Kesem-Kebena: A Newly Discovered Paleoanthropological Research Area in Ethiopia

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The Paleoanthropological Inventory of Ethiopia is a long-term project designed to assess the paleoanthropological resources of the Ethiopian rift system. Inventory work completed in 1989 has established several new research areas. One of these, the Kesem-Kebena area near the northern terminus of the Main Ethiopian Rift, has now been investigated by the inventory team, and several vertebrate palaeontological and archaeological localities have been discovered. The deposits range from >3.7 Ma (million years of age; Pliocene) to Late Pleistocene. Important stratigraphic units were dated by conventional K/Ar dating on basaltic lavas and ^{40}Ar/^{39}Ar on feldspar separates from key tephra horizons. Among the most significant discoveries from the extensive Kesem-Kebena sedimentary succession are Pleistocene Acheulian lithic assemblages and Acheulian fauna dating to ca. 1.0 Ma.

Introduction

The geological history of eastern Africa has provided a unique setting for the palaeontological and archaeological investigation of human origins and evolution. Research at Laetoli and Olduvai Gorge (Tanzania), East and West Turkana (Kenya), Omo, Hadar, Melka Kontoure, the Middle Awash (Ethiopia), and other areas (FIG. 1) has provided unique insights into hominid evolution and generated many new questions. These questions, in turn, have stimulated the search for additional research areas from which more data might be recovered.

We report here on a series of geological, archaeological, and palaeontological discoveries made by the Paleoanthropological Inventory of Ethiopia in 1988–1989. We first outline the history of paleoanthropological research in Ethiopia, introducing the inventory project, and then provide the regional and local geological framework for our discoveries. Finally, we describe the new discoveries and discuss the potential of these new areas for elucidating human technological and biological evolution.

Historical Background

Initial Ethiopian Discoveries: 1900–1960

The first vertebrate fossils reported from the Ethiopian rift system were found during an expedition led by the French explorer de Bozas who visited the area near the mouth of the Omo River in southern Ethiopia in 1902 (FIG. 1). The first geological reconnaissance and substantial palaeontological work in this southeasternmost part of the Ethiopian rift system was carried out by Camille Arambourg and colleagues in the early 1930s (Howell and Coppens 1983). No hominid remains were recovered by that effort; leaving the initial honors to another French project in the same decade at Porc Epic cave (1929 and 1933), near Dire Dawa (FIG. 1), far to the NE (Teilhard
and continued until 1982 (Chavaillon et al. 1979, and references therein). Meanwhile, in the late 1960s a joint French-American-Kenyan expedition returned to the Lower Omo Basin. The work of this International Omo Expedition resulted in the recovery of paleontological and archaeological resources from well-understood geological contexts (Howell 1978; Howell and Coppens 1974; Howell et al. 1987; de Heinzelin 1983). The Omo project established standards for multidisciplinary, large-scale paleoanthropological research in Africa.

Chavaillon, who was then excavating at Melka Kon- toure, encouraged a French graduate student in geology, Maurice Taieb, to proceed with geological survey along the Awash River in the late 1960s. Taieb recorded a variety of archaeological and paleontological localities in the Afar depression (Taieb 1974). He formed the Interna- tional Afar Research Expedition (I.A.R.E.) and began work at one of the areas he had found, Hadar (Johanson et al. 1982 and references therein). One I.A.R.E. partici- piant, Jon Kalb, subsequently dropped out of the Hadar work and formed the Rift Valley Research Mission in Ethiopia (R.V.R.M.E.). Kalb’s team proceeded to explore the Middle Awash region immediately south of Hadar (Kalb et al. 1982a, 1982b, 1982c, and references therein).

In the early 1970s, Fred Wendorf and associates inves- tigated a small study area with Middle Stone Age localities in the Gademotta area of the Lakes region (FIG. 1), which is the central sector of the Main Ethiopian Rift (Wendorf and Schild 1974). Another team under the direction of Clark undertook paleoanthropological work at Gadeb (FIG. 1), on the plateau along the SE edge of the Ethiopian rift (Clark and Kurashina 1979; Williams et al. 1979). Clark and White carried out reconnaissance studies in the Middle Awash in 1981 (Clark et al. 1984).

By the autumn of 1982, the Omo project was inactive and work at Gadeb and Gademotta had ended. Fieldwork at Melka Kontoure persisted. Research at Hadar had ceased in 1977 but was ready to resume in 1982, concur- rently with work in the Middle Awash. In the fall of 1982, however, all foreign scientists in archaeology, paleontology, and affiliated disciplines were informed that their Ethiopian permits were no longer valid and that all fieldwork was suspended until new national policies governing research had been formulated and legislated. As a conse- quence, no Ethiopian antiquities-related field research was done by foreign expeditions between the autumn of 1982 and September of 1990.

Ethiopia invests the authority to issue permits for field research with the Ethiopian Ministry of Culture and Sports Affairs (EMC). The Centre for Research and Conservation of Cultural Heritage (CRCCH; Antiquities) is
the EMC unit responsible for managing Ethiopian antiquities.

The Development of Ethiopian Paleoanthropology: 1982–1988

The history presented above shows a pattern of mostly unsystematic reconnaissance for new paleoanthropological areas, followed by discovery and intermittent or extended exploitation. Paleoanthropological collecting areas, once identified in Ethiopia, have then continued to attract paleontologists, geologists, and archaeologists. The results, in the very productive fossil fields such as Hadar and the Omo, have been spectacular increases in knowledge of the prehistory of this part of the world.

Paleoanthropological research in Ethiopia, before the Ethiopian Revolution in 1974, and for several years thereafter, was conducted by foreign-based expeditions investigating a few rich deposits, with little or no scientific collaboration of Ethiopian institutions or individuals. Ethiopian participation was mostly limited to administration; local scholarship and facilities went undeveloped. Artifacts and fossils were usually loaned for study to foreign institutions.

The 1970s and 1980s witnessed the emergence of several Ethiopian scholars working in paleoanthropology and allied disciplines, a development in which the CRCCH played a crucial role. Furthermore, the Centre oversaw the completion of laboratory and storage facilities on the National Museum compound in Addis Ababa. With the rapid development of national personnel and facilities for paleoanthropological research came the recognition that the history described above had left Ethiopia's paleoanthropological potential largely unexplored. The Ethiopian rift system had proven capable of yielding evidence needed to solve the basic problems of human origins, but the extent of paleoanthropological resources in this region was still poorly known. A systematic, comprehensive program of discovery and assessment was required.

The Paleoanthropological Inventory of Ethiopia

Goals

The Paleoanthropological Inventory of Ethiopia was formed in 1988 to allow Ethiopia to assess her overall antiquities resource base. Located within the Ministry of Culture, the project is designed to document the distribution and research potential of late Cenozoic sedimentary bodies and to place these deposits in a time-stratigraphic framework for the study of biotic and cultural change. It represents the primary research step in studies to elucidate hominid origins, diversification, and anatomical and behavioral adaptations.

From the Ethiopian and international perspectives, the traditional approach of exhausting a single research area before searching for another area is increasingly inappropriate. For many periods of interest to paleoanthropologists, localities are unknown or limited in extent. Even for better-known periods, proper antiquities management and research planning are still impossible because the extent of undiscovered research areas remains unknown. The inventory project was therefore designed to integrate Ethiopian national interests with international scientific concerns, allowing paleoanthropology to proceed in the known research areas while additional research areas are simultaneously sought.

Scope

The inventory project began its work in the Ethiopian rift system and adjacent highland areas. The most important data bearing on human origins and evolution have been found embedded and sealed in sedimentary units associated with the rift system. These primary and contextual data (artifacts, fossils, sediments) become susceptible to discovery as a result of geomorphic processes aided by faulting associated with rift evolution. For geomorphological reasons, fossiliferous occurrences in eastern Africa, as a very general rule, become rarer as their age increases—the older a deposit, the greater the chance of subsequent erosion or deep burial consistent with intense volcanotectonic evolution of the Main Ethiopian Rift and the Afar during the Neogene and the Quaternary periods. For example, middle and late Miocene deposits that might hold clues to the origin of the Hominidae are rarer and more disturbed than middle or late Pleistocene deposits. This "pull of the recent" bias has serious consequences for the inventory project.

