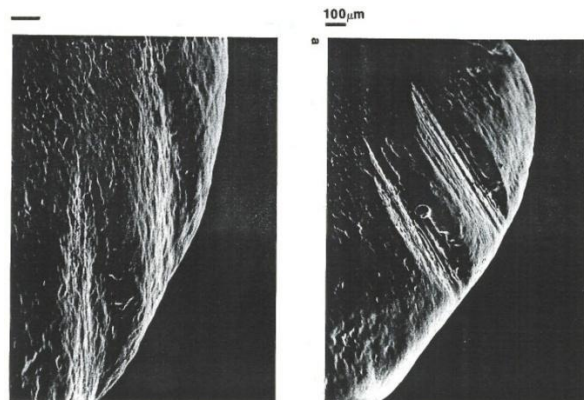
From Shipman and Rose (1983)

Figure 5-13: Specimen A-910 – Picture at top shows the polished, eroded surface of the bone fragment, likely due to fluvial transport. The SEM photograph on the left shows the eroded internal morphology of the A-910 mark. The SEM photographs on the right are of an experimentally produced cut mark showing internal mark morphology before and after simulated fluvial transport.
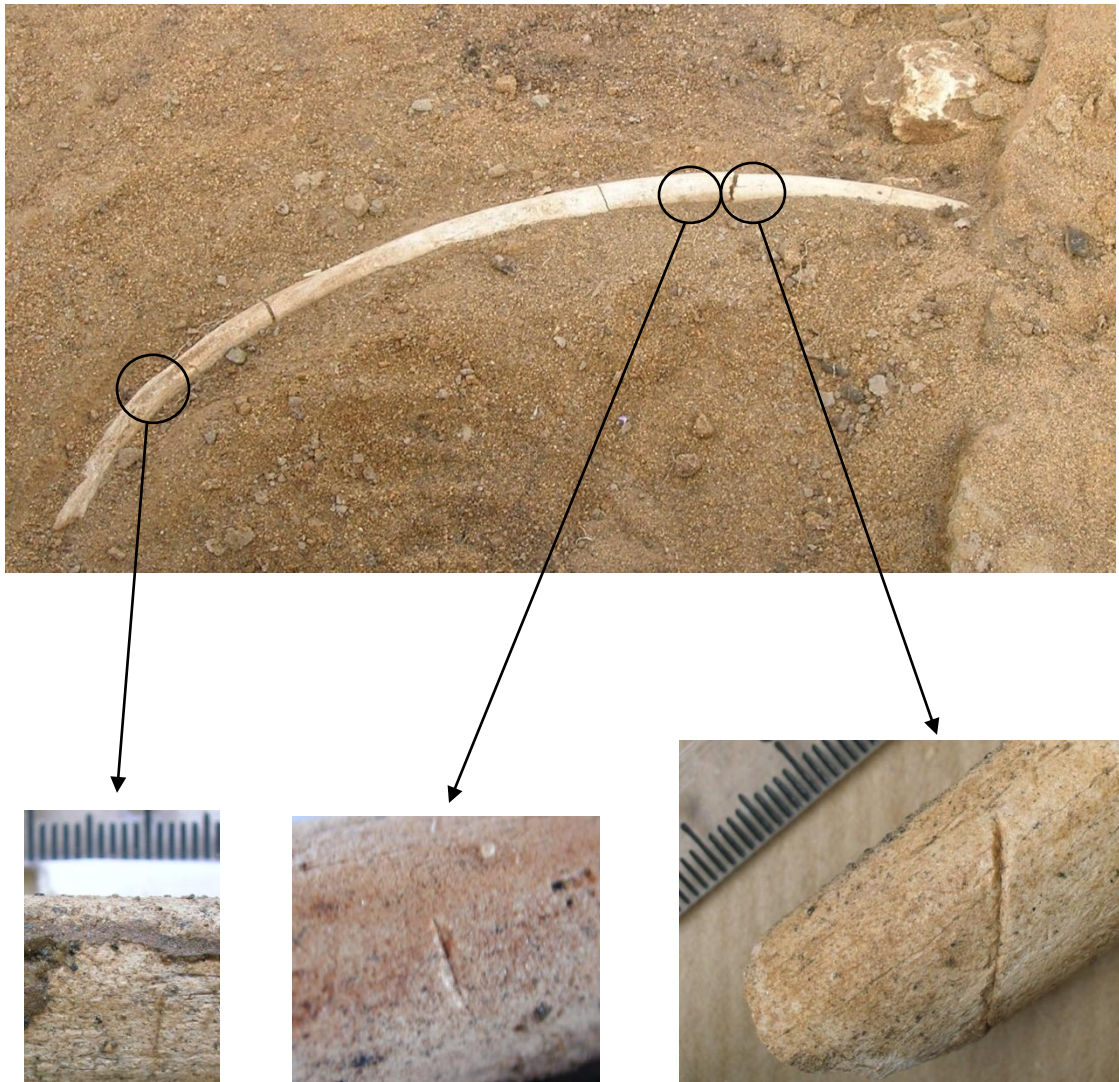
Figure 5-14: Specimen 5211 – Photograph of ungulate rib *in situ* in the FwJj20 excavation and photographs of the individual modification marks. The rib is in excellent condition but the original surface has been degraded during diagenesis and micro-morphological details of any surface modifications are absent.
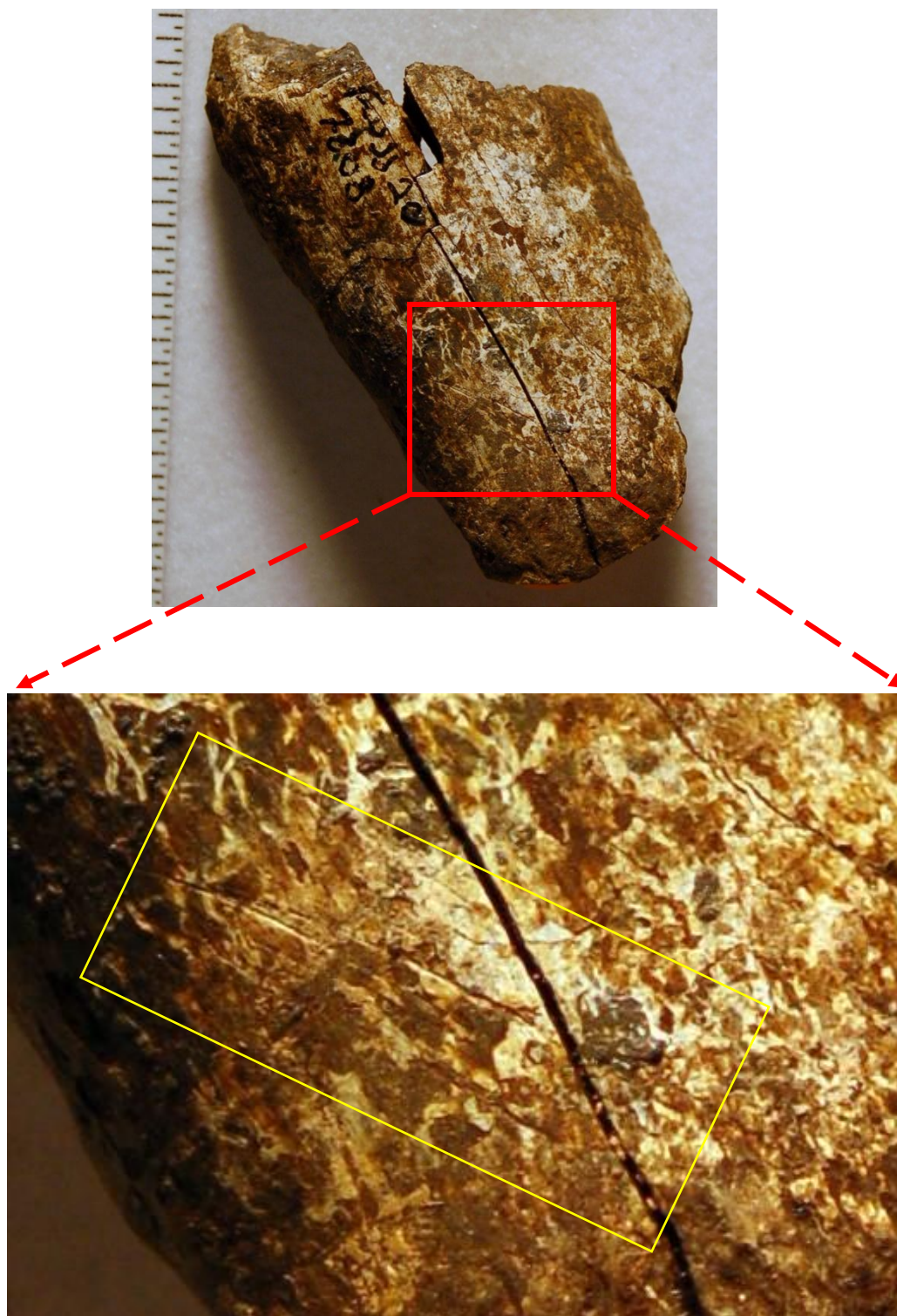
Figure 5-15: Specimen 7808 – Tibia midshaft fragment with series of fine deep marks consistent with slicing action.

Specimen 7808 is a tibia midshaft fragment (Figure 5-15). The cortical surface and the fracture planes of the fragment are eroded and pitted due to diagenesis. The fracture planes suggest "green fracture" but are too degraded for accurate measurement. Much of the outer cortical surface is also degraded but a series of five fine deep linear marks are preserved. These marks are suggestive of repeated slicing with a fine sharp-edged tool.

Area 130

As described in Chapter Four, widely scattered surface assemblages of terrestrial vertebrate fossils found in area 130 were smaller and less dense than the assemblage in area 41. Specimens of potentially modified bone were found in three of the five research locations in area 130. An unexpected issue was encountered when research in this area commenced. Faunal analysis had been restricted to "terrestrial vertebrate fossils" in Area 41. However, a hippopotamus distal humerus with possible cut marks was discovered near research location 130E. Since early hominin foraging behavior is a major focus of this research, the modified hippopotamus bone was of course collected and described. This issue did not arise in area 41 where this research began. A large number of hippopotami fossils were encountered in area 41 but very few specimens were postcranial and none of the bones showed evidence of modification.

Specimen B-059 (research location 130A) is a right proximal radius of a size class 3 bovid (Figure 5-16). The distal portion of this bone is missing likely due to post fossilization break. This fossil bone possibly preserves surface modification marks of three actors. Crocodile involvement is certain based on two clear bisected tooth pits on the distal portion of the specimen (Njau and Blumenschine, 2005). The two marks closer
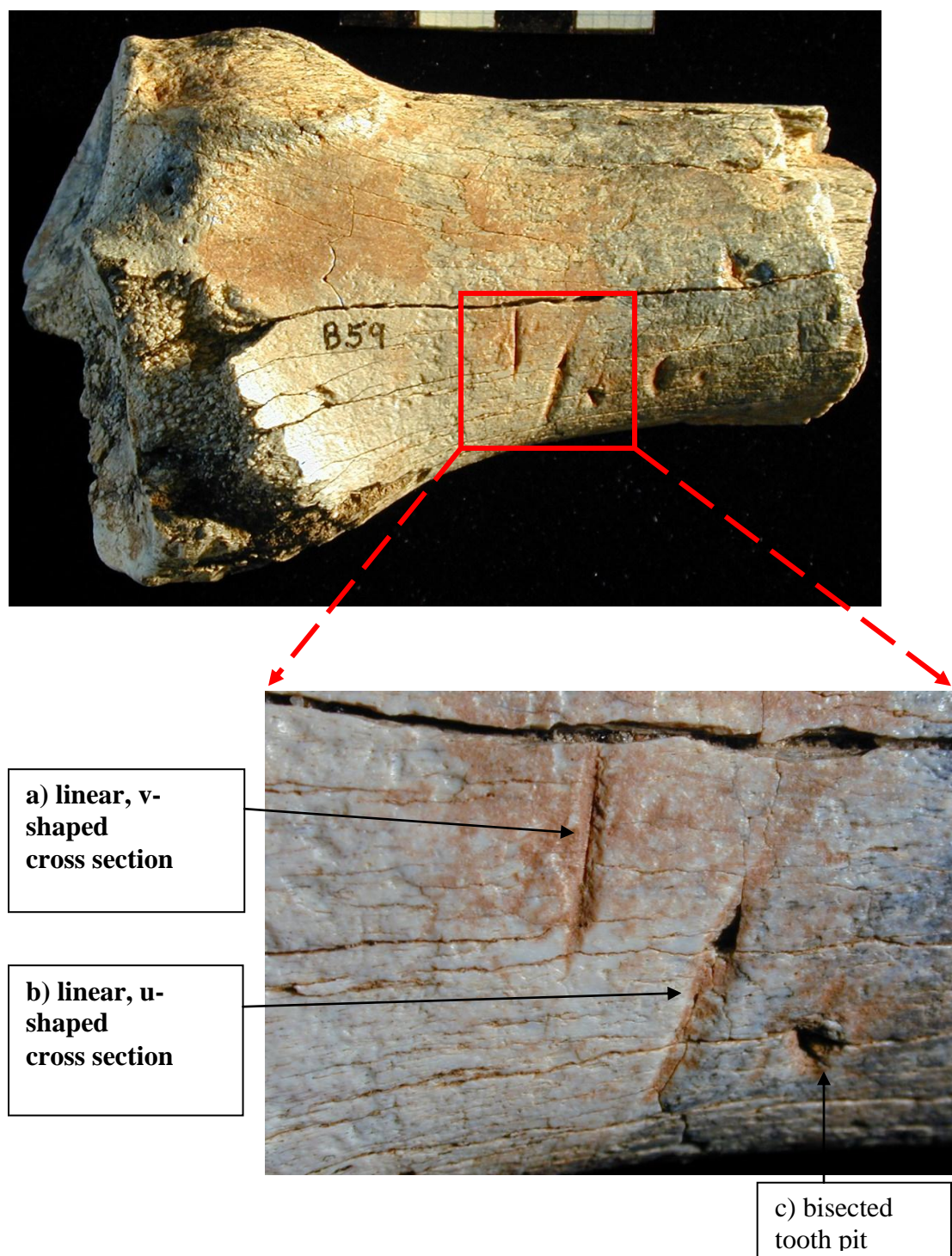
Figure 5-16: Specimen B-059 - Bovid right proximal radius. The inset shows three marks possibly created by three different actors: a) cut mark, b) tooth score, c) bisected tooth pit.
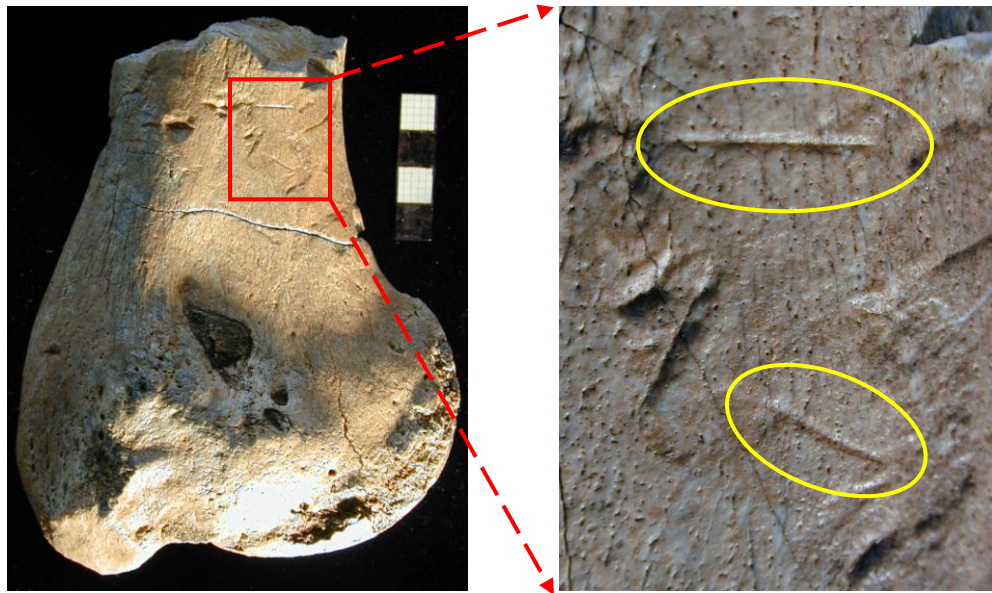
Figure 5-17: Specimen B-961 – Hippopotamus (cf. *Hippopotamus gorgops*) left distal humerus. Crocodile damage is ubiquitous on the midshaft and near epiphysis surface. Inset on the right shows example of the narrow, linear marks exhibiting v-shaped cross section.

to the proximal end of the specimen exhibit the classic characteristics of a tooth score and a cut mark. They appear to be different and distinct from the crocodile damage which appears to be limited to the midshaft. Large terrestrial carnivores produce tooth scores that are basically linear with a clear U-shaped cross section. The other mark is short, deep, and linear with the distinct v-shaped cross section of a sharp edged tool produced mark during bulk flesh or flesh scrap removal. The proximal epiphysis shows no carnivore damage and a large portion of the proximal articulation is missing; thus ruling out the unequivocal absence of carnivore gnawing.

