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Early MIS 3 occupation of Mochena Borago Rockshelter, Southwest Ethiopian Highlands: Implications for Late Pleistocene archaeology, paleoenvironments and modern human dispersals

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A R T I C L E I N F O

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A B S T R A C T

Between 70 and 50 ka BP, anatomically modern humans dispersed across and out of Africa to eventually populate all inhabitable continents. Knowledge of paleoenvironments and human behavioral patterns in Africa prior to and during these dispersals is crucial for understanding how and why hunter-gatherers were able to adapt rapidly to the new environments they encountered. However, few well-dated sites from this time period are known from the Horn of Africa, one of the purported staging areas for population movements into southern Arabia and Asia. Excavations at Mochena Borago Rockshelter, situated on the western slopes of a dormant volcano where the SW Ethiopian Highlands meet the Ethiopian Rift, have yielded the first securely dated archaeological sequence for later periods of the dispersal. Three major lithostratigraphic groups incorporating occupational episodes have yielded charcoal radiocarbon ages ∼53–38 ka calBP; deeper deposits have been tested but remain undated. Archaeological assemblages consist mainly of obsidian flaked stone artifacts manufactured from small, minimally prepared, single- to multi-platform flake cores; radially prepared cores are rare and blade cores are absent. Small unifacial to bifacial points from non-radial cores dominate the earliest shaped tool assemblages, and backed pieces first appear by ∼45 ka calBP. By ∼43 ka calBP, scrapers and backed pieces are predominant, rather than points. However, there is little evidence for technological change other than the appearance of bipolar technology. Mochena Borago's archaeological sequence thus cannot be neatly classified as Middle Stone Age, Later Stone Age or "transitional" and calls into question some of the principles by which archaeologists have attempted to classify African toolmaking traditions.

1. Introduction

The dispersals of *Homo sapiens* out of Africa ∼70 and 50 ka BP (uncalibrated dates appear as ka BP; calibrated dates, based on CalPal-2007 Hulu (Weninger and Jöris, 2008) appear as ka calBP) were landmarks in human history, signaling an evolutionary process responsible for the world's present genetic and cultural diversity. The subsequent rapid spread of anatomically modern humans into the new environments of Australia, Asia, Europe and eventually the Americas, would have posed novel challenges and opportunities requiring not just technological, social, and cultural innovations, but great behavioral flexibility, creativity, cooperation, and planning (Ambrose, 2002; Mellars et al., 2007; Hoffecker, 2009).

Archaeologists investigating this event have focused on two main topics: determining whether modern humans left Africa via

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the Nile and/or the Bab al Mandab (Van Peer, 1998; Vermeersch, 2001; Beyin, 2006; Rose, 2007; Rose et al., 2011) and documenting their progressive advance across the Eurasian land mass (Mellars, 2006; Oppenheimer, 2009). However, neither of these fields of research addresses the central task of explaining why modern humans spread across Africa and left the continent when they did and not earlier or later, and how they managed to adapt to such a diverse range of environments in such a short time.

These explanations require a solid understanding of human behavioral patterns in Africa just prior to and during the dispersals of the mitochondrial DNA (mtDNA) M and N descendant branches of the eastern African L3 haplogroup, the first anatomically modern human genetic group that produced multiple branches including those represented outside of Africa today (Forster, 2004; Gonder et al., 2007; Behar et al., 2008; Tishkoff et al., 2009; Fernandes et al., 2012). Such an understanding depends on knowing when modern humans left Africa, what kinds of African environments had shaped human experiences before leaving, and the technological and social capabilities humans had developed in an African context. Unfortunately, these areas of knowledge remain poorly studied.

This paper presents the first overview of recent Late Pleistocene archaeological research at Mochena Borago, a large rockshelter in the highlands of SW Ethiopia that has the potential to provide valuable new archaeological and paleoenvironmental data pertaining to hunter-gatherer behavior around the time of dispersal from Africa to Eurasia.

1.1. *Dating the departure*

Genetic evidence suggests that the gene pools for African and non-African populations of modern humans diverged sometime between ~70 and 50 ka BP (Ingman et al., 2000; Soares et al., 2009). There is little consensus on a more precise date within this interval, however, because uncertainty exists about assumed mutation rates (Sigurðardóttir et al., 2000; Ho and Larson, 2006; Soares et al., 2009). In addition, each genetic study relies on different source populations for DNA material, and may sample different parts of the human genome of nuclear, mitochondrial, and Y-chromosome DNA. Given variation in all these parameters, and the possibility of multiple and/or back-and-forth population movements between Africa and Eurasia, a low degree of precision in genetic "dating" is to be expected.

Chronometric dating of archaeological sites relevant to modern human dispersals out of Africa is also problematic. There are few consistently reliable methods of dating sites within the critical time range of ~70–50 ka BP. Historically, this time period has been considered too young for K–Ar, and too old for radiocarbon. TL is suspect in sites with heterogeneous deposits while OSL and U-series readings are not consistent in volcanic-rich areas such as eastern Africa (Richter, 2007; Tsukamoto et al., 2007). Furthermore, the ages of many Late Pleistocene sites are based on only a single technique or dating sample; dating of more than three or four samples per site is rare (see below).

1.2. *Environment and human behavior prior to departure*

These chronological ambiguities hinder ability to pinpoint environments in Africa around the time of the spread of modern humans. This is because the window of possible departure(s), which may have entailed multiple and/or multidirectional population movements, spans two major marine isotope stages (MIS) that had extremely different climatic conditions. MIS 4 (~73.5–60 ka BP) is characterized across the globe by largely cold and arid conditions. MIS 3 (~60–28 ka BP) was generally warmer and wetter but punctuated by many short and rapid climatic swings known as Heinrich and Dansgaard–Oeschger events (Hessler et al., 2010; Sanchez-Goni and Harrison, 2010; Wolff et al., 2010).

If groups of anatomically modern hunter-gatherers left Africa during MIS 4, dispersing populations would have already developed technological and behavioral strategies necessary for coping with countless generations of relatively constant low temperatures and extreme aridity. If they did so during MIS 3, then they would also have had to formulate flexible strategies capable of dealing with rapid and dramatic fluctuations in climate and resources. The banking of such knowledge and information would have been critical for hunter-gatherers to not only survive, but to flourish in the new environments they encountered as they migrated across and out of Africa into new continents.

For a number of reasons, the Southwest Ethiopian Highlands stand out as a prime region in which to test these hypotheses. First, the SW Highlands are a "hot spot" of human genetic diversity today, indicating that they may have been a source area for population radiations in prehistoric times (Tishkoff and Verrelli, 2003; Liu et al., 2006). Second, they are near to both hypothesized dispersal corridors: the Bab al Mandeb and the Nile Valley (Van Peer, 1998; Beyin, 2006; Petraglia, 2007). Third, modern circulation patterns suggest the SW Highlands are likely to have received more rainfall than surrounding regions of northern Africa and the Horn during prehistoric times, for three reasons: 1) the SW Highlands are close to the center of Inter-Tropical Convergence Zone (ITCZ) movements; 2) they now receive moisture from both Atlantic and Indian Ocean systems (Umer et al., 2004); and 3) as the first major topographic feature the moist Atlantic cells encounter in thousands of kilometers, they capture high orographic rainfall. If these combined circulation patterns allowed the SW Highlands to maintain higher rainfall than surrounding regions throughout the Late Pleistocene, then this area could have been one of only a few places near a dispersal corridor that provided a refugium for plants, animals, and humans during extended hyper-arid periods such as MIS 4, and shorter arid intervals such as the Heinrich events during MIS 3 when lowlands and drier regions may have become uninhabitable.

Unfortunately, Late Quaternary paleoenvironmental archives for the SW Ethiopian Highlands are limited: There is only one lake core from the SW Highlands, Shupa Pond in the Kafa region, which only extends back 930 years (H. Lamb, pers. comm.). East/northeast of the SW Ethiopian Highlands, the Ethiopian and Afar Rift lakes yield limited MIS 4 or 3 records indicating severe aridity during MIS 4 and generally wetter but fluctuating conditions during MIS 3 (Gasse et al., 1980). Farther afield, pollen records from Gulf of Aden cores attest to regional aridity throughout MIS 4, followed by wetter but fluctuating conditions during early MIS 3 (Van Campo et al., 1982). Nile paleohydrological records and sapropel events in the eastern Mediterranean also point to wetter conditions during early MIS 3 resulting from increased monsoonal activities in the northern Ethiopian Highlands – the main source of the Nile's water (Bar-Matthews et al., 2000; Revel et al., 2010). Speleothem records from Moomi Cave, on Socotra Island off the coast of Yemen, show fluctuations in monsoon patterns during MIS 3 that echo global high-latitude records of Heinrich and Dansgaard–Oeschger events (Burns et al., 2003, 2004).

Understanding the technological and social capabilities modern humans had developed in an African context before and during their range expansions through and out of Africa requires in-depth studies of archaeological sites with chronometrically dated stratified sequences in areas near dispersal corridors. Unfortunately, human behavioral responses to regional environmental changes in Ethiopia and the Horn of Africa during this period are poorly known because sites are few, and dated sites are even rarer (Brandt, 1986; Brandt and Gresham, 1991). In the Horn, only a few archaeological occurrences can be attributed to MIS 4/early MIS 3 (Fig. 1): In northern Somalia, Gud–Gud Cave has a small sample of chert artifacts in a stratum radiocarbon dated to >40 ka, while the youngest Levallois-based Middle Stone Age (MSA) levels at Midhishi 2 Shelter are also radiocarbon dated to >40,000 BP (Brandt and Brook, 1984; Brandt, 1986). On eastern Ethiopia's rift escarpment, Porc Epic Rockshelter contains material from MIS 4 and 3. Unfortunately, the complicated stratigraphy, the excavation methods employed there four decades ago, and the unreliability of obsidian hydration dates together impede accurate dating of the site (Clark and Williamson, 1984; Brandt, 1986; Pleurdeau, 2001, 2003, 2005). Near the junction of the Ethiopian Rift and the Afar Depression, K'one caldera encompasses a number of undated open-air MSA sites eroding from stratified sediments. Although lower portions of the sequence are thought to date to MIS 5–3, only a Later Stone Age (LSA) site in the upper strata has been radiocarbon dated, yielding a terminal Pleistocene age (Kurashina, 1978; Brandt, 1986). In the SW Ethiopian Highlands, the open-air site of Liben Bore in the Gilgel Gibe Valley has assemblages of flaked stone artifacts ("lithics") in the lower strata that could date to MIS 4 and 3, but these strata remain chronometrically undated (Brandt, 2001).

Recent excavations at Mochena Borago Rockshelter, an archaeological site on the eastern edge of the SW Ethiopian Highlands, have established the first well-dated archaeological sequence for much of MIS 3 in the Horn of Africa. The lowest excavated deposits in Mochena Borago correspond to the latest possible period of initial modern human movements out of Africa, but deeper strata remain to be excavated.

