The earliest long-distance obsidian transport: Evidence from the ~200 ka Middle Stone Age Sibilo School Road Site, Baringo, Kenya.

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Abstract:

This study presents the earliest evidence of long-distance obsidian transport at the ~200 ka Sibilo School Road Site (SSRS), an early Middle Stone Age site in the Kapthurin Formation, Kenya. The later Middle Pleistocene of East Africa (130–400 ka) spans significant and interrelated behavioral and biological changes in human evolution including the first appearance of *Homo sapiens*. Despite the importance of the later Middle Pleistocene, there are relatively few archaeological sites in well-dated contexts ($n < 10$) that document hominin behavior from this time period. In particular, geochemically informed evidence of long-distance obsidian transport, important for investigating expansion of intergroup interactions in hominin evolution, is rare from the Middle Pleistocene record of Africa. The SSRS offers a unique contribution to this small but growing dataset. Tephrostratigraphic analysis of tuffs encasing the SSRS provide a minimum age of ~200 ka for the site. Levallois points and methods of core preparation demonstrate characteristic Middle Stone Age lithic technologies present at the SSRS. A significant portion (43%) of the lithic assemblage is obsidian. The SSRS obsidian comes from three different sources located distances of 25 km, 140 km and 166 km from the site. The majority of obsidian derives from the farthest source, 166 km to the south of the site. The SSRS thus provides important new evidence that long-distance raw material transport, and the expansion of hominin intergroup interactions that this entails, was a significant feature of hominin behavior ~200 ka, the time of the first appearance of *H. sapiens*, and ~150,000 years before similar behaviors were previously documented in the region.

Keywords: Geoarchaeology; Obsidian Sourcing; Tephrostratigraphy; Lithic Technology; Middle Pleistocene; East Africa.

Introduction

The later Middle Pleistocene of East Africa is an important time period for understanding the evolution of our species. The earliest fossil *Homo sapiens* specimens date to 195 ka in the Kibish Formation of the Omo-Turkana Basin and between 154 and 160 ka in the upper Herto Member of the Bouri Formation in central Ethiopia (Clark et al., 2003; McDougall et al., 2005; White et al., 2003). Also during this period, the large hand-held stone tools of the Acheulean, such as handaxes and cleavers, were replaced by more diverse and smaller stone tools of the Middle Stone Age (MSA) characterized by diverse disc core preparation technologies, including multiple Levallois techniques, smaller cores and flakes, pointed pieces and hafted tools (Clark, 1988; Tryon et al., 2005).

Understanding human evolution in this period thus requires understanding of the timing and pattern in which behavioral changes, including new technologies, mobility patterns, subsistence strategies and ecological adaptations, were acquired in relation to biological changes and environmental circumstances (McBrearty and Brooks, 2000). In the Late Pleistocene, particularly of southern Africa, the chronology and pattern of technological and other behavioral innovations in the MSA is relatively well understood due to a robust and important body of work in this region (Deacon, 1979; Singer and Wymer, 1982; Wadley and Jacobs, 2006). A comparable chronology and pattern of behavioral and technological change is also being established for the Late Pleistocene in eastern Africa (Tryon and Faith, 2013). However, a similarly complete archaeological record is lacking

for the earliest MSA of the later Middle Pleistocene. This relative lack of Middle Pleistocene archaeology in Africa limits our understanding of this time period, leading to the perception that hominin behavior surrounding the appearance of *H. sapiens* was relatively homogenous and static (Klein, 2000; McBrearty and Tryon, 2006; Tryon and Faith, 2013). To address these issues, investigations on a limited but steadily increasing number of later Middle Pleistocene MSA archaeological sites in both southern Africa (Marean, 2010; Wilkins et al., 2012) and eastern Africa (Douze, 2014; Morgan and Renne, 2008; Sahle et al., 2014; Shea, 2008; Tryon et al., 2005) have been undertaken. Integrative work presented here, including tephrostratigraphy, chronology, excavations, lithic technology and geochemical obsidian sourcing at the Sibilo School Road Site (SSRS= GnJh-79) in the Kapthurin Formation of Baringo, Kenya, complements recent studies on the early MSA of Middle Pleistocene eastern Africa by demonstrating a ~200 ka Middle Pleistocene MSA site with significant quantities of obsidian (43% of the SSRS assemblage) deriving from three different sources located distances of 25 km, 140 km and 166 km from the site. This evidence of long-distance raw material transport is ~150 kyr (thousands of years) older than similar behaviors previously documented in the region. The SSRS thus provide unique evidence that long-distance raw material transport, and the expansion of hominin intergroup interactions that this entails, was a significant feature of hominin behavior associated with MSA technology ~200 ka in eastern Africa, the time of the first appearance of *H. sapiens*.