Specimen B-961(research location 130E) is a left distal humerus of a hippopotamus (cf. *Hippopotamus gorgops*) (Figure 5-17). The proximal portion of the bone is absent as the result of post fossilization break. The surface of the bone is generally uniform but a thin layer of the original cortical surface has been lost during diagenesis. The marks that remain on the surface are the result of major damage inflicted on the bone surface during the biostratinomic phase of its existence. There is considerable crocodile damage present in the form of bisected pits and broad tooth scores. There are also a few narrow, linear marks that tend to be v-shaped in cross section and are not associated with any tooth marks. The morphology of these relatively faint lines is very different from the obvious crocodile inflicted damaged and they are consistent with marks produced during flesh scrap removal using a sharp edged tool.

Rib fragments with individual linear marks that are v-shaped in cross section were found during surface survey at locations 130A (B-060), and 130E (B-962 & B-963) (Figure 5-18). These marks are difficult to interpret. Marks on the ventral surface of ribs

are characteristic of evisceration in historic hunter-gatherer cultures but these marks

could also have been created during flesh scrap removal.

Specimen B-925 (research location 130E) is a virtually complete left tibia of a

class size 2 bovid (Figure 5-19). The bone is in three pieces (recent break) but the

surface is remarkably well preserved. The proximal end had eroded out of a sand body

and was found less than 10 centimeters distant from the *in situ* distal sections. Again

there is evidence of multiple actors responsible for the surface modifications. Small

shallow tooth pits and evidence of gross gnawing (crenulated edges) on the proximal

epiphysis are indicative of small carnivore activity. There are also small bisected tooth

pits and transverse tooth scores radiating from the pits indicative of small crocodile

feeding. Moreover on the proximal end of the midshaft there are individual linear marks

both transverse and oblique that are v-shaped in cross section and not necessarily

associated with the carnivore damage. On the distal end of the midshaft there is a unique

scrape mark that is best explained by hominin exploitation. The mark is deep with

internal "shudder marks" often found in scrape marks created by metal knife or

stone tool (Figure 5-20). The diaphysis has not been fractured and the marrow cavity

apparently remained intact. There is one possible percussion mark on the distal midshaft

that could represent an unsuccessful attempt at fracture.

Specimen B-967 (research location 130C) is a left radius midshaft fragment of a

size class 2 bovid that was found during preliminary research in 2001 (Figure 5-21). The

bone exhibits multiple evidence of hominid exploitation. The proximal end is missing,

likely due to post-fossilization break but the distal end was detached due to fresh "green"

fracture. There are two prominent percussion marks with micro-striations emanating from the marks: one on the anterior surface and one on the lateral/anterior surface. There is a carnivore tooth score on the anterior surface that is shallow and u-shaped in cross section (Figure 5-23). It is superimposed over the striations emanating out of the percussion mark on the lateral/anterior side of the bone indicating carnivore ravaging subsequent to hominin access (Figure 5-22). A deep linear transverse mark that is v-shaped in cross section butts up against the end of the long oblique tooth score but does not intersect with it (Figure 5-23). A scanning electronic microscope photograph shows that the microstructure of the anterior end of this mark has been degraded but that shoulder effects indicative of a stone tool cut mark are still retained in the center of the lateral end of the mark.

Area 131

Only one fossil bone with a mark characteristic of sharp tool modification was found in area 131. Specimen C-221 is a poorly preserved rib fragment with a distinct, linear, transverse mark on the ventral surface that is v-shaped in cross section (Figure 5-24). While this modified bone is evidence of hominin presence it says little of specific foraging behavior.
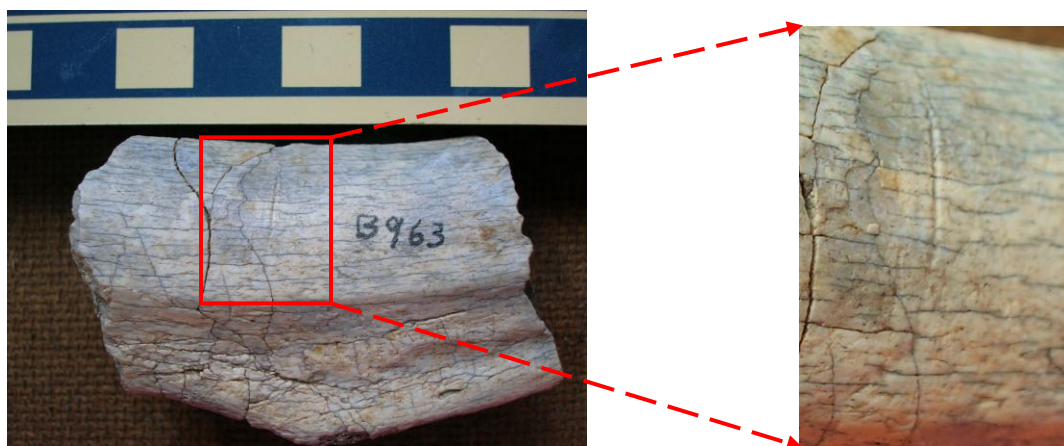
Specimen B-963
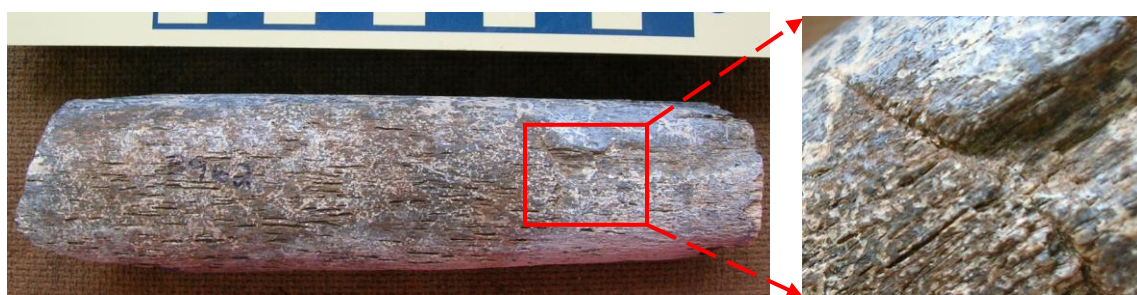
Specimen B-962

Specimen B-060

Figure 5-18: Specimens B-963, B-962, B-060 – Rib fragments with possible hominin modification.

Gross gnawing

Posterior surface view

Anterior surface view

Figure 5-19: Specimen B-985 – Bovid left tibia. Note carnivore gross gnawing on the tibia crest and anterior articular surface and distinct scrape/chop mark in lower right corner of anterior view.

Proximal medial midshaft   **Proximal lateral midshaft**

Central midshaft marks   **Distal anterior midshaft**

Figure 5-20: **Specimen B-925 - Circular tooth pits on proximal medial midshaft consistent with carnivore feeding (top left).   Bisected pits on distal lateral midshaft consistent with crocodile feeding (top right). Two views of central midshaft showing examples of linear transverse marks with v-shaped cross section (bottom left). Chop/cut/scrape mark on distal anterior midshaft (bottom right).**
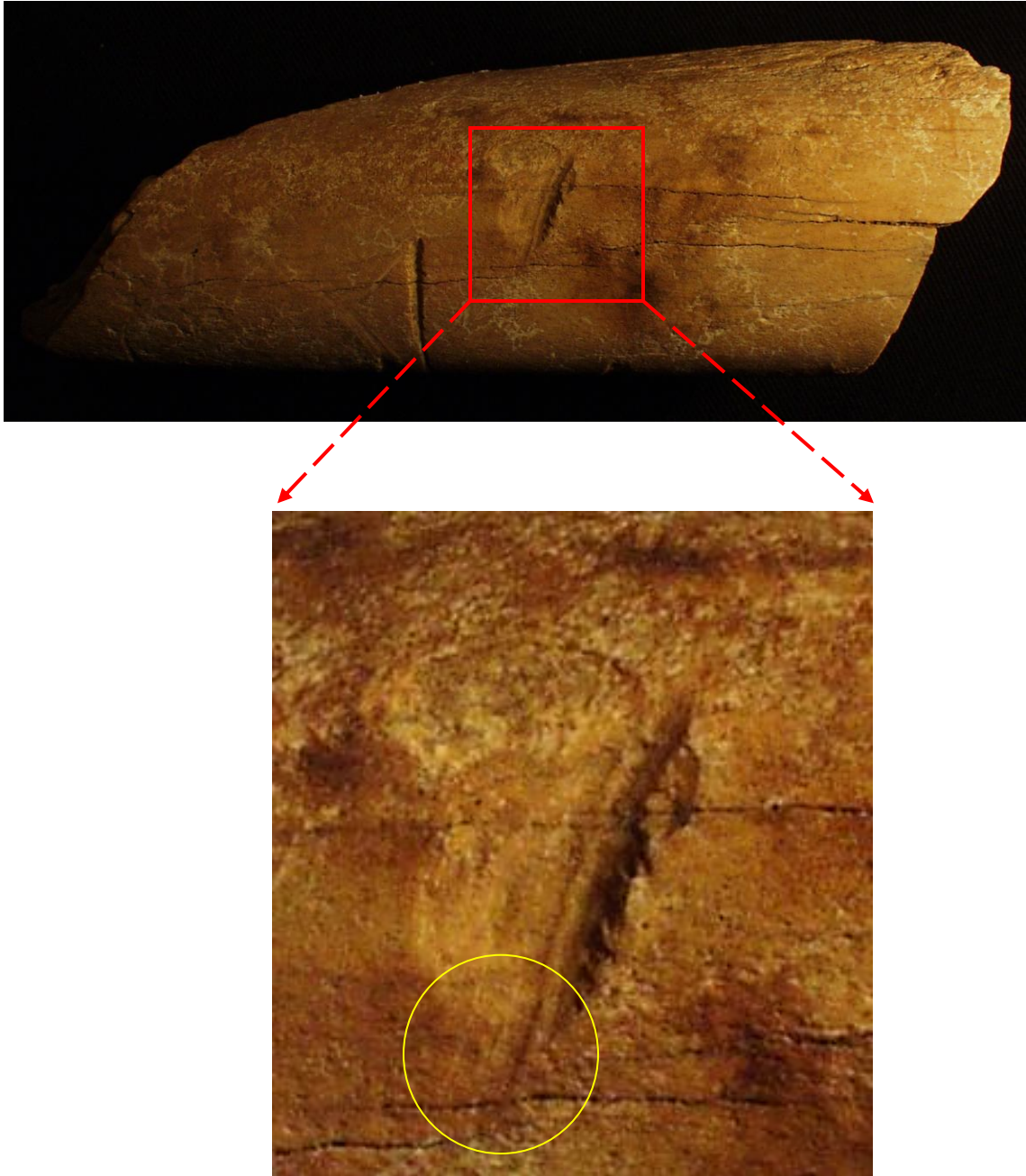
Figure 5-21: Specimen B-967 – Bovid right radius midshaft fragment. Inset is detail of percussion mark on the anterior surface. Note the striations emanating from the bottom of the percussion mark.
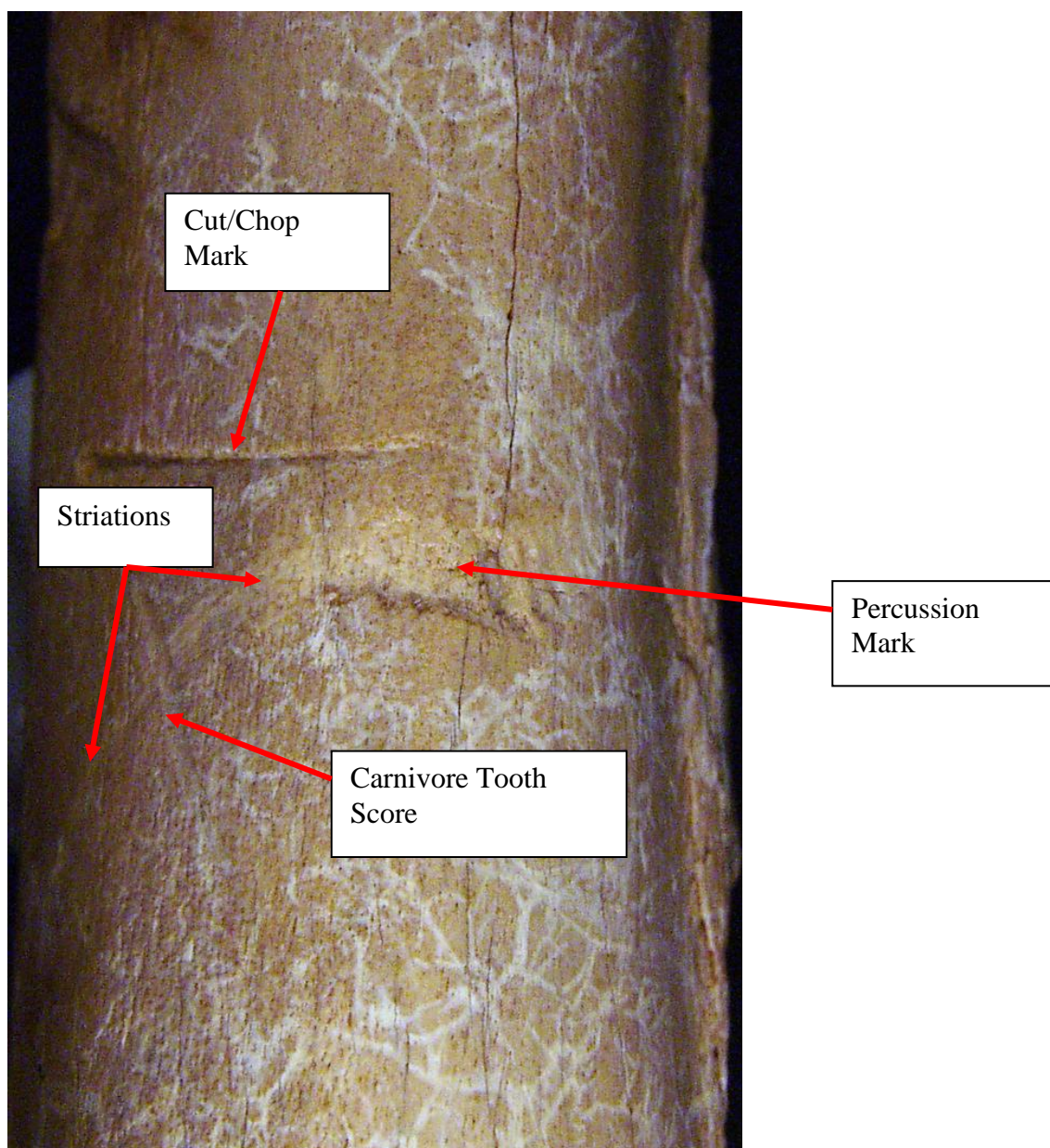
Figure 5-22: Specimen B-976 – Detail of percussion mark, carnivore tooth score, and cut/chop mark on the lateral/anterior surface. Note that the carnivore tooth score is superimposed over the striations emanating out of the percussion mark indicating hominin access prior to carnivore ravaging.
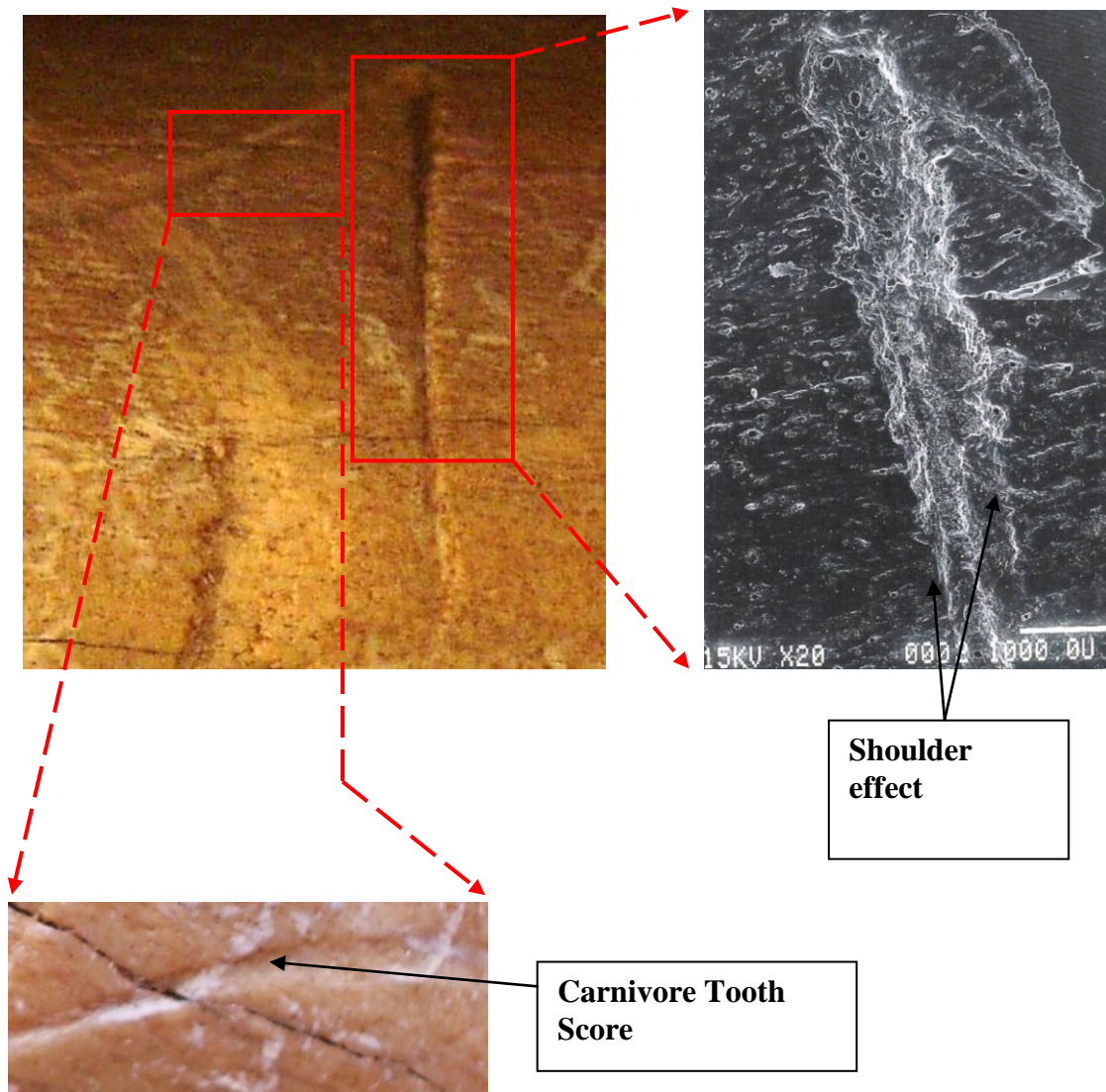
Figure 5-23: Specimen B-967 - Cut/Chop mark on the lateral/anterior surface of this radius midshaft fragment. The SEM image on the right shows the surviving shoulder effects on the lateral portion of the cut/chop mark.   The bottom image shows the shallow u-shaped cross section of the tooth score on the anterior surface of the bone.