2. Mochena Borago Rockshelter

Mochena Borago Rockshelter is situated on the southwest flanks of Mount Damota, a large trachytic volcano that rises steeply out of the surrounding plains ~320 km south of Addis Ababa in southwest Ethiopia (Fig. 2). According to oral history, it was named after *Moche Borago*, a prominent late 19th century local leader who was advisor to T'ona, the last king of the Wolaita people (Fisher, 2010, p. 65). Researchers who initiated work at the site recorded the name as "Moche Borago" in accordance with government information at the time (Gutherz et al., 2002), but updated official records and local residents confirm "Mochena Borago" as the correct name.

2.1. Geographical context

At 2908 m asl, Mt. Damota forms the boundary between the Southwest Ethiopian Highlands to the west and the southern Main Ethiopian Rift Valley to the east. Its slopes provide striking views of the central Main Ethiopian Rift Valley lakes to the distant north, the Bilate River and the southern Main Ethiopian Rift Valley to the east, Lake Abaya to the south, the Gibe/Omo River valley to the southwest, and the Wolayta Highlands to the west (Fig. 2). At the southern foot of the mountain lies the town of Sodo, the administrative and political capital of Wolayta Zone.

During the Plio-Pleistocene, many major trachytic volcanic complexes formed along the Rift's margins, including now-dormant Mt. Damota. These continued to be active during the Late Quaternary (WoldeGabriel et al., 1990, p. 447). On the

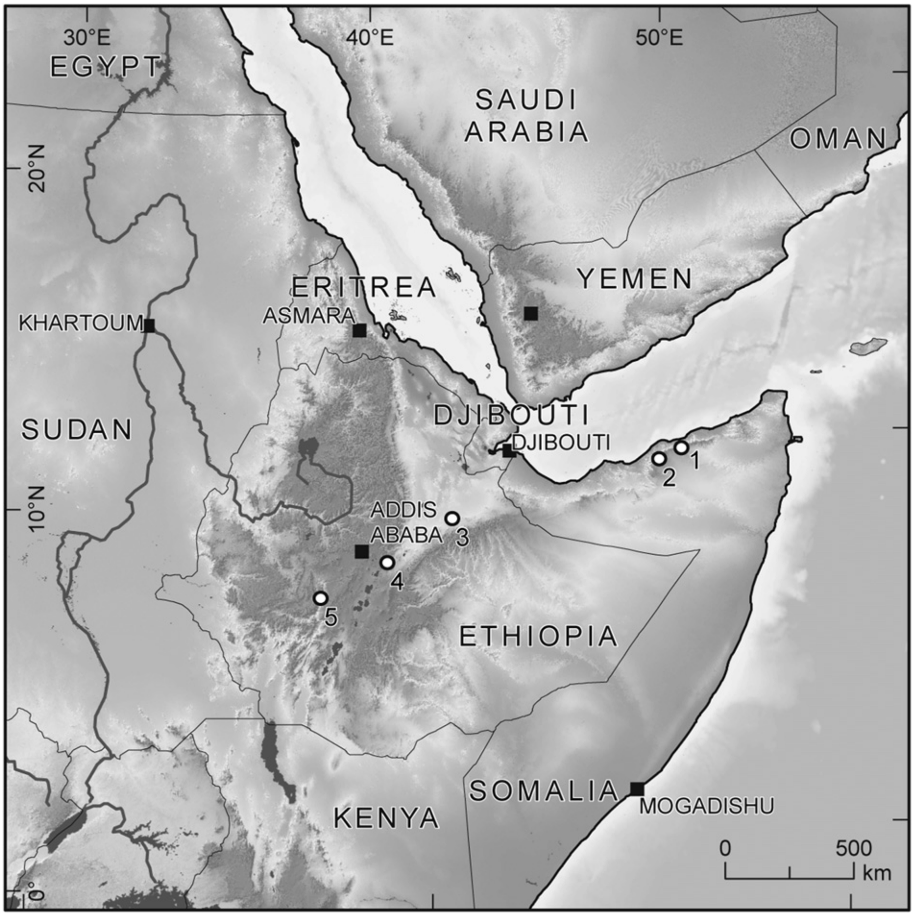

Fig. 1. Archeological sites in the Horn of Africa with assemblages attributed to MIS 4/early MIS 3: 1 – Gud–Gud; 2 – Midhishi Shelter; 3 – Porc Epic Rockshelter; 4 – K'one; 5 – Liben Bore.

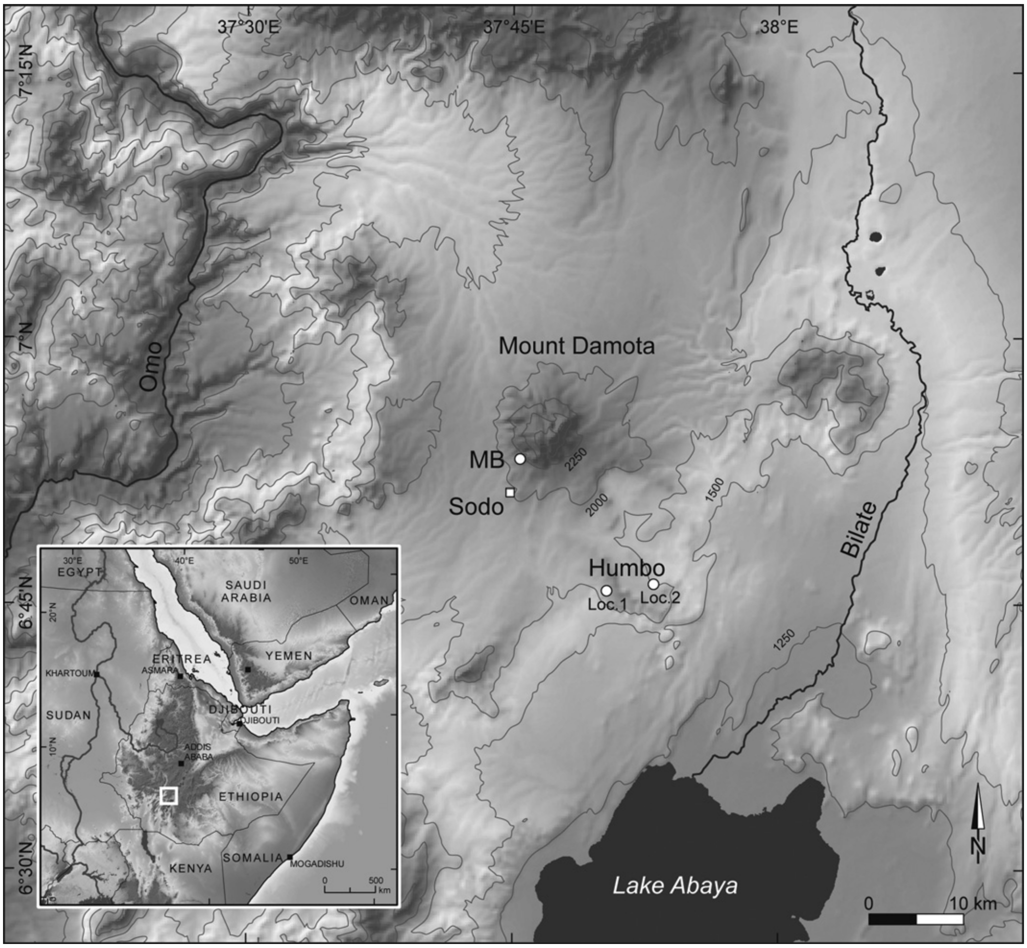

Fig. 2. Location of Mount Damota, Mochena Borago Rockshelter (MB) and the two known Humbo area obsidian sources (Loc. 1 and Loc. 2).

southwestern face of Mt. Damota, successive flow basalts have formed a complex ridge-and-ravine geomorphology, structuring the natural drainage system. These drainages often exhibit a broadly-stepped profile, possibly due to isolated truncations or terminations of the underlying basalts.

The entrance to Mochena Borago Rockshelter is at the head of such a steep ravine about halfway up a ~20 m high cliff. A small, seasonally active waterfall flows over the shelter's mouth into the ravine, contributing to a stream that forms an important water source for local farmers. The shelter is large – almost 70 m wide, 12 m high and 20 m deep – and can easily hold hundreds of people standing on the loose to compact sediments that cover the largely flat floor (Fig. 3). The shelter remains dry throughout the year, except during the peak months of the rainy season when water seeps through the back wall, dampening a small area at the rear of the shelter. Heavy rainstorms and high winds can also cause waterfall spray to splash onto a small area at the front of the shelter.

2.2. Local climate and ecology

Both the equatorial Atlantic and Indian Ocean climatic systems contribute to the research area's unimodal precipitation pattern. Rainfall usually falls throughout the year, with the majority accumulating from June to September (>200 mm/

Fig. 3. Spherical panorama of Mochena Borago Rockshelter, with the "Block Excavation Area" (BXA) in the foreground.

month). Less than 50 mm/month falls November–February, and 90–150 mm/month during the remaining months. Due to orographic effects, mean annual rainfall is highest on Mt. Damota (~1400 mm) while Sodo receives ~1200 mm (EMA, 1988; World Vision Australia, 2000). Rainfall declines sharply toward the east where the Bilate River, 40 km E/NE of Damota in the southern Main Ethiopian Rift, averages only 750 mm/year (Beles, 2009).

Population pressure, intensive farming and heavy erosion have impacted Damota's natural landscape to the extent that natural vegetation and wild bovids, carnivores and other large animals are only witnessed in and near ravines, rocky outcrops, steep slopes and other areas too difficult to settle, plow or hoe. Three of the major agro-ecological zones recognized by Ethiopian farmers on the basis of altitudinal changes in precipitation, temperature, soils and crop suitability (Hurni, 1998, pp. 18–19) are found on Mt. Damota: *dega, woyna dega* and *kolla*. Natural floral distributions seem to parallel these traditional agro-ecological zones. Mt. Damota's steep upper slopes, deep gorges, gentle lower flanks and other physiographic features also contribute to variation in vegetation within short distances. Knowledge of present potential vegetation near the site is useful when considering possible prehistoric environments in the area.

The *dega* (highland) zone prevails in the upper reaches of Mt. Damota ~2900–2600 m asl. There, Afromontane vegetation (sensu Friis, 1992), comprising shrubs, grasslands and remnant coniferous forests of *Podocarpus* and *Juniperus*, flourishes in the cool (~20–10 °C) moist highlands. Below ~2600 m the *woyna dega* (mid-altitude) zone has warmer, slightly drier conditions. As one descends through this zone, relict patches of natural vegetation are characterized initially by bamboo thickets (*Arundinaria alpina*), then by deciduous closed woodlands, and finally by open woodlands and grasslands with *Terminalia*, and *Acacia* at lower elevations. At ~2200 m asl, Mochena Borago Rockshelter is within the upper elevations of *woyna dega*, with bamboo growing nearby. Below the foot of Mt. Damota (~1900 m), lower-elevation portions of *woyna dega* continue down to ~1500 m asl to encompass flat fertile farmlands dissected by numerous streams, marshes and seasonal lakes fed by runoff from the mountain.

