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How the geological record affects our reconstructions of early Middle Stone Age settlement patterns: The case of an alluvial fan setting for Koimilot (Kapthurin Formation), Kenya

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Abstract. *Variation in artifact type, site function and location are among the variables used to assess behavioral changes in the archaeological record. However, our understanding of these variables is strongly conditioned by the depositional context of the recovered material. As an example, I explore the affects of an alluvial fan depositional setting on our understanding of Middle Pleistocene hominin behavioral variation in eastern Africa, focusing on artifact assemblages from the site of Koimilot, located west of Lake Baringo in the Gregory Rift Valley of Kenya. Koimilot is one of a small number of typologically Middle Stone Age sites that predate the last interglacial, and provides an important comparison with older Acheulian assemblages from the Kapthurin Formation. Alluvial fan settings provide a range of resources that may have attracted hominins, and also are conducive to archaeological site burial and preservation. Geological, environmental, and archaeological data suggest that Koimilot may preferentially preserve only a restricted portion of the full behavioral repertoire of past hominin foraging populations in the Baringo area.*

Résumé. *Les variations dans les types d'outils, la fonction des sites et leur localisation font partie des variables prises en compte pour l'évaluation des changements comportementaux dans le registre archéologique. Cependant notre compréhension de ces variables est fortement dépendante du contexte de mise en place du matériel retrouvé. A titre d'exemple, j'explore les effets du contexte de dépôt en cône d'alluvial sur notre compréhension de la variabilité comportementale des hominidés du Pléistocène en Afrique de l'est, en considérant tout particulièrement les ensembles lithiques du site de Koimilot, situé à l'ouest du lac Baringo dans la Gregory Rift Valley au Kenya. Koimilot fait partie de ces petits sites antérieurs à la dernière phase interglaciaire, attribués typologiquement au Middle Stone Age et apportant des éléments de comparaison importants avec les ensembles acheuléens plus anciens de la formation de Kapthurin. Le contexte de cône alluvial fournit un ensemble de ressources qui ont pu à la fois attirer les hominidés et favorisé l'enfouissement et la préservation des sites archéologiques. Les données géologiques, environnementales et archéologiques suggèrent que Koimilot n'aurait préservé qu'une portion restreinte de tout le répertoire comportemental des populations d'hominidés anciens ayant subsisté dans la région de Baringo.*

INTRODUCTION

Archaeological sites from the Kapthurin Formation of Kenya have played an important role in our understanding of the complex nature of change during the technological shift known as the Acheulian to Middle Stone Age (MSA) transition (McBrearty and Tryon 2005; Tryon and McBrearty 2006; Tryon et al. 2005). This transition is broadly coincident with, and in many places slightly precedes, the earliest appearance of *Homo sapiens* in Africa (McDougall et al. 2005), within the limited chronological control of first and last appearance datums for artifacts and fossils at this time depth. Technological differences between Acheulian and MSA assemblages are largely defined by changes in artifact typology that reflect (1) hominin abandonment of the production of handaxes and other ‘large cutting tools’, (2) the manufacture of stone and bone points of a variety of shapes and sizes for use as parts of knives, spears, or similar implements, and (3) the increased use of Levallois or similar methods for flake production. The apparent complexity in the archaeological record of the Kapthurin Formation derives from stratigraphic observations of the persistence of some stone artifact types, such as handaxes, well after the appearance of points, and the co-occurrence of Levallois technology at both Acheulian and MSA sites. This situation is not unique to Eastern Africa, as comparable patterns have been reported, at a different spatial and temporal scale, for Lower and Middle Paleolithic sites in Western Europe (Monnier 2006).

That the archaeological record suggests a complex process of change at the Acheulian-MSA boundary is itself not surprising. Technological change is risky, and rates of innovation and the dispersal of new ideas are largely products of population size (Fitzhugh 2001; Shennan 2001). Given the small and dispersed nature of hominin populations throughout most of the Pleistocene, local extinctions of biological communities and behavioral traditions were likely the norm (Hovers and Belfer-Cohen 2005; see also Butzer 1988). Furthermore, the spread of new ideas is subject to local modifications due to idiosyncratic choice or differences in local raw material availability, and may be periodically abandoned as needed. Finally, not all that is new is better, as new technology is mediated by local ecology as well as social choice, leading to geographically adjacent populations practicing different subsistence behaviors (Rowley-Conwy 2001; Layton 2001). All of these behavioral factors may lead to a complex sequence of technological change through time, particularly when combined with sampling biases resulting from variable rates of sedimentation and preservation and discontinuous exposure of ancient strata.

In order better to explain the observed patterns of change through time, we need a more complete understanding of variation in space. Studies of settlement patterns, or landscape archaeological approaches in general, are founded in part on the premise that when studying mobile foraging populations, no single site will preserve the full range of material traces of that group. Importantly, as noted by Binford (1983), subtle changes in land use by a single population in response to local social or environmental factors can produce an archaeological record that mimics behavioral change over time, but which instead reflects differential sampling of the total range of activities performed by that group due to changes in site function. Thus, any understanding of temporal change that lacks an appreciation of this spatial variation in activities and their material correlates is necessarily incomplete.

It is with this in mind that I return to the archaeological record of the Kapthurin Formation, shifting my perspective from one that has focused on diachronic change (e.g., Tryon and McBreaty 2006; Tryon et al. 2005) to one that instead examines synchronic variation in hominin behavior and paleoenvironment. I propose an alluvial fan depositional model for artifact-bearing sediments in the Kapthurin Formation and explore its implications for understanding the archaeological record there. I emphasize available geological data, observations of present-day sedimentation patterns in areas where the Kapthurin Formation is exposed, and my own excavations at the site of Koimilot. Sediments of the Kapthurin Formation crop out in an easterly-tilted half-graben, west of Lake Baringo in the Kenyan Rify Valley. The Baringo area today is characterized in part by alluvial fan sedimentation (Tiercelin 1990). Alluvial fans are common in tectonically active environments such as the Rift Valley (e.g., Blair and McPherson 1994b; Bull 1977; Tiercelin 1990), and ancient alluvial fans have been inferred as depositional settings for other artifact- and fossil-bearing localities in Kenya and Ethiopia such as the Turkana Basin (Burggraf and Vondra 1982) and in Tanzania at Olduvai Gorge and Peninj (Ashley and Hay 2002; Isaac 1967). As such, the results discussed here have implications for interpreting sites beyond the Kapthurin Formation.

THE KAPTHURIN FORMATION

Stratigraphy and chronology

The more than 150 km^2 of exposed sediments attributed to the Kapthurin Formation crop out west of Lake Baringo, in the Rift Valley of Kenya (~0°32’ N, 35°57’ E) (fig. 1). The Kapthurin Formation forms part of the sedimentary sequence of the Tugen Hills, an uplifted, faulted complex of lavas and sediments exposed west of Lake Baringo in the Gregory Rift Valley of Kenya (Chapman et al. 1978) (fig. 1). The Kapthurin Formation was originally mapped and described by McCall et al. (1967), Martyn (1969; Leakey et al. 1969) and Tallon (1976, 1978) (see Hill 2002 for further details on the history of geological investigation in the area). It consists of terrigenous and volcaniclastic sediments as well as intercalated lavas, and is divided into five members, numbered K1–K5 from bottom to top, as shown in figure 2. I focus here on portions of the sequence where most archaeological and paleontological sites occur: K3 (The Middle Silts and Gravels Member), with a cumulative thickness of 40 m, and K4 (The Bedded Tuff Member), with a cumulative thickness of >15 m (Tallon 1976, 1978). As its name implies, the Middle Silts and Gravels Member consists of sediments of a range of particle sizes, as well as rare paleosols, attributed by previous authors to upland, ‘fluvio-lacustrine,’ and a well-defined lacustrine facies. The overlying Bedded Tuff Member consists of 15 or more layers of airfall and reworked tephra as well as intercalated sediments and paleosols formed in environments comparable to those inferred for the Middle Silts and Gravels Member (Tryon and McBrearty 2006).