Localities discovered by the inventory project span the time period between the earliest Ethiopian vertebrate paleontological localities (perhaps Mesozoic; expected to be rare) and the latest Stone Age and Iron Age archaeological occurrences (far more common). Potential localities of all ages are recorded as encountered during inventory work, but project focus is on Middle Stone Age and earlier archaeological and paleontological resources embedded in their geological contexts. The inventory project is conducted outside of already established paleoanthropological research areas (the Lower Omo, Melka Kontoure, Gadeb, Middle Awash, Gademotta, and Hadar; FIG. 1) because the Ethiopian Ministry of Culture is already cognizant of the resources and potential of these areas.
Terminology

The term “site” has a variety of archaeological and paleontological meanings in eastern Africa, a circumstance that engenders substantial confusion. For example, Hadar, Olduvai, Laetoli, and the Omo are often called “sites,” while much smaller archaeological and paleontological occurrences within these “sites” are also routinely identified as “sites.” As Delson (1984) points out, areas such as those named above are more properly called “fields” in the vertebrate paleontology sense.

Different systems of nomenclature and spatial recording have “evolved” independently as different paleoanthropological research teams dealt with their respective discoveries in eastern Africa. For example, French and American teams defined collecting “localities” in the Omo, a system also applied at Hadar where, as Johanson et al. (1982: 379) describe, each locality represents “... a discrete geographic area of variable size and usually sampling a fairly restricted portion of the stratigraphic sequence.” In both the Omo and at Hadar, locality boundaries are circumscribed on aerial photographs. East of Lake Turkana (FIG. 1), Leakey and Leakey (1978: 8) describe three major “regions,” with a series of numbered “areas,” much larger than the Omo localities. These areas are “bounded either by natural vegetation cover or by easily recognizable topographic features (sand rivers, etc.).” At Koobi Fora, specimen provenance is individually recorded on aerial photographs, and paleontological “localities,” in the Omo sense, are not recognized. Archaeologists Isaac and Harris (in Leakey and Leakey 1978) use the terms “sites” and “localities” synonymously at Koobi Fora, using the SASES (Standard African Site Enumeration System) to place these spatially. In his survey work in Kenya, Pickford (1986) divides the country into six “areas,” recognizing smaller “areas” of paleoanthropological significance within these major areas. The smaller areas (for example, the “Koru/Songhor/Muhoroni area”) contain “sites,” synonymous with “localities” (for example, Site 15 at Koru). It can be seen from this brief review that there is no standardized terminology.

The Paleoanthropological Inventory of Ethiopia avoids the ambiguous term “site.” We recognize mappable deposits as “areas” (roughly equivalent to, but less formal than the “formations” or “groups” of the geologist; Bishop 1967; Stein 1987). For example, the Omo and Hadar would constitute “areas” in our terminology.

Like most workers, we use the term “locality” to describe a relatively discrete paleontological or archaeological occurrence within an area of paleoanthropological significance. Localities are defined on the basis of the geological, paleontological, and archaeological contents of delimited outcrops of one or a few stratigraphic horizons. Large fossil and artifact-bearing areas (fields) will contain many localities and may include beds traceable for more than 30 km (de Heinzelin 1983; Clark et al. 1984).

The surface content of the localities allows assessment of the paleoanthropological significance and potential of each area discovered by the inventory project. To summarize, we circumscribe areas of paleoanthropological significance by the outcrop of deposits and we characterize the areas by the surface content of the localities within them.

Methods

The Ethiopian rift and Afar are large geographic features (FIG. 1), but only relatively small outcrops within them constitute targets of research opportunity. To identify these targets, we employ an approach combining satellite and aerial remote sensing with ground-truth information acquired by vehicle and foot survey. Rather than starting small and working outward by chance, the project begins comprehensively and focuses incrementally (Asfaw et al. 1990).

This telescoping, or “stratified,” approach to area targeting makes the inventory geographically comprehensive without sacrificing spatial focus, meeting both scientific and EMC administrative concerns. The 1988–1989 inventory work has already established five new paleoanthropological research areas: Melka Werer; Burji; Fejej; Bilate; and the subject of the current contribution, the Kesem-Kebena (FIGS. 1, 2).

At the top of our sampling hierarchy is Landsat Thematic Mapper (TM) and Space Shuttle Large Format Camera (LFC) imagery. This imagery, when used with ground-truth information already acquired by fieldwork, allows areas with exposed continental sediments to be targeted (Asfaw et al. 1990). Foot and vehicle transects are then used to search for localities in the target areas. The localities, in turn, are used to characterize the nature and potential of each area. In large and rich areas, the discovery and assessment of all localities is impossible, and the inventory objective is limited to ensuring that a representative sample of localities is assessed.

Survey routes and discovery data are recorded in a daily log, cross-referenced to imagery hard copy, aerial photographs, 1:250,000 and 1:50,000 topographic sheets, GPS data, locality recording forms, and on-locality photographs and video—all archived in the Paleoanthropology Laboratory at the National Museum of Ethiopia. It is not the intent of the project to exploit the research potential
Figure 2. Inset map (A) shows the general location of the study area. Solid lines with ticks represent normal faults. Map (B) is a perspective view of a simplified geological map of the Kesem-Kebena area, western part of the northern sector of the Main Ethiopian Rift. The symbols represent: 1. recent sediments; 2. basaltic lavas and welded tuff units covered by a thin veneer of sediments; 3. basaltic conglomerate dominated by sediments intercalated with welded tuff units exposed along fault scarps and stream cuts; 4. rhyolite and basaltic lavas; 5. basaltic and silicic rocks of the rift escarpment; and 6. volcanic centers. The general location of the Kesem-Kebena area is indicated in Figure 1.

of localities discovered. Rather, the goal is documentation and geological sampling; excavation and collection of antiquities are not undertaken unless the remains are in immediate danger. Geological samples of volcanic material such as lavas or tephra are routinely taken for radiometric dating, stratigraphy work, and chemical fingerprinting. The last has become an increasingly important (Brown and Feibel 1986), but potentially unreliable (Aronson, Walter, and Taieb 1983), tool in correlating deposits within and between areas of Eastern Africa.

In the Kesem-Kebena work, some of the stratigraphically important samples were selected for major and minor analyses by X-ray fluorescence and by electron microprobe analytical techniques at Los Alamos National Laboratory, New Mexico. Analytical procedures for XRF and microprobe data are presented by Valentine (1983) and Warren, Beyers, and Caporuscio (1984), respectively. Information on K/Ar analyses is given in WoldeGabriel, Aronson, and Walter (1990). The $^{40}$Ar/$^{39}$Ar results were obtained at the Institute of Human Origins Geochronology Center in Berkeley, California. The center has a fully automated laser fusion $^{40}$Ar/$^{39}$Ar dating system. Samples and monitors are irradiated at the 8 MW Omega West reactor facility, Los Alamos National Laboratory, which has a fast neutron flux of $5.7 \times 10^{13}$ncm$^{-2}$s$^{-1}$. A sanidine from the Fish Canyon Tuff with a reference age of 27.85 Ma is used as a flux monitor. System blanks contain background levels of 2.7, 0.05, 0.03, 0.1, and 0.03 $\times 10^{-12}$ cc STP for...
Although evidence will continue to come from areas that are already known, it is the evidence from undiscovered areas that may hold the most potential for advancing scientific knowledge about human origins and evolution. In summary, the inventory project provides a basic framework for more traditional, intensive, area-oriented research to follow. We report here on the recently identified Kesem-Kebena area.

The Kesem-Kebena Area: Geography

In December of 1988, the Ethiopian Ministry of Culture launched its inventory project in a paleoanthropologically unexplored region near the northern terminus of the Main Ethiopian Rift. Further work in 1989 showed that this region, referred to here as the Kesem-Kebena area, bore important archaeological and paleontological evidence embedded in a substantial stratigraphic succession of sedimentary, basaltic, and silicic tephra units.

The Kesem-Kebena area (K-K) straddles two tributaries of the Awash River upstream from the Middle Awash and Hadar paleontology fields (FIG. 1). The area lies at the foot of the western Ethiopian Rift Escarpment, opposite Chorora (Sickenberg and Schönfeld 1975; Tiercelin, Michaux, and Bandet 1979; Asfaw et al. 1990), about 40 km NW of Awash Station and 220 km SSE of Hadar (FIGS. 1, 2). Before our inventory work, the Kesem-Kebena area was paleoanthropologically unknown; no vertebrate fossils had been reported from this side of the Awash River along the 300+ km between Melka Kontoure in the south and the Middle Awash to the north (FIG. 1).

The area is semi-arid, characterized by several gently dropping step-faulted blocks dominated topographically by the adjacent rift escarpment to the west and the Awash River and its floodplain to the east. Access from the paved Addis Ababa-Awash Station highway is via an all-weather, unsurfaced road that passes west of the volcano Fentale. Fentale lies ssw of the Kesem-Kebena area, and offset drainages north of the volcano Dofan delimit the area on the north (FIG. 2: inset map). A series of faults has dropped the Awash River base level relative to the Plio-Pleistocene sediments of the Kesem-Kebena, leading to dissection of these beds by streams draining toward the Awash River, the largest of these being the Kesem and the Kebena. The plantations of Sabure (Awara Melka) and Yalo Kebena have been established on the Awash floodplain (elevation 750–850 m), irrigated by these two major Awash tributaries which drain the adjacent highlands to the west (elevation 2800 m). These and adjacent, more ephemeral drainages such as the Sisale d’Ar and Tunfeta slice through the elevated Plio-Pleistocene sediments from west to east, forming deep canyons that expose dramatic stratigraphic sections in some places (FIG. 2).