Hotter, more arid conditions of the *kolla* (lowland) zone are present to the east, below ~1500 m asl, in the southern Main Ethiopian Rift Valley. Here, arid-adapted species of open woodland, bushland and grasses support pastoral nomads and a diverse array of wild "savanna" game. Thirty km SE of Mt. Damota, Ethiopia's largest rift lake, Lake Abaya, lies within the *kolla* zone at 1169 m asl. It covers more than 1100 km^2 and forms another significant regional biotope (Awulachew, 2006).

In summary, numerous vertical ecozones are compressed within a small geographic distance on and around Mt. Damota. Like other regions of the Southwest Ethiopian Highlands (Hildebrand et al., 2010), the area around Mochena Borago has offered high biodiversity and an abundant supply of natural and domesticated faunal and floral resources for exploitation by contemporary and past human populations (Lesur et al., 2007). The rockshelter's large size, easy accessibility, and flat, mostly dry interior would have made it attractive for human use and habitation.

3. Research history and methods

Since its initial documentation more than a decade ago, Mochena Borago has seen excavations by multiple teams interested in distinct research questions and time periods. This section reviews the history of research at the site, and the excavation and dating methods used by the current team.

3.1. Research history

In 1995, the French archaeological research team GEPCA (*Groupe pour l'Etude de la Protohistoire de la Corne de l'Afrique*) began a survey of the Wolayta region of SW Ethiopia under the direction of R. Joussaume (University of Nantes), which led to the documentation of many sites including Mochena Borago Rockshelter. In 1998, Joussaume directed test excavations at Mochena Borago that revealed almost 2 m of stratified Later Pleistocene and Holocene deposits. In February 2000, X. Gutherz (University of Montpellier) led the first of three GEPCA field campaigns to expand excavations at Mochena Borago, returning in November 2000 and December 2001 (Gutherz, 2000; Gutherz et al., 2002).

Because GEPCA's primary research objective was to recover evidence for early food production, Gutherz and his team concentrated on excavating the Holocene deposits, which extended ~1 m below surface. They excavated >20 m^2 in the NW part of the rockshelter, hereafter called the "Block Excavation Area" (BXA). The GEPCA team exposed Holocene deposits in two areas – the BXA, and a 1 × 2 m test unit (TU2) near the center of the shelter (Fig. 4) – and an additional ~0.8 m of Later Pleistocene deposits in a 1.5 m^2 test unit within the BXA (Gutherz, 2000; Gutherz et al., 2002).

These Late Pleistocene deposits attracted the interest of the *Southwest Ethiopia Archaeological Project* (SWEAP), under the direction of S. Brandt (University of Florida) and E. Hildebrand (Stony Brook University). SWEAP's main research objective was to test the

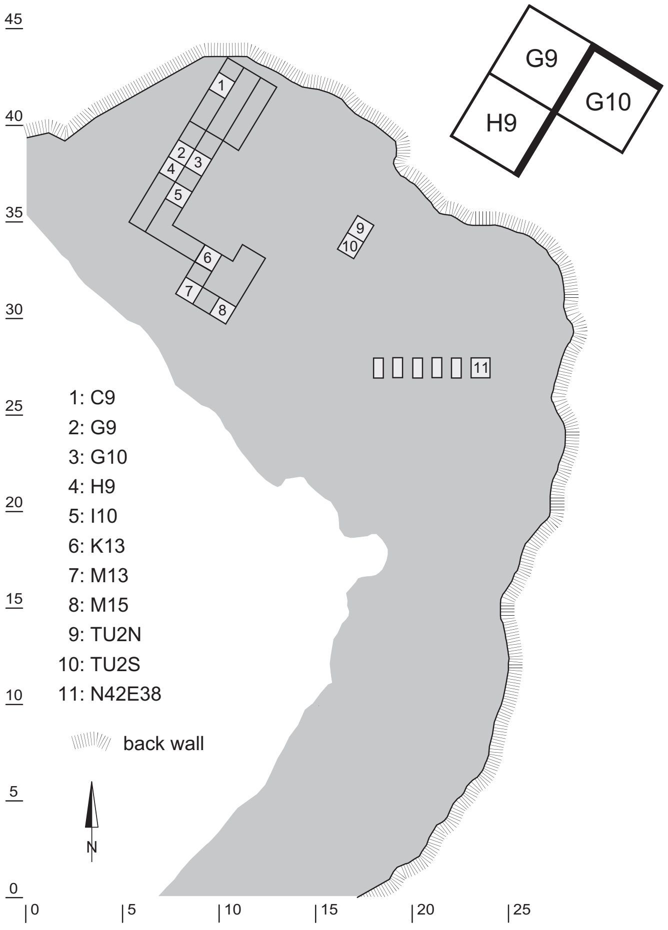

Fig. 4. Floor plan of Mochena Borago Rockshelter. Areas demarcated by black lines correspond to original GEPCA trenches. Numbered and/or lighter areas demarcate locations of CRC 806/SWEAP excavations. Detail shows position of the section drawing (Fig. 5).

hypothesis that the SW Ethiopian Highlands were a major environmental refugium during cold, arid periods within the last 70,000 years. In 2006 and 2007, S. Brandt and E. Hildebrand directed excavations of the Late Pleistocene deposits; E. Fisher carried out more focused doctoral fieldwork in 2008 (Fisher, 2010). SWEAP activities concentrated on three areas: BXA, TU2, and a new series of units (N42) in the SE part of the shelter that exposed both Holocene and Late Pleistocene deposits (Fig. 4).

Since 2009, this work has continued within the framework of the University of Cologne's Collaborative Research Centre 806 (CRC 806, http://www.sfb806.uni-koeln.de) on the theme *Our Way to Europe*. CRC 806 examines the cultural processes and environmental contexts of the dispersal of modern humans from Africa to Europe during the Late Pleistocene. Eastern Africa, as a potential source region for modern humans, is key to exploring these issues, and Mochena Borago presents one of the most complete records of human occupation in eastern Africa during the critical time period ~60–40 ka. Under the co-direction of S. Brandt and R. Vogelsang, CRC 806/SWEAP carried out additional fieldwork in 2010 and 2011. The main goals of these two six-week field seasons were to clarify the shelter's complex depositional history and to expand excavations of its oldest archaeological levels. This paper presents the first synthesis of CRC 806/SWEAP investigations at Mochena Borago.

3.2. *Excavation methods*

Mochena Borago presents archaeologists with several challenges: excavating a large rockshelter capable of having many different activity areas; untangling a complex stratigraphy with volcanic, aeolian, colluvial, fluvial, and cultural formation processes; documenting high densities of cultural materials; and examining a period in which the nature of technological change is poorly understood. Its large size, dry interior, and relatively easy access, however, have allowed CRC 806/SWEAP to use advanced methods for spatial and vertical data collection, curation, and analysis.

In areas of the shelter originally excavated by GEPCA, the 1 m^2 grid structure is arbitrarily aligned ~30° from true north (in line with the rockshelter), and their alphanumeric grid coding system (e.g. "G10"). To achieve geodetic control over new excavation areas, and to enable future researchers to easily tie into the coordinates, new control points were established throughout the shelter using a 1 m^2 grid pattern aligned to the global Universal Transverse Mercator (UTM) coordinate system. Within this new grid, each square meter is denoted by the coordinates of its SW corner (e.g. N42E38 = Northing 7625**42**.0, Easting 362438.0). These control points and grid system allow each of the two total stations (Trimble TS-305 and Leica TS02) to triangulate exact 3D positions of any location or object within the shelter, resulting in highly precise and accurate documentation of archaeological, geomorphological, and geochronological data.

Depending on the number of site personnel, field time and artifact volume, each 1 m^2 grid unit is either excavated wholly or split into four 50 × 50 cm quadrants that are excavated individually. Excavations follow natural stratigraphic units subdivided vertically into maximum 5 cm "levels" until another natural stratum is detected. Using trowels and smaller implements, excavators aim to leave *in situ* artifacts and ecofacts >5 mm in size. These are then piece-plotted using total stations connected to handheld data collectors that record provenience information such as grid unit, depth, level, and stratum, as well as material type (e.g. stone, bone, charcoal), orientation, and other attributes. Each find is then bagged individually and assigned a unique identification number. Materials <5 mm remain within the excavated matrix, and are recovered via dry sieving using 2 mm mesh size.

Total stations are employed to map each stratum, feature or natural disturbance as it is exposed, and forms record information on sedimentology, spatial and vertical configurations and other relevant data. Micromorphology samples are taken at key locations, as are bulk sediment samples from each stratum to support later analyses of magnetic susceptibility, geochemistry, and macro- and microbotanical remains. Stratigraphic profiles are mapped by the total station and on grid paper, while digital photographs of stratigraphic plan views and profiles use targeting chits to enable the photos to be geo-rectified.

All excavation data are stored in a MS Access database that links the spatial data recorded for each archaeological find or stratigraphic layer to non-spatial attributes such as artifact descriptions, photos or analyses. These data are, in turn, integrated into a multidimensional GIS database that shows the rockshelter and each excavation unit in 3D alongside piece-plots of all archaeological and faunal materials, 2.5D surfaces of each stratigraphic unit, 3D geo-rectified stratigraphic section drawings, as well as 3D geo-rectified digital photography mosaics of most stratigraphic profiles.

These excavation strategies reflect recent methodological improvements that require a slower pace of excavation, but yield great dividends in terms of the quality of research strategies and datasets (Marean et al., 2004; McPherron et al., 2005; Dibble et al., 2007). Immediate access to 3D GIS data in the field allows team members to recognize complex anthropogenic and geogenic features, understand their spatial relations, and use these data during day-to-day decisions about excavation. Obtaining precise spatial data also improves the quality of specialist analyses (e.g. by revealing concentrated areas or horizons of lithic artifacts) and chronological control (e.g. by showing precise locations of dating samples relative to complex stratigraphy). Piece-plotting all artifacts and ecofacts allows typological, technological, and taphonomic datasets to be linked to spatial-temporal distributions in novel ways that reveal human behavioral patterns.

3.3. *Dating methods*

Deposits relevant to the question of human dispersal out of Africa are difficult to date because they are chronologically close to the radiocarbon "dating barrier," historically regarded as ~40 ka BP. Recently, improved sample pre-treatment procedures, application of AMS technology, and longer and more accurate calibration curves that use high-resolution cave speleothem and marine coral records have allowed radiocarbon dating of materials >50 ka BP in age (Hughen et al., 2006; Weninger and Jöris, 2008; Reimer et al., 2009; Rebollo et al., 2011). At the same time, novel dating methods such as OSL have become available, and $^{40}Ar/^{39}Ar$ has been successfully applied to materials as young as 2 ka BP (Renne et al., 1997; Fattahi and Stokes, 2003; Wintle, 2008).

With these advances in mind, CRC 806/SWEAP team has pursued the use of several dating methods to build a secure chronological framework for the site. Because charcoal is abundant in most anthropogenic layers at Mochena Borago, the most intensive efforts have focused on radiocarbon. They have yielded 31 AMS and 6 conventional dates on charcoal recovered during CRC 806/SWEAP excavations between 2006 and 2011. These dates range in age from ~133 years to 53,224 ka calBP, with 19 dates >40 ka calBP. All radiocarbon ages presented here are calibrated using Cologne CalPal-2007 Hulu (Weninger and Jöris, 2008).