Area 105

The surface survey in the area south of FxJj-3 yielded three specimens of bone
modified by sharp edged tools. Specimen D-022 is a beautifully preserved suid atlas with
three linear parallel marks with a v-shaped cross section and undercut along the
anterior/cranial edge (Figure 5-25). The marks are consistent with the removal of the
head from the spinal column as described based on actualistic observations by Binford
(1981). Specimen D-023 is a hippopotamus (cf. *Hippopotamus gorgops*) first phalanx
with two fine linear transverse marks on the anterior distal surface (Figure 5-26).The
surface of the fossil bone is pitted and somewhat degraded but the two marks clearly
retain their v-shaped morphology. These marks are consistent with skin or periosteum
removal prior to additional butchery (e.g. percussion fracture). Specimen D-057 is a rib
fragment with a deep v-shaped cut/chop mark (Figure 5-26). The surface of the bone is
badly eroded but the mark retains its morphology and is very similar to the mark on
specimen A-910 from area 41.

Surface survey in the "valley of the giants" location in area 105 yielded several
specimens of modified bone, likely from one hippopotamus carcass (cf. *Hippopotamus
gorgops*). There is evidence of multiple scavengers exploiting this carcass. Marks
consistent with sharp tool use to remove flesh scraps are present on specimen D-003
(femur midshaft), specimen D-150 (proximal radioulna) (Figure 5-27), and specimen D-
004 (distal radius) (Figure 5-28). Large terrestrial carnivore ravaging is evidenced by
large tooth scores on specimen D-004 (Figure 5-28) and crocodile involvement in the

form of a distinctive "j-shaped" tooth score (Njau and Blumenschine, 2005) is seen on

specimen D-005 a hippopotamus rib fragment (Figure 5-29).

In the final chapter a hypothesized model of early Homo foraging behavior in the East

Turkana Basin during Upper Burgi Member times will be postulated and then integrated

into a larger temporal and geographic context based on published data from other

Pliocene sites in Ethiopia and Kenya. Possible avenues of future research will also be

discussed.
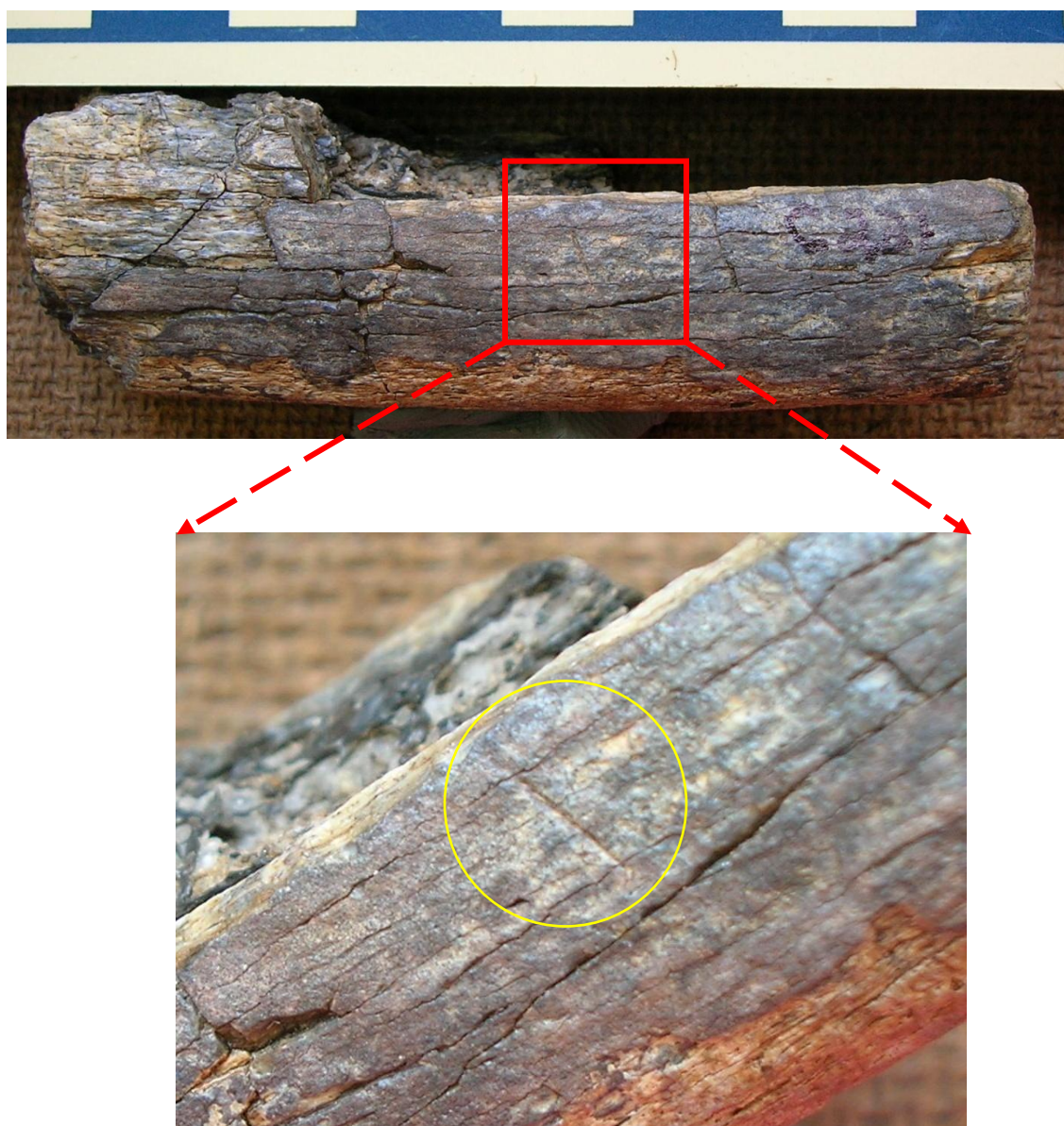
Figure 5-24: Specimen C-221 – Rib fragment with transverse mark on the ventral surface.

Cut marks CV-1

Cut marks CV-2

Ventral view
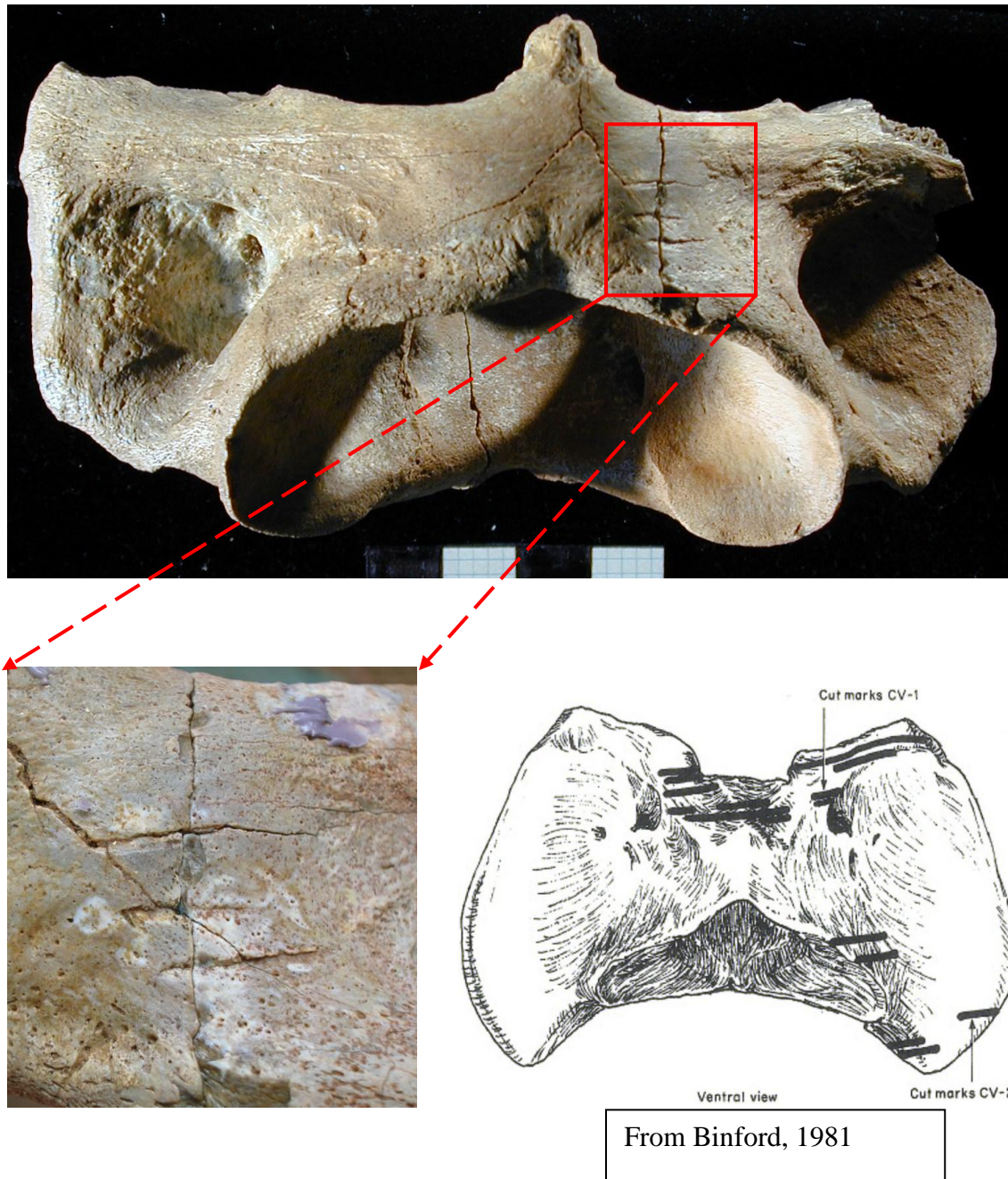
From Binford, 1981

Figure 5-25: **Specimen D022 – Suid atlas – Inset shows details of three linear transverse marks. The top mark is somewhat obscured by a transverse crack. The two lower marks are undercut on the cranial edge. Illustration from Binford, 1981 (lower right) shows actualistic observations of marks produced on a bovid atlas during removal of the head from the spine.**