Background and previous research

To appreciate the contribution of the SRSS to our understanding of later Middle Pleistocene hominin behavior it is necessary to situate the site in its regional and temporal contexts, considering Middle Pleistocene eastern African sites in well-dated contexts and of similar age, as well as eastern African Early Stone Age (ESA) and MSA sites for which geochemically informed obsidian-sourcing studies have been undertaken.

Middle Pleistocene MSA archaeology in eastern Africa Relatively few ($n < 10$) later Middle Pleistocene MSA sites in eastern Africa preserve archaeological material in well-dated contexts. Two in situ MSA archaeological occurrences in the Kibish Formation—Kamoya's Hominid Site (KHS) and Awoke's Hominid Site (AHS) in Member I are dated to ~195 ka (Brown and Fuller, 2008; McDougall et al., 2005, 2008; Shea, 2008). Middle Stone Age and Acheulean material dated between 154 and 160 ka is known from controlled surface collections at Herto (Clark et al., 2003). In the Kapthurin Formation two localities from the ~200–300 ka site of Koimilot provide MSA materials such as Levallois points and diverse methods of Levallois flake production (Fig. 1; Tryon, 2003, 2006, 2010; Tryon et al., 2005). The MSA sites of the Gademotta Formation in the middle Ethiopian Rift (>183–279 ka) show evidence of trimmed and shaped uni- and bifacial point production as well as diverse prepared cores made of locally available obsidian (Fig. 1; Douze, 2014; Morgan and Renne, 2008; Sahle et al., 2014; Wendorf and Schild, 1974).

Obsidian sourcing studies in Pleistocene Africa Raw material transport studies are used to track hominin social and ecological behaviors in prehistory, including hominin mobility,

intergroup interactions and the expansion of social networks. In the African MSA, long-distance transport of fine-grain raw materials factors prominently into arguments about the origins of modern human behavior in the southern African Howieson's Poort ~60 ka (Ambrose and Lorenz, 1990), though ambiguities about the source of these chemically homogenous rocks as well as their prevalence in secondary outcrops of rivers and conglomerates obscures interpretation (Ambrose, 2006; Minichillo, 2006). Geochemical sourcing relies on the principle that inter-source variation exceeds intra-source variation (Neff, 2000; Pollard et al., 2014; Weigand et al., 1977). Obsidian sources in East Africa are, with few exceptions, geographically restricted and well-defined points on the landscape characterized by chemically diagnostic fingerprints (Brown et al., 2013). As a result, evidence for long-distance transport, at distances of ~50 to >150 km, of obsidians in eastern Africa factors prominently into arguments for expansion of hominin intergroup interactions important to the origins and evolution of modern human behavior (McBrearty and Brooks, 2000: 513–517).

Obsidian artifacts are rare at Acheulean sites in the Early and Middle Pleistocene of eastern Africa. When present, obsidian comprises a tiny proportion (< 0.1%) of the overall lithic artifact composition (Ambrose, 2012). Four obsidian handaxes from Gadeb, Ethiopia are asserted to derive from as far away as 100 km (Clark, 1987; Féblot-Augustins, 1990), but these are not geochemically confirmed and many sources in this region remain to be documented (see Ambrose, 2012). Geochemically confirmed examples of Acheulean obsidian transport include Melka Kunture in the Ethiopian rift, where obsidian comes from 7 km away (Negash et al., 2006), and Kariandusi, Kilombe and Katabuya in the central Kenyan Rift (Merrick et al., 1994). None of the obsidian

from these central Kenyan Rift sites demonstrates transport distance >15–30 km. The obsidian at all the Acheulean sites listed above was probably not acquired farther away than the sources of other, coarser grained, raw materials such as lavas (Merrick and Brown, 1984; Merrick et al., 1994). The only geochemically confirmed exception is a single obsidian artifact found in the excavations of the Acheulean site Isenya on the Athi-Kapiti Plain, Kenya, sourced to Kedong ~60 km away (Merrick et al., 1994). The Middle Pleistocene MSA sites of Gademotta are situated at the source of the Worja obsidian, and this seems to be the raw material used for most (> 94%) of their lithic raw materials (Sahle et al., 2014).