Criteria and techniques for radiocarbon sample collection changed as excavations progressed. During the first CRC 806/SWEAP field season (2006), charcoal pieces were plotted that were >4 mm and structurally intact, thinking only these would have sufficient mass after cleaning to generate an AMS date. Smaller and more fragmented charcoal pieces found in the sieve were collected in a single bag for each level. Both piece-plotted and sieve samples were submitted to the Radiocarbon Dating Laboratory of the Illinois

State Geological Survey, University of Illinois for dating. Piece-plotted samples yielded ages consistent with each other and with expectations, whereas sieve samples varied substantially and in unexpected ways that suggested they were vulnerable to contamination. In addition, the 2006 samples were larger than the minimum mass required for dating. Given the limited utility of sieve samples and the possibility to date smaller plotted samples, in 2007 it was decided to piece-plot all charcoal fragments >2 mm in size.

Standard acid-base-acid (ABA) pre-treatment was used for AMS ^{14}C dating of Mochena Borago charcoal samples: All samples were boiled for 1 h in 2M HCl and rinsed to neutrality using distilled water; then soaked in cool 0.125 M NaOH for 1 h and rinsed to neutrality using distilled water; then soaked in 2M HCl for 30 min and rinsed to pH 6 using distilled water. Samples were dried in an oven overnight at 80 °C. About 3–5 mg materials of charcoal samples and wood background and working standards were placed into preheated quartz tubes with Cu granules for sealed quartz tube combustion. The combustion was programmed for 2 h at 800 °C. Then quartz tubes were cooled from 800 °C to 600 °C for 6 h to allow Cu to reduce the nitrogen oxides to nitrogen gas. The same pre-treatment was also applied to the ISGS ^{14}C-free wood background and wood working standard samples that include IAEA C5 (Two Creek forest wood), FIRI-D (Fifth International Radiocarbon Inter-comparison D wood), and ISGS Reiley AC (about 3 half-life wood) samples (Wang et al., 2003).

Following combustion and cooling, purified CO_2 was submitted to the Keck Carbon Cycle AMS Laboratory of the University of California-Irvine for AMS ^{14}C analysis using the hydrogen-iron reduction method. A split of purified CO_2 was also analyzed for $\delta^{13}C$ values at the ISGS using a Finnegan MAT 252 IRMS (isotope ratio mass spectrometer) with a dual inlet device. All results have been corrected for isotopic fractionation according to the conventions of Stuiver and Polach (1977), with $\delta^{13}C$ values measured on prepared graphite using the AMS spectrometer.

The AMS analysis indicated that all working standards are within 1–2 standard deviations, and background samples are older than 53,300 ^{14}C yr BP (>57,000 calBP; Hughen et al., 2006) against internal background of AMS facility. This suggests that charcoal samples with ^{14}C ages from 41,580 (45,082 calBP) up to 48,850 (53,224 calBP) are true ages. The full list of dates, and their association with specific stratigraphic units at Mochena Borago, will be published elsewhere. Here, radiocarbon ages are presented as a series of "weighted means" for each major stratigraphic grouping. Weighted mean ages are calculated using a Central Age Model, which considers both the average and standard deviations of a population of samples that are assumed to have similar external influences (Galbraith and Laslett, 1993; Van der Touw et al., 1997; Galbraith et al., 1999, 2005).

In addition to radiocarbon, three other dating methods were attempted: $^{40}Ar/^{39}Ar$, OSL, and ESR. $^{40}Ar/^{39}Ar$ seemed a promising method to use on Mochena Borago's four distinct tephra layers. However, feldspar crystals from BWT, a tephra at the base of the Holocene strata, yielded an age >3 ma, suggesting that these crystals were in fact derived from the roof and walls (see Section 4.1) (L. Morgan, Berkeley Geochronology Lab, pers. comm.). Seventeen OSL samples were collected from Late Pleistocene and Holocene deposits in the BXA. However, they did not yield reliable OSL and IRSL age determinations due to the volcanic nature of some of the sediments, the lack of quartz and feldspar grains, the dimness of the luminescence signals from the minerals that were present, and the high rates of anomalous fading observed from feldspars (Gliganic, 2011). ESR sampling was confined to a single tooth from near the base of the BXA, which unfortunately was lost in transport (R. Grun, Australia National University, pers. comm.). Although none of these three additional dating methods were successful, they may merit further consideration in the future.

4. Formation processes

The depositional and occupational history of Mochena Borago Rockshelter is complex, incompletely understood, and still under study. The site's lithostratigraphic sequences reflect complex inputs from volcanic, fluvial, colluvial, and aeolian processes, mechanical and chemical erosion, and human activities. This section summarizes current perspectives on how the formed, and offers an initial view of the natural and cultural processes that shaped the deposition of sediments inside the shelter.

4.1. Formation processes of Mochena Borago Rockshelter

Mochena Borago Rockshelter formed within three layers of volcanic rock. A thick mafic lava flow of indeterminate thickness and age was overlain by a debris flow consisting of softer, vesiculated volcaniclastic materials ~12 m thick, which in turn was capped by another mafic lava flow ~10 m thick. The rockshelter cavity formed only within the soft debris flow that, judging by occasional well-rounded 7–10 cm wide pumice clasts, may be a non-welded ignimbrite. The debris flow, which constitutes portions of the roof and walls of the rockshelter, has not been dated directly, but is believed to be the source of feldspar crystals found in a Holocene tephra (BWT, see below). The feldspars yielded an $^{40}Ar/^{39}Ar$ age of 3.16 ± 0.07 ma (L. Morgan, pers. comm.), which is similar in age to other Plio-Pleistocene volcanic events along the margins of the central and southern sectors of the Main Ethiopian Rift (WoldeGabriel et al., 1990).

Observations suggest that the rockshelter cavity formed largely as the result of fluvial activities that caused mechanical and chemical erosion of the soft debris flow. Corrasional back-rearing from one or more waterfalls likely initiated the cutting of the rockshelter; spray and mist have continued to shape deposits at the front of the site until today. Gypsum deposits on the rockshelter walls show that the debris flow is also hydrated. Thus, the deeper cutting of the shelter is attributed to secondary phreatic corrosion from water percolating through these rocks. These processes have not completely removed the upper reaches of the debris flow that forms the roof, however, and eroding chunks of it have been incorporated into sediments accumulating inside the shelter.

4.2. Deposits within Mochena Borago Rockshelter

Current excavations show that each of the excavation areas has its own distinct lithostratigraphic sequence resulting from divergent processes in different parts of the rockshelter. Understanding the relations between these sequences is challenging. Therefore, this initial overview of Mochena Borago's deposits only outlines the major stratigraphic groups within BXA, the main "block excavation area" (Fig. 5). Many of these groups consist of several distinct stratigraphic units that will be described individually in subsequent publications.

- *DF-Group*, which appears in one 1 m^2 unit in the BXA, is currently the oldest deposit exposed. It is at least 1 m thick, and characterized by a very hard yellowish brown (10YR4/4) clay matrix with abundant glass, semi-angular ash, and lapilli inclusions. These deposits are volcanic in origin, currently undated and archaeologically sterile. It is not yet clear what kind(s) of volcanic activity they represent.
- *T-Group* sediments (~40 cm thick) unconformably overlie the DF-Group. The spatial extent of T-Group sediments is unknown outside of the BXA. The T-Group has been subdivided into Upper and Lower facies, based on vertical changes in sediments:

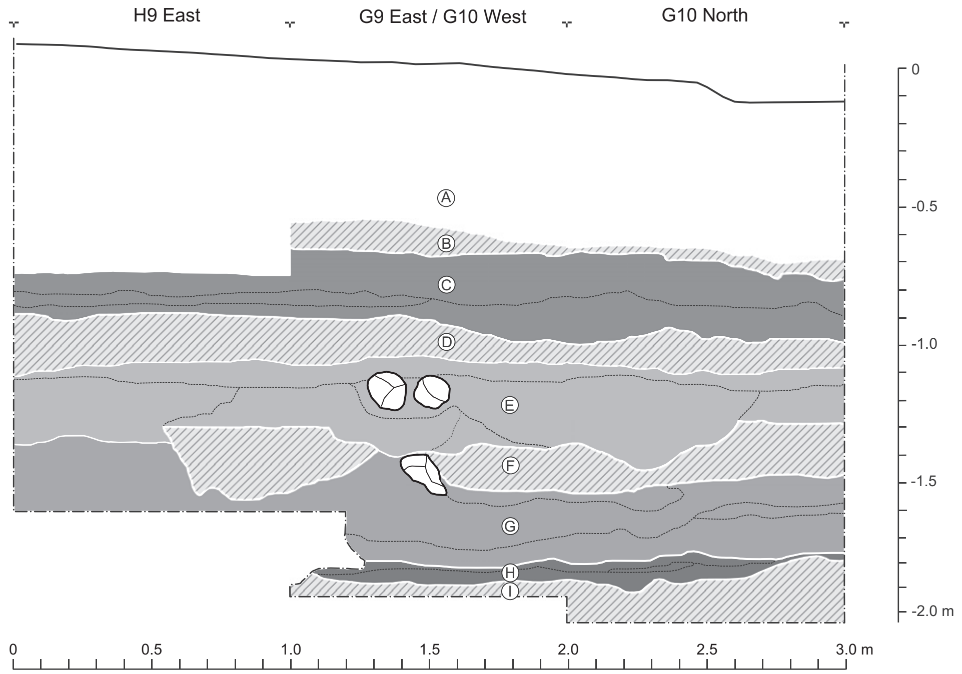

Fig. 5. Section drawing H9 East, G9 East/G10 West, G10 North, showing the major stratigraphic groups: A – Holocene deposits; B – BWT tephra; C – R-Group; D – YBS mud flow; E – S-Group; F – YBT tephra; G – Upper T-Group; H – Lower T-Group; I – DF-Group.

Lower T-Group deposits are hard, gravelly ashes and clay-rich sands that appear to be more heavily weathered than overlying deposits. Reworked clay fillings visible in thin sections from the Lower T-Group suggest that water was also periodically present in the rockshelter around the time of deposition. Abundant lithics, fragmented faunal remains, and rare charcoal and ochre pieces from this deposit are, so far, the earliest definitive evidence of human occupation at the site. A single AMS charcoal date of 53,224 ± 2662 calBP from near the top of these deposits provides a minimum age for Lower T-Group.

Upper T-Group deposits have higher clay content and redder coloration. Micromorphology shows that numerous compacted aggregates of fine, iron-rich illuvial clay bands were deposited through colluvial activities. Several burning episodes created a banded wall profile. The upper surfaces of some of the clay bands appear to have been moderately eroded and stabilized. Upper T-Group deposits contain the same range of artifacts as Lower T-Group, but with higher frequencies of charcoal. The weighted mean of three charcoal AMS dates from Upper T-Group is 45,164 ± 982 calBP.