All sediments and sites discussed in this paper are Middle Pleistocene in age, defined here as the interval between ~780 ka and ~130 ka, bounded by the Brunhes-Matuyama paleomagnetic polarity shift and the onset of the last interglacial (Gibbard 2003; Singer et al. 2002; Sarna-Wojcicki et al. 2000). All Kapthurin Formation sediments and intercalated lavas are normally magnetized (Dagley et al. 1978). Sediments of the Middle Silts and Gravels Member (K3) are underlain by the Pumice Tuff Member (K2), dated to 543 ± 4 ka; additional chronological control in some portions of K3 are provided by the discontinuously exposed Grey Tuff, dated to 509 ± 9 ka (Deino and McBrearty 2002) (fig. 2). Two tephra layers within the upper portions of the Bedded Tuff Member are dated to 284 ± 12 ka and 235 ± 2 ka (Deino and McBrearty 2002; Tryon and McBrearty 2002, 2006). The cessation of Kapthurin Formation sedimentation is largely defined by a series of faulting events that led to the onset of the current erosional regime (Tallon 1976). Age estimates that span ~198–345 ka for these faulting episodes are provided by U-series dating of thermal silica that formed in fault-related cracks in local lavas (Le Gall et al. 2000). This suggests an upper age limit of ~200 ka for all Kapthurin Formation sediments (fig. 2).

Archaeology and paleoenvironments

More than 60 artifact- and fossil-bearing sites have been recorded from the Kapthurin Formation since research formally began there in 1967, of which a small sample are shown in figure 3 (e.g., Leakey et al. 1969; Cornelissen et al. 1990; McBrearty and Tryon 2005; Tryon 2002; see McBrearty 1999, 2005 for details of the history and extent of research in the

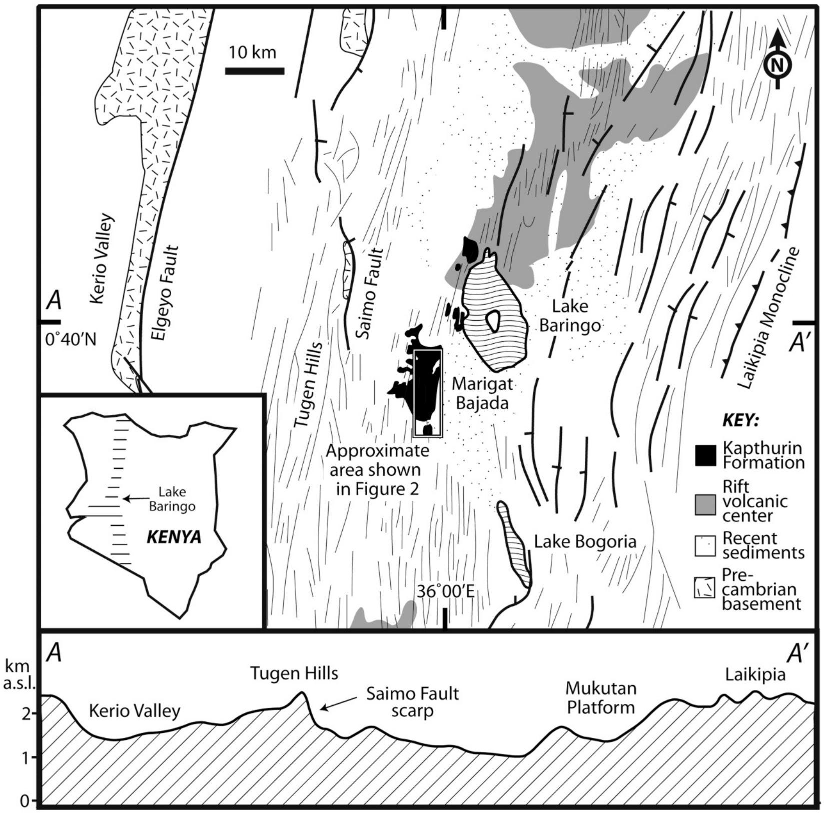

Fig. 1. Simplified map of the topography, structure, and geology of the Lake Baringo area, including location of selected major and minor faults. Note that for major faults (those with throws of several hundred meters), tick denotes downfaulted side. On the schematic cross-section, vertical axis is exaggerated five times relative to the horizontal axis. Inset map shows position of the Rift Valley within modern political boundaries of Kenya. After Dunkley et al. (1993) and Hautot et al. (2000).

region). In addition to several artifact collections, summarized below, the Kapthurin Formation has produced a diverse fauna, including specimens attributed to *Pan* and *Homo*, the latter most recently attributed to *Homo rhodesiensis* (see McBrearty 1999; McBrearty and Brooks 2000; McBrearty and Jablonski 2005; Wood 1999). Although the effects of spatial and temporal variation cannot be separated, habitat diversity is particularly reflected among the suids. Specimens from the Middle Silts and Gravels Member include those attributed to the grassland-dwelling warthog (*Phacochoerus*), the wide–ranging bushpig (*Kolpochoerus*) (McBrearty et al. 1996) and giant forest hog (*Hylochoerus*) (Tryon 2003: 340).

Following the terminology of Tallon (1978), most archaeological sites, with and without associated fossils, can be attributed to broadly defined upland/subaerial, lacustrine, or fluviolacustrine facies of the Middle Silts and Gravels Member (K3) and the Bedded Tuff Member (K4), although this is not always a straightforward endeavor in the field. As shown schematically in figure 3, these facies vary laterally along a West-East gradient (with localized outcrops suggesting alluvial or fluvial settings). The upland facies records areas receiving little active sedimentation, typically exposed in western outcrops, characterized in places by channel incision of the fluvial facies. The lacustrine facies currently provides our best understanding of the paleoenvironment and its possible effect on the archaeological record.

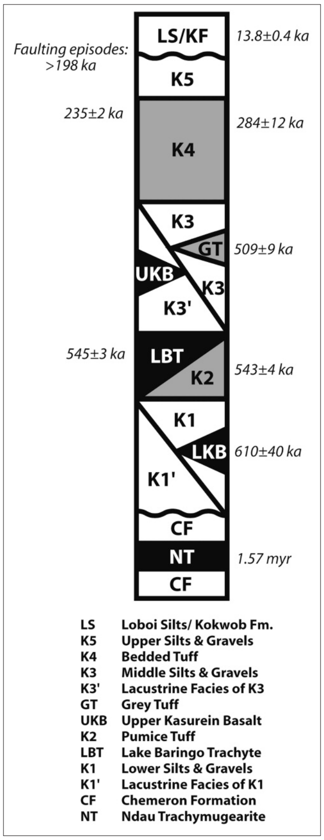

Fig. 2. Schematic stratigraphic section of the Kapthurin Formation including available radiometric age estimates, after Deino and McBrearty (2002), Le Gall et al. (2000), and Renaut and Owen (1980).

The lacustrine facies of K3 reflects the shore line of a fluctuating hyperalkaline lake, characterized by surface-collected archaeological assemblages notable for their lack of handaxes or other shaped pieces (McBrearty 1999; Renaut et al. 1999, 2000). Evidence of flaking technology consists of a variety of simple core forms derived from the extensive reduction of small lava cobbles. More recent investigations have also identified perennial freshwater springs in lake-marginal sediments suggesting local wetlands within the Middle Silts and Gravels Member (Johnson et al. 2009).

A greater number of excavated sites occur in sediments deposited in fluviolacustrine facies. Sites that can likely be attributed to the fluviolacustrine facies are notable for their variation in tool types and flake production methods, and are consistent with a complex, mosaic process of change during the Acheulian to Middle Stone Age transition (reviewed in Tryon and McBrearty 2006). Features of some of the lithic assemblages include handaxes,