Middle Stone Age sites in western Kenya provide obsidian artifacts transported 145 km at Songhor and 185–190 km at Muguruk (McBrearty, 1981, 1986; Merrick and Brown, 1984; Merrick et al., 1994). Transport distances of 250 km have recently been shown for obsidians associated with MSA technologies in the >50-100 ka exposures of Karungu (Faith et al., 2015). The rockshelters of Nasera and Mumba in northern Tanzania demonstrate obsidian transport distances of 240 and 307–325 km respectively (Mehlman, 1989; Merrick and Brown, 1984; Merrick et al., 1994). While all the above sites demonstrate long transport distances, obsidian constitutes only a very small part (< 0.1 %) of the total lithic assemblages (Ambrose, 2006, 2012; Faith et al., 2015; McBrearty, 1981, 1986). In MSA layers of Porc Epic, Ethiopia, obsidian constitutes 5.5% of the lithic assemblage and derives from multiple sources with distances up to 150–250 km from the site (Negash and Shackley, 2006). The multicomponent MSA site of Prospect Farm, imprecisely dated to the earlier half of the Late Pleistocene between ~120 and 50 ka, is

situated on the obsidian source in the Eburru Volcanic Complex north of Lake Naivasha (Michels et al., 1983). Perhaps expectedly, most of the obsidian through all levels is acquired locally (≤ 40 km) from Eburru and the Naivasha Basin sources, though obsidian from sources such as Kisanana, ~ 75 km north of the site, occurs in low proportions throughout the sequence (Merrick et al., 1994). In the MSA levels of site GvJm-16 at Lukenya Hill, obsidians comprise 5–8% of the total lithic assemblage by individual pieces. In the earlier MSA levels, 53% of the obsidian is transported from sources < 65 km away and 31% of the obsidian (2% of the total lithic assemblage) derives from Central Rift sources between 105 and 135 km away. In the later MSA levels, between 47 and 62% percent of this obsidian is transported from a variety of Central Rift sources located 65–130 km from the site (Merrick et al., 1994). While GvJm-16 is undated, it is certainly Late Pleistocene, and recent work on the technologically similar Lukenya Hill site GvJm-22, located ~ 0.5 km from GvJm-16, shows MSA levels to be ~ 40 ka (Tryon et al., 2015). In the latest MSA layers of Prolonged Drift (~ 35 ka) in the Nakuru Basin, 90% of the obsidian is transported from Naivasha Basin sources 45–55 km from the site (Merrick, 1975; Merrick et al., 1994).

In summary, no Early or Middle Pleistocene sites show evidence of geochemically confirmed obsidians transported distances > 60 km (Merrick and Brown, 1984; Merrick et al., 1994). No sites in this time period in which obsidian constitutes a substantial portion of the lithic assemblage show transport distances > 30 km. All of the MSA sites reviewed above demonstrating long-distance obsidian transport, with the possible but undated exception of Muguruk, are from Late Pleistocene contexts. The sites in which non-local

obsidians constitute significant portions (> 1.0 %) of the lithic assemblage are even younger, dating to < 50 ka by best estimates. These sites are thus younger than the earliest MSA sites in the Middle Pleistocene of East Africa by perhaps 80 –150 kyr (Ambrose, 2012; Tryon and Faith, 2013). The lack of obsidian sourcing studies in Middle Pleistocene contexts demonstrating long-distance transport of substantial amounts of obsidian leads to the currently valid critique (Ambrose, 2012: 64) that the trend towards longer transport distances of greater quantities of raw material did not begin until the very late MSA and thus transport of substantial amounts of obsidian raw material was not an important part of the Middle Pleistocene hominin behavioral repertoire. This, in turn, would suggest the patterns of increased mobility and/or stronger intergroup interactions for hominins in Africa did not begin until <50 ka, some ~150 kyr after *H. sapiens* evolved in the region (Ambrose, 2012: 65).

The reviews of East African Middle Pleistocene MSA sites and obsidian sourcing studies presented above emphasize: 1) the relative rarity of well-dated later Middle Pleistocene MSA sites, and 2) the complete absence of well-dated Middle Pleistocene sites containing substantial amounts of obsidian transported long-distances. Work at the SSRS presented here provides the unique opportunity to address these gaps in the later Middle Pleistocene archaeological record and produce evidence of a ~200 ka site containing MSA technology and evidence of long-distance obsidian transport.