Specimen D-023

Specimen D-057

Figure 5-26: Specimen D-023 (top) – Hippopotamus phalanx with two possible cut marks on the distal anterior surface.
Specimen D-057 (bottom) – Rib fragment with short linear mark v-shaped in cross section.
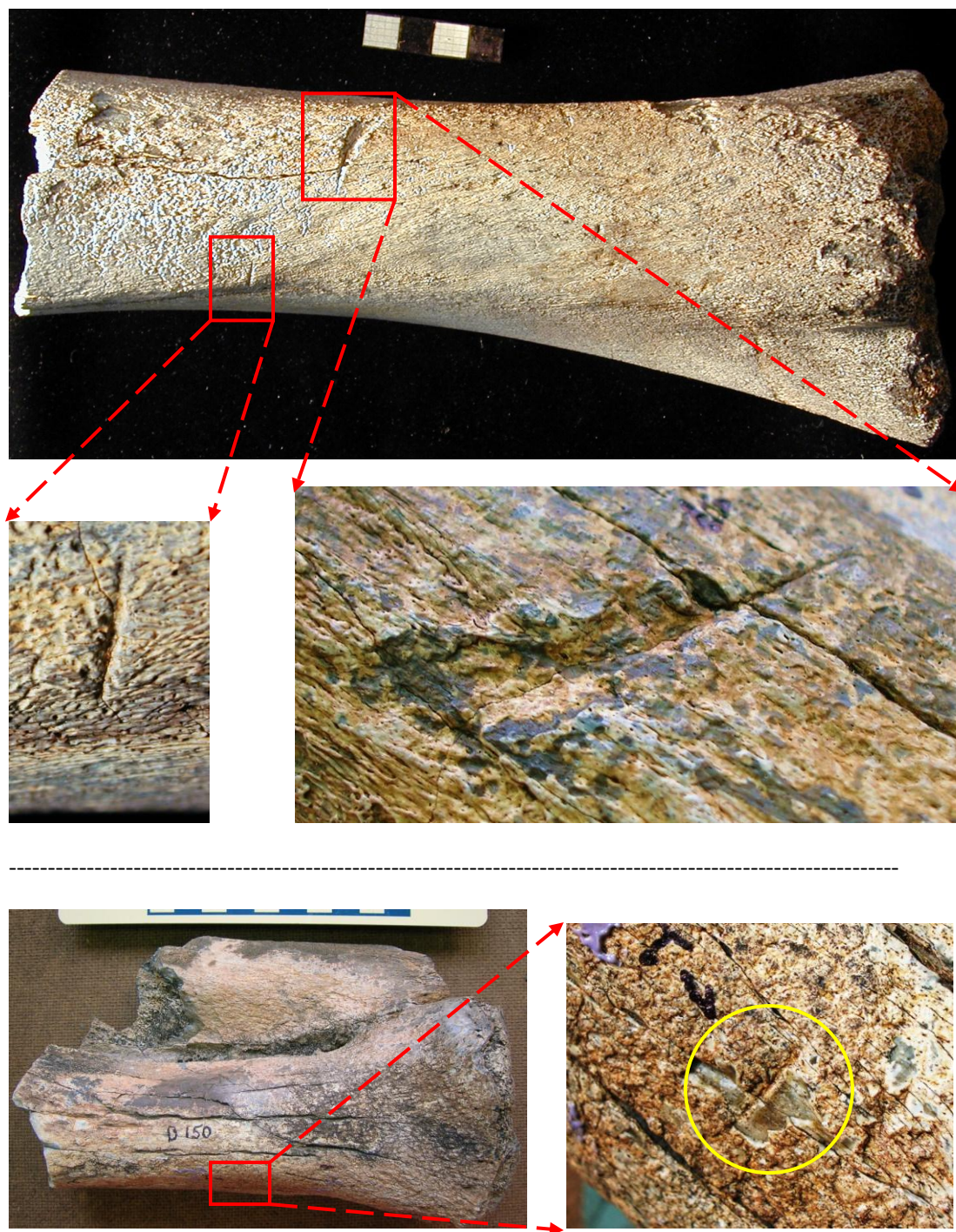
Figure 5-27: Specimen D-003 (top) – Hippopotamus femur midshaft with marks on the posterior surface. Specimen D-150 (bottom) – Proximal radioulna with small, linear, transverse mark on medial surface.
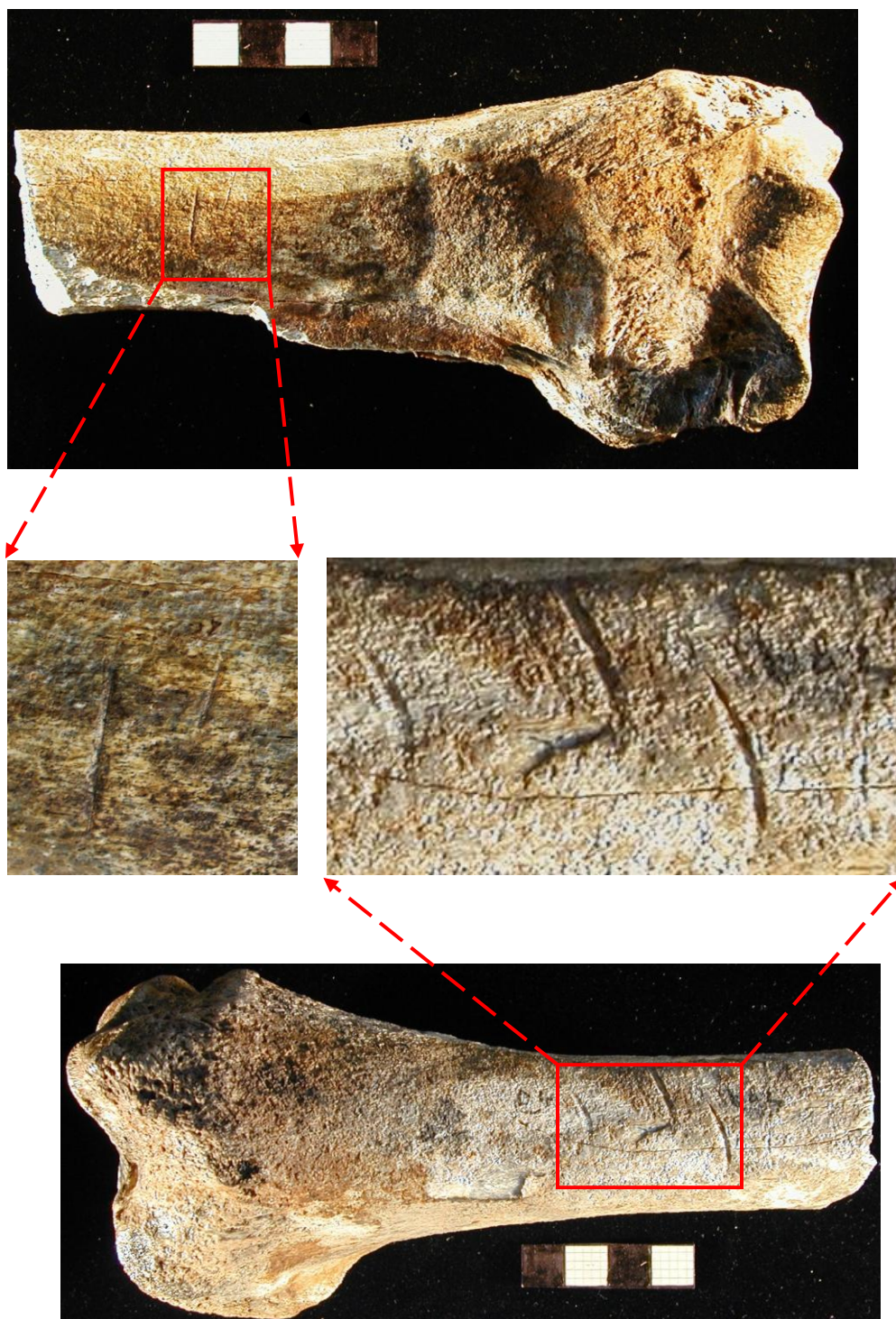
Figure 5-28: Specimen D-004 – Hippopotamus distal radius. Possible cut marks on the anterior surface (top). Carnivore tooth scores on the posterior surface (bottom).

Figure 5-29: Specimen D-005 – Hippopotamus rib fragment with "J-shaped" crocodile tooth score. Note "v-shaped" cross section of the tooth score.

Chapter 6: Analysis of Data and Implications for Future Research

Introduction

This research was successful in addressing several unresolved issues concerning hominin diet, foraging behavior, and an evolving ecological niche during a time interval at Koobi Fora when members of the genus *Homo* first appeared. During extensive surface survey of Upper Burgi Member exposures, isolated pockets of terrestrial vertebrate fossils were identified. Hominin modified bone found in close association with these fossil fauna (and also a dense accumulation of Oldowan stone tools at area 41) confirmed hominin presence on the ancient landscape. Paleogeographic reconstruction derived from depositional environments and stable oxygen isotope analysis, coupled with reconstruction of the paleoecology based on fossil flora and fauna analysis allowed for the identification of habitats where hominins exploited meat and marrow in the East Turkana Basin during the late Pliocene. Hominin modified bone was confirmed to be a suitable proxy for early hominin presence on the ancient landscape when the more traditional evidence of stone tools is absent. The modified bone evidence also provided insights into evolving Pliocene hominin diet and foraging behavior.

It is important to note that the evidence discovered during this research was recovered from exposed sediments of a depositional environment that is conducive to bone preservation. Evidence of activities conducted proximate to perennial or ephemeral sources of flowing water are more liable to be rapidly covered with sediment and hence have a far better chance to enter the fossil record than activities conducted in virtually

any other environment. Consequently, while it is valid to conclude that specific carcass

butchery activities were conducted in the described environments, it is not necessarily

true that these environments represent hominin preferred habitats and in fact may only

have been visited occasionally (Blumenschine, 1987; Mann, 1981).

Foraging Behavior

It is clear that changes in diet and foraging practices represent important cultural

and biological factors that separate the genus *Homo* from their early ancestors. Habitual

or obligate carnivory was an important catalyst for evolving physical changes such as an

enlarged brain and reduced dental morphology. As discussed in Chapter Five,

omnivorous chimpanzee foraging practices are useful modern analogs for basic early

hominin behavior. Small animal (size class 1) hunting along with marginal scavenging

for meat scrapes and exposed marrow (e.g. using modified stick to extract marrow from

bones fractured by carnivores) from abandoned carnivore kills would be well within the

mental and physical capabilities of the australopithecines based upon observations of

modern chimpanzee troops in the wild (Boesch, 1991; Stanford, 1999). However, a large

brain is a very "nutritionally expensive" organ to maintain and simple "chimp-like" tools

are not effective enough to enable the extraction of sufficient high quality nutrition from

elements of a large carcass to support the positive reinforcement cycle that drove human

evolution:

improved diet quality → brain expansion → behavioral innovation

The adoption of habitual meat and marrow consumption along with the use and manufacture of tools that facilitate the chopping, slicing, and pounding actions necessary to exploit this resource from large mammal carcasses would eventually enable a population (or populations) of early *Homo* to evolve based on this significant adaptive advantage (Isaac and Crader, 1981).

Furthermore the ability to use and manufacture these tools would be adaptive only if regular and relatively risk-free access to the meat and marrow resource was available. As discussed in Chapter One, australopithecines and early *Homo* probably foraged in tree and brush covered habitats (for plant forage and predation avoidance) with ready access to a perennial water source. During the Pliocene extinct large sabertooth felids, adapted for ambush hunting rather than pursuit, probably killed large herbivores in these habitats and when satiated would have abandoned carcasses with significant meat still available for scavenging (Marean, 1989; Blumenschine, 1987). In a wildlife ecology study conducted in the Serengeti National Park and at Ngorongoro Crater in northern Tanzania, Blumenschine (1987) described similar scavenging opportunities where partially consumed and abandoned felid kills of medium and large herbivores are fairly common in riparian woodland settings, particularly during the dry season when plant forage might be diminished (Foley, 1987). In a study of Serengetti leopards in Tanzania, Cavallo and Blumenschine (1989) observed these felids storing fresh kills of small and medium herbivores in the branches of trees and periodically abandoning (at least temporarily) the partially consumed carcasses; presenting a rich, regular scavenging opportunity for a smart, omnivore with some vestigial arboreal adaptations. Personal observations during this research in Kenya confirmed that these scavenging opportunities are not uncommon

even today and remain valid and useful analogs for the Plio-Pleistocene East Turkana Basin (Figure 6-1).   Other less predictable scavenging opportunities available in this habitat could include carcasses resulting from mass drowning of migrating ungulates or the occasional stray detached limb from the violent and unique way by which crocodiles tear apart and consume a large carcass (Njau and Blumenschine, 2005). Lion kills in more open savanna habitats could also provide relatively safe and still fresh scavenging opportunities. During research in Zaire, Tappen (1995) observed lions dragging freshly killed bovids off the open savanna and into tree lines or isolated stands of trees for consumption in the shade and shelter provided. Carcasses or carcass parts abandoned in a brush covered arboreal setting are often shielded from the view of vultures and other carnivorous birds by the vegetation canopy and consequentially the absence of these birds in the sky above a fresh kill removes the usual visual signal of a scavenging opportunity that always attracts distant terrestrial scavengers (e.g. hyenas). This combination of scenarios capable of producing potential scavenging opportunities greatly enhanced the likelihood that a terrestrial omnivorous primate foraging in a relatively closed-vegetation riverine or bush-land forest habitat would encounter scavenging opportunities that were productive, regular, and relatively low risk (vegetation cover and trees providing predator avoidance and escape opportunities) (Blumenschine, 1987) thereby providing a significant differential evolutionary advantage.

The archaeological evidence uncovered during this research is associated with fluvial or deltaic depositional environments. The large but fluctuating Lorenyang Lake, fed by the large perennial Proto-Omo river and ephemeral streams from the eastern basin margin, dominated the eastern Turkana Basin during Upper Burgi Member times.

Tree stored leopard kills
Segera Ranch, Kenya
2005

Zebra killed on brush-land distal
Floodplain by lion.
 Sosian Ranch, Kenya 2006

Eland killed on proximal
floodplain of small ephemeral
stream by lion Sosian Ranch
2007

Figure 6-1: Scavenging Opportunities on the Modern East African
                Landscape

Abundant plant forage and carcass scavenge opportunities would therefore be available year-round "along the wide band on either side of the Omo all along its course through the Koobi Fora region" (Bunn, 1994, page 251) and also along the course of the larger ephemeral streams. The archaeological evidence from this research does not indicate one simple foraging strategy was employed by early *Homo* within the Upper Burgi Member environment but rather reflects two distinct modes of behavior at different places on the landscape. The evidence suggests that the foraging behavior was a function of access to stone tool raw material. On the Karari Escarpment and Aberegaya Ridge that were distant from the source of stone tool raw material during Upper Burgi Member times, the foraging, butchery, and consumption behaviors appear to be non-centralized and randomly associated with isolated scavenging opportunities. In the Il Dura region during this same time period the proto-Omo River and/or the ephemeral streams that flowed from the east carried and deposited stone clasts suitable for tool manufacture. The loci of these stone clast deposits appear to have been the focus of butchery and consumption activity.