- The *YBT tephra* conformably overlies T-Group. 20 cm of yellow-brown (2.5YR6/3), prominently graded ash (silt particle size) is variably intermixed with soil aggregates that include some sand-sized particles. Thin clay laminae suggest synsedimentary deposition in a fluvial environment, due to either sub-aerial precipitation during the volcanic activity and/or pre-existing deposits of water in the rockshelter. Three charcoal AMS samples provide a calibrated weighted mean age of 43,403 ± 1213 calBP. With only a handful of artifacts, all of which appear to be in secondary context, YBT represents the first major occupational hiatus after deposition of the T-Group.
- The *S-Group* is a ~30 cm thick deposit of clay-rich silts that conformably overlie YBT. They appear to have been variably reworked by fluvial processes, with a paleofluvial channel cross-cutting S-Group deposits in G10. Outside the channel, however, S-Group deposits in parts of G10 and in H9 exhibit much less evidence for fluvial activities, suggesting fluvial channels were localized. Micromorphology shows that deposits adjacent to the paleofluvial channel contain an unsorted heterogeneous mix of charcoal, phytoliths, and bone fragments, indicating colluviation and possible trampling (P. Goldberg, pers. comm.). The S-Group contains dense concentrations of lithics, some natural and worked ochre, and poorly preserved faunal remains. Some levels show significant artifact abrasion, particularly those in and near the paleofluvial channel. Other levels have lithics with minimal abrasion, no visible size-sorting or orientation to the assemblages, abundant smaller fractions of sediments (clays and silts) and anthropogenic materials (charcoal, bone fragments, and micro-debitage). This suggests that fluvial activity in these latter levels may have been low-energy with minimal, if any, post-depositional artifact disturbance. Three charcoal samples taken from a ~20 cm vertical span within S-Group layers provide a tightly constrained weighted mean age of 43,480 ± 443 calBP.
- *YBS* is an ash- and gravel-rich volcaniclastic mud flow ~12 cm thick that conformably overlies the S-Group. YBS has a mineral magnetic character identical to the underlying clay and silt deposits because it has undergone mixing, likely as the tephra slurry washed into the rockshelter. Currently, there is only one dated radiocarbon sample from YBS, providing a calibrated age estimate of 43,121 ± 692 calBP. The few lithics from this stratum were recovered in secondary context, suggesting that YBS represents a second occupational hiatus.
- *R-Group* deposits overlie YBS. About 30 cm thick, they are very dark brown (7.5YR2.5/2) clay and silt sediments with a distinct reddish hue that may be due to sub-aerial oxidation of iron. Rounded to sub-rounded gravel lag deposits are also common. Micromorphological analysis has shown a porous microstructure in upper R-Group layers, with voids filled by oriented and laminated reddish orange clay particles. These structures, along with the change in iron oxidation, high clay content, and gravels, together suggest that low-energy pools of water may have been located in various areas across the site. R-Group deposits have high frequencies of lithics. Eleven radiocarbon

ages provide a weighted mean age estimate of 41,159 ± 783 calBP.

- The *BWT tephra* caps a major unconformity in the Late Pleistocene sequence. This early Holocene deposit is a dense, homogeneous, white ash with thin clay laminae about 20 cm thick. Thin sections show that the base of BWT is weathered and iron-stained. Six radiocarbon ages on charcoal provide a weighted mean age estimate of 7589 ± 689 calBP. Why the Late Pleistocene sequence is missing ~33,000 years of deposits is unknown, but excavations in other areas of the shelter may resolve this question.
- *Early to Late Holocene deposits* excavated largely by the GECPA team overlie BWT and have a complex stratigraphy spanning more than a meter (Gutherz et al., 2002). Excavations have exposed additional early to mid Holocene sediments, artifacts, and fauna, which are currently undergoing analyses.

5. The archaeological sequence

CRC 806/SWEAP excavations of the Late Pleistocene deposits have yielded more than 30,000 lithics, groundstone fragments and worked ochre from five 1 m^2 units excavated to varying depths. So far, detailed typological and attribute analyses are confined to a total of 6257 lithics recovered from the T-Group and S-Group deposits of two BXA excavation units: G10 ($N = 2886$) and H9 ($N = 3371$). Erich Fisher analyzed all lithics from G10 as a major component of his dissertation (Fisher, 2010), while S. Brandt and R. Vogelsang examined the H9 lithics. This analysis excluded lithics from a few levels that might be in secondary context, pending further sedimentological study. Analyses of R-Group lithics are only in the beginning stages and are not included here. The lithics of excavation units G10 and H9 (Table 1) form the analytical sample used here to provisionally describe and compare assemblages from the Lower T, Upper T and S-Group lithological units that also demarcate distinct periods of human occupation and abandonment.

5.1. Lithic raw materials

Almost all of the lithics (~98%) are made from obsidian (Table 2). Artifacts flaked from other volcanic raw materials such as basalt and rhyolite comprise less than 2% of the total sample. Cryptocrystalline silicates (CCS: e.g. chert, jasper, and chalcedony) and a single quartzite flake fragment from the S-Group form the residual 0.6% of raw materials. Most of the CCS is gray in color – but also present are brown, red and pink lithics, a few of which show signs of thermal alteration. The vast majority of the obsidian is a homogeneous, shiny, jet-black type (~94%), with the remainder gray (~5%), green, or brown in color.

Preliminary field results of a portable X-Ray Fluorescence (pXRF; Bruker III–V Tracer+) analysis of black obsidian samples from Mochena Borago suggest that most obsidian artifacts may share a common and distinctive chemical signature (Warren, 2010). Possible sources for the obsidian may lie within an extensive series of obsidian flows and quarries in Humbo *Woreda* (District) (*Woreda*) ~20 km SE of Mochena Borago at the foot of the Southern Main Ethiopian Rift (Fig. 2). However, identification of any specific obsidian quarry as the source for Mochena Borago obsidian artifacts must be considered tentative until planned systematic regional surveys for obsidian are conducted.

Although Mt. Damota, and perhaps even the shelter walls of Mochena Borago itself may be sources of non-obsidian volcanic raw materials, specific sources have yet to be identified. Quartzite and CCS sources also remain unknown. Because the closest limestone formations are hundreds of kilometers away from Mochena Borago and no river systems in the vicinity of Mt. Damota drain through these formations (Kazmin, 1972), Mochena Borago's CCS artifacts may derive from distant sources.

Table 1
Frequency and percentage of flaked stone artifacts (lithics).

Flaked Stone	Lower T-Group		Upper T-Group		S-Group		Total	
	N	%	*N*	%	*N*	%	*N*	%
Cores								
Radial (Discoidal/Levallois)	3		2		1		6	
Single/Double/ Multi Platform	14		16		13		43	
Bipolar	–		–		7		7	
Other/Irregular	–		–		1		1	
Fragments	–		–		5		9	
Total	17	1.6	18	0.9	27	0.8	62	1.0
Debitage								
Angular Waste/Shatter	4		50		142		196	
Burin Spalls	1				6		7	
Core Trimming Flakes	9		12		38		59	
Levallois Flakes	3		2				5	
Levallois Points	–		–		1		1	
Flakes/Blades	174		364		801		1339	
Flake/Blade Fragments	815		1398		2073		4286	
Total	1006	95.0	1826	93.5	3061	94.3	5893	94.2
Unshaped Tools								
Modified	7		12		28		47	
Utilized	8		44		61		113	
Total	15	1.4	56	2.9	89	2.7	160	2.6
Shaped Tools								
Backed Pieces	–		11		24		35	
Scrapers	7		11		30		48	
Points	13		23		10		46	
Drills/Awls/Becs	–		2		2		4	
Notches	–		1		–		1	
Burins	1		3		2		6	
Irregular/Fragments	–		2		–		7	
Total	21	2.0	53	2.7	68	2.1	142	2.3
Total Lithics	1059		1953		3245		6257	

An alternative explanation is that CCS comes from more local inorganic sources formed by silicification within volcanic cavities and lacustrine deposits (Hesse, 1989; Kerrich et al., 2002). One possible source could be the Upper Omo/Gibe Valley ~28 km west of Mt. Damota where red CSS was observed *in situ* in basalt deposits just above the current river bed (S. Ambrose and W. Schultz, pers. comm.). Other possible sources may include the surroundings of Lake Abaya, as well as sources used by the hideworkers of Gamo, ~60 km SSW of Mochena Borago, who still regularly manufacture CSS scrapers for processing hides (Brandt, 1996; Weedman, 2006).

Virtually all non-obsidian artifacts, including CCS of possible exotic origin and non-obsidian volcanics of probable local origin, are debitage and none are shaped tools. The only exceptions are the three utilized pieces of basalt and rhyolite from the Lower T-Group deposits, and a basalt core from the lowest levels of the Upper T-Group deposits.

Table 2
Frequency and percentage of lithic raw materials.

Raw Materials	Lower T-Group		Upper T-Group		S-Group		Total	
	N	%	*N*	%	*N*	%	*N*	%
Obsidian	1000	94.3	1894	96.9	3239	99.8	6133	98.0
Non-Obsidian Volcanics	31	2.7	55	2.9	1	<0.1	87	1.4
Cryptocrystalline Silicates	28	2.9	4	0.2	4	0.1	36	0.6
Quartzite	–		–		1	<0.1	1	<0.1
Total Lithics	1059		1953		3245		6257	

Some evidence for temporal shifts in raw material use can be seen in the frequency of non-obsidian raw materials. These comprise 6% of the lithics in the Lower T-Group sample, but drop to ~3% in the Upper T-Group and then virtually disappear in the S-Group (Fig. 6). In the Upper T-Group deposits this reduction is due largely to a decrease in CCS artifacts, and by S-Group times, interest in non-obsidian raw materials seems to have vanished except for one CCS and one quartzite flake fragment. Non-black obsidian reveals a similar trend, with the highest percentage in Lower T-Group and the lowest in the S-Group. Whether these small fluctuations in the proportion of non-obsidian artifacts reflect sampling biases, possible shifts in mobility patterns or changes in technological, functional and/or cultural demands for certain raw materials, will remain uncertain until ongoing lithic analyses and sourcing studies are completed.

5.2. *Lower T-Group lithic assemblages (>53 ka calBP)*

The 1059 flaked stone artifacts from the Lower T-Group deposits in G10 represent the earliest dated evidence of human occupation at Mochena Borago. Debitage forms 95% of the sample. The balance is comprised of cores, unshaped (informal) tools and shaped (formal) tools (Table 1; Fig. 7). Unshaped tools are defined as having minimally invasive edge damage/retouch ('utilized') or irregular, discontinuous retouch ('modified'), whereas shaped tools have more invasive, patterned, and repetitive retouch.

Most cores are tabular-shaped single, double and multi-platform ("SDM") types with minimal platform preparation. They usually yield ovate to elongated flakes; more rarely, blades are struck by direct, probably hard hammer percussion. The 13 complete SDM cores are small on average (~25 mm), although a few are longer than 35 mm. Flake removal patterns dominate on SDM cores, with only 6% of removals indicative of blades or bladelets (length ≥ 2 × breadth). Complete flakes reveal the same pattern: they are small on average (~20 mm) and rarely exceed 35 mm in length, while only ~10% can be considered blades with length/breadth ('L/B') ratios of 2.0 or greater (Fig. 8). Radially-prepared discoidal and Levallois cores (Fig. 9.11) and flakes exemplify the other major core reduction strategy, but they are represented by only one discoidal core, one Levallois core, and three Levallois flakes. Both cores are small, as are the flakes.