Geochronology of the Kapthurin Formation

The Kapthurin Formation is a series of sedimentary and volcanic units 125–150 m thick and exposed over an area of ~150 km² west of Lake Baringo in the Central Rift Valley of Kenya (Fig. 2). The formation is divided into five members, abbreviated K1–K5 from lowest to highest stratigraphically (Fig. 2B). All Kapthurin Formation sediments are normally magnetized (Dagley et al., 1978), and thus postdate the Matuyama–Brunhes boundary, currently estimated at 778.0 ± 1.7 ka (Love and Mazaud, 1997). The Pumice Tuff Member (K2) separating K1 and K3 comprises a voluminous pumiceous eruption, the Pumice Tuff, coincident with a large effusive lava flow, the Lake Baringo Trachyte. The Pumice Tuff and Lake Baringo Trachyte are $^{40}\text{Ar}/^{39}\text{Ar}$ dated to 543 ± 4 ka and 545 ± 3 ka respectively (Fig. 2B; Deino and McBrearty, 2002; Tallon, 1976). The Grey Tuff, from the Middle Silts and Gravels Member (K3), is directly $^{40}\text{Ar}/^{39}\text{Ar}$ dated to 509 ± 9 ka (Deino and McBrearty, 2002). The Bedded Tuff Member (K4), is composed of over a dozen alternating sedimentary and volcaniclastic (tuff) units measuring a maximum thickness of 35 m (Tallon, 1976, 1978; Tryon, 2003). The Bedded Tuff Member has previously produced two $^{40}\text{Ar}/^{39}\text{Ar}$ dates of 284 ± 12 ka and 235 ± 2 ka (Fig. 2B; Deino and McBrearty, 2002). This member contains both Acheulean and MSA sites (McBrearty, 1999, 2001; McBrearty et al., 1996; McBrearty and Brooks, 2000; McBrearty and Tryon, 2006; Tryon et al., 2005). Because it is not possible or practical to $^{40}\text{Ar}/^{39}\text{Ar}$ date every tuff (Feibel, 1999) tephrostratigraphy has been used to assess stratigraphic position and relative age of archaeological sites capped by individual tuffs in the Bedded Tuff Member (Tryon, 2003; Tryon and McBrearty, 2002, 2006). The chemical compositions of Bedded Tuff Member tuffs show a general compositional trend from tuff units containing less compositionally evolved (more dense) basaltic glass, located

stratigraphically lower in the Bedded Tuff Member section, through tuffs containing progressively more evolved (less dense) basaltic and trachytic glass stratigraphically higher in this member (Fig. 3). The compositional change occurs along a single trendline, observable in element oxide bivariate plots (Fig. 3). This trend reflects the chemical evolution of a single cooling magma source by fractional crystallization as denser minerals crystallize out of solution leaving a compositionally altered residual magma chamber that produces glass of a more compositionally evolved chemical composition in successive eruptions (McBirney, 1984; Tryon, 2003; Tryon and McBrearty, 2002, 2006). Thus, the chemical composition of a Bedded Tuff Member tuff falling along this compositionally evolving trendline indicates the tuff's inclusion within the Bedded Tuff Member as well as its relative stratigraphic position within this member in relation to other tuffs encasing archaeological sites or those directly dated by the $^{40}\text{Ar}/^{39}\text{Ar}$ method (Fig. 3). This method has proven extremely useful in establishing a relative chronology and age of Acheulean and MSA archaeological sites found at or below the base of the Bedded Tuff Member and currently estimated to date >284 ka (Tryon, 2003; Tryon and McBrearty, 2002, 2006). Large scale faulting accompanied and postdated the deposition of the Bedded Tuff Member. The ages of these faulting events are estimated between ~198–345 ka by the uranium-series (U-series) method on hydrothermal silica in-filling faulted cracks (Le Gall et al., 2000). Importantly, both the $^{40}\text{Ar}/^{39}\text{Ar}$ dating of tuffs and the radiometric dating of extensional faulting postdating deposition of the Bedded Tuff Member show that deposition of the Bedded Tuff Member of the Kapthurin Formation dates to > 200 ka. Fluvial deposits of the Upper Silts and Gravels Member (K5) overlie the Bedded Tuff Member (Tallon, 1976, 1978). In places, the Kapthurin Formation is

unconformably overlain by terminal Pleistocene/ Holocene sediments of the Kokwob Formation and the Loboil Silts (Bishop et al., 1971; Renaut and Owen, 1980).

Materials and methods

The Sibilo School Road Site

The SSRS is located in the northern part of the Kapthurin Formation ~5 km southwest of the town of Loruk (Fig. 2A) at the intersection of a small dirt track and a dry seasonal drainage (Fig. 4). Andrew Hill and John Kimengich discovered the site on February 1, 1988. The artifact and fossil-bearing exposure at the SSRS measures approximately ~50m long, ~20m wide and ~4.5m thick. Controlled excavations were not carried out prior to this study because of the isolated location of the site and because the ambiguous lithology of the coarse pumiceous tuff capping local exposures (Fig. 4B, G) obscured its stratigraphic position and age.