Karari Escarpment and Aberegaya Ridge

In areas 105, 130, and 131 no stone tools were identified during surface survey or *in situ* from geological trenches or the limited excavation conducted in area 130. However, the proxy of modified bone was present to different degrees in all three research locations. The larger number of modified bone specimens in areas 130 and 105 reflects a degree of hominin involvement that is not observed in area 131; perhaps due to the drier, more open paleoenvironment in that area as indicated by the depositional

environment (Chapter Three) and faunal signal (Chapter Four). No specific pattern of

butchery is evident, with both axial and appendicular elements of multiple taxa (suid,

bovid, and hippopotamus) exploited. The modified bones from these locations were not

grouped together in any tight association on the surface but rather were scattered about

the research locations suggesting isolated events of butchery for meat or marrow likely

followed by immediate consumption. There was no evidence of transport or

accumulation. The hippopotamus bones show a lack of intensive butchery (e.g. fracture

for marrow extraction) but rather exhibit only a few cut marks consistent with removal of

bits of meat. Mann (1981) uses the term "snack factor" to describe this type of foraging

activity where a significant percentage of the diet is consumed during the day's forage

route. The behavior suggested by the faunal evidence is conservatively described here as

marginal scavenging of abandoned carnivore kills for remaining meat and marrow;

similar to that hypothesized by Binford (1981, 1988). The modified bones and their

associated context is similar to surface collected evidence from Bouri (de Heinzelin *et al*.,

1999) and Gona (Dominguez-Rodrigo *et al*., 2005), perhaps representative of the onset of

a foraging behavior that is beginning to include meat and marrow into the hominin diet.

Characteristics of the faunal evidence are summarized below (Table 6-1) and speak to the

nature of the resource encountered and the competitive context of the environment.

Area (# sites)	MNI	Mammalian families present	Tooth marked (% NISP)	Cut Marked (% NISP)	Percussion fractured (% NISP)	NISP (limb bone)	Epiphyses (% NISP)	Midshaft
Area 130(5)	24	7	28 (27.5)	6 (6.0)	24 (23.5)	102	42 (41)	60
Area 131(2)	14	7	8 (9.7)	1 (1.2)	0	82	68 (83)	14
Area 105(4)	19	7	19 (24)	6 (7.5)	14 (17.5)	80	46 (58)	34

Table 6-1: Summary of nature and character of fossil fauna from research locations 130, 131, and 105 (tooth marked numbers include specimens of notches produced by carnivore static tooth pressure and percussion marked numbers include specimens evaluated by fracture plane angle and notch characteristics)

All research locations yielded the remains of many individual animals and a rich diversity of taxa. Evidence of carnivore activity is significant, but relatively low, based on tooth mark frequencies (9.7% - 27.5%) and the high number of epiphyses present (41% - 83% limb bone NISP). Blumenschine (1988) observed that the depletion or complete destruction of grease rich epiphyses by bone-crunching scavengers almost universally occurs in "open vegetation, fat-rich simulated sites" and that spotted hyenas prefer open-vegetation habitats. Since evidence of extensive ravaging by bone-crunching carnivores is absent, these actualistic observations tend to confirm the interpretation of a more-closed vegetation environment for the research locations that is indicated by the depositional environments (Chapter Three) and faunal signal (Chapter Four).

It is almost certain that these surface assemblages are palimpsests that were created over relatively long periods of time (Stern, 1993). The taxonomic diversity and high number of individuals present at each location is probably consistent with repeated occurrences of felid kills over time at a place on the landscape that would "yield

successful and repeated predation" (Tappen, 1995). Unfortunately this data does not

allow for any meaningful inference to be drawn as to the timing of hominin involvement

in the faunal assemblage (hunting or aggressive/confrontational scavenging versus

marginal scavenging). Blumenschine's (1988, 1995) actualistic models of the timing of

access to a carcass are based on experiments with tight spatial and temporal controls and

may not be applicable to a time averaged assemblage without such limits. Early carcass

access cannot be ruled out by this research but the assumption of small bodied early

Homo coupled with a lack of knowledge about foraging group size or social dynamics of

such a hominin would make any such assertion specious and therefore passive marginal

scavenging is the more parsimonious interpretation.

Il Dura Region

The spatial boundaries and temporal resolution at the area 41 location are better

defined than the other research locations and the complementary stable isotope and fossil

wood evidence provide additional confirmation of the paleoenvironmental reconstruction.

Initially two observations differentiated this location from those on the Karari

Escarpment and Aberegaya Ridge: 1.) the higher density of the surface fossil assemblage

and, 2.) the presence of freshly eroded stone tools on the surface. Extensive excavation

conducted at the site of a surface scatter of freshly eroded stone tools eventually yielded

more than 2800 stone artifacts. The stone artifacts represent the entire range of early

Oldowan technology (cores, flakes, debitage) produced from a wide variety of raw

materials (chert, jasper, basalt, quartz) not seen in other late Pliocene stone tool

assemblages (Figure 6-2). This archaeological site (FwJj-20) not only has the oldest
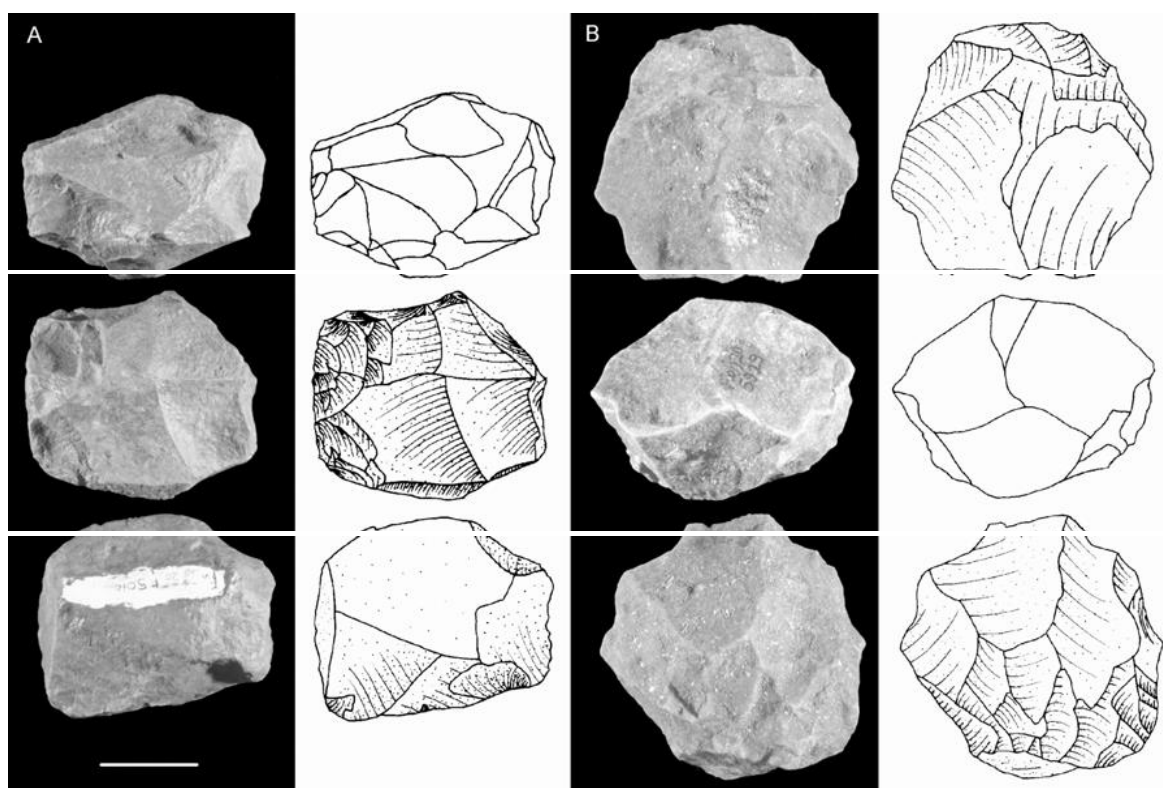
Stone artifacts from the FwJj20 locality. These are multidirectional cores made on large cobbles. These specimens are characteristic of the core forms at FwJj20. Scale bar 2 cm. Drawings by Liezl van Pletzen-Vos.

Category	*In Situ*	Surface
Whole Flakes	623	76
Broken Flakes	179	13
Angular Fragments	1170	62
Cores	161	29
Core Fragments	184	0
Hammerstones	30	3
Worked pebbles	165	6
Unmodified Pebbles	121	27
Total	2633	216

Figure 6-2: Oldowan Stone Tools from the Area 41 Research Location FwJj-20 (Adapted from Braun *et al*., in press)

stone tools yet discovered at Koobi Fora but also represents the largest *in situ*

accumulation of closely associated stone tools, mammalian fossils, and modified bone

from well dated late Pliocene sediments (Braun *et al*., in press). Characteristics of the

faunal assemblage from area 41 are summarized in Table 6-2.

	MNI	Mammalian families present	Tooth marked (% NISP)	Cut Marked (% NISP)	Percussion fractured (% NISP)	NISP (limb bone)	Epiphyses (% NISP)	Midshaft
Area 41 Survey	43	9	78 (29)	10 (3.7)	28 (10.3)	272	117 (43)	155
Area 41 Excavation	33	9	3 (4)	6 (8.5)	4 (5.6)	71	40 (56)	31
Area 41 Composite	65	9	81 (24)	16 (4.7)	32 (9.3)	343	157 (46)	186

<u>Table 6-2</u>: Summary of nature and character of fossil fauna from research location 41(tooth marked numbers include specimens of notches produced by carnivore static tooth pressure and percussion marked numbers include specimens evaluated by fracture plane angle and notch characteristics)

Sixty five individual animals, including 8 genera of bovids, 3 genera of suids, and 2

genera of equids were identified from this relatively limited research location (13,000

meters^2). As discussed in Chapter Four, there is compelling evidence that most of the

terrestrial vertebrate fossils collected on the surface originated from the even more

restricted area represented by the excavation at FwJj-20 (see Figure 4-2). To date the

excavation alone (~ 250 meters^2) has yielded *in situ* fossil bones of 33 individual animals

including 8 genera of bovids, 3 genera of suids, and 1 genus of equid. Of the 343 long

bones and long bone fragments identified at this research location, 186 are midshaft

fragments (not epiphyses or near epiphyseal fragments) and 42 (23%) of those are tooth

marked.   Carnivore involvement in the assemblage is confirmed by a significant number

of tooth marked specimens but the high number of epiphyseal fragments present in the

assemblage coupled with the 23% tooth mark frequency on long bone fragments [well

below the experimental threshold of 67% for "carnivore only" involvement

(Blumenschine, 1988)] lessens the likelihood that carnivores were the primary

accumulator or that extensive ravaging by bone crunching scavengers was involved. In

Chapter Three it was shown that the depositional context of sediments surrounding the

artifact horizon made it possible to reject the interpretation of the fossil and artifact

assemblage as a "hydraulic jumble". The site shows no indications of significant fluvial

transport. Small and large fossil bones and artifacts are found in close association

indicating absence of winnowing. Large linear bones show no preferred orientation and

the artifacts maintain fresh sharp edges with no evidence of rounding. Also, no

unmodified stone clasts of sizes similar to the fossil bones and artifacts were present at

the site or anywhere else in the sand unit which is exposed both at and laterally away

from the site. Open air archaeological sites (not a cave or den) such as this with large

numbers of bones and stone artifacts in close association that are not accumulated by

moving water provide good evidence that hominins were involved in the accumulation of

the bones for marrow exploitation, since non bone-crunching carnivores are not known to

produce such dense accumulations of bone fragments in this environmental context

(Blumenschine, 1988; Bunn and Kroll, 1986). The large MNI and diverse taxa present at

FwJj-20 in such a limited excavation area and from a narrow, low energy stratigraphic

horizon (6 centimeters of clay) is consistent with this observation. The close association

of a large number of long bone fragments (some clearly modified) with stone artifacts in

this extremely limited area suggests a foraging strategy different than that described for

the Karari Escarpment and Aberegaya Ridge above. While this evidence does not

support all the behavioral implications of "home base behavior" it is suggestive of a

rudimentary form of "central place foraging" (Isaac & Crader, 1981; Isaac, 1983) and it

certainly represents more complex behavior than "ape-like routed foraging" (Binford,

1981, 1988) or "snack factor" immediate consumption (Mann, 1981).

The question of interest becomes: why utilize this specific location on the

landscape?   Several researchers have hypothesized that a location-specific "ephemeral

affordance" such as a large shade tree proximate to flowing water could attract and

support such behavior (Blumenschine, personal communication 2008; Bunn & Ezzo,

1993; Potts, 1996; Schick, 1987). A large fluvial channel flowed near the site and would

likely be a reliable source of lithic raw materials. Fossil wood from the area indicates

that such trees, which survive for tens or even hundreds of years, were present at this

location when the stone tools and bone refuse were accumulated. Repeated episodes of

transport and butchery over time could have contributed many of the unmodified fossil

bones that created the large MNI and diversity of taxa evidenced at this location. The

surrounding vegetation of such an affordance would shield hominin butchery behavior

from carnivorous birds, limiting competition from dangerous large terrestrial scavengers

and also provide multiple escape venues. Both of these factors would reduce the risk of

predation. Also at this location, there is faunal evidence of butchery of elements of the

manus/pes, possibly for marrow removal (e.g. cut marked equid metapodial and phalanx).

Such behavior is time consuming and yields relatively little nutrition. It requires removal

of skin and periosteum prior to fracture and would only be conducted in an area of

relatively low predation risk (Pobiner *et al*., 2008).