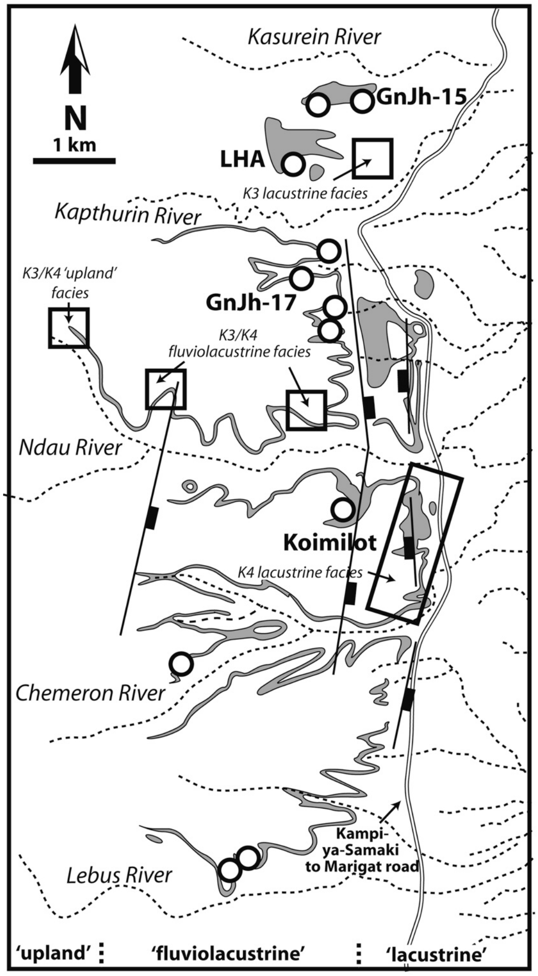

Fig. 3. Simplified map of Kapthurin Formation outcrops, showing (in grey) exposures of Bedded Tuff Member (K4) sediments that cap local ridges and overlie those of the Middle Silts and Gravels Member (K3). Selected archaeological sites shown as circles, drainages as dashed lines. Depositional environments (shown in boxes) are those proposed by Tallon (1976). Boxes denote local interpretations based upon detailed stratigraphic sections measured by Tallon (1976), with inferred lateral ranges of each depositional environment (upland, fluviolacustrine, or lacustrine) shown at the base of the figure. Selected major faults shown, with tick on down-thrown side.

cleavers, and points, as well as controlled blade production and implementation of various Levallois methods for the manufacture of blanks ranging in size from 4 cm to a remarkable 22 cm in length.

LESSONS FROM MODERN ANALOGUES IN THE BARINGO AREA

I turn now to the modern environment in the Baringo area because it holds important clues for interpreting the depositional modes of Kapthurin Formation sediments and the local distribution of archaeological sites.

Topographic and environmental variation

The area west of Lake Baringo is today a sparsely vegetated *Acacia* thorn scrub or brush land, with woody vegetation accounting for only 5–20% areal coverage. Other groundcover is rare except for annual grasses, common only at the lake margin or in swamps at the southern end of the lake. Low-lying areas near the lake at ~900 m above sea level (a.s.l.) receive ~400–760 mm of rain per year, with peak rainfall in the late spring and early fall. Rainfall is highly variable, droughts are frequent, and evapotranspiration rates exceed annual precipitation levels. Average daily temperature in this semi-arid environment is 25° C (77° F), with recorded daily maximum temperatures reaching 46° C (115° F). In comparison with land near Lake Baringo, upland areas in the Tugen Hills (fig. 1) at ~2300 m a.s.l receive ~1100–1400 mm per year with average temperatures of 14° C (57° F). The highlands are characterized as a humid subtropical region, with montane forest covering many areas (Anderson 2002; Hodder 1982; Kipkorir 2002; Little 1992; Survey of Kenya 1970; Sutherland 1991; Thom and Martin 1983).

Topographic height largely controls modern ecological diversity, in large part due to higher rainfall and lower temperatures in the uplands (Thom and Martin 1983). This has a pronounced impact on the distribution of the local Tugen, Pokot, and Il Chamus (Maasai) agro-pastoralist communities in the area today. Population density is considerably higher (by up to an order of magnitude) in the more densely vegetated uplands than low lying areas near Lake Baringo (Thom and Martin 1983), although this is in part due to the extensive reliance upon agriculture at higher altitudes. Precisely how this would have impacted foraging populations is unclear, further complicated by the fact that the modern conditions are a poor reflection of the distribution of fauna in the past, as livestock and extensive hunting by European colonists in the late 19th and early 20th centuries has driven off most local game (Anderson 2002; Little 1992).

It is important to emphasize that much of the present-day ecological variation, from semi-arid lowlands to humid subtropical uplands occurs along a West-East axis < 30 km in length. The Tugen Hills have represented a local topographic high point since the Miocene (Chapman et al. 1978; Hautot et al. 2000; Le Gall et al. 2000), suggesting considerable antiquity for this ecological gradient. The < 30 km transect between upland and lowland resources is well within the foraging range of modern populations (Kelly 1995), and individuals routinely move between these areas in Baringo on a daily to seasonal basis (e.g., Hodder 1977). In contrast, archaeological sites of the Kapthurin Formation occur along a North-South transect due to sediment exposure initiated by faulting and subsequent westward migration of streams along nickpoints (fig. 3), sampling a range of alluvial and near-shore environments.

This alone should give us pause when attempting to use the archaeological record to interpret the settlement patterns of mobile foraging populations in the Baringo area.

It is widely recognized that there is a problem interpreting hominin use of ancient landscapes only from preserved sediment traps which rarely if ever include upland areas receiving little sedimentation (Potts et al. 1999, 2004; White 1988). It is at present impossible to assess whether the site distribution in the Kapthurin Formation reflects a biased sample as an artifact of preservation and exposure, or whether it reflects the preferential exploitation of the ecotone between upland and lowland resources as proposed by Ambrose (2001) for elsewhere in the Rift Valley. What we know is still less than what we would like to know.

Sedimentation

The North-South trending series of steep normal faults that defines the easternmost exposures of Kapthurin Formation sediments (fig. 3) also serves as the modern boundary of the Marigat *bajada* (Butt 1993; Le Turdu et al. 1995; Tiercelin et al. 1987; Tiercelin 1990). Following Bates and Jackson (1984), a bajada, from the Spanish word for slope, or descent, is a gently inclined land surface formed by the lateral coalescence of a series of alluvial fans, and in the area west of Lake Baringo it marks where sediment deposition shifts from streamflow-dominated transport to sheetflooding along multiple low angle (1–2°) alluvial fans (see figs. 1 and 3). An alluvial fan is defined as “a sedimentary deposit located at a topographic break, such as the base of a mountain front, escarpment, or valley side, that is composed of fluvial and/or debris flow sediments and which has the shape of a fan either fully or partially extended” (Schumm et al. 1996: 6–7). A number of West-East flowing rivers drain the Tugen Hills and deposit sediment towards the center the rift, today occupied by Lake Baringo. However, most rivers do not deposit sediment into Lake Baringo, instead, distributary channels on the Marigat bajada shallow and disappear, dispersing sediment by sheetflooding.

Although now exposed in an area of erosion, the Kapthurin Formation sediments accumulated in an area actively accumulating sediment, and the Marigat bajada serves as an appropriate modern analogue for paleoenvironment reconstruction, and has (often implicitly) been used this way by both geologists and archaeologists working in the Baringo area (e.g., Cornelissen et al. 1990; Le Turdu et al. 1995; McBrearty et al. 1996; Tallon 1976, 1978; Tiercelin et al. 1987). Importantly, the series of faults that delimits the exposure of Kapthurin Formation sediments are but the most recent of a series of rift-parallel normal faults (of a variety of scales) west of Lake Baringo (fig. 1) (Chapman et al. 1978; Hautot et al. 2000; Le Gall et al. 2000; Le Turdu et al. 1995). In addition to contributing to the uplift of the Tugen Hills and exposure of ancient sediments, these have created a succession of lake basins with fault-defined western margins that record the eastward migration of the axis of the rift, and thus suitable areas for the formation of alluvial fans, throughout the Neogene (Owen and Renaut 2000; Renaut et al. 2000).

OUTLINING AN ALLUVIAL FAN MODEL AND ITS ARCHAEOLOGICAL IMPLICATIONS

Due to their presence in the Baringo area today on the Marigat bajada and potential relevance for interpreting Kapthurin Formation sediments, I outline a model for alluvial fans based on syntheses by Blair and McPherson (1994a, 1994b) and comparison of ancient and modern alluvial fans formed in arid and semi-arid rift valleys (e.g., Blair 1999; Bull 1972, 1977;

Collinson 1996; Harvey et al. 2005; Nilsen 1982). Key components of this model are outlined in figures 4 and 5. Although alluvial fans occur today in a wide range of environmental settings (Harvey et al. 2005), I limit discussion here to areas near to or adjoining uplifted blocks bounded by high-angle normal faults because these have the highest potential for preservation in the stratigraphic record (Blair and McPherson 1994a). In addition, because I am interested in those depositional environments that would preserve rather than destroy archaeological sites, I do not describe in detail high energy portions of some alluvial fans such as coarse (cobble or larger-sized) debris flow deposits. I focus instead on lower or distal portions of alluvial fans ('stage 3' portion of alluvial fans of Blair and McPherson 1994a; see fig. 5B), typical of the Baringo area today.