Geological tephra sampling methods A total of 182 individual shards on nine tuff samples from the Kapthurin Formation were analyzed for chemical characterization and tephrostratigraphic analysis (Table 1). Of these, five ‘NTB’ samples (71 individual shard analyses) were newly collected in the field from 2011–2014, the other four samples (111 individual shard analyses) were reanalyzed from previous studies (Tryon, 2003; Tryon and McBrearty, 2002) to increase the number of shards per sample and for comparative consistency.

Archaeological excavation methods Excavations at the SSRS were carried out over four weeks in the winter of 2013-2014 and two additional weeks in June of 2014. Spatial data were collected in three dimensions using a 6” Leica total station connected to a PC laptop (Fig. 4B) operating EDM for Windows (Microsoft) excavation software (McPherron and Dibble, 2002). Prior to excavation, artifacts and fossils on the surface or exposed in situ at the surface were recorded and collected. A 1 x 1 m alphanumeric grid was laid out over the intended area of excavation. Excavations were carried out in arbitrary 10 cm horizontal levels because of the absence of any visible natural stratigraphy within the artifact and fossil-bearing matrix. All in situ lithic and fossil faunal material with a maximum dimension >2 cm was piece-plotted. All material with a discernible long axis was plotted with two points, one at either end of the elongated axis. All excavated sediment was screened through 1/8” mesh and sieved material was collected in bags specific to date, square and level.

Artifact analysis Analysis and measurement of lithic artifacts from the SSRS was conducted from June – August 2014 in the Archaeology Division of the National Museums of Kenya, Nairobi where the material is permanently housed. The methodology for lithic analysis of MSA sites is disparate and there is no single analytical system always used by all researchers. To standardize data collection as much as possible, lithic analysis procedures and terminology follows that of recent studies of MSA and prepared core technologies in the Kapthurin Formation (Tryon, 2003, 2006; Tryon et al., 2005). Artifact data reporting follows recent studies of Middle Pleistocene MSA material in eastern Africa (Sahle et al., 2014; Shea, 2008).

Tephra and obsidian analysis The geochemical analysis of tephra and obsidians focuses on electron probe microanalysis (EPMA) of eleven major element oxide proportions in volcanic glass from tuffaceous deposits, sediments and obsidian artifacts. Preparation protocols for tephra analysis and microprobe analysis for tephra and obsidian follow University of Utah Microprobe facilities equipment and methodologies outlined in Blegen et al. (2015) for tephra analysis and Brown et al. (2013) for obsidian analysis. Electron probe microanalysis of major element oxides on volcanic glass is the favored method of obsidian sourcing because this method has been tested and proven valid for obsidians from stone-age assemblages in eastern Africa (Brown et al., 2013; Merrick and Brown, 1984; Merrick et al., 1994). A large comparative dataset of geological obsidian sources characterized by EPMA is available (Brown et al., 2013).

Obsidian sampling strategy Each obsidian specimen from the SSRS was macroscopically characterized based on the texture of its cortex and patina at the National Museum of Kenya, Nairobi. Twenty-eight pieces of obsidian recovered in situ at the SSRS were then sampled for chemical characterization by microprobe analysis. The goals of this sampling strategy were: 1) to identify chemically the source or sources of the obsidian and 2) to characterize the cores and flaked materials to determine the diversity of sources represented in the flaked waste and abandoned cores from the site. To fulfill these objectives, small chips (<0.5 mm; $n=28$) were sampled from the flakes, flake fragments and angular waste of the three dense concentrations in the main trench of the SSRS (shown in Fig. 4F) and from 16 separate 1×1 m² units from the main trench where

obsidian was less densely concentrated. Three obsidian samples were taken directly from each of the three obsidian cores.

Correlation of SSRS artifactual obsidians to sources Correlation of the chemical compositions of SSRS obsidian artifacts and discrete chemical and geographic sources required the overlap of the oxide values of all measured major element ± 2 standard deviations, visual inspection of the data in bivariate plots and an empirically informed similarity coefficient methodology for correlating volcanic glass of discrete modal compositions based on Borchardt (1972) and outlined in Blegen et al. (2015). The only departure from the methodology defined in Blegen et al. (2015: 100) is the addition of three elements, Si, Na and K, because these could be measured accurately and consistently in the obsidians studied here. The element-oxide MgO was excluded from similarity coefficient analysis in this study because its proportional representation was too low (often ≤ 0.02 wt. %) for consistently accurate measurement of this element in the majority of obsidians considered here.