The 15 unshaped tools are evenly divided in frequency between 'utilized' (Fig. 10.5) and 'modified' tools. Most unshaped tools are made on ovate end-struck flakes from SDM cores. They are on average the longest of any tool class (31 mm), perhaps indicating differential selection of long flakes for specific, as yet undetermined functions.

Shaped tools are restricted to 21 artifacts from only three classes: points, scrapers and burins. Over 60% are small points that – judging from striking platforms, dorsal scar patterns and primary blank types when visible – are made on small ovate or triangular-shaped end-struck flakes from SDM cores. Only three of the 13 points are whole, the rest being proximal, medial, distal and indeterminate point fragments in fairly equal proportions. None of the whole or fragmentary points are longer than 29 mm, but the three complete points are more elongate than most other shaped tools. All have their widest measurements near the butt, tapering symmetrically toward the tip. More than 60% are unifacial points with marginal to semi-invasive retouch, followed by parti-bifacial (29%) and bifacial points displaying semi to fully invasive retouch produced by direct percussion with a soft or controlled hard hammer. Some of the points show repetitive morphologies suggestive of a specific functional and stylistic pattern, such as the two triangular-shaped parti-bifacial points: platforms are plain and broad, retouch is finer toward the tip, and lateral edges may show shallow notching above the base, possibly for hafting. Others are more "teardrop" in shape and have ventral bulbs partially or completely trimmed, again suggestive of hafting (Fisher, 2010).

Scrapers form the second largest class of shaped tools ($N = 7$) and include small end, side and denticulated types (Fig. 9.15). All are made on flakes from SDM cores, except one side scraper on a Levallois flake. The only other shaped tools are a small dihedral burin on an end-struck flake (Fig. 9.16), and three indeterminate fragments.

5.3. *Upper T-Group lithic assemblages (~45 ka calBP)*

The proportion of major artifact classes is fairly consistent between Lower and Upper T-Group assemblages (Table 1), as are their sizes and shapes. Core reduction patterns, blank types and plan forms are also similar. Small SDM cores make up almost 90% of all cores (Fig. 9.12–14). Among SDM cores, single platform types dominate. The only other cores are two radial forms: a Nubian Levallois point core and a discoidal core that, at 15 × 49 × 43 mm, is the largest formal core from Mochena Borago.

Debitage patterns also show strong continuity with Lower T-Group assemblages in emphasizing the removal of small, end-struck, ovate shaped flakes from SDM cores. A few small Levallois flakes attest to the continued, but rare, use of radial core reduction. Core trimming flakes are still rare, and burin spalls are absent. The percentage of angular waste or shatter increases slightly from Lower T-Group to Upper T-Group. However, there is still little evidence (e.g. cortical fragments, core trimming flakes) for significant core reduction taking place in this area of the site.

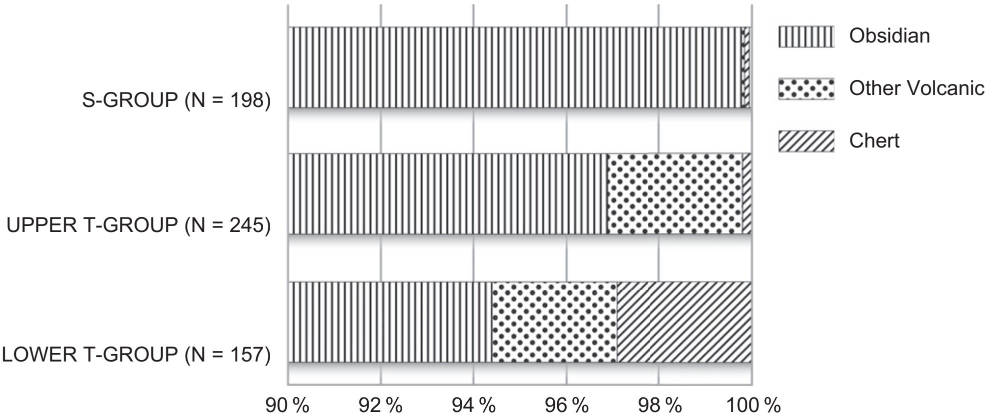

Fig. 6. Frequency and percentage of lithic raw materials.

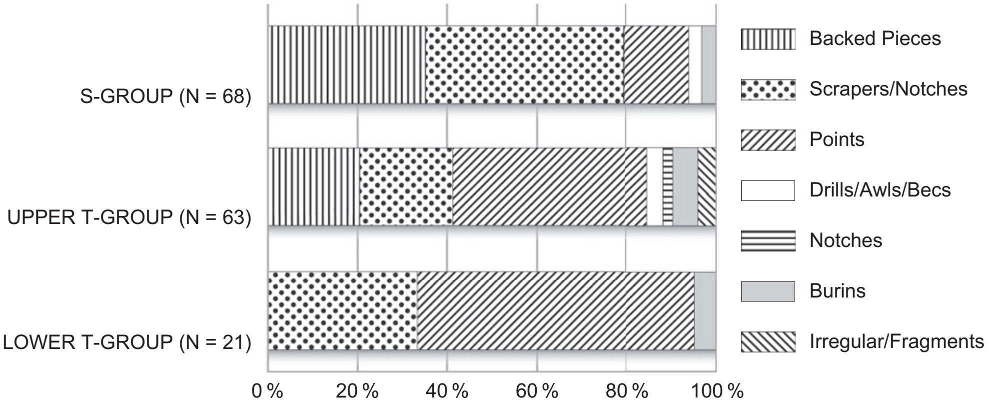

Fig. 7. Frequency and percentage of shaped tools.

Unshaped tools are generally of the same size and shape as those from Lower T-Group, and change little in percentage. Upper T-Group's shaped tool sample is again dominated by points (Fig. 9.3,4,7,9). They exhibit the same patterns in core reduction (end-struck flakes from SDM cores), retouch (>60% are unifacial), plan form (ovate and triangular), size, and shape as the Lower T-Group points.

Backed tools ($N = 11$) make their earliest appearance at Mochena Borago in the middle levels of the Upper T-Group deposits. They form, along with scrapers, the second highest proportion of shaped tools. Although all but one are broken and non-conjoinable, most backed pieces appear to be made on small elongated end-struck flakes from SDM cores. The only complete example is a crescent measuring 30 × 8 × 3 mm (Fig. 9.5). No fragmentary piece is >35 mm in length. Most are straight-backed forms, but curved and irregular backed pieces are also present.

Scrapers from Upper T-Group display essentially the same types (end, side, notched) and percentages as those from Lower T-Group. However, the seven complete scrapers are on average longer and more laminar, including a notched scraper 51 × 17 × 6 mm. Excluding fragments, three burins, two awls and one notch complete the shaped tool sample. The burins are unusually long and laminar, perhaps suggesting that either some of the discarded or exhausted SDM cores were once considerably longer, or that long blades were struck from cores elsewhere and brought to the shelter.

5.4. S-Group lithic assemblages (~43 ka calBP)

From a technological and morphological perspective, the 3245 lithics from the S-Group deposits differ little from the T-Group assemblages, with one important exception. Like the T-Group assemblages, small SDM cores dominate core types. However, there is a reduction in percentage of SDM cores from >80% of the T-Group cores to <50% in the S-Group. This is due largely to the earliest appearance at Mochena Borago of bipolar technology in the form of seven small obsidian bipolar cores that comprise 25% of all S-Group cores (Fig. 10.4). A few of these bipolar cores appear to have been first used as SDM cores, perhaps indicating that bipolar technology may have been initially employed as a way of extending the use-life of an SDM core, rather than as a method of generating flakes from nodules at the initial stage of core reduction. As in the T-Group, a single Levallois core (29 × 19 mm; Fig. 10.6) and one Levallois point 45 mm in length (L/B ratio = 1.6) attest to the continued – albeit extremely rare – use of radially prepared cores during S-Group times.

A sample of 198 flakes from G10 and H9 points to the continued production of small flakes averaging ~20 mm in length. Platforms and dorsal scar patterns suggest that the flakes were struck largely from SDM cores using direct percussion. L/B scatter plots and ratios (Fig. 8) provide little evidence for a focus upon blade production, although rare blades are present, including one more than 55 mm in length (L/B ratio > 4). The absence of cores that could produce such large blades, together with the low frequency of all cores, angular waste and core trimming flakes, lends little support for extensive core reduction, and in particular large blade core reduction in this part of the BXA.

Small, modified and utilized unshaped tools ~23 mm in average length (L/B ratio = 1.6), continue to represent 2–3% of all artifacts, as do the shaped tools. None of the shaped tool types show any major change in size: Artifacts from each type are usually less than

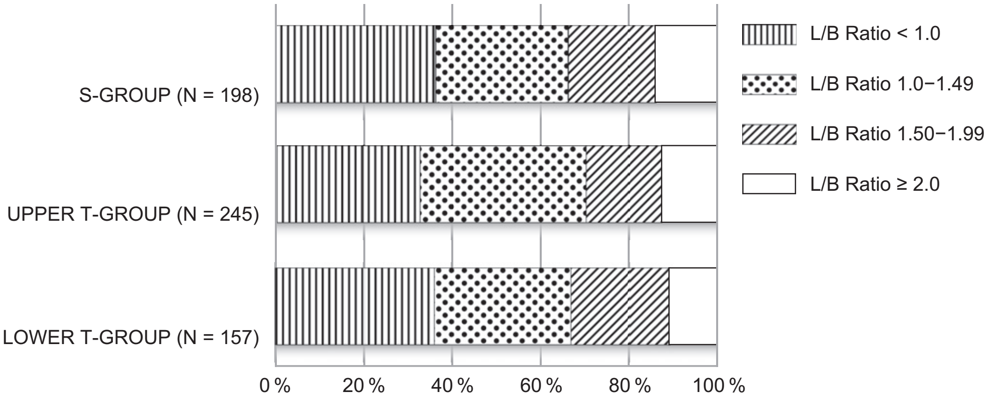

Fig. 8. Length/Breadth (L/B) ratios of flake samples.