An alluvial fan depositional model

The model consists of several key landscape features (fig. 4). The *piedmont* is the sloping area that connects mountainous or fault-defined highlands to adjacent plains and local base level. Piedmonts are typically composed of eroded bedrock or pediments and alluvial fan depositional features (Bates and Jackson 1984; Denny 1967; Ritter et al. 2002). I consider here alluvial fans dominated by sheetflood rather than debris-flow processes (see fig. 5B), and follow definitions provided by Blair and McPherson (1994a, 1994b). *Alluvial fans* have

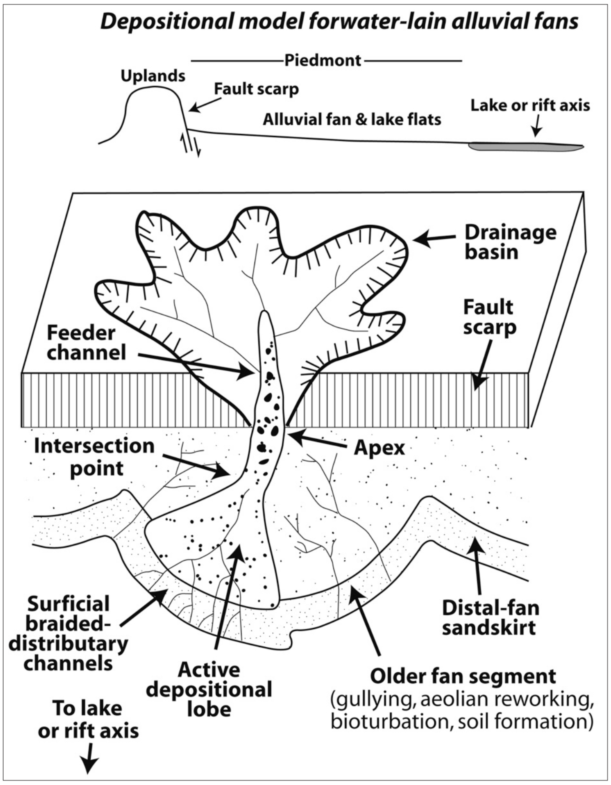

Fig. 4. Schematic alluvial fan depositional model. Sediment deposition at the distal-fan sandskirt is dominated by sheetflood processes down-fan of the intersection point. Sheetflooding causes wide dispersion on the active depositional lobe of rapidly deposited poorly sorted bedload and suspended sediment (sand and silt). Bedding is obliterated by various processes on older fan segments, as well as by migration of the active depositional lobe. Note that there is a general down-fan reduction in grain-size. Cobbles and other large clasts occur in gravel stringers, thalwegs, and bars of seasonally inundated braided distributary channels, some concentrated as lag deposits during flood recession. After Blair and McPherson (1994a, 1994b).

concave upwards radial profiles and convex downwards cross sections, are semi-conical in morphology, with sediment radiating out from a single point source. This point source is the *apex* (fig. 4). At the *intersection point*, material that is transported along incised *feeder channels* from an upland drainage basin during sediment-charged flash floods is deposited by sheetflooding on the *active depositional lobe* of the fan (fig. 4). Sheetfloods are relatively low frequency, high magnitude unconfined water flows that expand as they move down fan (Hogg 1982). During sheetflooding, near-simultaneous deposition of bedload and suspended sediment over broad, unchannelized areas is due to the loss of lateral confinement by the channel margins. This results in sheet-like sedimentation in an arc controlled by the conical

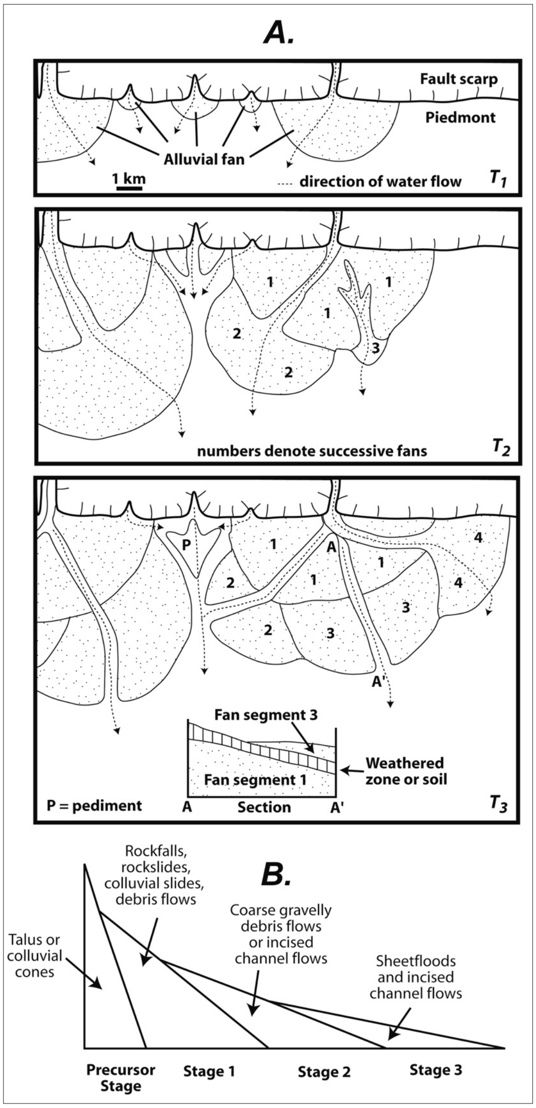

Fig. 5. Models of alluvial fan building. **A.** Plan view maps showing diverse processes of alluvial fan building in successive time (T) steps. Processes shown include migration of the active depositional lobe, formation of rills, gullies, and effects of local stream piracy. Weathered surfaces, including paleosols, develop on older fan segments, shown along section A-A' in T_3. **B.** Stages of fan development showing influence of slope angle on deposit type. After Denny (1967) and Blair and McPherson (1994a).

fan morphology. Sheetflood sediment is poorly sorted and generally decreases in size down fan, the terminal portions of which are termed the *distal-fan sandskirt* (fig. 4). During flood recession, a network of *surficial braided distributary channels* (fig. 3) forms as streams incise and deposit poorly sorted, coarse-grained bedloads.

Sheetflooding on the active depositional lobe is what Blair and McPherson (1994a, 1994b) term a primary sedimentary process, which results in the transfer of water and sediment concentrated in the uplands of a drainage basin to low-lying areas. A number of secondary processes (Blair and McPherson 1994b) also operate on the *older fan segment* of figure 4 during and between the more rare flood events. These secondary processes include rill and gully formation, overland flow on the fan surface during brief rainstorms, pedogenesis, turbation by plants and animals, and wind erosion or sediment redeposition.

Alluvial fans are complex, dynamic sedimentary environments that are formed during episodic periods of growth, interrupted by periods of non-deposition, erosion, and sediment reworking. This is shown schematically in figure 5A, which describes three successive time steps, T_1–T_3, in the evolution of alluvial fans. T_1 shows a simple scenario of fans formed by sheetflooding at the base of adjacent fault scarps. T_2 shows the more realistic and complex situation where fan-head trenching has occurred due to local changes in slope and flow velocity during sedimentation. This results in the formation of incised feeder channels within alluvial fan sediments, and the transfer of sediments to more distal portions of the piedmont (Schumm 1977). These successive fans are numbered sequentially as 1 and 2. Fan 3 at T_2 formed as a result of rill and gully formation on an older fan segment. During T_3, continued incision of channel 3 has led to stream piracy, and migration of the active depositional lobe. Note that the constriction of lateral fan margins, as in a bajada, promotes down fan progradation (Blair and McPherson 1994b).

Alluvial fans may be difficult to distinguish in the stratigraphic record from other alluvial deposits, in part because they are features defined in modern settings by their plan and profile morphology, which may not be apparent at the scale of a single outcrop or archaeological excavation. One method of identification includes an estimation of the probability of their presence based on expectations derived from modern environments. Alluvial fans typically form in tectonically active areas such as rift valleys that are characterized by uplifted or faulted blocks of bedrock adjacent to sedimentary basins, usually in close proximity (< 5–10 km) to base marginal faults. Sediments are typically poorly sorted and texturally immature as a result of infrequent rapid sedimentation over relatively short transport distances, with oxidized sediments and incipient soil profiles being particularly common in arid and semi-arid settings. Major changes in lateral and vertical facies are characteristic, as are depositional bodies consisting of stream or sheetflow deposits with lenticular or wedge-shaped geometries (Blair and McPherson 1994a; Bull 1972; Nilsen 1982).