Results

Geological context and age of the Sibilo School Road Site

SSRS local stratigraphy Establishing the age of the archaeological material from the SSRS requires linking the site's local stratigraphy to the larger known tephrostratigraphic and chronostratigraphic framework of the Bedded Tuff Member (Deino and McBrearty, 2002; Tryon and McBrearty, 2002, 2006). The local stratigraphy of the SSRS consists of

three lithologically distinct units (SSRS Units 1 to 3, from stratigraphically lowest to highest). Unit 1) is a light brown, massive tuffaceous silty-soil over 1.5 m thick and exposed at the base of the dry seasonal drainage. This unit contains all in situ archaeological material at the SSRS (Fig. 4A, C, D, E, F). The SSRS Unit 1 tuffaceous soil is capped by Unit 2) a non-tuffaceous silty-clay soil, ~1m thick and displaying vertic structures and slickenslide features. This silty-clay soil is eroded at the top and disconformably overlain by Unit 3) a vitric, coarse pumice tuff composed of fresh, angular to subround pumices, 1-5 cm in diameter (Fig. 4B, D, G). The local exposures of the SSRS are structurally tilted $\sim 9^\circ$ north. This feature can be most clearly seen in geotrench profile looking west (Fig. 4G).

SSRS tephra analysis Glass from both SSRS Units 1 and 3 along with reanalysis of tephra samples shows that tuffs encasing the SSRS clearly belong to the series of chemically related pumiceous trachytic tuffs stratigraphically located near the top of the Bedded Tuff Member (Table 1; Fig. 5) and $^{40}\text{Ar}/^{39}\text{Ar}$ dated to 235 and 284 ka (Deino and McBrearty, 2002). These $^{40}\text{Ar}/^{39}\text{Ar}$ ages, as well as the U-series ages for faulting, postdating deposition of the Bedded Tuff Member (Dagley et al., 1978) provide a minimum age of 200 ka for the SSRS (Figs. 5, 6). This is a conservative age estimate. A more precise and slightly older date for the SSRS may be possible as pumiceous trachytic tuffs from the top of the Bedded Tuff Member have previously been dated as old as 284 ± 12 ka (Deino and McBrearty, 2002). Currently, $^{40}\text{Ar}/^{39}\text{Ar}$ dating of pumices from SSRS Units 1 and 3 is being undertaken for this purpose.

Excavation of the SSRS

Excavations in the tuffaceous silt SSRS Unit 1 cover a total area of 80 m² in two separate trenches east and west of the road (Fig. 7A). A single contiguous excavation could not connect these trenches due to the presence of the dirt road intersecting the drainage. A total of 2544 lithic artifacts were recovered in situ from SSRS Unit 1 including 1479 individually piece plotted lithic artifacts. Tables 2, 3 and 4 list all general assemblage attribute data for excavated lithic material. Vertical distribution of all piece-plotted material is close to two meters (1.84 m; 1.15 - 2.99 m below datum) over the entire site, although artifact depths gradually increased (relative to the datum) toward the western edge of the site (Fig. 7B). The main trench east of the road covered 66 m², and was excavated to an average depth of ~70 cm below surface. This trench preserves abundant lithic and faunal materials (Fig. 7). In this trench, elongate artifacts and fossils show no preferred orientation (Fig. 7C and caption). The small trench west of the road preserves mostly bones in a small ~0.50 m wide by > 6 m long channel feature. Most pieces plotted with two points were weakly aligned parallel to flow through the channel or perpendicular to it (Fig. 7D and caption).

Analysis of SSRS artifacts

Taphonomic context of SSRS lithic archaeological material The fine-grained tuffaceous silty matrix in which in situ artifacts and bones are preserved at the SSRS indicates a low-energy depositional environment. Stone artifacts occur in discrete patches at the site with large and small cores and flakes of the same raw material found in discrete clusters (Figs.

4C, 7A). The west and the main trenches, separated by the road, sample the same land surface, gently sloping toward a linear depression or small channel feature occupying a topographic low in the western trench (Figs. 7A, B). This is supported by the lower average depth below datum of piece-plotted material in the west trench versus the main trench (Fig. 7B) as well as the weak alignment of bones and lithic artifacts with the original flow of the channel (Fig. 7D and caption). In the SSRS main trench, east of the road, artifacts occur at slightly higher elevations relative to the datum (Fig. 7B) and have no preferred orientation (Fig. 7C and caption). Size class analysis of all flaked stone artifacts shows that 72.4 % of all artifacts are ≤ 2 cm in maximum dimension. This pattern holds for each of the four identified categories of raw material (see below; Table 5, Fig. 8). When compared to experimental evidence, these numbers suggest on-site knapping preserved in undisturbed, primary context (Schick, 1986). The SSRS thus likely documents deposition of material on a single land surface over a short period of time.