The standard geological map of Ethiopia designates rocks in the Kesem-Kebena area as Holocene sediments (1:2,000,000 scale; Kazmin 1975), whereas Taieb and others mapped this area as Trap basalts and Upper Pleistocene sediments (1:500,000 scale; Taieb 1974). According to a recently compiled map (1:100,000), the Kesem-Kebena area consists of several volcanic and sedimentary rocks that become progressively younger toward the Awash flood plain (EIGS 1989). The major units are represented by older pre-Miocene Trap basalts that are probably underlain by Mesozoic sedimentary formations and crystalline basement rocks (seen on the western escarpment); Miocene and Plio-Pleistocene volcanics of the rift margin; and Plio-Pleistocene alluvial fans, slope deposits, and gravel terraces intercalated with pyroclastics and basalt flows of the rift floor. Geologic cross-sections along the Kesem canyon upstream from the Kesem-Kebena area expose basaltic and silicic rocks that span the Miocene period (23-7.7 Ma) (Rex, Gibson, and Dakin 1971; Justin-Visentin et al. 1974; Jones 1976). Our attention was drawn to the Kesem-Kebena area by TM and LFC imagery which suggested, on the basis of reflectance, structural, and geomorphological considerations, that late Cenozoic sediments might be found (Asfaw et al. 1990). Initial work in 1988 introduced the paleoanthropological potential of Kesem-Kebena, and further work in 1989 established the extent and content of these rocks.

In 1989 we established a camp at Yalo-Kebena on the edge of the Kebena River, adjacent to the cotton plantation headquarters (FIG. 2). This site is central to the sedimentary outcrops discovered by our pilot work the previous year. We performed foot and vehicle transects from the Awash River floodplain toward the western rift escarpment, penetrating the rough terrain via tributaries of the Awash River such as the Kebena, Tunfeta, and Kurreti, which slice from west to east through the variably tilted sedimentary succession (FIG. 2). Multiple transects were made across the area between Sabure and the NW edge of the volcano Dofan, a distance of approximately 45 km (FIG. 2).
Kesem-Kebena: Pliocene

Geology and Geochronology

Reconnaissance geological survey along the western margin of the northern sector of the Main Ethiopian Rift between the Kesem and the Kebena rivers north and west of the Quaternary rift axis volcanoes of Fentale and Dofan, respectively, revealed volcanic flows intercalated with fluvial and lacustrine sedimentary deposits (FIG. 2). The rift margin in this region is broad and drops gently toward the rift floor. It is cut by densely spaced and partially weathered normal fault scarps that form synthetically and antithetically rotated step-faulted blocks. Several sections were studied and sampled to constrain the age and stratigraphic relationships of the various units across several fault blocks throughout the Kesem-Kebena area (FIG. 3).

In the NW part of the study area, several lithologic units are exposed along a major NE-SW-trending fault scarp up to 200 m high. The fossiliferous K-K1 and K-K2 localities occur along normal fault scarps and are less than 2 km apart (FIG. 2). The NW-SE-trending normal faults that run between these two localities prevent the units at each from being traced laterally, even across that short distance. Because of these cross-cutting faults, the lateral distribution of the various lithologic units is local in extent.

The rift axis-oriented fault scarp at the K-K1 locality exposes a section more than 150 m thick (FIG. 3) that comprises a basal fossiliferous sedimentary deposit (ca. 75 m thick) capped by a 20 m thick, partially fractured and weathered aphanitic basalt (KK-1A) that grades to a vesicular, amygduloidal, and porphyritic flow (KK-1B). The thick sedimentary sequence is fluvial and lacustrine in origin. Calcite-cemented conglomeratic lenses underlie the fossil-bearing silty-clay sedimentary horizon. The base of the overlying basalt at the contact with this sedimentary unit is weathered, probably due to interaction of the initial lava flow with water or wet sediments. The basalt is covered by poorly consolidated conglomeratic fluvial deposit (ca. 50 m thick). The top of the section is capped by a strongly welded (volcanic rocks fused by heat soon after eruption) crystal- and lithic-rich greenish tuff (KK-1C) that is 15-20 m thick. Across from this section, similar units are exposed in the eastern wall of a deep canyon cut by a seasonal stream that runs along a transverse fault zone. There, a thick (ca. 20 m) welded tuff (KK-1D) caps unconsolidated gravel-rich sediments (ca. 60 m) that are underlain by a 5 m thick, lithic-rich, platy, and perlitic welded tuff (KK-1E). At the base of the section a calcite-filled vesicular and aphanitic basalt (KK-1F) is exposed.

Geochemically, the KK-1A/B basalt is transitional tholeiitic with low K$_2$O and high total FeO (TABLE 1). It is enriched in Sr, V, and Ba and depleted in Rb, like many contemporaneous rift floor basalts. The welded tuff units
Table 1. X-ray fluorescence major and trace element analyses of samples from the Kesem-Kebena area of the northern sector of the Main Ethiopian Rift.

<table>
<thead>
<tr>
<th>Element</th>
<th>89KK-1A</th>
<th>89KK-2A</th>
<th>89KK-2E</th>
<th>89K-1</th>
<th>89K-2*</th>
<th>89K-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>48.06</td>
<td>45.28</td>
<td>46.81</td>
<td>47.87</td>
<td>45.20</td>
<td>47.87</td>
</tr>
<tr>
<td>TiO₂</td>
<td>2.71</td>
<td>3.01</td>
<td>2.85</td>
<td>2.71</td>
<td>2.25</td>
<td>2.40</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>16.39</td>
<td>15.81</td>
<td>14.54</td>
<td>18.29</td>
<td>15.76</td>
<td>16.38</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>14.11</td>
<td>14.58</td>
<td>15.22</td>
<td>12.06</td>
<td>14.58</td>
<td>13.08</td>
</tr>
<tr>
<td>MnO</td>
<td>0.18</td>
<td>0.19</td>
<td>0.20</td>
<td>0.17</td>
<td>0.19</td>
<td>0.15</td>
</tr>
<tr>
<td>MgO</td>
<td>4.81</td>
<td>7.06</td>
<td>6.36</td>
<td>4.68</td>
<td>6.77</td>
<td>5.97</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.98</td>
<td>0.92</td>
<td>1.06</td>
<td>0.75</td>
<td>0.93</td>
<td>0.80</td>
</tr>
<tr>
<td>Na₂O</td>
<td>3.70</td>
<td>2.87</td>
<td>3.13</td>
<td>3.34</td>
<td>2.91</td>
<td>3.14</td>
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<tr>
<td>P₂O₅</td>
<td>0.41</td>
<td>0.56</td>
<td>0.67</td>
<td>0.29</td>
<td>0.55</td>
<td>0.36</td>
</tr>
<tr>
<td>Total</td>
<td>99.97</td>
<td>99.34</td>
<td>99.83</td>
<td>99.35</td>
<td>98.94</td>
<td>100.14</td>
</tr>
</tbody>
</table>

*R=Replicate analysis of 89KK-2A

Table 2. ⁴⁰Ar/³⁹Ar single crystal laser fusion age data on rocks and minerals of the Kesem-Kebena area and adjacent region of the northern sector of the Main Ethiopian Rift. All locations are indicated in Figure 2.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Location</th>
<th>Material</th>
<th>³⁹Ar/³⁹Ar</th>
<th>³⁹Ar/³⁹Ar</th>
<th>³⁹Ar/³⁹Ar</th>
<th>% RAD</th>
<th>J</th>
<th>Age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>89KK-4A</td>
<td>K-K4</td>
<td>Sanidine</td>
<td>0.0089</td>
<td>0.0093</td>
<td>3.0915</td>
<td>89</td>
<td>1.88 x 10⁻⁴</td>
<td>1.049 ± 0.082</td>
</tr>
<tr>
<td>89KK-6A</td>
<td>K-K6</td>
<td>Sanidine</td>
<td>0.0039</td>
<td>0.0023</td>
<td>3.0558</td>
<td>88</td>
<td>1.88 x 10⁻⁴</td>
<td>1.038 ± 0.011</td>
</tr>
<tr>
<td>89KK-6G</td>
<td>K-K6</td>
<td>Sanidine</td>
<td>1.7145</td>
<td>0.0761</td>
<td>2.9863</td>
<td>63</td>
<td>1.88 x 10⁻⁴</td>
<td>1.002 ± 0.041</td>
</tr>
<tr>
<td>89KK-7</td>
<td>Tunfeta</td>
<td>Sanidine</td>
<td>0.0296</td>
<td>0.0037</td>
<td>5.8955</td>
<td>96</td>
<td>1.88 x 10⁻⁴</td>
<td>2.007 ± 0.022</td>
</tr>
<tr>
<td>89KK-11</td>
<td>Tunfeta</td>
<td>Sanidine</td>
<td>0.0158</td>
<td>0.0085</td>
<td>5.4354</td>
<td>90</td>
<td>1.84 x 10⁻⁴</td>
<td>1.847 ± 0.026</td>
</tr>
</tbody>
</table>