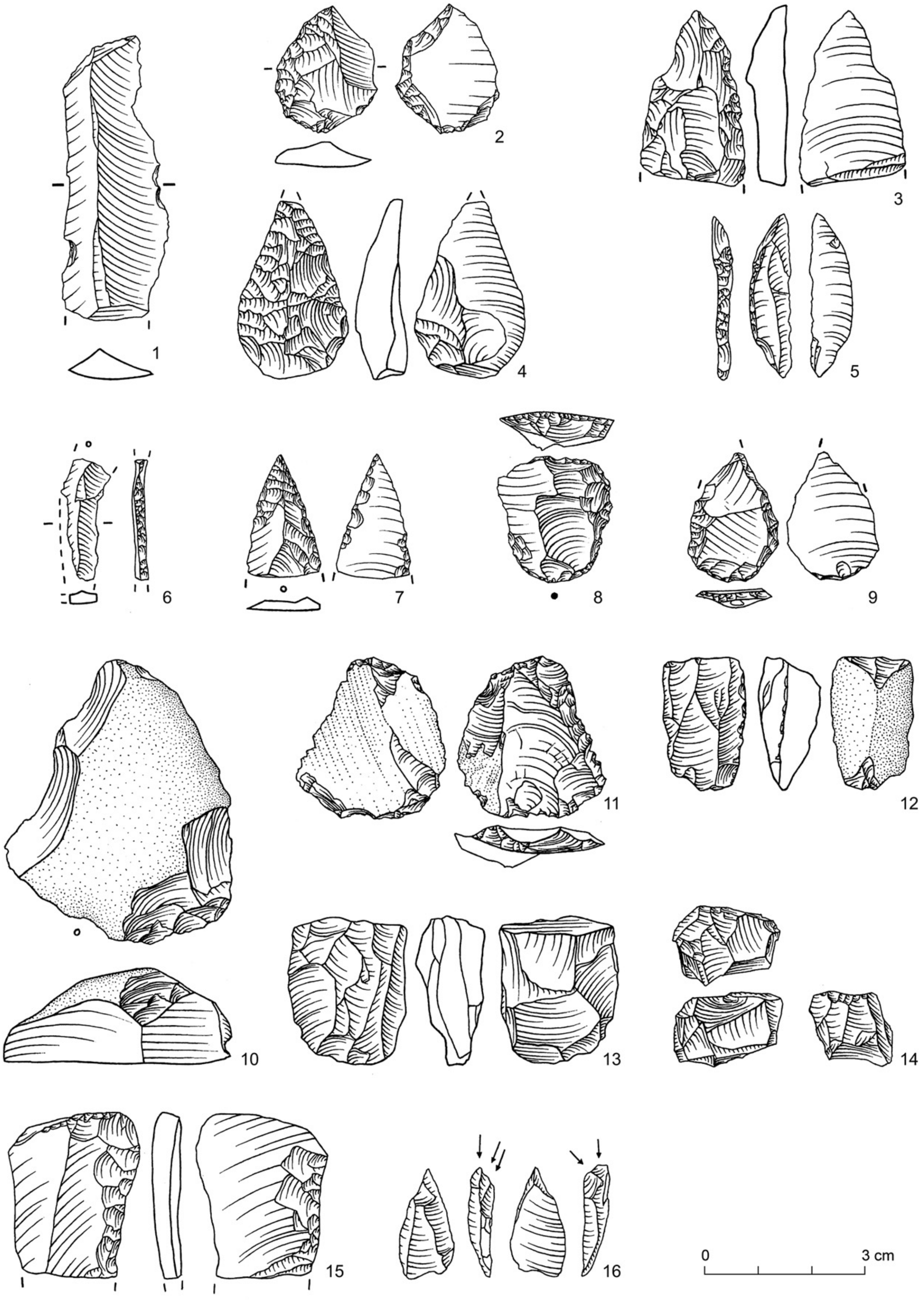

Fig. 9. T-Group lithics: 1 Blade fragment; 2 parti-bifacial point; 3 unifacial point fragment; 4 parti-bifacial point; 5 crescent; 6 backed piece; 7 unifacial point fragment; 8 end and sidescraper; 9 unifacial point; 10 core; 11 Levallois (point?) core; 12 double-platform core; 13, 14 multi-platform cores; 15 double sidescraper; 16 dihedral burin. 1 and 10 are made from non-obsidian volcanics; all others obsidian.

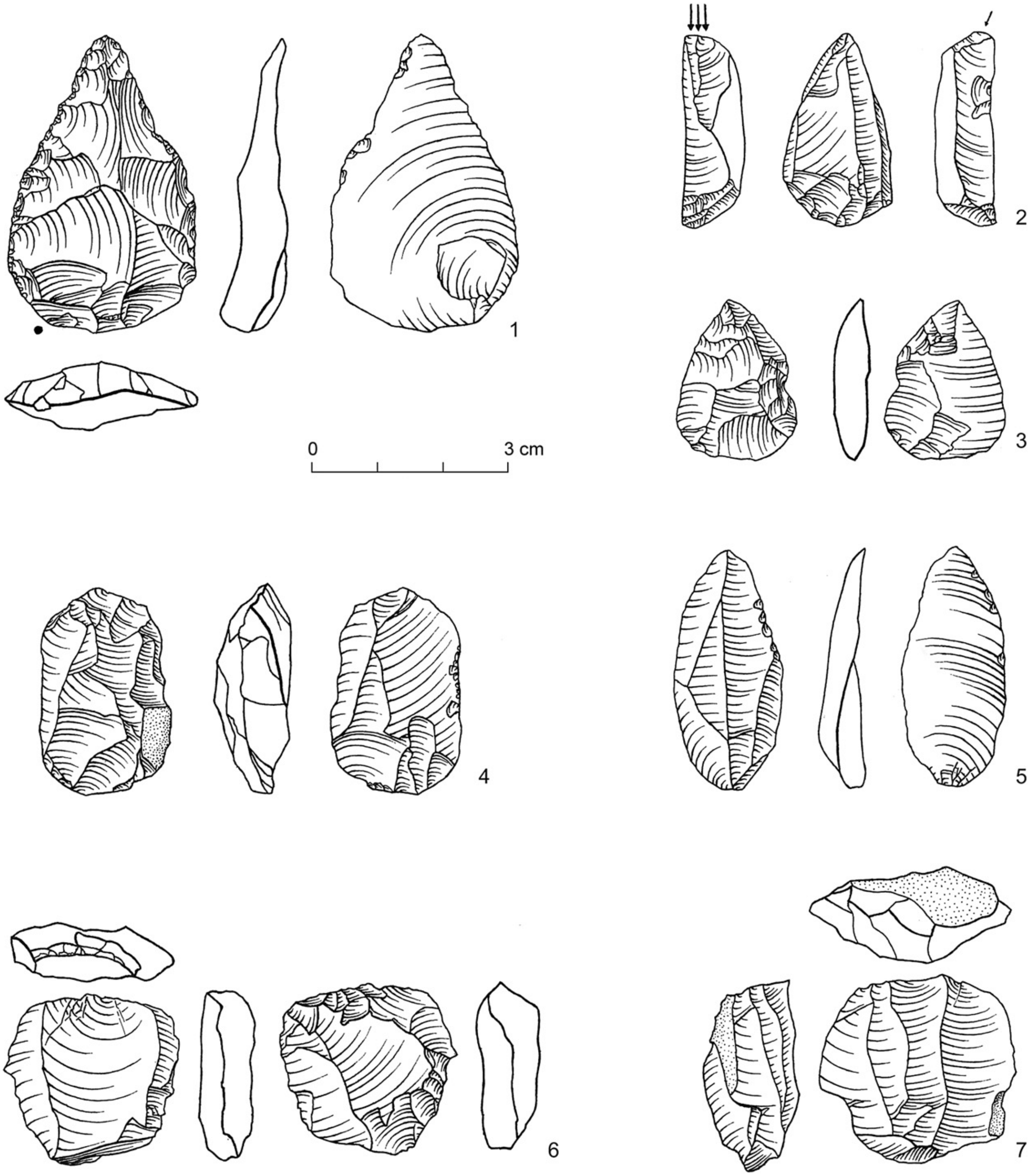

Fig. 10. S-Group lithics: 1 Unifacial point; 2 endscraper and dihedral burin; 3 parti-bifacial point; 4 bipolar core; 5 utilized blade; 6 Levallois core; 7 double platform core. All are made from obsidian.

30 cm in length with mean L/B ratios similar to those in T-Group deposits. Backed pieces continue to increase in frequency over time, as do scrapers. Both are, for the first time, found in greater frequencies than points. Small end scrapers with an average length of 22 mm (L/B ratio = 1.3) form the highest percentage of this class, although side, end-and-side, and notched examples are also present. Curved backed pieces dominate this class, followed by straight-backed forms and truncations. Geometric forms are absent. The one complete curved backed piece is 31 mm in length (L/B ratio = 2.0), while the one complete straight-backed example is 20 mm long (L/B Ratio = 2.1). Points comprise only 15% of the total shaped tools – a significant decrease from the 40–60% of shaped tools they represent in the Lower and Upper T-Group assemblages. Unifacial forms dominate but bifacial and parti-backed types also occur. The S-Group points reveal only subtle differences in size and morphology from T-Group forms, suggesting temporal continuity (Fig. 10.1 and 3).

6. Paleoecology and subsistence

Sedimentological observations within the Mochena Borago sequence hint at changes in local moisture between >53 and 41 ka BP. Although direct indications of local vegetation and animal communities would help flesh out this picture, organic preservation is poor in the Pleistocene layers at Mochena Borago excavated thus far. This section outlines recovery efforts to date and complementary paleoecological sampling undertaken in the surrounding area.

6.1. Faunal remains within the rockshelter deposits

Of faunal remains recovered from Pleistocene deposits, only specimens from basal layers up to and including YBS have been analyzed so far. Of 1569 bones that were recovered from these layers, 99.4% are unidentified.

This low identification rate is due to poor bone preservation in the Pleistocene layers. A quarter of the analyzed specimens show surface damage via sediment corrosion. More than half are blackened and/or calcined, indicating intensive burning. In addition, sediment compaction provoked a very strong fragmentation. Because 80% of the specimens are <1 cm long, and 92% of them are only splinters, few remains can be identified. Furthermore, anthropic marks on bones (e.g. cut marks) have been completely obliterated by post-depositional surface alteration.

Only nine bones have been identified to body part and taxon, all from a single layer within Upper T-Group. They consist of one cervical vertebra (Bovini), five cheek teeth (one Hippotragini and four Alcelaphini), one talus (Bovidae Size Class 4), and a horn core and cheek tooth only classifiable as Bovidae.

Species belonging to the three tribes identified are predominantly grazers and live in wooded to open grasslands with access to water, suggesting a landscape similar to, or slightly drier than, the present one. Analysis of much better-preserved fauna from Holocene layers of Mochena Borago deposits (Lesur, 2007) has shown strong continuity in species representation through several well-documented fluctuations in regional environmental conditions, suggesting that changes in local ecology on Mt. Damota were muted. The limited number of identifiable taxa from Pleistocene layers does not contradict this impression. However, a much larger faunal sample will be needed to fully test this hypothesis.

6.2. Macrobotanical remains and wood charcoal within rockshelter deposits

A series of 10-L sediment samples has been collected from each stratigraphic group for the purposes of archaeobotanical recovery. Only a few of these, from upper stratigraphic groups, have been subject to flotation at the time of writing, and analysis of floated samples is ongoing. Despite the preliminary stage of this work, a few observations are possible.

First, some clayey aeolian/anthropic sediments such as those from the R-Group yield charred material, but in small quantities. So far, the plant material has not included reproductive parts identifiable as portions of seeds and fruits that could have been dietary elements. Rather, archaeobotanical assemblages viewed to date consist of wood, stem, and/or unidentifiable tissue. The small size of charred wood pieces (most <1 mm in floated samples) makes for a dubious prospect of identifying sufficient material to assess spatial and diachronic variation.