Archaeological implications of the model

The model described here has important implications for the interpretation of archaeological sites in the context of ancient landscapes. (1) Distal portions of alluvial fans have multiple, shifting loci of rapid sediment deposition. (2) Provided suitable ‘primary’ sources in the uplands, numerous ‘secondary’ sources of variably sized clasts suitable as raw material for stone tool production are found in the surficial braided distributary channels. These occur on both active and inactive portions of the fan. These sources of coarse clastic rocks in a landscape otherwise dominated by finer-grained sediments could have served as resource magnets (*sensu* Potts 1994) attracting hominin groups. (3) The precise location of these raw material resource areas would have varied on a seasonal to decadal (or longer) scale with changes in sedimentation patterns on the distal sandskirt and elsewhere on the fan. (4) Rapid sedimentation and shifting resource location would lead to a paleolandscape with few areas of repeated hominin use, and thus the spatial preservation of the material remains of brief occupations or activities (Ferring 1986; Waters 1992: 92–97; see also Brooks and Yellen 1987; Dewar and McBride 1992), factors which may limit the number and diversity of artifact types recovered. (5) Such sites may preserve traces of only a small portion of the full range of activities of any given group of hominins. In the Kapthurin Formation specifically, correlation of tephra deposited concurrently in the Bedded Tuff Member can serve to link disparate low-density sites into a wider picture of the full behavioral repertoire of mobile foraging populations (see Tryon and McBrearty 2006).

APPLYING THE MODEL: EVIDENCE FROM KOIMILOT

Site introduction

I apply the model for alluvial fans outlined above to results from my excavations at the site of Koimilot, which lies within the Bedded Tuff Member. Koimilot serves as a useful example because it has archaeological and geological features that I believe are characteristic of many

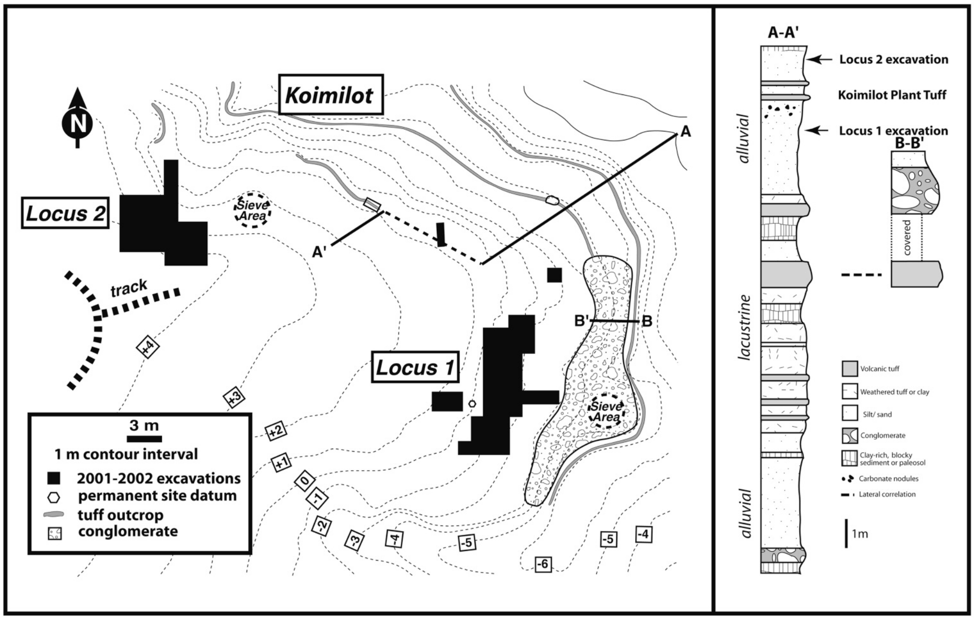

Fig. 6. Topographic map showing 2001-2002 excavations and outcrops of major geological strata at Koimilot. A-A' and B-B' are measured sections shown in adjacent summary stratigraphic column (horizontal scale is relative).

sites from the Kapthurin Formation. The Koimilot artifact aggregate is dominated by flaking debris and cores, rare retouched or shaped tools, and on-site reduction of lava cobbles locally available in channel deposits, suggested by spatially discrete clusters of debitage and extensive sets of refitted artifacts. Finally, the sedimentary sequence is largely composed of sands and conglomerates, broadly comparable to that seen at other sites in the fluviolacustrine facies (e.g., Cornelissen 1992; Cornelissen et al. 1990; Leakey et al. 1969; McBrearty 1999; Tallon 1978), here exposed in excavations sufficiently extensive (64 m^2, up to 4 m deep) to observe lateral and vertical variation in sedimentary units.

Koimilot consists of two spatially and stratigraphically distinct artifact loci (fig. 6). Of these, Locus 1 is older, overlain by Locus 2, separated by the Koimilot Plant Tuff, a local marker bed. The site has an estimated age range of ~200–250 ka on the basis of geochemical correlation of the tephra found at Koimilot with better dated deposits exposed elsewhere in the Bedded Tuff Member (Tryon and McBrearty 2006). In addition to the 64 m^2 excavations that targeted archaeological levels, several geological trenches were also dug to clarify strati-

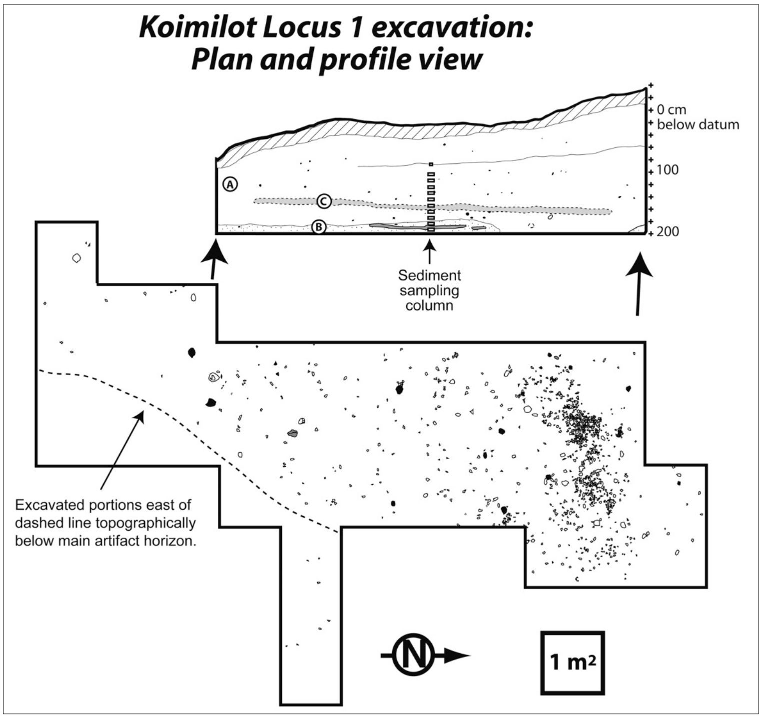

Fig. 7. Locus 1 plan view and profile, with sediment sampling column shown. Outlines of all plotted artifacts shown in plan view. Sedimentary units shown in profile include Unit A, a massive sand with ‘blocky’ texture suggesting incipient soil development. Rootcasts and carbonate nodules are present. Unit B: Fining upwards sand with gradational upper contact. Sparse rootcasts present only near base of unit. Unit C: Dark brown manganese-stained layer with a ‘blocky’ texture interpreted as a paleosol. Northern boundary diffuse. Hatched area indicates loose pebbly sand or soil (colluvium).