Table 3. Conventional K/Ar age data on rocks and minerals of the Kesem-Kebena area and adjacent region of the northern sector of the Main Ethiopian Rift. All locations are indicated in Figure 2.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Location</th>
<th>Rock type</th>
<th>K₂O (Wt. %)</th>
<th>⁴⁰Ar* x 10⁻⁶ (mol/g)</th>
<th>⁴⁰Ar* %</th>
<th>Age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>83W-43B</td>
<td>Dofan</td>
<td>Obsidian</td>
<td>4.15</td>
<td>0.074</td>
<td>20</td>
<td>0.12 ± 0.01</td>
</tr>
<tr>
<td>89BT-128</td>
<td>Awash Gorge</td>
<td>Basalt</td>
<td>1.03</td>
<td>0.301</td>
<td>28</td>
<td>2.02 ± 0.13</td>
</tr>
<tr>
<td>89K-10</td>
<td>Tunfeta</td>
<td>Basalt</td>
<td>0.77</td>
<td>0.024</td>
<td>7</td>
<td>2.16 ± 0.07</td>
</tr>
<tr>
<td>89KK-1A</td>
<td>K-K1</td>
<td>Basalt</td>
<td>0.99</td>
<td>0.316</td>
<td>13</td>
<td>2.23 ± 0.04</td>
</tr>
<tr>
<td>89KK-2E</td>
<td>K-K2</td>
<td>Basalt</td>
<td>1.05</td>
<td>0.057</td>
<td>40</td>
<td>3.76 ± 0.06</td>
</tr>
<tr>
<td>83BT-123</td>
<td>Awash Gorge</td>
<td>Basalt</td>
<td>0.96</td>
<td>0.779</td>
<td>30</td>
<td>5.6 ± 0.32</td>
</tr>
</tbody>
</table>

are peralkaline to mildly peralkaline in composition (TABLES 2, 4) and probably erupted from the same center (e.g., Fentale or Dofan; FIG. 2). A K/Ar dating of this basalt (KK-1) above the fossiliferous sediments yielded a date of 2.23 Ma (TABLE 3), demonstrating major tectonic and geomorphic modification of the region since the eruption of these volcanic units in the Late Pliocene.

The stratigraphic sequence at the K-K2 locality consists of basaltic flows, tephra beds, an altered basalt, and a fossiliferous sediment at the base of the section (FIG. 3). The basal flow (KK-2A) of the lava sequence is fairly porphyritic with plagioclase phenocrysts. In the middle of the section, several beds of tephra underlie the lavas and consist of poorly consolidated and weathered ash fall (KK-2B) that is underlain by a welded and fissile vitric tuff (KK-2C). The base of the tephra units consists of bedded and laminated vitric ash fall layers (KK-2D). The basalt flow (KK-2E) below the ash beds is strongly weathered and crops out atop the fossil-bearing sediments.

Geochemical data (TABLE 1) indicate that the younger
Table 4. Electron microprobe glass analyses of various tephras from the Kesem-Kebena area normalized to 100 wt % (n = number of glass shard analyses).

<table>
<thead>
<tr>
<th>Element</th>
<th>89KK-1d</th>
<th>89KK-1e</th>
<th>89KK-4a1</th>
<th>89KK-4a2</th>
<th>89KK-4c</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>72.79</td>
<td>72.17</td>
<td>75.82</td>
<td>67.71</td>
<td>69.14</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.24</td>
<td>0.28</td>
<td>0.12</td>
<td>0.39</td>
<td>0.52</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>8.86</td>
<td>11.48</td>
<td>11.05</td>
<td>13.67</td>
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<tr>
<td>Fe₂O₃</td>
<td>7.17</td>
<td>4.32</td>
<td>2.89</td>
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<td>3.12</td>
</tr>
<tr>
<td>MnO</td>
<td>0.24</td>
<td>0.26</td>
<td>0.10</td>
<td>0.31</td>
<td>0.09</td>
</tr>
<tr>
<td>MgO</td>
<td>0.02</td>
<td>0.14</td>
<td>0</td>
<td>0.07</td>
<td>0.50</td>
</tr>
<tr>
<td>CaO</td>
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<td>0.15</td>
<td>0.18</td>
<td>1.19</td>
<td>1.59</td>
</tr>
<tr>
<td>BaO</td>
<td>0.05</td>
<td>0.09</td>
<td>0.03</td>
<td>0.07</td>
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<tr>
<td>Na₂O</td>
<td>5.57</td>
<td>5.45</td>
<td>4.61</td>
<td>5.37</td>
<td>4.66</td>
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<tr>
<td>K₂O</td>
<td>4.71</td>
<td>5.64</td>
<td>5.21</td>
<td>5.90</td>
<td>4.26</td>
</tr>
<tr>
<td>Total</td>
<td>94.5</td>
<td>94.82</td>
<td>94.7</td>
<td>94.7</td>
<td>93.2</td>
</tr>
<tr>
<td>n</td>
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<td>3</td>
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<table>
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<tr>
<th>Element</th>
<th>89KK-4F</th>
<th>89KK-4E</th>
<th>89KK-4G</th>
<th>89KK-4J</th>
<th>89KK-4K</th>
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<td>SiO₂</td>
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<td>68.07</td>
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<td>TiO₂</td>
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<td>Al₂O₃</td>
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<td>15.95</td>
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<td>5.16</td>
</tr>
<tr>
<td>MnO</td>
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</tr>
<tr>
<td>MgO</td>
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<td>0.29</td>
<td>0.01</td>
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<tr>
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<td>0.33</td>
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<tr>
<td>BaO</td>
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<td>0.02</td>
<td>0.12</td>
<td>0.03</td>
<td>0.06</td>
</tr>
<tr>
<td>Na₂O</td>
<td>4.75</td>
<td>3.38</td>
<td>5.74</td>
<td>4.21</td>
<td>3.62</td>
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<tr>
<td>K₂O</td>
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<td>4.70</td>
<td>4.13</td>
<td>5.54</td>
<td>5.62</td>
</tr>
<tr>
<td>Total</td>
<td>91.62</td>
<td>92.61</td>
<td>92.17</td>
<td>93.54</td>
<td>91.39</td>
</tr>
<tr>
<td>n</td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>7</td>
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<table>
<thead>
<tr>
<th>Element</th>
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<th>89K-3</th>
<th>89K-7</th>
<th>89K-8</th>
<th>89K-11</th>
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<td>71.08</td>
<td>71.56</td>
<td>73.34</td>
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</tr>
<tr>
<td>TiO₂</td>
<td>0.20</td>
<td>0.30</td>
<td>0.37</td>
<td>0.26</td>
<td>0.30</td>
<td>0.36</td>
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</tr>
<tr>
<td>Fe₂O₃</td>
<td>2.97</td>
<td>4.06</td>
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<td>4.03</td>
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<tr>
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<td>0.16</td>
<td>0.16</td>
<td>0.24</td>
<td>0.20</td>
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</tr>
<tr>
<td>MgO</td>
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</tr>
<tr>
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<td>0.30</td>
<td>1.51</td>
<td>0.70</td>
<td>0.27</td>
<td>0.39</td>
</tr>
<tr>
<td>BaO</td>
<td>0.03</td>
<td>0.10</td>
<td>0.01</td>
<td>0.05</td>
<td>0.15</td>
<td>0.03</td>
<td>0.08</td>
</tr>
<tr>
<td>Na₂O</td>
<td>3.33</td>
<td>4.77</td>
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<td>4.13</td>
<td>2.74</td>
<td>5.89</td>
<td>5.15</td>
</tr>
<tr>
<td>K₂O</td>
<td>6.74</td>
<td>4.65</td>
<td>4.78</td>
<td>6.46</td>
<td>6.75</td>
<td>3.90</td>
<td>4.81</td>
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<tr>
<td>Total</td>
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<td>92.29</td>
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<td>96.99</td>
<td>92.28</td>
<td>97.64</td>
<td>91.52</td>
</tr>
<tr>
<td>n</td>
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<td>7</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>7</td>
</tr>
</tbody>
</table>

basalt (KK-2A) is slightly more enriched in MgO, TiO₂, Al₂O₃ than the early Pliocene (3.76 Ma) basalt (KK-2E) above the fossiliferous sediments. The Late Pliocene basalt (2.23 Ma) at the K-K₁ locality that caps the fossil-rich sediments is slightly different from the K-K₂ flows.