Basin-wide Foraging Behavior

Why did this apparent dichotomy of behavior exist in the East Turkana Basin during Upper Burgi Member times and what is the explanation for the presence of modified bones but no stone tools at some locations? Bunn (1988) observed a suite of hominin stone tool mediated carnivorous behaviors in the East Turkana Basin at the more recent Okote Member (1.64- 1.39 mya) time horizon that roughly mirrors the archaeological evidence uncovered during this research. At a site (GaJi-3) in area 103 near the shores of modern Lake Turkana, Bunn identified large numbers of hominin modified bone but no stone tools. Other penecontemporaneous Okote Member sites on the Karari Escarpment (e.g. FxJj-50 in area 131) yielded stone tools in close association with fossil fauna and hominin modified bone. Bunn attributed the disparity between the two sites to the availability of stone tool raw material. Bunn hypothesized that the Karari Escarpment sites represented places on the landscape where the Proto-Omo River and/or the ephemeral streams from the basin margin had transported and deposited lithic raw material during KBS and Okote Member times. Portions of hunted carcasses or scavenged and abandoned carnivore kills were transported to this place and butchered using small sharp flakes that were produced, utilized, and discarded on site. Bunn hypothesized that these hominins also foraged far away from this raw material source ranging along the riverine forests that lined the perennial and ephemeral streams. Where raw material was not present, hominins carried tools with them on their foraging route in the form of cores or large flakes. Some butchery was conducted where carcasses were encountered utilizing these tools and also portions of the carcasses were transported to a

place on the landscape where they were consumed and the bone refuse discarded. Because the raw material for stone tools was not available away from the basin margin, cores and flakes were not discarded after use but rather were curated and carried along on the forage route. On the Koobi Fora Ridge in area 103 scattered fragments of modified bone and concentrated accumulations of fossil fauna and modified bone but no stone artifacts attest to this behavior. Bunn also hypothesized that it would be possible to confirm these different modes of foraging behavior based on the morphology of the cut marks on the fossil bones at the different types of sites. Cut marks on fossil bones at sites with no stone tools would be deeper, less frequent, and have greater absolute width with a less acute V-shaped cross section profile because of the large flakes and cores used to produce them. Cut marks on fossil bones found in close association with stone tools and debitage would be more frequent and exhibit a lesser absolute width with a V-shaped cross section that is more acute due to the small sharp flakes used to produce them (Bunn, 1988).

While there are some striking similarities between the archaeological evidence from Bunn's study and this dissertation research, Bunn's hypothesis likely does not serve as a perfect analog for Upper Burgi Member hominin foraging behavior (and in fairness he never presented it as such). First, at 1.64 million years ago, *Homo ergaster* was presumably the hominin responsible for the Okote Member archaeological sites. This species of hominin was larger, stronger, smarter, and able to range over greater distances and exploit a wider variety of habitats (Rogers *et al*., 1994) and is not necessarily a useful analog for the hominin (early *Homo*) hypothesized to be responsible for the archaeological evidence from this research. Second, the qualitative differences in cut

mark morphology reported (and which are also observed in this research) are not supported by quantitative data. Stephen Merritt of Rutgers University has conducted extensive quantitative actualistic research on stone tool cut mark morphology and he finds considerable overlap exists in the important cut mark metrics created by a variety of cores and flakes. Merritt (personal communication) suggests that it is not possible to statistically identify the stone tool size or type from the morphology of the mark alone.

The foraging behavior described by Bunn appears to be a natural evolution of the more ancestral and less complex behavior indicated by this research. FwJj-20 in area 41 and the Okote Member sites on the Karari Escarpment appear to represent very similar types of behavior: central places on the landscape where stone raw material is present, expedient sharp flake tools can be created, and to which carcass parts could be transported, butchered, and consumed in relative safety. These were also possibly the places where prepared cores and large flake tools were produced to be carried on the daily forage route. Bunn hypothesized that Okote Member hominins ranged and foraged long distances from these central places, often transporting scavenged carcass parts when encountered to an *ephemeral affordance* on the landscape where the carcass parts were butchered and consumed, with bone refuse but not the stone tools discarded on site (e. g. GaJi-3). Another example of this behavior was found at a very similar Okote Member site (FwJj-14 A&B) near the village of Ileret with many modified bones but no stone tools (Pobiner *et al*., 2008). This dissertation research found evidence that Upper Burgi Member hominins indeed foraged far from the stone raw material source. Modified bone was discovered more than 25 km from the closest known source of raw material. At these modified bone locations there is no evidence of carcass portion transport to any

type of landscape affordance for additional processing, and each modified bone discovered in all likelihood represents an individual episode of carnivory consistent with routed foraging, passive scavenging, and immediate consumption.

Bunn's explanation for the absence of stone tools at the remote modified bone sites is compelling but not supported by any quantitative archaeological or actualistic evidence. As mentioned above tool type cannot presently be identified with any statistical certainty from cut mark morphology alone. This research found no evidence of remote caches of stone manuports (Potts, 1991) during extensive geographic survey of Upper Burgi exposures nor was there any stone debitage at the locations of the individual modified bones. Some sort of "pre-Oldowan" tool technology, perhaps utilizing non-durable or archaeologically unrecognized raw material (e.g. shell, bone, wood, tooth) cannot be excluded by this research (Panger *et al*., 2002). The cultural tradition of an Oldowan stone tool industry is well established at FwJj-20 (1.95 mya) and also at much older East African sites such as Gona, Ethiopia (2.5 mya) and Lokalalei, Kenya (2.35 mya) and, if indeed a widespread and identifiable pre-Oldowan technology did exist, it was probably a pre-2.6 million year old phenomenon (Dominguez-Rodrigo *et al*., 2005). Consequently Bunn's hypothesis of stone tool transport and curation is a reasonable one that has also been suggested to explain the absence of stone tools at the Bouri modified bone site (de Heinzelin *et al*., 1999) and that can be applied to describe the modified bone evidence of individual acts of carnivory from the remote Upper Burgi Member locations uncovered during this research.

Which Upper Burgi hominin

Only one probable hominin bone (figure 4-10: distal fibula from area 131) was recovered during this research and unfortunately it did not provide evidence as to the specific genus (*Homo* or *Australopithecus*) to which it belonged. All of the exposures in each research location are positioned down section from the KBS Tuff and therefore are of late Pliocene age (older than 1.87 million years ago). The area 41 exposures were dated by paleomagnetic analysis to about 1.95 million years old. At Koobi Fora four hominins are known from this time interval (Appendix 1-1): *Australopithecus boisei* (e.g. KNM-ER-417/1469/1803/3729)*, Homo hablis* (e.g. KNM-ER-1813/3732), *Homo rudolfensis* (e.g. KNM-ER-1470) and *Homo ergaster* (e.g. KNM-ER-1506/1812/3228). There is presently no evidence that unequivocally ties the Pliocene archaeological record to any specific hominin genus. The Australopithecines are known from the fossil record for at least three million years as a very conservative evolutionary genus (Figure 1-2). The hominin fossil record begins to change dramatically at about 2.5 million years ago with a significant adaptive radiation reflected by brain expansion and reduction in dental morphology in some hominin populations. The earliest stone tool artifacts also appear around this time.

Sometime after seven million years ago a population (or perhaps populations) of hominoids crossed a major evolutionary rubicon and became bipedal. A second major rubicon, involving changes in diet and foraging behavior, was approached at the end of the Pliocene, likely the product of a positive reinforcement loop of larger brain driving innovative new behaviors (more complex cultural interactions & expanded tool utilization) leading to better nutrition which in turn led to continued expansion of the

brain and ultimately resulted in increased reproductive success. The populations that

crossed this rubicon represent the beginning of the *Homo* lineage. Those that did not,

continued on a different evolutionary path that eventually led to the specialized, and more

derived, "megadont" *Paranthropus*. Based upon stable isotope analysis from tooth

enamel, it has been hypothesized (Sponheimer and Lee-Thorp 1999; Sponheimer *et al*.,

2006) that South African *Paranthropus* and *Australopithecus* may have ranged

extensively onto more open-vegetation grasslands. However, utilizing habitat preference

models based on fossil bovid faunas, Shipman and Harris (1988) found that

Paranthropus boisei preferred "closed/wetter habitats" and also there is abundant

paleontological evidence that the East African australopithecines were not open savannah

foragers as originally hypothesized but were more plausibly tied to habitats with

significant tree and brush cover and a perennial water source such as riverine gallery

forest or delta distributary channel (Andrews, 1989; Blumenschine, 1987; Feibel, 1997;

Klein, 1999; Shipman and Harris, 1988; Behrensmeyer, 1978).   Early *Homo* almost

certainly evolved in this same environment and would have retained many of the

postcranial attributes of the ancestral australopithecines. The cultural and behavioral

changes along with the changes in cranial and dental morphology that differentiate our

lineage from that of the australopithecines limit the ability of cladistic analysis of skeletal

morphological characteristics alone to define the genus *Homo*. The fact that the

morphology of australopithecine hand bones does not exclude them as an Oldowan stone

tool maker (Panger *et al*., 2002) does not offset the overwhelming lack of archaeological

evidence that these genera ever made or used stone tools, and when viewed from the

broader perspective of evolving physiology along with existing archaeological evidence

of evolving behavior and culture it is becoming increasingly apparent the late Pliocene Oldowan tool maker was early *Homo* and not an australopithecine.

The first appearance datum for early *Homo* in East Africa is ~2.4 mya (UR501) at Malawi and ~2.2 mya (AL666) in Ethiopia. *Homo ergaster* first appears in Kenya at ~1.8 million years ago at Koobi Fora (Klein, 1999: Plummer, 2004). *Homo ergaster* postcrania is very similar in stature to modern humans (Walker and Leakey, 1993) and they are known to have ranged extensively and exploited a variety of habitats (Rogers *et al*., 1994); venturing off the African continent by 1.8 million years ago (Lordkipanidze *et al*., 2005). However, all of the archaeological evidence uncovered during this research is from well watered depositional environments with faunal and floral evidence representative of more wooded or riverine gallery forest and consistent with habitats hypothesized to have been exploited by small bodied early *Homo*. There was also no evidence found of the Karari or Acheulean tool industries usually associated with *Homo ergaster*. While *Homo ergaster* cannot be ruled out, it is more reasonable to assume that either *Homo habilis* or *Homo rudolfensis* is responsible for the archaeological traces (including the early Oldowan stone tools from area 41) discovered during this field research.

A Model of Early *Homo* Foraging Behavior at Koobi Fora

The evidence developed by this research suggests the following interpretation of the evolutionary context and the adaptive niche available during Upper Burgi Member times in the eastern Turkana Basin. The model is based on analysis of depositional environments at the locations of the surface fossils. These depositional environments

describe specific characteristics of the ancient landscape and coupled with the stable isotope and fossil wood analysis make accurate reconstruction of the paleoenvironments possible. The composition of the animal communities at each research location was determined based on the taxonomic identification of the fossil fauna and the hypothesized paleoecological interactions and paleohabitat preferences of these communities were constructed based on the analogous behavior of closely related modern African animals. Hominin carnivory is evidenced by the cut marked and percussion fractured fossil bone identified at each research location. Strong relational analogies, constructed and confirmed by actualistic studies conducted by many researchers, tie this trace evidence to the actor responsible for the trace. The data developed and strong analogies proposed by this research serve as the basis for the following inferences about evolving hominin behavior during the late Pliocene in East Africa.

Early *Homo* ranged and foraged along the riparian woodland environments of the large proto-Omo river and the ephemeral rivers that flowed off the uplifted eastern basin margin. There was competition with other large bodied terrestrial primates such as *Theropithecus oswaldi* and *Australopithecus boisei* for plant forage, but due to an expanded brain which enabled the culturally acquired ability to manufacture and use stone tools, early *Homo* was able to supplement plant forage with calories provided by animal protein, mostly obtained from the abandoned carcasses of carnivore kills particularly during the dry season when normal plant forage was significantly reduced [fat resource from the bone marrow of many ungulates is also significantly reduced during dry season due to reduced forage (Speth, 1989)]. This unique and extremely rich resource gradually grew in importance to the diet of early *Homo* but this evolving

behavior had little initial impact on the Pliocene carnivore guild, primarily because of the nature of the resource and the limited environment where it was exploited. Ancestral-like routed foraging for these diverse resources was still the dominant feeding behavior, but occasionally at places on the landscape near flowing water, where stone raw material was available, and where the vegetation cover provided shade and protection from predation a different kind of foraging behavior evolved. Scavenged animal parts (and perhaps plant foods) were transported to these *central places* where Oldowan stone tools were fabricated in order to more extensively exploit these resources. Activities did not necessarily involve a protracted stay but the affordances at such locations would plausibly attract repeated visits over perhaps long periods of time. The research location in area 41 (including the excavation at FwJj-20) represents one of these *central places*. This type of site at this time horizon at Koobi Fora is unique right now but certainly many similar such locations were utilized during the Pliocene and remain to be discovered. Also some kind of stone implements may have been produced at these locations to carry along on the continuing forage route in case a scavenging opportunity was encountered. The modified bones from Areas 130 and 105 are suggestive of this tool curation behavior [similar to Bunn's (1994) hypothesis] but the use of expedient stone tools not recognized as such, or tools made of less durable materials not preserved in the geological record cannot be excluded based on this research evidence.

The older late Pliocene sites at Gona, Bouri and Lokalalei may also fit this pattern of early *Homo* behavior. The depositional environment [large meandering fluvial system (proto-Awash River)], along with the density and technology level of stone tools at the 2.6 million year old archaeological site at Gona, Ethiopia (Semaw *et al*., 1997) are similar

to those of FwJj-20, but the Gona site has no associated fossil fauna or modified bone. This site may represent a different type of behavior or simply differences in taphonomic factors that did not allow for the preservation of associated animal or plant remains. Survey of exposures surrounding the original Gona artifact site (Dominguez-Rodrigo *et al*., 2005) yielded fossil remains of isolated individual acts of stone tool mediated carnivory (modified bones but no stone tools) which are similar to those discovered at areas 130 and 105 during this research.

The 2.5 million year old site at Bouri, Ethiopia (de Heinzelin *et al*., 1999) also produced modified bone but no stone tools. The depositional environment at this site is indicative of low relief, grass-covered lake margin deposits. While this paleoenvironment was more open, probably more dangerous, and yielded less productive forage than that of area 130 it is similar to the paleoenvironment described for area 105 and the modified bone evidence is similar in character to the evidence from both of those areas. The behavior represented by the Bouri site (interpreted by the researchers as a place on the landscape where brief butchery activity was conducted using stone tools that were curated and not discarded) is the same as that hypothesized by this research for area 130 and area 105.

The excavation in area 41 (FwJj-20) and the 2.35 million year old site at Lokalalei, Kenya (Kibunjia, 1994; Kibunjia *et al*., 1992) are both situated in the Turkana Basin and share many characteristics. The depositional environment of the Lokalalei site (the top of several upward fining sediment cycles) is interpreted as a large meandering river (proto-Omo) "near the interface with two ephemeral streams". Stone tools along with associated fossil faunal remains and perhaps three modified bones were recovered

from this excavation. Unfortunately the preservation of the bones at this site was poor

and full faunal analysis and specific details of the modified bone have yet to be

published. However, both sites fit well within the concept of *central place* described

above.

Table 6-3 summarizes the characteristics of these archaeological sites from the

Pliocene.