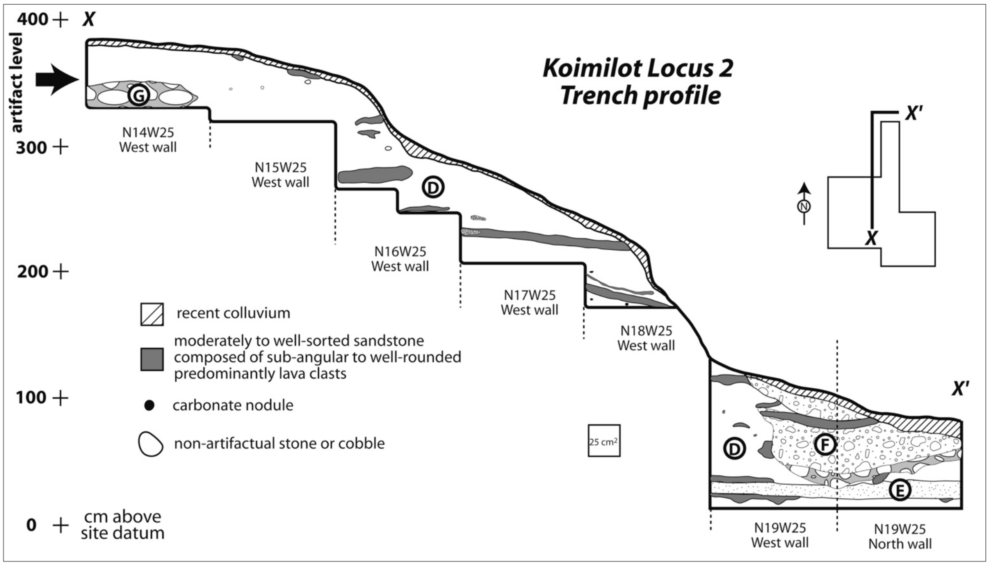

Fig. 8. Profile of Locus 2 trench at Koimilot. Sedimentary units shown in profiles include Unit D, a massive (turbated?) sand with rootcasts and manganese staining. Unit E is a well-sorted tuffaceous sand. Unit F is a cut and fill channel complex consisting of poorly sorted lava clasts grading from bottom to top from matrix to clast supported. Average clast size is 10 cm. Unit G is a very poorly sorted matrix-supported conglomerate with 10-40 cm clasts. Matrix of unit G is a poorly sorted sand with angular to rounded grains. Artifacts occur at D/G interface.

graphic relationships, and the locations of all excavated areas and measured stratigraphic sections are shown in figure 6. Figures 7 and 8 show the profile and plan view of the Locus 1 and Locus 2 excavations, respectively. Both Locus 1 and Locus 2 preserve lithic assemblages attributed to the early portion of the Middle Stone Age, with a combined total of 4,102 recovered pieces. These assemblages are characterized by flake production from Levallois, discoidal, and other core types (for details and comparisons, see Tryon 2005, 2006; Tryon et al. 2005). Figure 9 shows the spatial distribution of lithologically distinct varieties of trachytic and phonolitic lavas that comprise the Locus 1 lithic assemblages. The clustering by raw material (RM) type, as well as refits within these clusters (Tryon 2003), is consistent with the preservation of individual episodes of cobble reduction. No such clustering was apparent at Locus 2, which is likely winnowed as a result of stream action.

The stratigraphic section exposed in gullies at the site (fig. 6) suggests a near shore setting not far from the margins of a fluctuating lake. Three lines of evidence suggest proximity to a lake. (1) Koimilot lies ~200 m west of a sequence of deposits that include abundant trace fossils of reeds still in growth position that Tallon (1976) attributes to a lacustrine facies of the Bedded Tuff Member, shown in figure 3. (2) The ‘Koimilot Plant Tuff’ also contains reeds, here lying parallel to the bedding plane, comparable to those found near the shoreline of Lake Baringo today, which include the cattail *Typha domingensis* (Kayo 2002). (3) The middle portion of the section shown in figure 6 includes a number of beds of tephra altered to clay with textures resembling those found in the lacustrine facies of the Middle Silts and

Gravels Member (K3); olivines in these beds are altered, and zeolites may be present, all characteristics suggestive of deposition near an alkaline lake (Hay 1963). Conglomerates and sands at the base and summit of the section suggest deposition within an alluvial environment.

Application: Site stratigraphy

To what extent do the artifact-bearing conglomerates and sands near the summit of the Koimilot stratigraphic sequence reflect alluvial fan sedimentation? How can the model described above be used to understand the environment better during the formation of the archaeological residues at Koimilot? I address these questions using two sets of data: examination of sedimentary features at the site, and initial assays of the grain size distribution of the site's sediments. The Koimilot excavation profiles (figs. 7 and 8) preserve a number of sedimentary features that are consistent with an alluvial fan setting, especially in the distal fan sandskirt (see fig. 3). These include the following:

1. Homogenous beds of poorly sorted sands with dispersed carbonate nodules and frequently 'blocky' textures (unit A of fig. 7 and unit D of fig. 8). These are the most widespread sediment type at both Locus 1 and Locus 2, and their lack of apparent stratification may result from sheetflooding and/or postdepositional turbation and soil formation

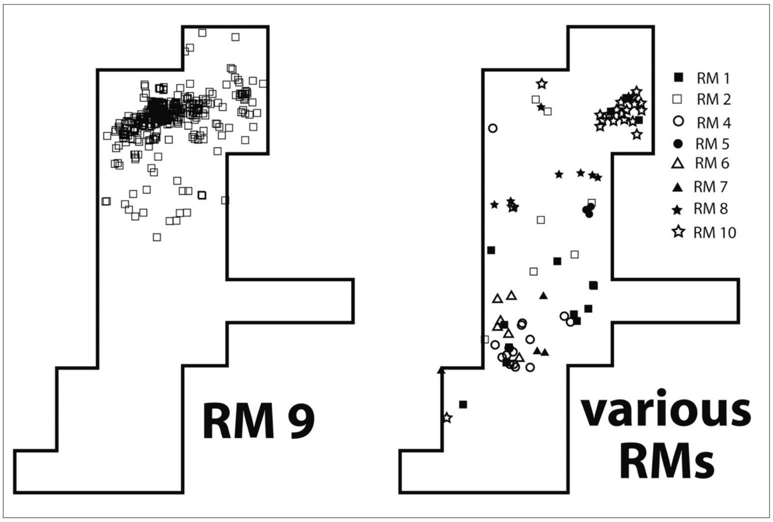

Fig. 9. Koimilot Locus 1 raw material (RM) type distribution. Each RM reflects artifacts with a shared suite of macroscopically and microscopically visible lithological features. They include a range of phonolitic, trachytic, and trachyphonolitic rocks, as determined in thin section (fuller definitions may be found in Tryon, 2003). These rock types are comparable to those described from lavas in the Tugen Hills (Chapman, 1971; Chapman et al., 1978; Lippard, 1973; Walsh, 1969). The spatial distribution of the different RM types suggests the preservation of discrete knapping episodes.

during periods of stability and non-deposition. This unit is extensively sampled in the analysis of sediment grain size and sorting.

2. A 6–8-cm-thick dark-brown, manganese-stained layer with blocky texture (unit C) is interpreted as a weakly developed, shallowly dipping (~2°) paleosol at Locus 1 (fig. 7). Such soils are characteristic of (although not unique to) fans, forming as a secondary process of older fan segments (see inset of fig. 5A). The angle of dip is equivalent to that of the alluvial fans that now form the Marigat bajada. Artifacts occur immediately beneath the paleosol at Locus 1, although it could not be determined in the field which portion of the soil profile (e.g., A, B, or fragipan) unit C represents, and thus its depth below a formerly stable landsurface is unknown (e.g., Birkeland 1999; Retallack 2001).

3. Tabular beds of moderately sorted sand of varying thicknesses (~5–20 cm), consistent with sheetflood sedimentation. These include the coarse sand unit underlying the Locus 1 excavation (unit B of fig. 7) and that beneath the channel at the base of the Locus 2 trench (unit E of fig. 8). Similar deposits are present throughout both excavations, shown in grey in both profiles, but are particularly common at Locus 2.