Northeast of the K-K₁ locality, the Kebena River cuts across southeasterly dipping (S18E) welded tuff, basaltic lava, and sedimentary units forming the walls of a deep (ca. 300 m) and narrow box canyon. Here, a basalt flow (K-1) and a welded tuff (K-3) were collected. About 2 km NE of this canyon, the Tunfeta ephemeral stream runs through a similar box canyon exposing the same lithologic succession with an average dip of 20° to the SE. As shown in Figure 3, the Tunfeta section consists of bedded sediments, lithic-rich welded tuff (K-7), bedded pumiceous fall (K-8 and K-9), a porphyritic basalt (K-10) with a 1 m-thick baked zone, and a crystal-rich and strongly welded tuff (K-11). Because of the attitude of the units and the widespread faulting, most of these units cannot be traced laterally except in the adjacent box canyon of the Kebena River. Based on the degree of welding and proximity, the welded ash flow and ash fall tuff units were probably erupted from either of the nearest Quaternary center of Fentale or Dofan to the SW and SE of the section, respectively, whereas the basaltic flow is fissural in origin. These units are buried under thick (>200 m) basalt-dominated sand, gravel, and conglomerate deposits that were transported from the adjacent western rift escarpment (FIG. 2).

The three tuff units from the Tunfeta section are generally mildly peralkaline, whereas the sample from the
Kebena River is peralkaline, with higher iron (ca. 6 wt%) content than the others (Table 4). K/Ar and 40Ar/39Ar data on three samples from the Tunfeta Canyon yielded Late Pliocene ages (Tables 3, 4). The 40Ar/39Ar dating of sanidine separates from the basal lithic-rich (K-7) and the upper crystal-rich (K-11) welded tuff units yielded results of 2.01 and 1.85 Ma, respectively, whereas the basalt flow between the two tuffs provides a slightly older K/Ar date of 2.16 Ma (Table 3). The minor variation in age may be due to contamination by older rock or phenocrysts in the basalt. The basalt is compositionally similar to other flows from the adjacent localities (e.g., K-K1, K-K2, and K-1 from the Kebena River).

**Paleontology**

**LOCALITY K-K2**

As noted in the preceding section, two vertebrate localities were described for the Kesem-Kebena area, K-K1 and K-K2. The older locality, K-K2, is located in an embayment of an escarpment called "Adon-Adas" (Fig. 2). Here, the fauna comprises fragmentary chelid remains and proboscidean remains found in situ and on an outwash lag surface below some silts that underlie the basalt dated at 3.76 Ma.

**LOCALITY K-K1**

The most important Pliocene vertebrate locality thus far discovered in the Kesem-Kebena area is K-K1, found by Yonas Beyene in 1988 on a steep slope ca. 13.5 km north of Sabure (Fig. 2). Dozens of vertebrate fossils were exposed on the surface here, and a search of the slope identified the fossiliferous stratum as a gray silty sand poorly exposed on the steep slope about 25 m below the 2.23 Ma basalt. The excellent preservation of the vertebrate remains and their abundance indicate that a productive quarry could be established on this hillside.

The K-K1 surface fossil assemblage is diverse in taxa and body parts, with fish, turtle, crocodile, and hippopotamus remains indicating a nearby permanent water source at the time of deposition. The bovid assemblage is diagnostic, comprising, cf. Reduncini, Tragelaphini(?), cf. Damalops, Aepyceros cf. shungurensis, and Syncerus/Ugandac. The Aepyceros is larger than the Hadar form, and matches the Omo Shungura B/C or more recent representatives. The bovine mandible shows a fourth premolar whose metaconid slants posteriorly, a trait seen in Syncerus from Omo Shungura B and C, from Koobi Fora Area 203, and from Hadar. Other details, however, differ from the Hadar Ugandac.

One primate is known from K-K1, a form of Theropithecus represented by an immature, edentulous mandible and a right lower third molar. The latter specimen measures as follows: length: 22.1 mm; breadth: 12.7 mm; height at entoconid: 9.9 mm. In size and relative crown height, the specimen lies intermediate between the Hadar T. darti and the Omo Shungura Member C specimens of T. brumpti. We attribute this specimen to Theropithecus brumpti/baringensis.

Biochronologically, the K-K1 locality is clearly Pliocene, best fitting between Hadar and Omo Shungura Member C. Thus, a biochronological placement of ca. 3.0–2.5 Ma would best fit the known fauna. The discrepancy between this estimate and the superimposed basalt date of 2.23 Ma will only be resolved by further field research, but both lines of evidence place the K-K1 occurrence firmly in the Pliocene. This is a period of considerable importance in mammalian, and particularly hominid, evolution in Africa.

The Kesem-Kebena Pliocene sediments described in the previous section on geology comprise many beds deposited by rapidly flowing water. This, and the fact that the beds are not well exposed horizontally, contribute to the limited number (two) of Pliocene vertebrate localities established by inventory project personnel. Isolated vertebrate fossils, Hippipon teeth and a phalanx, were found on Pliocene strata exposed in the walls of the Kebena river canyon NE of the K-K1 and K-K2 localities. More detailed paleontological survey will undoubtedly produce additional vertebrate paleontological localities in the Kesem-Kebena Pliocene strata. The inventory team found no evidence of lithic technology or hominid-based bone modification in the Pliocene deposits.

**Kesem-Kebena: Pleistocene**

**Geology and Geochronology**

The volcanic flows and the interbedded sediments of the Kesem-Kebena area get progressively younger in age toward the rift axis and away from the western rift escarpment. The Late Pliocene rocks are generally covered by tephras in elevated terranes and tephras and sediments in the low-lying areas. Several sections consisting of Early to Middle Pleistocene volcanic and sedimentary deposits occur along fault scarps and stream cuts. In the Bara locality, about 3 km SE of the K-K1 locality (Fig. 2), vertebrate bone-bearing conglomeratic and silty sediments occur below reworked tuff and ash fall that are capped by an agglomeratic unit. Northeast of the Bara section and about a kilometer east of the K-K1 locality, clastic beds and tephra units crop out along gullies. Most of these sediments are devoid of fossils except for localized, low den-
The Late Pliocene rocks exposed along the Kebena and Tunfeta River Canyons are overlain by lithic-rich welded tuffs, ash falls, and gravel and silty clay deposits of fluvial origin. The welded tuff units form resistant cliffs along fault scarps and stream cuts.

In the K-K4 locality, north of the Tunfeta stream, several tephra layers are exposed between fossil-bearing sediments. There, a welded tuff (KK-4A) occurs below and above a pumice (KK-4B) and an ash fall (KK-4C) unit, respectively (FIG. 4). These tephras blanket light-brown fossiliferous sediments. About a kilometer to the NW of this section, a bedded vitric ash (KK-4E) that grades down to a strongly welded fiamme-rich greenish tuff (KK-4D) crops out. These units are gently tilted to the SE. About 3 km NE of the fossil-rich section (KK-4A), two ash fall units (KK-4F and G) and a densely welded tuff (KK-4H) are intercalated with light reddish-brown silty clay sediments and occur along deeply dissected ephemeral stream banks. Southeast of the KK-4A section, thin (<10 cm) ash layers (KK-4I, J, and K) occur interbedded with thick (15-20 m) and consolidated light orange-brown sedimentary deposits along the Sissale D’ar stream banks.

The silicic tephras of the K-K4 locality are geochemically variable (TABLE 2). They range from alkaline to per-alkaline in composition, suggesting variable source areas or a center that erupted compositionally variable flows. Sample KK-4A contains two types of volcanic glasses (KK-4A; KK-4A2) suggestive of magma mixture prior to eruption. Some of the glasses are silica-poor and iron-rich, whereas the opposite is true for the other type (TABLE 2). Some of the tephra units were recognized in other sections around the K-K4 locality. Major element contents of KK-4G and KK-4C are similar, whereas some of the glasses in KK-4A are compositionally correlative to glasses in KK-4J.

Sanidine separates from the lithic-rich welded tuff (KK-4A) above the fossiliferous sediments yielded an $^{40}\text{Ar}/^{39}\text{Ar}$ age of 1.05 Ma. Based on the local stratigraphic relations, this unit is older than most of the ash falls except for the southeasterly-tilted, green welded tuff (KK-4D and E).