Table 6-3: Pliocene East African archaeological sites with evidence of hominin carnivory through the presence of modified bone

Location	Age (mya)	Stone Artifacts	Modified Bone (#)	Depositional Environment
OGS6 Ounda Gona, Ethiopia (Dominguez-Rodrigo *et al.*, 2004)	2.6	Yes	Yes (1)	Lower Busidima Formation: fining upward sequences deposited as the ancestral Awash River migrated laterally across the floodplain
EG13 Kada Gona, Ethiopia (Dominguez-Rodrigo *et al.*, 2004)	2.6	Yes	Yes (1)	Lower Busidima Formation: fining upward sequences deposited as the ancestral Awash River migrated laterally across the floodplain
WG9 Kada Gona, Ethiopia (Dominguez-Rodrigo *et al.*, 2004)	2.5	Yes	Yes (2)	Lower Busidima Formation: fining upward sequences deposited as the ancestral Awash River migrated laterally across the floodplain
Bouri, Ethiopia (de Heinzelin et al.,1999)	2.5	No	Yes (3)	Fluvial processes associated with floodplains along distributary deltaic channels close to a shallow fluctuating lake
Lokalalei 2C West Turkana, Kenya (Roche *et al.*, 1999)	2.34	Yes	Yes (NR)	top of several upward fining sediment cycles, interpreted as a large meandering river (proto-Omo) near the interface with two ephemeral streams
DAN2 Kada Gona, Ethiopia (Dominguez-Rodrigo *et al.*, 2004)	2.1	Yes	Yes (5)	Lower Busidima Formation: fining upward sequences deposited as the ancestral Awash River migrated laterally across the floodplain

Kanjera South, Kenya (Plummer, 2004)	ca. 2.0	**Yes**	**Yes (NR)**	Wooded to open grassland at basin margin with braided ephemeral streams
Area 41 (FwJj20) Koobi Fora, Kenya	**1.95**	**Yes**	**Yes (16)**	The artifact and bone bearing clay horizon likely represents a flood deposit on a fluvial (deltaic) bar. This was a subaerial surface upon which the bones and artifacts were deposited before being covered by coarse sands and silts as the fluvial bar continued to develop
Area 130 Koobi Fora, Kenya	**>1.87**	**No**	**Yes (16)**	130 A-D: silty-clay surface at the base of a sand body interpreted as alternating deposition layers of sand and silty-clay indicative of delta channel lateral movement or lake transgression/regression cycles 130 E: sand body at terminal end of delta channel (subaqueous delta front)
Area 131 Koobi Fora, Kenya	**>1.87**	**No**	**Yes (1)**	a series of silty-clays representing a delta front that are capped by a large sand body that was formed in a deltaic channel and subsequently reworked as a beach
Area 105 Koobi Fora Kenya	**>1.87**	**No**	**Yes (11)**	sandy clays and sandy-silty-clays inter-fingered with sand lenses which represent fluvial/deltaic floodplain facies; and areas exhibiting alternating layers of sand and silt that represent delta or delta channel floodplain facies

Table 6-3: Pliocene East African archaeological sites with evidence of hominin carnivory through the presence of modified bone

Implications of this Research and Future Research Directions

The behavior model described above is proposed as a possible template by which to explain the foraging practices and habitat exploitation by the earliest members of the genus *Homo* in a specific region of East Africa. Previous archaeological evidence from Ethiopia at 2.6 million years old and similar evidence from Kenya at 2.35 million years old mark the onset of changes in hominin diet and associated expansion of cultural and technological capabilities. That evidence is consistent with the evidence reported from this dissertation research conducted in the Upper Burgi Member at Koobi Fora and perhaps extends the temporal span of this hypothesized "behavior set" by at least 800,000 years. Unfortunately, there remains a paucity of sites from this time period and additional studies such as this dissertation research need to be conducted. And while this research has provided a possible model against which to test future research, the ultimate definition of the earliest human behaviors has yet to be determined. For instance one unpublished two million year old site from western Kenya at Kanjara has apparently yielded stone tools, abundant fossil fauna, and modified bone (Plummer, personal communication). The paleoenvironment appears to be different from the Upper Burgi member locations and may represent very different foraging behavior thereby emphasizing the need to broaden the data base.

After 1.8 million years ago, *Homo ergaster* first appears and earlier members of the genus *Homo* disappear from the fossil record with consequent dramatic changes in behavior which have been richly described based on evidence from archaeological sites of the KBS and Okote Members at Koobi Fora as well as many other sites in Africa. A

real dearth of behavioral information exists as the result of the lack of an archaeological record prior to 2.6 million years ago. Modified bone has proved to be a useful proxy for hominin behavior in late Pliocene deposits where no other archaeological evidence had previously been found, and it should be a major consideration when conducting research into the origin of the human lineage in even older deposits. Future research should involve additional fieldwork as well as a re-examination of pre-2.6 million year old fossil bone collections residing in museum laboratories with a focus on the many unequivocal characteristics of modified bone that represent many aspects of evolving hominin behavior.

APPENDICES

Appendix 1-1:	Upper Burgi Member Hominins				
compiled from:					
Koobi Fora Research Project: Volume 1; Feibel *et al.***, 1989;**					
National Museum of Kenya data base February 2006, Nairobi					
KNM-ER-	**Area**	**strata**	**genus**	**species**	**fossil**
417	129	mid UBU Mb	*Australopithecus*	*boisei*	left parietal fragment / C
811	104	upper UBU Mb	*Homo*	*indeterminate*	parietal fragment / C
1462	130	ca. GPC	*Homo*	*indeterminate*	left LM3 / D
1469	131	KBS-13m	*Australopithecus*	*boisei*	left HMAND fragment / M
1470	131	KBS-36m	*Homo*	*rudolfensis*	cranium / C
1471	131	KBS-27m	*Homo*	*indeterminate*	right Tibia proximal 1/3 / P
1472	131	KBS-30m	*Homo*	*indeterminate*	right femur / P
1473	131	KBS-25m	*Homo*	*indeterminate*	right humerus proximal fragment / P
1474	131	KBS-32m	*Homo*	*indeterminate*	parietal fragment / C
1475	131	KBS-25m	*Homo*	*indeterminate*	right femur proximal fragment & shaft fragment / P
1481	131	KBS-12m	*Homo*	*erectus*	left lower limb fragments (femur, tibia, fibula) / P
1482	131	KBS-26m	*Homo*	*indeterminate*	mandible fragment / M
1483	131	KBS-4m	*Homo*	*indeterminate*	mandible fragments / M
1500	130	KBS-	*Homo*	*indeterminate*	axial skeletal elements small adult individual / M,P
1501	123	C4-40m	*Homo*	*indeterminate*	right HMAND / M
1502	123	C4-12m	*Homo*	*indeterminate*	right HMAND found close to KNM-ER-1813 / M

1503	123	C4-5m	*Homo*	*indeterminate*	right femur proximal fragment / P
1504	123	C4-5m	*Homo*	*indeterminate*	right humerus distal end / P
1505	123	C4-5m	*Homo*	*indeterminate*	left femur head & neck / left femur distal shaft fragment / P
1800	130	GPC-	*Homo*	*indeterminate*	cranial fragments / C
1801	131	F-	*Homo*	*indeterminate*	left mandible fragment / M
1802	131	GPC-	*Homo*	*habilis*	mandible fragment / M
1803	131	KBS-12m	*Australopithecus*	*boisei*	right mandible fragment / M
1810	123	C4-7m	*Homo*	*indeterminate*	left tibia proximal fragment / P
1812	123	C4-6m	*Homo*	*erectus*	right mandible fragment / proximal radius fragment / M,P
1813	123	C4-11m	*Homo*	*habilis*	cranium / C
1822	123	C4-5m	*Homo*	*indeterminate*	right femur midshaft fragment / P
2596	15	KBS-9m	*Homo*	*indeterminate*	left tibia distal shaft fragment / P
2598	15	KBS-4m	*Homo*	*erectus*	occipital fragment / C
2601	130	KBS-	*Australopithecus*	*boisei*	right LM crown / D
3228	102	C1-10m	*Homo*	*erectus*	P
3728	100	C2+5	*Homo*	*indeterminate*	P
3729	102	C4-13m	*Australopithecus*	*boisei*	M
3731	115	GPC+1m	*Homo*	*indeterminate*	M
3732	115	GPC+1m	*Homo*	*habilis*	C
3734	115	GPC+1m	*Homo*	*indeterminate*	M
3735	116	F-4m	*Homo*	*indeterminate*	C,M,P
3736	105	KBS-6m	*Homo*	*indeterminate*	P
3953	105	KBS-6m	*Homo*	*indeterminate*	D
3956	106	C4-19m	*Homo*	*indeterminate*	P
5879	123	C4-12m	*Homo*	*indeterminate*	C
5880	106	C4-24m	*Homo*	*indeterminate*	P

1506	121		*Homo*	*erectus*	right HMANT M1&M2, isolated P3&P4
		C1=marker bed 66m below KBS Tuff			**Crania {C}, Mandibles {M},**
		C2=marker bed 50m below KBS Tuff			**Postcrania {P}, Isolated teeth {D}**
		C4=marker bed (1.86+/-0.05 my)			
		KBS=KBS Tuff (1.88+/-0.02 my)			
		GPC=marker bed 20m below the KBS Tuff			
		F=marker bed 30m below the KBS Tuff			

Voorhies Dispersal Groups: Bones of Sheep and Coyote which are transported together in a flume with current velocities of up to 152 cm/sec.

Group I	Group II	Group III
RIBS	FEMUR	SKULL
VERTEBRAE	TIBIA	MANDIBLE
SACRUM	HUMERUS	(ramus)
STERNUM	METAPODIAL	
(scapula)	PELVIS	
(phalanx)	RADIUS	
(ulna)	(scapula)	
	(ramus)	
	(phalanx)	
	(ulna)	
Immediately transported by flotation or by saltation	Transported later than Group I, usually by traction	Resisted transport, lagging far behind other groups.

Parentheses indicate occurrence on more than one group. (From Voorhies, 1969)

Behrensmeyer Dispersal Groups: Dispersal potential of bones of modern African mammals determined by weight and/or density. These elements will disperse in a similar manner to Voorhies Group III skeletal elements (lag) shown above.

Reduncine	Suid	Alcelaphine	Equus
SKULL	SKULL	SKULL	SKULL
MANDIBLE	MANDIBLE	MANDIBLE	MANDIBLE
FEMUR	FEMUR	FEMUR	FEMUR
HUMERUS	HUMERUS	HUMERUS	HUMERUS
RADIUS	RADIUS	RADIUS	RADIUS

(Adapted from Behrensmeyer, 1975)

Appendix 4-1: Dispersal Potential of Animal Bones in Fluvial Environments and the Impact on the Thaphonocoenose

Appendix 4-2: Isotope values for selected teeth from area 41 excavation
(Data compiled by Dr. Naomi Levin and presented with her permission)

Taxon		SampleID	$\delta^{13}C$ VPDB	$\delta^{18}O$ VPDB	Tooth position
Bovidae	Aepycerotini	FwJj20-1478	-0.9	-2.3	rm3
Bovidae	Aepycerotini	FwJj20-9577	1.5	-0.4	m frag
Bovidae	Aepycerotini	FwJj20-5638	0.3	-3.6	m
Bovidae	Aepycerotini	FwJj20-8372	-3.3	-1.8	lm3
Bovidae	Alcelaphini	FwJj20-10340	1.7	-1.6	m frag
Bovidae	Alcelaphini	FwJj20-6595	1.1	-0.7	rm3
Bovidae	Alcelaphini	FwJj20-7624	1.2	-0.3	rm3
Bovidae	Alcelaphini	FwJj20-6932	1.2	0.1	rm3
Bovidae	Alcelaphini	FwJj20-6957	1.3	-1.1	rm3
Bovidae	Alcelaphini	FwJj20-6958	1.8	-1.0	rm3
Bovidae	Alcelaphini	FwJj20-8173	1.0	0.1	rm3
Bovidae	Alcelaphini	FwJj20-8523	1.5	-0.7	rm3
Bovidae	Hippotragini	FwJj20-7923	1.8	-0.5	lm3
Bovidae	Reduncini	FwJj20-1271	1.3	-1.1	M3
Bovidae	Reduncini	FwJj20-1946	0.5	-0.8	lm3
Bovidae	Reduncini	FwJj20-1812	1.0	-2.3	m
Bovidae	Reduncini	FwJj20-6596	1.3	-2.2	rm3
Bovidae	Reduncini	FwJj20-5619	0.7	-3.7	m
Elephantidae	gen. sp. indet.	FwJj20-10350	-0.4	-2.6	plate frag
Elephantidae	gen. sp. indet.	FwJj20-5270	-0.6	-3.9	plate frag
Elephantidae	gen. sp. indet.	FwJj20-5042	-0.5	-3.2	plate frag
Elephantidae	gen. sp. indet.	FwJj20-5452	0.0	-3.6	plate frag
Elephantidae	gen. sp. indet.	FwJj20-5940	-0.5	-3.7	plate frag
Elephantidae	gen. sp. indet.	FwJj20-8275	-0.6	-2.9	plate frag
Equidae	gen. sp. Indet.	FwJj20-7531	-0.4	-1.3	m or p
Equidae	gen. sp. Indet.	FwJj20-7710	-0.8	-1.2	m or p
Equidae	gen. sp. Indet.	FwJj20-6754	-0.3	1.7	m or p
Equidae	*Eurygnathohippus* sp.	FwJj20-1830	0.2	-0.3	m or p
Equidae	*Eurygnathohippus* sp.	FwJj20-5493	0.1	-1.3	m or p
Equidae	*Eurygnathohippus* sp.	FwJj20-8384	0.7	-0.4	m or p
Giraffidae	gen. sp. indet.	FwJj20-1800	-10.7	-0.3	m
Giraffidae	gen. sp. indet.	FwJj20-8599	-12.0	-0.8	m
Hippopotamidae	aff. *Hippopotamous gorgops*	FwJj20-5076	-0.7	-4.8	lm3
Hippopotamidae	aff. *Hippopotamus karumensis*	FwJj20-5654	-2.2	-6.4	lm3
Hippopotamidae	aff. *Hippopotamus karumensis*	FwJj20-5850	-1.7	-6.0	lm3
Hippopotamidae	aff. *Hippopotamus karumensis*	FwJj20-8390	-2.0	-4.7	lm3
Hippopotamidae	aff. *Hippopotamus karumensis*	FwJj20-5238	-0.7	-5.9	lm3

Hippopotamidae	aff. *Hippopotamus karumensis*	FwJj20-6869	-1.2	-5.6	rm3
Hippopotamidae	aff. *Hippopotamus karumensis*	FwJj20-7081	-0.4	-5.4	rm3
Hippopotamidae	aff. *Hippopotamus karumensis*	FwJj20-8657	-2.1	-5.4	rm3
Hippopotamidae	aff. *Hippopotamus karumensis*	FwJj20-8684	-1.9	-4.9	rm3
Hippopotamidae	*Hippopotamus* sp.	FwJj20-2287	-0.4	-5.8	tusk frag
Rhinoceratidae	*Diceros* sp.	FwJj20-7818	1.1	-3.3	m
Rhinoceratidae	*Diceros* sp.	FwJj20-8403	0.9	-1.6	m
Suidae	*Kolpochoerus* sp.	FwJj20-6364	-0.1	-3.7	m frag
Suidae	*Kolpochoerus* sp.	FwJj20-6591	0.2	-2.6	m frag
Suidae	*Kolpochoerus* sp.	FwJj20-7312	-0.4	-2.0	m/M3
Suidae	*Kolpochoerus* sp.	FwJj20-8037	-0.2	-3.4	m frag
Suidae	*Kolpochoerus* sp.	FwJj20-8144	-0.6	-1.2	m/M3
Suidae	*Kolpochoerus* sp.	FwJj20-8391	-0.2	-3.5	m/M3
Suidae	*Metridiochoerus* sp.	FwJj20-1630	-0.9	-3.2	m/M3
Suidae	*Metridiochoerus* sp.	FwJj20-7932	-0.9	-1.9	m/M3
Suidae	*Metridiochoerus* sp.	FwJj20-7942	-1.5	-0.9	m/M3
Suidae	*Metridiochoerus* sp.	FwJj20-8633	-0.7	-2.5	m/M3
Suidae	*Metridiochoerus* sp.	FwJj20-10368	-1.2	-2.9	m3
Suidae	*Notochoerus* sp.	FwJj20-10381	-0.6	-2.8	m3
Suidae	*Notochoerus scotti*	FwJj20-10394	-0.3	-1.3	m3
Suidae	*Notochoerus* sp.	FwJj20-144	-1.1	-2.2	m
Suidae	*Notochoerus* sp.	FwJj20-1699	-0.8	-1.0	m/M3
Suidae	*Notochoerus* sp.	FwJj20-7943	-0.6	-2.4	m/M3
Suidae	*Notochoerus* sp.	FwJj20-8698	-1.0	-0.3	m

Abbreviations for tooth position are as follows: r, right; l, left; m, molar; p, premolar.
Uppercase and lowercase letters refer to the maxillar and mandibular teeth, respectively.