4. As shown in figure 6, poorly sorted, matrix-supported conglomerates are present at Locus 1 (underlying the Locus 1 excavated levels of fig. 7), as well as at the base and summit of the Locus 2 excavated trench (unit F and unit G of fig. 8). No imbrication was evident in the outcrop at Locus 1 or in the extensively exposed laterally equivalent conglomerates found in gullies adjacent to the site and thus flow direction could not be reliably inferred. At Locus 2, artifacts occur in or on the conglomerate-filled channel visible near the summit of the excavation (unit G of fig. 8), the geometry of which suggests flow directions towards the east or southeast; that is, towards the axis of the rift and thus

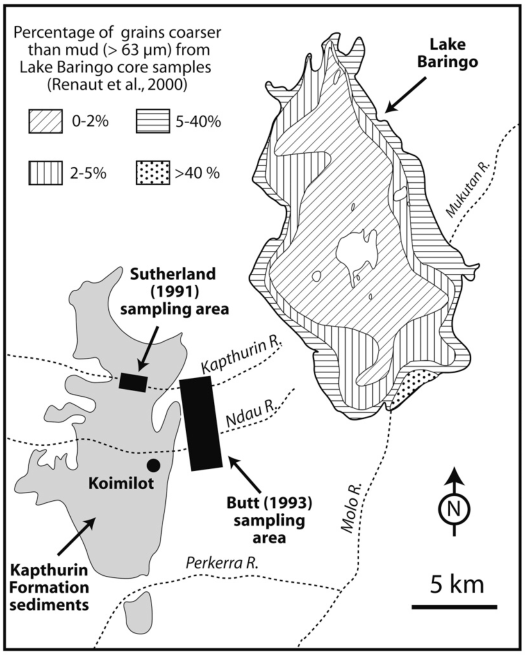

Fig. 10. Simplified map showing sediment sampling locales of modern analogues in the Baringo area. Based on data from Renaut et al. (2000), Butt (1993) and Sutherland (1991).

down-fan. The lowermost portion of the sediments exposed at Locus 2 is a cut-and-fill sequence that may record secondary processes of channel incision and sediment reworking.

Application: Comparative grain size analysis

Because poorly sorted sediments are characteristic of sheetflood deposits in alluvial fan settings, grain size analysis has the potential to support or reject the proposed alluvial fan depositional model. The analysis of the size and dispersion of grain or clast size in sediments has traditionally been applied to the reconstruction of ancient depositional environments (Folk 1974; for an excellent application to the East African geological record, see Frostick and Reid 1986). It may be particularly useful for the Kapthurin Formation because post-depositional turbation processes have obliterated many primary depositional features among sediments of the Middle Silts and Gravels Member and Bedded Tuff Member.

Studies of recent sedimentation in the Baringo area provide an important but still limited comparative baseline (Butt 1993; Renaut et al. 2000; Sutherland 1991; Sutherland and Bryan 1989). Figure 10 shows the previously studied locations relative to Koimilot, with mean grain size distributions summarized in table 1. These data allow the application of broad constraints on depositional environment based on modern analogues. As shown in figure 10, core samples from Lake Baringo (Renaut et al. 2000) indicate that lake sediments are dominated by silt or clay-sized particles, with sand-sized particles comprising >40% by weight of samples only near the Molo River delta at the southern end the lake. Sutherland (1991) reports grain-size analyses of colluvial, streambank, and within-channel sediments he sampled from

Table 1. Summary of sedimentological data for the Baringo area compared to sediments from the archaeological site of Koimilot, listing mean % abundance by weight. Alluvial fan data are from Butt (1993); colluvial, streambank, and channel sediment data are from Sutherland (1991). Sediments most similar to Koimilot are italicized. See text for discussion.

Context	% Pebble-Boulder (>4 mm)	% Granule (2-4 mm)	% med.-v. coarse sand	% v. fine-fine sand	% mud
Alluvial fan debris flow	23.7	29.7	21.2	12.2	13.3
Alluvial fan gravel flow	51.2	28.8	14.2	2.7	3.1
Alluvial fan coarse flow	18.2	46.1	27.7	4.5	3.5
Alluvial fan well sorted flow	*0.2*	*4.0*	*38.5*	*29.7*	*26.3*
Alluvial fan poorly sorted flow	0.1	4.7	40.1	29.4	25.6
Alluvial fan coarse intermediate flow	*0.0*	*2.5*	*37.3*	*17.2*	*42.8*
Alluvial fan intermediate flow	*0.0*	*0.7*	*10.8*	*39.3*	*49.2*
Alluvial fan mudflow	0,2	2.8	18.7	23.9	54.5
Alluvial fan settling	0.0	0.1	2.3	25.7	71.5
Colluvial area	0.0	2.0	4.3	9.0	84.7
Streambank	4.7	23.2	46.9	14.3	10.9
Channel sediments	8.4	28.5	57.1	4.5	1.5
Koimilot	0.0	0.4	64.0	22.8	12.8

the middle reaches of the Kapthurin River (table 1, fig. 10). Colluvial sediments are dominated by fine silt or clay-sized ('mud') particles (*cf.* Sutherland and Bryan 1989), whereas the streambank and channel deposits are characterized by relatively coarse clasts, with > 30% of the sediment by weight greater than sand-sized. Butt (1993) conducted a detailed sampling program of alluvial fan sediments in the Baringo area (fig. 10). She demonstrated substantial variation in sediment grain-size associated with different depositional regimes within the Marigat bajada (summarized in table 1). However, she found no spatial patterning among the data that reliably distinguished proximal, medial, or distal portions of the alluvial fan, except for the widely recognized tendency for down-fan grain-size reduction and the predominance of very fine-grained silty sediments ('settling' of table 1) at the extreme distal margin of the fans she studied. Her results instead emphasize the substantial variation among Baringo-area alluvial fans that she attributes to differences in sediment supply and seasonal water availability.

Nine 50–79 g sediment samples were collected from Koimilot Locus 1 at 10 cm intervals from a one-meter vertical column from the west wall the excavation (fig. 7). Initial grain-size analysis assays resulted in incomplete disaggregation of peds that formed during post-depositional incipient soil formation characteristic of most Kapthurin Formation sediments. As such, results from Koimilot presented in table 1 are not directly equivalent to available comparative data, and are thus used only in a general fashion. However, the predominance of coarse-to-medium sand size grains strongly supports an alluvial, rather than lacustrine, depositional mode for the sediments within the Locus 1 excavation (see fig. 10). None of the fluvial sediments match those from Koimilot Locus 1, which lack the granules and pebbles found within the channel and channel-margin bedload sediments sampled by Sutherland (table 1). The Locus 1 sediments are also much coarser-grained than typical levee or floodplain sediments of fluvial environments, which are deposited by suspension, and are fine sand-sized or smaller (see Cazanacli and Smith 1998). In general, the closest match is with the sandy deposits characteristic of the Baringo-area fans (table 1, italicized), although this comparison is suggestive rather than conclusive.

Thus, grain-size analyses from Locus 1 suggest that sediment there is poorly sorted medium or coarse sand, unlike that from comparative modern Baringo fluvial or lacustrine environments. However, such poorly sorted medium sands are similar to the massive, poorly sorted sands that are a widespread facies on the present-day Marigat bajada, described by Tiercelin et al. (1987:315) and quantified by Butt (1993). Equivalent poor sorting and post-depositional modification is typical of older fan segments subject to secondary depositional processes. Although the results cannot be considered conclusive, the sediments from Koimilot are consistent with sheetflood sedimentation, formation of syn- or post-depositional cobble-bearing channels, and weak soil development, processes typical of alluvial fan environments.

Summary of model application

The alluvial fan model provides a method for better interpreting the sediments at Koimilot in the context of depositional processes likely active in the Baringo area. As geomorphological features, identifying alluvial fans in the sedimentary record at the scale of a single archaeological excavation remains difficult. For Koimilot, the presence of alluvial fans is likely. This is due to rift-parallel faulting throughout at least the Pleistocene, which would have created a succession of topographic breaks perpendicular to the axis of stream flow, situations conducive to the formation of alluvial fans. Sediment structures visible at both the Locus 1 and Locus 2 excavations are accommodated by the alluvial fan model, including paleosols with shallow (2º) dips that mimic those of the present-day Marigat bajada and a succession of poorly sorted conglomerates within finer-grained sediments. Although limited by initial analytical results, grain-size analyses from Koimilot are consistent with sediment deposition by sheetflooding, and show little correspondence with other sampled depositional environments west of Lake Baringo today. Returning to figure 4, Koimilot is inferred to have formed on the distal fan sandskirt on a region on or near the active depositional lobe. Upland areas to the west (fig. 3) would have provided sediment to form alluvial fans, the margins of which would have fluctuated with local rises in lakes or ponds formed at the rift depocenter, as suggested by lacustrine sediments visible in the measured stratigraphic section at Koimilot (fig. 6).