Northeast of the K-K4 locality, several fossil- and artifact-rich sediments crop out along stream gullies (FIG. 2). At the K-K3 locality, a vitric tuff (KK-3) occurs between two conglomeratic and silty clay deposits along an older stream terrace on the south side of the Kurteti seasonal stream bed. The fossiliferous sediment overlies the vitric tuff.

The K-K6 locality to the NW of the KK-3 outcrop is a
heavily dissected badland topography containing the richest fossil and artifact concentration in the Kesem-Kebena area. The fossil-rich sediments are underlain by thick (>30 m), pumiceous tuff units that are exposed along deep and narrow box canyons of the Haraftei seasonal stream and its adjacent tributaries (FIGS. 2, 3, and 6). These tephras are tilted to the SE (5°–10°). The basal unit (KK-6A) consists of poorly sorted coarse pumice fragments (<15 cm diameter) embedded in a matrix of vitric ash, and grades to an ash fall (KK-6B). This unit is followed by a fines-depleted pumice fall (KK-6C). A fairly weathered yellowish pumice bed blanketed by a pumice fall (KK-6D) forms the top of the pyroclastic sequence. The upper half of the section is dominated by the fossil- and artifact-rich lacustrine and fluvial volcaniclastic and silty clay deposits. A partially reworked pumice fall (KK-6G) occurs in the lower part of the sedimentary deposit and most of the fossil- and artifact-rich horizon crops out just below it. A thin (ca. 10 cm), dark-gray ash layer (KK-6E) intercalated with the silty clay occurs at the top part of the section. To the NNW of the K-K6 locality, a 20 m-thick, southeasterly dipping (ca. 10°), densely welded tuff (KK-6F) underlies bedded pumice fall. Isolated low density fossils and artifacts were discovered in the sediments above the pumice fall.

Northeast of the K-K6 locality, a 1.5 m thick unconsolidated vitric ash (KK-7) was recognized between light brown silty clay deposits. Along the seasonal stream banks of the K-K7 locality, the sandy clay deposit above the tuff is about 10 m thick, whereas the underlying massive deposit is about 4 m thick. Fossils and artifacts eroded from sediments above the vitric tuff horizon were recognized in the section.

Geochemical data from the basal ash flow tuff (KK-6A) and the partially reworked pumice fall (KK-6G) indicate a peralkaline and mildly alkaline composition, respectively. The 40Ar/39Ar data, however, suggest that the tephras are similar in age. Ages of 1.04 and 1.0 Ma were obtained on the basal pumiceous tuff and the pumice fall above the fossiliferous zone, respectively (TABLE 2). The similarity in age and the variation in chemistry suggest that the units were erupted from separate source areas more or less at the same time as the tephras of the K-K4 locality, probably from Dofan and Fentale (FIG. 2), the closest Quaternary volcanic centers in the area. At Dofan, just east of the K-K3, K-K6, and the K-K7 localities, some of the youngest obsidian flows (83W43B) are much younger than the tephra units encountered at the K-K6 locality to the north (TABLE 3).

Based on major element glass chemistry, some of the tephra units were correlated to each other within the study area (TABLE 4). For example, a tuff unit (KK-1D) from the K-K1 locality is similar to KK-4E that crops out in a stream below the KK-4A welded tuff (1.05 Ma). Both KK-4A and KK-6A yielded similar ages (TABLE 2) and have very similar chemistry (TABLE 4). Another unit (KK-4J) from the vicinity of the K-K4 locality is also correlated to both tuffs. Some of the younger tephras from the adjacent K-K4 and K-K6 localities are also similar. For example, KK-4G and KK-6G (1.0 Ma) have similar major element chemistry. The SD-1 tuff exposed SE of the K-K1 locality (FIG. 2) is also correlated to K-11 (1.85 Ma) from the top part of the Tunfeta Canyon (FIG. 3).

Paleontology and Archaeology

The Pleistocene deposits in the Kesem drainage area west of Awara Melka (Sabure) are sterile, except for abundant rootcasts, but their counterparts to the north are increasingly fossiliferous and implementiferous, particularly west of the volcano Dofan (FIG. 2). All of the transects north of the Tunfeta drainage encountered archeological evidence in the form of flakes, debitage, and occasional isolated handaxes. The established localities all represent occurrences with concentrations of vertebrate fossils. Our survey of middle Pleistocene rocks established four paleoanthropological localities in the Kesem-Kebena area.

LOCALITY K-K4

The most southerly locality, K-K4, is a rich vertebrate locality with a diverse surface and exposed in situ fauna (FIG. 4). No artifacts were seen directly associated with the K-K4 vertebrate assemblage, but about 20 m to the west, in the same geological unit, a denticulated sidescraper made of welded tuff was found in situ. Excavations of the poorly-consolidated, fossiliferous silty sands which yield the diverse, well-preserved fauna will be necessary to establish the archeological content of the locality—a few flakes and chunks, mostly of welded tuff, were identified on adjacent slopes, and more surface artifacts, including handaxes, sidescrapers, and unretouched flakes on welded tuff and chalcedony, were found ca. 500 m to the west.

The K-K4 faunal assemblage shows a wide range of body parts, some articulated, and includes the taxa *Metriodiochoerus modestus* (partial cranium), Tragelaphini, Alcelaphini, *Antidorcas* cf. *recki*, a large Equus, *Theropithecus owaldi* (distal tibia), *Colobus* sp. (2 maxillae), and *Viverridae*. The biochronological placement of this fauna is rendered difficult by the limited sample size of the surface specimens, and by a rarity of well-dated middle Pleistocene assemblages elsewhere in Africa. It is notable that aquatic elements are absent in this assemblage. The deposits are
vertebrate fauna including the suid *Kolpochoerus majus*, a taxon also found in the Bodo deposits of the Middle Awash Valley (Harris and White 1979; Clark et al. 1984), as well as the remains of Rhinocerotidae, Hippopotamidae, Alcelaphini, and Antilopini. The bone was well fossilized, and specimens range from unabraded to highly rolled bone pebbles. The unit yielding these remains also contained a few in situ welded-tuff flakes and chunks, but no handaxes were present. The artifacts, although unabraded, were judged to be in secondary context. Outcrops of the same geological unit were traced across to the western bank of the Kurteti where they were also observed to yield vertebrate fossils and occasional artifacts.

**LOCALITY K-K6**

The K-K6 locality is an extensive outcrop of Pleistocene sediments farther west of the volcano Dofan in the Haraftili and adjacent drainages (FIGS. 2, 6). Concentrations of artifacts (particularly Acheulian bifaces) and vertebrate fossils were found in an area measuring approximately 50,000 sq m, but we chose to identify the entire continuous outcrop as one locality because at least a thin scatter of artifacts and fossils was present wherever the relevant sediments outcropped. The locality is dissected into thirds by the two forks of the Haraftili drainage (below whose junction the drainage is called the “Edegaho”). Fossils and artifacts were found from the top to the bottom of this section (FIG. 5), but a widespread, light-grey tuffaceous deposit yielded the greatest concentration of surface artifacts and vertebrate fossils.

Abundant vertebrate fossils found on surfaces of the K-K6 outcrops, particularly on the light grey tuffaceous deposits, included remains of *Elephas* sp., Bovini, Alcelaphini, Reduncini/Hippotragini, *Kolpochoerus olduvaensis*, *Phacochoerus* sp., *Hippopotamus* sp. (FIG. 6), Rhinocerotidae, *Equus* sp., Crocodilia, Pisces, and Aves. Fish, crocodile, and hippopotamus fossils were particularly abundant, indicating a permanent water source at the time of deposition. Found on surfaces of the same outcrops were a low-density background scatter of flakes, and a few bifaces, mostly on welded tuff and rhyolite.

In one location, KK-6b, between the Haraftili drainage arms, an approximately 20 × 20 m remnant patch of tuffaceous silts had exposed on its surface 21 unabraded handaxes (FIG. 7). One was found in situ in the light gray tuffaceous deposit. Very few whole flakes and sidescrapers were found with the handaxes (they had obviously been made elsewhere and imported), in contrast to other K-K6 exposures of the same stratum where flakes were common but bifaces rare.

In addition to the miscellaneous small tools and flakes,
shallow trimming is present on the ventral faces. Flaking was probably done with hard hammer (handaxes found at other locations within the K-K6 locality showed evidence of soft hammer retouch). Many of the handaxes retain cortical butts, showing that the raw material took the form of stream worn boulders and cobbles. All of them are heavy-duty; sections are plano-convex for the specimens conserving the cortex, and bi-convex for those without cortex. The lone exception is a trihedral pick with a quadrangular section. These tools and flakes are extremely fresh, with unaltered phenocrysts in the flake scars and with sharp, unabraded edges, all circumstances indicating minimal disturbance or transport.