Raw material categories at the SSRS Four different, macroscopically distinguishable general categories of raw material are present: 1) a light colored lava consisting of a fine-grained light-brown groundmass with a banded appearance that is macroscopically indistinguishable from Tryon's (2003) raw material type 3 phonolite, 2) a dark lava resembling the Lake Baringo Trachyte in hand sample (Type 6 in Tryon, 2003), 3) a yellow welded tuff and 4) obsidian (Fig. 9). These four categories of raw material include both locally available and exotic raw materials. The light and dark lavas are found as variously-sized cobbles in the conglomerates of the Kapthurin Formation and modern riverbeds west of Lake Baringo (Fig. 2; Tryon, 2003). The yellow welded tuff is a

common and abundant raw material in the north of the Kapthurin Formation from Rorop Lingop to at least ~15 km north of Loruk (Fig. 2). These three materials derive from older extrusive volcanic flows of the Tugen Hills (Chapman, 1971; Chapman and Brook, 1978) and constitute the locally available (< 5 km distance from source to site) tool stones used at the SSRS (56.57% by individual pieces, 94% by weight= 7678.45 g; Tables 2–4; Fig. 9). Obsidian forms a significant portion (43.43% by individual pieces and 6 % by weight= 471.39g; Tables 2–4; Fig. 9) of the SSRS assemblage and is not local to the Tugen Hills west of modern Lake Baringo (see below). These four macroscopically distinguishable raw material categories are found in discrete patches of knapped stones (Fig. 7A) and have produced refitting sets with flake fragments conjoining, multiple flakes refitting to one another and/or to a single core or multiple core fragments refitting to one another.

Lithic Technology of the SSRS Twenty-two triangular pointed pieces including 12 Levallois points representing all three locally available raw materials were recovered from the excavations (Table 2; Fig. 10). Nineteen cores and two core fragments were also recovered in situ. One additional core was recovered from the surface. Seven cores are made on the light lava, eight cores are made on the dark lava, three cores are made on the yellow welded tuff and three cores are made on obsidian (Table 4; Fig. 11-13). Two core fragments are made on dark lava. Six of the cores are technologically Levallois cores of various types including four preferential flake cores and two recurrent centripetal Levallois cores (Fig. 11-13). One of these obsidian cores is a preferential Levallois core and another is a discoid core, rectangular in plan view (Figs. 12C, 13C). The Levallois

preferential flake method of flake production was applied to all of the four major categories of raw material used on the site. However, despite the presence of Levallois cores made on obsidian, there are no Levallois points made on obsidian at the site.

Refitting Two recurrent centripetal cores made on light lava have refitting flakes (Fig. 13). One of these shows five refitting centripetal removals from a single debitage surface (Fig. 13A). The single obsidian Levallois preferential-flake core at the site could be refitted with three successive preparation flakes on the right edge of the core's debitage surface (Fig. 13C). Additionally, seven pieces of yellow welded tuff from adjacent squares refit together. This large refitting set, as well as the relatively small number of total pieces of yellow welded tuff recovered on-site (13 whole flakes, 42 total pieces Table 2), suggests much of this material derives from the same large cobble. Multiple refitting sets of artifacts (Fig. 13) from the main trench on the east side of the site (Fig. 7A) support the argument that lithic artifacts at the SSRS represent relatively undisturbed products of a single occupation.

Geochemical analysis and obsidian sourcing

Three compositionally distinct obsidians were identified at the SSRS by EPMA (230 analyses on 36 samples; see Table 6). These samples have categorically different normalized total-alkali silica (TAS) chemical compositions (Fig. 14A; Le Bas et al., 1986). The SSRS obsidian type #1 is a phonolite, SSRS obsidian type #2 is a rhyolite and SSRS obsidian type #3 is a trachyte (Fig. 14A). The SSRS obsidians can be further differentiated to source by the composition of their major element oxides and correlation

with source data (Brown et al., 2013). The SSRS obsidian type #1 phonolite is from the closest obsidian source to the SSRS, the volcano Karau on the east side of Lake Baringo (Supplementary Online Material [SOM] Table S1). This source is a ~25 km straight-line distance from SRSS (Fig. 14D), but would have been farther if the lake was present and hominins had to walk around it (Merrick et al., 1994). At the SSRS this obsidian is macroscopically distinct from others. Surfaces of the SSRS obsidian type #1 phonolite exhibit a matte black patina on old flaking surfaces (Figs. 12A, B). The unflaked, cortical surfaces have a rough weathered and oxidized texture (Fig. 12A). Two cores (samples NTB2015-380, 381; Fig. 12A, B) and a single size class 4 flake (sample NTB2015-583) from unit N08E02 (Fig. 7A) are of this composition. Of the chemically analyzed obsidian samples, only pieces exhibiting the matte patina on their flaked surfaces have a phonolitic composition, and all of these correlate with the phonolite of Karau.