Element	Area 41 (survey)	Area 130	Area 131	Area 105	Area 102
Group III					
Skull	22	9	2	7	
Mandible	8	6	7	7	
Femur	5	7	15	8	
Humerus	17	5	11	6	
Radius	8	4	11	8	
Tibia	7	7	9	3	
Group I/II					
Ulna	7	2	10	3	0
Metapodials	50	14	13	11	1
Vertebrae	4	1	0	2	0
Phalanges	33	3	21	3	2
Astraglas	20	6	1	9	0
Calcanum	15	2	3	3	2
Teeth	373	57	13	16	5
NISP$_{taxon}$	614	124	134	94	12

Appendix 4-3: Number of skeletal elements in each dispersal group per research location as defined by Behrensmeyer (1975) and Voorhies (1969).

Skeletal Element	130A	130B	130C	130D	130E	131A	131B	131 Random Survey	105 GPS-X	105 GPS-Y	105 GPS-Z	Fxlj-13 Area	102
Group III													
Skull	5	1	0	3	0	2	0	0	3	1	3	0	
Mandible	1	0	3	1	1	5	1	1	5	1	1	0	
Femur	2	3	0	1	1	9	6	0	4	3	0	1	
Humerus	0	1	0	2	2	8	3	0	2	1	3	0	
Radius	1	1	0	0	2	8	2	1	3	1	4	0	
Tibia	2	1	0	1	3	6	0	3	0	0	3	0	
Group I&II													
Ulna	1	0	1	0	0	8	1	1	2	0	1	0	0
Metapodial	6	0	2	3	3	9	4	0	6	3	0	1	1
Vertebrae	0	0	1	0	0	0	0	0	1	0	1	0	0
Phalanges	0	1	0	2	0	14	7	0	0	1	2	0	2
Astragalus	0	2	0	4	0	1	0	0	0	1	8	0	0
Calcaneum	1	0	0	1	0	2	1	0	0	1	2	0	2
Scapula	2	0	2	0	0	2	0	0	1	1	0	0	1

Appendix 4-4: Number of skeletal elements in each dispersal group from each individual "site" and research location as defined by Behrensmeyer (1975) and Voorhies (1969).

Specimen Number	Notch Breadth	Notch Depth	Ratio NB/ND	Estimated Notch Angle	Comments
A-397	11.35	0.85	13.35	30	flake scar deep & braod
A-525 (1)	21.35	1.56	13.69	>30	very worn
A-525 (2)	11.52	1.12	10.29	<30	very worn
A-557	8.48	1.51	5.62	>30	large broad surface flake removed
A-844	6.96	1.63	4.27	45	small bone
B-81	27.27	3.51	7.77	30	
B-82	4.46	2.72	1.64	<30	
B-086	30.33	1.69	17.95	>30	PM&PN
B-167	15.91	2.26	7.04	<30	PM&PN large flake scar
B-178	11.48	0.72	15.94	>30	very small fragment
B-935	13.62	1.58	8.62	<30	
B-938	5.8	1.62	3.58	<30	very small fragment & flake
B-941	40.32	3.06	13.18	>30	
B-944	18.95	1.69	11.21	45	
B-950	26.54	2.3	11.54	>30	PM & striations very worn
B-953	27.01	1.79	15.09	<30	small fragment size 1
D-118(1)	19.1	1.99	9.6	30	broad flake scar hinged
D-118(2)	22.35	2.49	8.98	<30	
D-151	31.74	3.95	8.04	<30	
D-171	13.53	1.73	7.82	>30	very worn
D-179	13.81	1.5	9.21	>30	very worn

Appendix 5-1: **Measurements of notches found on shaft fragment specimens; Areas 41, 130, 105**

Appendix 5-2: Shaft Fragment
Fracture Plane Angles

Specimen Number	Boundry Number	Fracture Plane Angle	Size Class	Element	Comments
A028	O1	108/112	2	PSH	area 41
A074	T1	106/108	2	LBN/MSH	area 41
A074	O1	71/72	2	LBN/MSH	area 41
A193	L1	92		LBN/MSH	area 41
A235	L1	86/87	2	LBN/MSH	area 41
A279	L1	120		LBN/MSH	area 41
A381	O1	101	2	LBN/MSH	area 41
A397	L1	65	2	LBN/MSH	area 41
A397	O1	142	2	LBN/MSH	area 41
A400	O1	75	2	RAD/MSH	area 41
A408	O1	74		LBN/MSH	area 41
A408	O2	47		LBN/MSH	area 41
A417	O1	79		LBN/MSH	area 41
A419	O1	64	3	LBN/MSH	area 41
A427	L1	88	1	FEM/MSH	area 41
A427	L2	75	1	FEM/MSH	area 41
A462-A	L1	69		LBN/MSH	area 41
A462-A	L2	68		LBN/MSH	area 41
A462-B	O1	77		LBN/MSH	area 41
A473	L1	63		LBN/MSH	area 41
A493	O1	90/94		LBN/MSH	area 41
A493	L1	104		LBN/MSH	area 41
A508	O1	53		LBN/MSH	area 41
A523	L1	83	2	LBN/MSH	area 41
A525	O1	72		LBN/MSH	area 41
A583	L1	103		LBN/MSH	area 41
A621	O1	64		LBN/MSH	area 41
A786	O1	54		LBN/MSH	area 41
A801	L1	104	2	TIB/MSH	area 41
A801	L2	90	2	TIB/MSH	area 41
A811	O1	69	2	LBN/MSH	area 41
A811	O1	65	2	LBN/MSH	area 41
A814	O1	93		LBN/MSH	area 41
A814	O2	79		LBN/MSH	area 41
A815	O1	96		LBN/MSH	area 41

A816	L1	79	2	HUM/MSH	area 41
A837	O1	72	2	HUM/MSH	area 41
A844	O1	55	2	RAD/MSH	area 41
A844	L1	114	2	RAD/MSH	area 41
B086	O2	118		LBN/MSH	area 130
B090	O1	125		LBN/MSH	area 130
B127	O1	50		LBN/MSH	area 130
B129	O1	56		LBN/MSH	area 130
B129	O2	88		LBN/MSH	area 130
B130	O1	62	2	LBN/MSH	area 130
B150	L1	92		TIB/MSH	area 130
B154	O1	56		LBN/MSH	area 130
B926	O1	60		LBN/MSH	area 130
B940	O1	76		LBN/MSH	area 130
B940	O2	137		LBN/MSH	area 130
B943	L1	94		FEM/MSH	area 130
B943	O1	117		FEM/MSH	area 130
B947	O1	83	2	TIB/MSH	area 130
B947	O2	56	2	TIB/MSH	area 130
B947	O3	80	2	TIB/MSH	area 130
B950	L1	62	2	LBN/MSH	area 130
B951	O1	26		LBN/MSH	area 130
B952	O1	87	2 or 3	LBN/MSH	area 130
B957	L1	107		FEM/MSH	area 130
B960	L1	72		LBN/MSH	area 130
B960	O1	62		LBN/MSH	area 130
C214	L1	99		LBN/MSH	area 131
C212	L1	91		LBN/MSH	area 131
C210	O1	91		TIB/MSH	area 131
D113	O1	111	2	FEM/MSH	area 105
D113	O2	134	2	FEM/MSH	area 105
D114	O1	65	2	FEM/MSH	area 105
D118	O1	39	2 or 3	HUM/MSH	area 105
D119	O1	57		HUM/MSH	area 105
D120	O1	102	2 or 3	HUM/MSH	area 105
D120	O2	102	2 or 3	HUM/MSH	area 105
D120	O3	84	2 or 3	HUM/MSH	area 105
D133	L1	84		LBN/MSH	area 105
D135	O1	60		HUM/MSH	area 105
D144	O1	109	2	FEM/MSH	area 105
D152	O1	60	2	FEM/MSH	area 105

D153	O1	54	2	RAD/MSH	area 105
D177	O1	108		FEM/MSH	area 105
D177	T1	95		FEM/MSH	area 105
D179	O1	82		HUM/MSH	area 105
D180	T1	84		HUM/MSH	area 105
D180	O1	90		HUM/MSH	area 105

Characteristics of Marks on Bone Surfaces

Type	Plan Form	Cross-Section Shape	Orientation to Bone's Long Axis	Other Features
Carnivore Tooth Marks				
Pit	circular to polygonal, size variable	bowl-shaped to irregular	N.A.	internal surface crushed; isolated or associated with other tooth marks; microstriations rare
Score	linear; straight usually broader than cut marks	U-shaped, rarely V-shaped	variable, tending to transverse	same as tooth pits
Puncture	circular, usually large	bowl-shaped	N.A.	occurs on cancellous bone, with thin cortical bone depressed into trabeculae
Furrow	linear, usually large and straight	U-shaped	perpendicular to break edge	usually occurs on cancellous bone
Sharp-edged Tool Marks				
Cut	linear, usu. narrower than tooth scores	V-shaped	filleting is oblique, disarticulation is transverse	lacks internal crushing of tooth marks. Internal sur-surface with parallel microstriae; isolated or often in multiple, sub-parallel sets
Chop	linear, large, broad, deep	V-shaped	usually transverse	deepest (successful) chops fracture bone, and occur on edge
Saw	similar to chop	rectangular	usually transverse	internal walls with longitudinal striae
Scraping	long, shallow linear series of parallel striae	individual striae too shallow to discern X-section	always longitudinal	mark surface has shaved appearance, often with dimpling. Sub-parallel scraping marks often overlap. Often with a series of transverse, short "cuts" (= chatter marks)

Appendix 5-3: Bone Surface Modification Morphological (page 1of 2) Characteristics (Courtesy of Robert Blumenschine)

Type	Plan Form	Cross-Section Shape	Orientation to Bone's Long Axis	Other Features
Percussion (Pounding Tool) Marks				
Pits	similar to carnivore tooth pits	bowl-shaped to irregular	N.A.	internal surface usually without crushing, and usually with microstriations within +/or emanating from mark in transverse orientation. Usually within 5 mm of fracture edge.
Patch of Micro-striations	dense series or shallow, narrow, parallel, linear striae	individual striae too shallow to discern X-section	transverse	usually within 5 mm of fracture edge. Can occur as isolated patch or in association with other percussion marks.
Groove	deeply embed-ded patch of microstriations	individual striae V-shaped	transverse	As with percussion pits and isolated patches of microstriations
Trample Marks				
	like cut marks	like cut marks	variable	individual marks like cuts but random location and orientation relative to soft tissue anatomy dis-tinguishes trample marks
Rodent Gnaw Marks				
	broad, shallow parallel pairs of linear marks	rectangular	variable	usually occur in dense, extensive patches, greatly reducing bone thickness, and often creating a "window" through bone
Root Etching				
	broad, shallow sinuous mass of marks	U-shaped, often with cortical "shelving"	variable	difficult to mis-diagnose after seeing these once
Preparator's/Excavator's Marks				
	usually linear, with variable length, breadth and depth		variable	internal surface always different color than unscathed surface, including internal surface of pre-fossilization marks

(handwritten annotation near Root Etching cross-section: "lipping" with arrow pointing to U-shaped diagram)

Appendix 5-3: Bone Surface Modification Morphological   (page 2 of 2) Characteristics (Courtesy of Robert Blumenschine)

Appendix 5-4: List of specimens field identified as modified								
spec. #	skeletal Part	port.	side	size	taxon	Modification	comments	area
A026	TIB	PSH	R		I	TM, TS,CM		41
A077	MET	DS	L		Equid	CM/TM	CM? badly worn & rounded	41
A121	PHA1	PX	R		Equid	CM/TS	Cut mark	41
A365	HUM	DSH	L	3	Bovid	CM/TP		41
A400	RAD	MSH			I	CM/PM/TM	2 pieces	41
A533	MCM			2	Bovid	CM?	3 pieces no refit	41
A668	HUM	DS	R	2	Bovid	CM/TM		41
A723	MET	DS		2	Bovid	CM/TM	one condyle	41
A825	RAD	PX	L		Suid	CM/TS/TM	CM on top of TS	41
A831	HUM	NEF			I	CM		41
A860	TIB	MSH			Bovid	CM	see FwJj20 gps only 2005	41
A910	LBN	NEF			I	CM	GPS: FS5CM	41
A927	PHA1	CO		2	Bovid	CM	see FwJj20 gps only 2006	41
2023	RIB				I	CM		41
5211	RIB	FR			I	CMs		41
5399	TIB	MSH	R	3	Bovid	TP/CM		41
6243	RIB	NEF			I	CM		41
6255	MAND				Bovid	CM	condyle	41
6282		FR			I	CM?	flat bone	41
6371	VERT				I	CM		41
6523	Flat bone	FR			I	CM		41
6603	RIB	MSH			I	CM		41
6726	LBN	MSH			I	CM?		41
7808	TIB	MSH	L	2	I	CMs		41
7867	RIB				I	CM?		41
8549	LBN	MSH			I	CM		41
8602	TIB	MSH	R	2	Bovid	CM		41
8604	SCA	GLEN	L	2	Bovid	CM		41
8624	MET			2	Bovid	CM		41
B059	RAD	PX	R	3	Bovid	CM	TM, TS gps	130

							920CMR	
B060	RIB	MSH			I	CM	0214478/0463 473 TS	130
B962	RIB	MSH			I	CM	TM	130
B962 A	RIB	MSH			I	CM	gps: near FxJj83 2/05	130
B963	RIB	MSH			I	CM	0214020/0463 605 CMRIB3	130
B074	TIB	CO			Bovid	CM TSTM	2 pieces	130
B961	HUM	DS	L		Hippo	CM/TS/TP	0214161/0463 176 2 pieces, TM, TS	130
B967	RAD	MSH	R	3	Bovid	CM/TS/TP	gps: 37N0213201/0 462696 (collected 2001)	130
C186	RIB	MSH			I	CM	? Worn	131
C217	RADUL N	DS	L	2	Bovid	CM	gps: JUL4CM-1	131
C221	RIB				I	CM	131A	131
D003	FEM	DS			Hippo	CM	0206844/0450 721 (sub adult)	105
D004	RAD	DS	L		Hippo	CM	0206844/0450 721 TS	105
D022	ATL	CO			Hippo	CM	0207840/0449 222	105
D023	PHA1				Hippo	CM	0207851/0449 217	105
D057	RIB	MSH			I	CM	0207857/0449 222	105
D150	RADU	PX	R		Hippo	CM	0206844/0450 721: TP/TS	105
D005	RIB	MSH			Hippo	CM/TP/TS	0206844/0450 721	105

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