The handaxes from K-K6 fall into four types, pointed handaxes, trihedral picks, converging cleavers (Bachereau bifaces), and cleaver and core axes. Dimensions of 19 K-K6b bifaces range in maximum length from 152–222 mm (mean=183 mm), maximum breadth from 72–120 mm (mean=99 mm). Thickness values show a homogenous “thick” aspect to these tools. Bifaces from other outcrops of the same geological unit were not so spatially concentrated, and included thinner, more finely-flaked forms than those observed at KK-6b.
Figure 8. Bifaces from the KK-6B locality, dorsal and ventral faces illustrated.
The depositional context of the Kesem-Kebena locality K-K6 fossils and their co-occurrence with unabraded stone tools on the freshly-eroded outcrops strongly implies contemporaneity of these remains in undisturbed, primary contexts—ideal settings for archaeological investigation. There are many outcrops of the fossiliferous, soft grey tuffaceous silt in locations where very little overburden would have to be removed in a horizontally large excavation. Furthermore, study of the lateral variation in assemblage types and stone tool concentrations (as in Jones 1979; Potts 1989) should prove highly effective in this region. Thus, the Kesem-Kebena Middle Pleistocene deposits are full of potential for future archaeological research.

**LOCALITY K-K7**

The K-K7 locality lies NE of K-K6. It yielded remains of *Kolpochoerus cf. majus, Phacochoerus* sp. and medium and small bovid, as well as late Acheulean artifacts. The sediments themselves are judged, from field aspect, to be younger than those of K-K6. These sediments represent a good lithological and archaeological match for occurrences on the eastern side of the Awash River at Melka Werer (discovered by the inventory project in 1988–1989; FIG. 2). Diminutive ovate and elongate ovate bifaces on obsidian and welded tuff (with biconvex sections and shallow retouch) are common in this area, but all were surface finds. The K-K7 locality marked the northernmost extent of the 1989 inventory project work in this area. Further research to extend knowledge northward is planned, as is work to correlate between the volcanic horizons of Kesem-Kebena (particularly at K-K7) and those of Melka Werer.

**Kesem-Kebena: Late Pleistocene**

**Geology**

Silty and conglomeratic sediments are disconformable above the youngest vitric ash deposits along stream terraces in the vicinity of most of the fossil- and artifact-bearing localities described above. These later sedimentary deposits occur primarily as isolated patches. One of the well documented outcrops occurs at the K-K5 locality between the K-K3 and K-K6 Pleistocene sections (FIGS. 2, 9). The sedimentary rocks at locality K-K5 consist of a moderately consolidated light-brown, silty clay with conglomeratic lenses exposed along a stream bank to the north of the Kurteti seasonal stream. In a terrace adjacent to the northern bank of the stream a dense concentration of artifacts with small fragments of bone was discovered (FIG. 10).

**Paleontology and Archaeology**

The thin veneer of late Pleistocene sediments between localities K-K3 and K-K6 has deflated due to erosion at locality K-K5, revealing a rich concentration of Later Stone Age artifacts (FIG. 10). The locality is placed on a terrace about 20 m above the local drainage floors. The artifacts include fire-altered rocks, end scrapers, flakes from prepared cores, sidescrapers, microliths, blade cores, blades, and debitage. Most of the artifacts are on welded tuff, but some are on obsidian and chalcedony. There is friable vertebrate bone and some charcoal associated with the assemblage. There are many large blades on obsidian and welded tuff at this extensive locality, but none of the fauna was identifiable. Smaller occurrences with similar content were seen in much of the area west of Dofan volcano, always unconformably superimposed on the earlier Pleistocene sediments.

Middle Stone Age assemblages are notably absent from the Kesem-Kebena area, with the exception of surface occurrences near the “Asa Kela” drainage where Levallois flakes, and cores, small bifaces, denticulated sidescrapers and notched flakes on welded tuff were encountered on the surface during survey. No locality was assigned to these assemblages.

**Plio-Pleistocene Evolution of the Kesem-Kebena Area**

In its northern sector, the Main Ethiopian Rift (MER) broadens toward the Afar depression. The rift margin in the Kesem-Kebena area is characterized by broad, step-faulted, synthetically- and antithetically-tilted, and extensively dissected blocks that gently drop toward the rift floor. According to Morton and Black (1975), this is a manifestation of rifting and crustal thinning that developed as a result of normal faulting and block tilting and ductile deformation within the upper and lower crustal layers, respectively. Mohr (1983), however, disputed this hypothesis and suggested an alternative process of dilation and ductile deformation that was enhanced by heat flow from dike injections to create this kind of rifting mechanism. Although no dikes were observed in the Kesem-Kebena area, magma injections that led to basalt fissural eruptions along border faults of the marginal grabens may have facilitated dilation and block tilting, resulting in the present tectonic and geomorphic features of the broadly-faulted western rift margin. The rift shoulder of the western escarpment of the northern sector of the MER between Addis Ababa and Debre Berhan (FIG. 2) consists of Oligocene and Miocene basaltic and silicic flows, whereas
Figure 9. Locality KK-5, a Late Stone Age occurrence. View is to the east. Artifacts are seen on the surface, recently deflated from a thin veneer of late Pleistocene sediments that mantles the Early to Middle Pleistocene beds below.

Figure 10. Artifacts from Locality KK-5.
the younger volcanic sequence is divided into Miocene “Alaji Series” (15–16 Ma) and Pliocene “Balchi Series” (Justin-Visentin et al. 1974; Zanettin et al. 1974). In the Addis Ababa sector of the western rift-margin Early Miocene (22 Ma) silicics are the dominant units (Morton et al. 1979). Rifting in the northern sector began in the Middle Miocene (15–14 Ma) as a broad downwarped basin with marginal grabens along the foothills of both escarpments (Kazmin and Berhe 1978). Although this kind of structural feature is locally present in the region today, the ancestral structural and geomorphic setting probably looked like the marginal grabens of the central sector of the MER. The rift axis in the central sector is bifurcated and runs along marginal grabens represented by the Wonji and Silti-Debre Zeit Fault Belts of the eastern and western escarpments, respectively (Mohr 1967; Di Paola 1972; WoldeGabriel et al. 1990). The median part of the rift floor acts as a watershed for both marginal grabens, and most of the lakes in this region are confined to the eastern marginal graben (i.e., Lakes Ziway, Langano, Abyata, etc.).

The fossiliferous fluvial and lacustrine sediments of the Kesem-Kebena area occur at the base of several step-faulted blocks along the foothills of the western rift escarpment. These sediments were not recognized in the Awash River Gorge close to the present day axis of the rift floor that exposes Plio-Pleistocene basalts and silicic tephras (WoldeGabriel 1987). The confinement of the sediments to the Kesem-Kebena area is attributed to marginal grabens that acted as sediment traps during the evolution of the escarpment and the adjacent rift floor. A generalized discussion on the structural evolution of the Kesem-Kebena area that highlights the existence of ancestral marginal grabens is presented below.

The existence of ancestral marginal grabens in the northern sector of the MER is indicated by the occurrence and the confinement of Neogene sediments along the present foothills of both escarpments (FIG. 2). For example, it is suggested that the Late Miocene Chorora lacustrine sediments (FIGS. 1, 2) were deposited in a narrow, marginal graben that was bounded on its western margin by a horst and several Neogene silicic centers (Gara Ghumbi, Asebot, Afdem, Woldoyi, etc.) that erupted along the western border fault of this marginal graben (Kazmin and Berhe 1978). The thickening of the Nazret Group Silicics within this old marginal graben and their total absence in the Awash Gorge to the west and close to the present day rift axis support the argument. The basalt flows at the Awash Gorge section are younger (Pliocene), however, and the late Miocene sediment or tephras of the Chorora deposits may be buried below the Pliocene basalts of the gorge. The Plio-Pleistocene fluvial and lacustrine sediments of the Kesem-Kebena area directly across from the Chorora sediments are solely confined to the foothills of the western escarpment, and such sediments are totally absent from the Awash Gorge to the south. The Awash Gorge near the Karayou Lodge of the Awash National Park exposes more than 150 m of Late Miocene to Late Pliocene (5.6–2.1 Ma; TABLE 3) basalt flows that are capped by densely welded Pleistocene tuff layers. The tuff beds are separated by a ca. 50 cm-thick paleosol.