DISCUSSION

Given the West-East topographic gradient in rainfall and vegetation present in the Tugen Hills-Lake Baringo transect today, with higher annual rainfall and denser vegetation with increased topographic height, we expect hominins to have exploited this range of habitats and resources each region afforded, from lake-side to highlands and land in between, whether on a daily or seasonal scale. If present topography is a correct analogue for the past (and available evidence suggests that the Tugen Hills have been a topographic high point since the Miocene), then the alignment of known sites on a North-South transect is significant, and suggests that the Kapthurin Formation archaeological record may be sampling only a very narrow segment of the spatial range, and by inference, behavioral repertoire, of the hominin populations that produced it. That is, many sites, particularly those in the fluviolacustrine facies, may be located at the region intermediate between upland and lowland areas where abundant sources of stone raw material were available. According to the model presented above, portions of this region would be characterized by the presence of alluvial fans.

The alluvial fan model presented here serves as a general model for interpreting sediment deposition at Koimilot, and I do not wish to suggest that it applies to all Kapthurin Formation sites in the fluviolacustrine facies. Fuller demonstration of the existence of alluvial fans and recognition of their distinctive signature in the ancient sedimentary record of the Baringo area requires substantially more geological fieldwork. Furthermore, both the modern environment as well as massive, well-sorted conglomerates from Kapthurin Formation sediments (Tallon 1976) indicates the co-occurrence of major channels of seasonal or perhaps perennial rivers. These, in addition to lacustrine sediments and the variety of habitats suggested by the fossil fauna of the Middle Silts and Gravels Member, indicate a complex and dynamic mosaic of depositional environments and paleohabitats at any point in time (McBrearty 1999; McBrearty and Jablonski 2005; Tallon 1978). The area near the lake margin is relatively flat today, such that large expansions of lake size, and thus the area where lake and lake-marginal sediments are deposited, are possible with even modest increases in lake depth, which have fluctuated over a range of 4 m in depth over the last quarter century (Renaut et al. 2000).

However, if the alluvial fan model presented here is useful for interpreting the stratigraphic record at Koimilot and possibly other Kapthurin Formation sites, then we have a better understanding of some of the factors underlying (1) site function, (2) assemblage composition, and (3) artifact distribution, three components of the archaeological record integral to understanding past settlement systems.

At Koimilot, artifact assemblage composition suggests that acquiring and reducing cobbles was a key, and possibly the sole activity performed by hominins there, likely as a result of exposed cobble sources adjacent to softer sandy substrates. Following the alluvial fan model presented above, the conglomerates may represent surficial braided distributary channels on the active deposition lobe of figure 4, or subsequent channel formation during incision and sediment redeposition on an older fan segment.

The evidence for cobble reduction at Koimilot includes the preservation of spatially discrete clusters of flaking debris of different types of lava at Locus 1 (fig. 9), and preservation of stream cobble cortex on ~25% of the flakes and flake fragments at Locus 1 and Locus 2 (Tryon 2006). Extensive sets of refitted artifacts, in many cases showing decortication and reduction of stream cobbles, are found at several other Kapthurin Formation sites, including GnJh-17 (Cornelissen 1992), GnJh-15 (McBrearty 1999), and the Leakey Handaxe Area (McBrearty 1999; Tryon et al. 2005). Proximity to a raw material source may be a partial explanation for the rarity of retouched or shaped tools at Koimilot (n = 1), as the spatial fragmentation of areas of tool production, use, and discard has been demonstrated at a number of sites, perhaps most strikingly at Maastricht-Belvedere in the Netherlands (e.g., Roebroeks et al. 1995; see also Hallos 2005). Areas of raw material procurement may be quite distinct from area of tool use and discard, which may occur at locations more distant from sources of raw material.

The rapid burial of the site by sheetflood deposited sands serves to explain the preservation of discrete behavioral episodes, such as the reduction of fewer than a dozen cobbles. Sites in alluvial fan settings are limited to single or few visitations to the same area prior to reburial on geologically short time scales, a phenomenon characteristic of many alluvial settings (Ferring 1986), making compound assemblages rare.

DIRECTIONS FOR FUTURE RESEARCH

Although verifying the alluvial fan model requires substantially more geological fieldwork, testing some of the archaeological implications may be more straightforward. The degree of both core reduction and raw material conservation should increase with distance from raw material source(s), and several measures of these attributes have been proposed in the archaeological literature (e.g., Andrefsky 1994; Bamforth 1986; Roth and Dibble 1998; Kuhn 2004). If stream channels in alluvial fan deposits served as areas of raw material procurement, then we should expect increased amounts of reduction and raw material conservation at sites not in alluvial fan settings, or otherwise distant from raw material sources. The best means of testing this hypothesis is to compare contemporary sites in very different depositional settings, for example, between sites in alluvial fans versus those in lacustrine sediments or in areas closer to the axis of the Rift were large clasts suitable for flake production are unavailable.

Establishing a baseline of raw material economization may provide an important new way of examining the Acheulian to Middle Stone Age transition, particularly the associated origin and spread of Levallois technology. The manufacture and transport of Levallois flakes and cores represent an efficient technology for mobile foraging populations because of their combined high utility, measured as either the ratios of useable cutting edge length to flake weight or the high number of large blanks per core (Brantingham and Kuhn 2001; Wallace and Shea 2006; see Mackay 2008 for a similar discussion for backed pieces). The Kapthurin Formation has a wide range of Levallois flakes and cores produced by diverse methods, numerically abundant at the sites of Koimilot and the Leakey Handaxe Area (Tryon et al. 2005), both in fluviolacustrine sediments, and Nyogonyek and Rorop Lingop, where artifacts occur in lacustrine sediments (McBrearty 1999; Tryon 2003). The presence of large Levallois flakes and cores at Acheulian sites such as the Leakey Handaxe Area and smaller ones at some MSA sites in Baringo (Tryon et al. 2005) may suggest a historical connection in the development of this technology, but does little to explain its origin. Instead, the local widespread production of Levallois flakes at MSA sites in the Kapthurin Formation may result from changing mobility strategies and resource use, a possibility that can be explored through changes in landscape use and raw material transport and conservation of Levallois cores and flakes.

CONCLUSION

Alluvial fans are a depositional environment common in rift valley settings that have distinct impacts on the formation of the archaeological record. I explore the significance of alluvial fans using as a case study the Middle Stone Age site of Koimilot, found in sediments of the Kapthurin Formation, west of Lake Baringo, in the Rift Valley of Kenya. As sites of the Kapthurin Formation serve as an important reference point for earlier sites attributed to the Middle Stone Age, this study of sedimentary processes that contributed to lateral variation in ancient depositional environments serves as an important complement to prior research, much of which has focused on temporal variation in lithic technology. Four key points arise as a result of the comparison of modern variation in topography and ecology with the sediments and archaeological sites of the Kapthurin Formation:

1. Modern topographic variation in the Baringo area is primarily along an East-West axis, perpendicular to the outcrop exposures along which most archaeological sites occur. Artifact assemblages occur in Middle Pleistocene sediments of the Kapthurin Formation exposed at these outcrops, the nature of these sediments as well as the preserved fossil fauna suggest variation along a continuum of near shore (lacustrine and alluvial) depositional settings and habitats.

2. The North-South orientation of Kapthurin Formation sediment exposures is defined by a series of faults that parallel the axis of the Rift Valley. Fault-bounded depositional basins in rift valleys are typical settings for alluvial fans, which are common in the Baringo area today.

3. Comparison of modern and ancient sediments in the Baringo area suggests that some archaeological sites, particularly the site of Koimilot, occur in sediments deposited by alluvial fans. In order to explore this possibility, I outline a general model of alluvial fan sedimentary processes common to low-angle fans in rift valleys at distances < 5–10 km from fault-defined upland source areas. I apply the model to Koimilot, and support it with stratigraphic observations of shallowly dipping tabular sands and paleosols as well as grain-size analyses and the identification of poorly sorted coarse sands.

4. Alluvial fan settings have a number of implications for the archaeological record and reconstructing settlement systems, as areas of rapidly shifting loci of sedimentation (a depositional setting that contributes to the preservation of relatively brief periods of artifact deposition), and as potential source areas of stone raw material. In the case of Koimilot, it likely explains site function (raw material procurement), composition (stream cobble reduction), and artifact distribution (preservation of multiple spatially discrete reduction episodes).

Reconstructing settlement dynamics can proceed only with an understanding of where sites occur, why hominins were (or were not) drawn to particular areas, and the nature and rate of sediment deposition and erosion that affect their composition and chance for recovery.

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