Second, preservation of plant remains in Mochena Borago's anthropic deposits is much poorer in Pleistocene portions than in Holocene layers, which yield significant quantities of dried and charred macrobotanical remains and wood charcoal. Inferior preservation of plants in Pleistocene deposits is probably due in part to the greater elapsed time since deposition. High moisture during depositional episodes within the R-Group may have contributed to the destruction of botanical material.

It is still possible that wood charcoal may be recovered in sufficient size and quantity for identification and meaningful comparison across space and time. Analysis of phytoliths from rockshelter deposits, though not yet undertaken, may also reveal diachronic or spatial differences. However, assemblages of either material would result from a complex interplay of human actions and natural processes that could pose interpretive dilemmas. For example, variable representation of wood taxa might point to changes in local ecology, or to people selecting certain taxa for fires built for different purposes at different times.

6.3. Paleoecological investigations outside the rockshelter

Sampling for paleoecological indicators away from the rockshelter is advantageous because one can assume that natural processes, rather than human actions, were shaping the vegetation. 118 soil and volcanic ash samples were collected for the purposes of analysing stable carbon isotopes, providing material to other specialists interested in pollen and phytolith research, and correlation with volcanic layers in the Mochena Borago sequence. These analyses may also provide an environmental baseline with which to compare more human-impacted assemblages from inside Mochena Borago. Samples were collected in eight excavated step trenches with depths ranging from 1.5 to 5.5 m below the modern soil surface along an altitudinal transect from 1224 m, above the edge of the Omo River gorge c. 28 km west of Mt. Damota, to 2912 m near Mt. Damota's summit. Eight sections contain a total of 16 volcanic ash and pumice horizons that may in the future be found to correlate with each other and with one or more of the tephras within Mochena Borago shelter; chemical comparison of the various tephras is ongoing (G. WoldeGabriel, pers. comm.). Carbon isotopic analyses were performed on HCl-treated soil organic matter (SOM) and humic acids (HAF) prepared using methods described in Ambrose and Sikes (1991).

Carbon isotope ratios of SOM and HAF correlate closely, and show that sites below 1935 m have the highest $^{13}C/^{12}C$ ratios, reflecting predominantly C_4 grass biomass. Sites above 2130 m have lower $^{13}C/^{12}C$ ratios, reflecting higher proportions of C_3 plants, including woody plants and high elevation cold-adapted C_3 grasses. There are no systematic directional shifts in carbon isotope ratios within stratigraphic sections. Therefore, there is not yet clear evidence for shifts in altitudinal boundaries between local vegetation zones that differ in their proportions of trees to grasses (C_3 and C_4 photosynthetic pathways). However, there is a large gap in this transect between 2150 and 2850 m. Previous soil isotope research has shown that shifts in the savanna-montane forest ecotone in the Ethiopian Highlands and Kenya Rift Valley occurred in soil sections between 2300 and 2800 m (Ambrose and Sikes, 1991; Eshetu and Högberg, 2000; Eshetu, 2002). Future soil isotope research on the Damota elevation transect should concentrate on filling this gap.

7. Discussion and conclusion

Although analyses are still ongoing, it is evident that data from Mochena Borago Rockshelter have the potential to reshape conversations about modern human dispersals across and out of Africa in several fundamental ways:

1) refining the chronology for the Horn of Africa so that it extends back into early MIS 3 or possibly MIS 4;
2) furnishing the first chronologically secure and detailed early MIS 3 environmental sequence for an area near a dispersal corridor; and
3) documenting changes in technology, landscape use, and other aspects of human behavior around the time of range expansion of the L3, M and N haplogroups out of Africa.

Refined laboratory preparation methods and AMS datings of plotted charcoal have established the first secure radiocarbon sequence for the Horn of Africa that extends beyond 40 ka BP, thereby providing a better understanding of early MIS 3 human behavior and paleoenvironments at the time of modern human dispersals across and out of Africa. Late Pleistocene hunter-gatherers occupied Mochena Borago Rockshelter at varying times and intensities between ~53 and 38 ka calBP. However, the earliest date of 53,226 ± 2662 calBP from the Lower T-Group deposits must be viewed as a minimal age for initial use of the shelter, as more than 20 cm of undated deposits lie below the dated level before reaching the archaeologically sterile DF-Group deposits. It would not be surprising if additional radiocarbon dates from the Lower T-Group deposits push back the earliest occupation of the shelter toward the beginning of MIS 3 (i.e. ~ 60 ka BP), or perhaps even into MIS 4.

Mochena Borago's complex lithostratigraphic sequence suggests that human populations encountered frequent, sudden, and unpredictable changes in living conditions, triggered by local and regional changes in volcanism, hydrology, and climates. The tephras and mud flows within the rockshelter attest to periodic volcanic events that must have had dramatic effects upon local, if not regional, natural and cultural landscapes, environments, and resources (e.g. Fedele et al., 2008). Fluctuations in moisture within Mochena Borago may reflect geological events on Mt. Damota and/or shifts in local rainfall patterns. Further paleoenvironmental investigations outside the rockshelter, combined with additional radiocarbon ages and a more precise chronometric sequence within the shelter, will clarify and enlarge understanding of these events. This could allow comparison of the data to well-established marine and speleothem records of early MIS 3 paleoclimatic sequences, including such short-term fluctuations as the Heinrich and Dansgaard–Oeschger events (Burns et al., 2003; Huber et al., 2006).

Attempts to recover floral and faunal remains from Mochena Borago's Late Pleistocene deposits have met with issues of poor preservation, difficulties in identification, and interpretive dilemmas that are not easily resolved. Diversifying excavation areas to include different depositional contexts within the rockshelter, and contrasting data drawn from archaeological vs. paleoecological contexts, may yield a more robust local picture. The present study is not alone in facing these challenges. To the authors' knowledge, no other archaeological site in eastern Africa has provided a securely dated floral or faunal record for early MIS 3 or 4 (Willoughby, 2007, pp. 246–267), from which models of hunter-gatherer subsistence and settlement can be developed and tested against regional, continental and global terrestrial, lacustrine, fluvial and marine paleoenvironmental proxies (Marean, 1997). Only one other site in the Horn of Africa has yielded identifiable fauna potentially dating to early MIS 3 or 4: Porc Epic Rockshelter, which is situated at a lower elevation in a drier environment than Mochena Borago (Fig. 1). Dominated by bovids, including Bovini and Alcelaphini (Assefa, 2006), Porc Epic's assemblage of several hundred elements suggests a more open, grassland-dominated habitat than is present today. However, the site's chronology is too insecure to reconstruct diachronic changes or compare with other sites (Brandt, 1986). The nine identifiable bones recovered from Mochena Borago do not permit detailed faunal reconstruction, but include Alcelaphini suggestive of environments similar to or slightly drier than today, at least for the period ~45 ka.

Analysis of Mochena Borago's flaked stone assemblages suggests that the earliest occupants of the shelter were manufacturing, deploying, and maintaining a distinctive lithic industry. They focused upon using direct percussion, probably with hammerstones, to produce elongated flakes from small, tabular-shaped and minimally prepared single to multi-platform obsidian cores. Radial core reduction strategies were present, but rarely practiced. Prismatic/pyramidal blade cores are absent from undisturbed contexts in T- and S-Group deposits, suggesting that most blades/bladelets were produced fortuitously and infrequently from SDM cores.

Although lithic technology changed little during the ~15,000 years of Late Pleistocene site use, shifts in the frequency of specific artifact types probably reflect changing activities, functional needs, and/or stylistic preferences. In the earliest excavated Lower T-Group deposits, shaped tools include scrapers and burins, but are dominated by small unifacial and bifacial points, a few of which show repetitive morphologies suggestive of functional and/or stylistic patterning. In Upper T-Group assemblages this pattern continues, but tool kits begin to incorporate small backed pieces by ~45 ka calBP. Following a brief abandonment of the site caused by a massive volcanic mud flow into the shelter ~43 ka calBP, S-Group assemblages document the re-occupation of Mochena Borago by hunter-gatherers bearing a lithic tradition technologically and typologically almost identical to earlier T-Group assemblages – including the continued, albeit very rare use of radial core technology. However, scrapers and backed pieces now supercede small points in frequency. Determining what functions points, backed pieces, and scrapers may have served (e.g. as hafted elements of composite tools as part of hunting, gathering, or processing activities) is the subject of ongoing microwear studies (V. Rots, pers. comm.) along the lines of others for the region (Ambrose, 2010; Shea and Sisk, 2010; Rots et al., 2011).

An industry of this age, whose shaped tools are dominated by unifacial and bifacial points, and with radial technology present, would usually be classified in eastern Africa as "Middle Stone Age" (Clark, 1982). However, Mochena Borago's flintknappers emphasized small, non-radial flake core reduction, even for making points. On the other hand, industries with small backed pieces are usually classified as "Later Stone Age" (Ambrose, 1998). At Mochena Borago, backed pieces first appear in assemblages exhibiting strong technological continuity with earlier, prevailing reduction methods: non-radial flake cores, rare radial cores, and small flake-derived points. Although the site's deposits show clear contextual integrity, no major change in lithic technology appears suddenly or gradually at any time 53–43 ka BP. Mochena Borago's archaeological sequence thus cannot be neatly classified as "MSA" or "LSA." The authors are not suggesting that there is an absence of technological change at Mochena Borago based on the limited samples size presented here, but there is no evidence for technological changes that can be described as an "MSA–LSA transition" (Marks and Conard, 2008; Hovers, 2009). Furthermore, Clark's (1969) scheme of technological "modes" does not apply well to Mochena Borago, because its assemblages cannot be easily classified as Mode 3 (radial core), Mode 4 (prismatic blade), or Mode 5 (geometric microlith) technologies. Late Pleistocene lithic assemblages from Mochena Borago thus may challenge some of the fundamental principles by which archaeologists have attempted to classify African toolmaking traditions, and suggest these principles merit reexamination (see also Diez-Martín et al., 2009).

Comparison of Mochena Borago lithic assemblages with those from nearby regions is ongoing (Fig. 1). The oldest "MSA" assemblages in the region, drawn from sites at Gademotta, Omo Kibish, and K'one have more prominent use of radial technology, and lack backed pieces (Wendorf and Schild, 1974; Kurashina, 1978; Shea, 2008). Somewhat younger "MSA" sites at Aduma and Porc Epic appear to have smaller components that may resemble material from Mochena Borago, but dates for these sites remain insecure (Michels and Marean, 1984; Pleurdeau, 2001; Yellen et al., 2005). These chronological and comparative dilemmas within the Horn of Africa are daunting: It will take many years to develop a securely dated Late Pleistocene culture-historical sequence, as well as significantly improve understanding of prehistoric hunter-gatherer behavior. However, these challenges underscore the fact that Mochena Borago offers the first anchor for comparing paleoenvironments and well-dated archaeological assemblages from MIS 4 or 3 sites near African dispersal sources, to those of the first diaspora populations beyond the Red Sea and Indian Ocean (Petraglia et al., 2009; Rose et al., 2011).

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