As presented in the geologic descriptions of each locality, the Kesem-Kebena area is characterized by intercalating deposits of sedimentary and volcanic units that have been cut by swarms of rift-axis (NE-SW) oriented normal faults that are occasionally displaced by transverse faults (FIG. 2). Today, there is more than 300 m of vertical displacement between the K-K1 and K-K2 localities and the flood plain of the Awash River and its major tributaries, the Kesem and the Kebena Rivers, that drain across the study area from the adjacent rift shoulder (FIG. 2). The Kesem-Kebena area has dramatically evolved geomorphologically from a gently dipping and downwarped terrane draped by flood basalt and tephra units of the Middle to Late Miocene time (FIG. 11A) to an area dominated by antithetically-tilted fault blocks that bounded several parallel marginal grabens characterized by flood plain and fresh water depositional environments during the Pliocene (FIG. 11B). In the Pleistocene, the Kesem-Kebena area continued to be affected by major basaltic and silicic eruptions and intense faulting and tilting and evolved to a set of gently dropping step-faulted and rotated blocks (FIG. 11C) that currently feed the Awash floodplain along the axis of the rift with abundant sediments of volcanic and sedimentary origin.

The fossiliferous sediments of the K-K2 locality underlying the Pliocene basalt (3.76 Ma) are well sorted and are dominated by silty clay probably deposited in a shallow water environment. The presence of shallow water or wet sediments is also indicated by the strong weathering in the overlying basalt, most likely as a result of water and hot lava interaction during the eruption. This basalt is generally weathered, unlike the overlying tephra and basaltic units. Thus the eruption of these volcanic units filled the basin at the K-K2 locality, disrupting the sedimentation processes.

The fossiliferous sedimentary beds at the K-K1 locality gently dip to the west and are terminated by a transverse fault that runs between this section and that of the K-K2 locality. As shown in Figure 3, the lithologic units at the adjacent K-K1 and K-K2 localities are different, consistent with the ages of the overlying basalts, the lithology of the sedimentary units, and the type of fossil assemblages. The
Figure 11. Schematic block diagram on the geological and structural evolution of the Kesem-Kebena area. Figure 11A represents a downwarped region prior to Early Pliocene intense faulting and marginal graben formation (FIG. 11B). Antithetic block faulting and tilting were dominant. The marginal grabens acted as sediment traps that deposited in fresh water environments during rift evolution. In the Pleistocene the marginal grabens were extended and filled with sediments and volcanic rocks, and subsequently faulted. Older rocks and structures were buried under younger units, and today the area is characterized by synthetically-tilted, step-faulted blocks (FIG. 11C).

calcite-cemented conglomeratic sediments and the overlying fresh water sediments at the K-K1 locality are overlain by a 2.3-Ma basalt. The poorly-sorted basal conglomeratic lenses represent a mass transport of basaltic cobbles from the adjacent Oligocene and Miocene flows of the rift shoulder. The volcaniclastic beds were deposited in a fresh water environment as indicated by the fossil remains of bovids, fish, turtle, crocodile, and hippopotamus. Fissural basalt flows probably erupted along border faults of the marginal grabens and filled the sedimentary basin about 2.23 Ma. This basin possibly continued subsiding, and ca. 50 m of poorly sorted, non-fossiliferous sands and gravels were deposited above the basalt flow. The eruption of an early Pleistocene, densely welded tuff that caps the section heralded the end of this basin. Most of the K-K2 locality rocks were probably faulted before the accumulation of the K-K1 units. Both localities were subsequently affected by major faulting episodes in the Early Pleistocene. Today this part of the study area is characterized by step-faulted blocks that drop gently toward the rift axis. The low-lying area is dominated by Pleistocene gravel deposits that are intercalated with minor tephra deposits. These units are
cut by swarms of densely spaced normal faults of recent age (FIG. 2).

Northeast of the K-K1 and K-K2 localities, the Kebena River runs along a major transverse fault that has displaced most of the older rocks to the east. The older units recognized at the K-K1 and the K-K2 localities are not exposed in the deep canyon cut by the lower Kebena River. The section here consists of younger rocks and is capped by a densely welded early Pleistocene tuff. The faulting probably preceded the deposition of these rocks. The poorly sorted and consolidated gravel deposits that make up most of the section (>250 m) were probably transported from the adjacent rift shoulder. In Figure 3, the lithologic units are represented by intercalating volcanic flows and sedimentary deposits as in the K-K1 and K-K2 localities, suggesting the existence of grabens that acted as depositional environments. Subsequent faulting and tilting of older fault blocks and basaltic eruption modified the basin, halting sedimentation processes. The age of the rocks decreases eastward and toward the rift axis. The densely welded tuff that caps most of the units west of the K-K4 locality thickens to the SW and was possibly erupted from Mt. Fentale. In the NE half of the Kesem-Kebena area, the ash flow tuffs and vitric ashes are blanketed by fluvial and lacustrine sediments consistent with the fresh water fossil remains recognized in the K-K3, K-K6, and K-K7 localities. The thick gravel deposits of the Kebena River section are not apparent in K-K4, K-K6, and K-K7 localities (FIG. 2).

Conclusion
The Kesem-Kebena area, like some of the other, better-known paleoanthropological areas in Africa, samples a substantial range of time. The abundance and variety of volcanic rocks interstratified with fossil- and artifact-bearing strata in the Kesem-Kebena hold the promise of excellent geochronological calibration and eventual tephrostratigraphic correlation with other areas in the region. For example, the Middle Awash (now “Messalu-Gewane”; Clark 1987; White 1986; Williams et al. 1986), located farther north in the Afar depression of Ethiopia, shares with Kesem-Kebena a long sequence of Pleistocene sediments with Acheulian tools and vertebrate remains. Archaeologists are currently seeking patterns in the climatic, biological, and technological records of the middle and late Pleistocene hominids to better understand the origins of our species (Binford 1981, 1984; Clark 1988; Rightmire 1985; Wolpoff 1984). The possibility of linking these areas by isochronous tephra, and of linking their terrestrial African records of global climatic change found in the deep sea drill cores from the nearby Gulf of Aden (Sarna-Wojcicki et al. 1985) holds great promise for the future of paleoanthropology. The wealth of Acheulian localities in and adjacent to the Ethiopian rift and Afar depression, spread across a wide range of environments, holds great promise for archaeologists and paleontologists.

The Paleoanthropological Inventory of Ethiopia has confirmed, in the two years of its existence, the presence of several new areas of great potential for geological, archaeological and paleontological research. For example, the Burji area is Ethiopia’s first Middle Miocene vertebrate paleontological area (WoldeGabriel et al. 1991). The Bilate area has extensive outcrops of late Pleistocene sediments with a rich record of lithic technology. Inventory work has established the Chorora and Fejej regions as large, stratigraphically complex, multiple component research areas with great potential for future investigation (Asfaw et al. 1990; Asfaw et al. 1991). The Pliocene and Pleistocene deposits of the Kesem-Kebena area, with their interstratified volcanics, well-preserved vertebrate fossils, and extensive archaeological evidence, will now join other better known paleoanthropological research areas as the quest to reveal human origins and evolution continues.

Acknowledgments
The Paleoanthropological Inventory project of the Ethiopian Ministry of Culture and Sports Affairs was begun under Minister Girma Yilma and is supported by the Committee for Research and Exploration of the National Geographic Society (4134-89), the Anthropology Program of the National Science Foundation (BNS88-19735), the Wenner-Gren Foundation for Anthropological Research, the Japan Society for Promotion of Science, and the Japan Shipbuilding Industry Foundation. Part of this work by GWG was done under the auspices of the U.S. Department of Energy, Office of Basic Energy Sciences Research, and by the Earth and Environmental Sciences Division of the Los Alamos National Laboratory. Typing and editorial work by Barbara Hahn and drafting by Anthony Garcia, both of Los Alamos National Laboratory, is greatly appreciated.

Thanks to J. Heirtzler, Head, Geology and Geomagnetism Branch, NASA/Goddard Space Flight Center, for providing collaborative access to Landsat Thematic Mapper and Large Format Camera images; and to C. Ebinger and D. Harding for their advice, encouragement, and support. Thanks to Elisabeth Vrba for assistance in bovid identification, and to Andy Cohen for assistance with the invertebrate fossil identification. The 1988–1989 field team at Kesem-Kebena included Tadesse Terfa, Head,
Centre for Research and Conservation of Cultural Heritage, and Alemu Ademasu, Tekle Hagos, Yohannes Haile-Selassie, Pelaji Kyauka, Agazi Negash, Chernet Tilahun, and Tamirat Wodajo. Thanks to the officials of the National Museums of Ethiopia (Mamo Tessema and Wol-desenbet Abomsaa) and Kenya for access to comparative materials, and to J. Desmond Clark for encouragement and advice. Thanks to Akelom Mohamed, Ishmail Hussein, Ali Abduke, Ebrahim, and Ali Babile—the Afar people whose field support made the project possible.

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