The SSRS obsidian type #2 rhyolite matches several samples from Eburru, Ilkek (Brown et al., 2013), a source located ~140 km south of the SSRS in the region just north of Lake Naivasha (SOM Table S1; Figs. 14B, C, D). Only a single flake fragment recovered from the west trench of the SSRS in square N14W19 (Fig. 7A) matched this rhyolitic composition. None of the SSRS obsidian cores matches the chemistry of this source.

The SSRS obsidian type #3 trachyte matches the composition of the source Olagirasha east of Nopneydo Hill (sample MER 59) collected from erosional exposures along moderately steep valleys outside the Gregory Rift on the western side of the Mau escarpment (Brown et al., 2013). Olagirasha obsidians are found among volcanic ashes

and poorly consolidated coarse pumiceous tuffs collectively referred to as the Mau ashes. The fresh cortex reported for obsidians at the Olagirasha source indicates these have not been transported far from their vent source. The nodule size of obsidians at the Olagirasha source is reported as small, and the flaking quality of Olagirasha obsidians is reported as very good to excellent (Brown et al., 2013: supplementary notes). The site to source distance from Olagirasha to the SSRS is ≥ 166 km and at least a ~ 1000 m climb in elevation over the topography of the western shoulder of the Gregory Rift (Fig. 14b, c, d; Brown et al., 2013). The majority of obsidian material sampled from the SSRS (118 analyses from 24 samples) match this source including multiple samples from each of the three obsidian patches in the main trench of the SSRS and all of the sampled debitage dispersed throughout the main trench of the site (Fig. 7A, B). One single preferential flake Levallois core (Fig. 12C) and two preparation flake refits from its debitage surface (Fig. 13C) are of SSRS type #3, indicating that this obsidian was imported in raw material form, partially decortified, prepared, flaked and discarded at the SSRS (Pollard et al., 2014).

Because of the macroscopically distinguishing characteristics of the Karau obsidian as well as the preponderance of pieces chemically sourced to Olagirasha, the vast majority of obsidian at the SSRS, including a small Levallois core (sample= NTB2014-382) derives from Olagirasha. Subtracting the four individual pieces at the SSRS shown to be from sources other than Olagirasha (2 cores + 2 flakes= 356.96g) the SSRS total lithic assemblage is constituted of 43% Olagirasha obsidian by individual pieces and 4.4% Olagirasha obsidian by weight. The obsidian component of the SSRS lithic assemblage is

thus composed of 99.5% Olagirasha obsidian by individual pieces and 75.7% Olagirasha obsidian by weight.

Discussion

Sibilo School Road Site obsidian transport

The SSRS obsidian data differ significantly from previously documented Early and Middle Pleistocene ESA and MSA contexts. The amount of obsidian at the SSRS and transport distances of ≥ 166 km are currently only comparable to well-dated MSA assemblages from Late Pleistocene eastern Africa younger than ~ 50 ka (Ambrose, 2012; Merrick and Brown, 1984; Merrick et al., 1994; Negash and Shackley, 2006; Negash et al., 2006). The large proportion of obsidian at the SSRS (43% by individual pieces; 6% by weight; Fig. 9) also differs from many sites documenting early (> 50 ka) evidence of long-distance obsidian transport, such as Muguruk, Songhor, Karungu, Prospect Farm, Mumba and Nasera, in which obsidian is an extremely small part of the whole lithic assemblage (Faith et al., 2015; McBrearty, 1986; Mehlman, 1977; Merrick and Brown, 1984; Merrick et al., 1994). The SSRS obsidian is instead most similar in transport distance and assemblage proportions to the MSA levels at the sites of Lukenya Hill (GvJm-16) and Prolonged Drift. The MSA levels of these sites are certainly Late Pleistocene and probably date to < 50 ka (Merrick, 1975; Tryon et al., 2015). They are thus ~ 150 kyr younger than the SSRS.

The earliest evidence of increased hominin intergroup interactions at the Sibilo School Road Site

Mobility or intergroup interactions? A common question asked in obsidian sourcing studies of the Pleistocene is whether long-distance transport in the archaeological record represents ecological evidence of hominin mobility and use of the landscape, or evidence of social developments in the form of intergroup exchange (Ambrose, 2001, 2012; Merrick et al., 1994). In the East African literature, data on long-distance obsidian transport has been used to support both these positions. The maximum home range foraging zone for Pleistocene hunter-gatherers defined by Gamble (1993) and Gould and Saggers (1985) is a ~40 km radius, but perhaps there are reasons to suspect this distance should be even smaller for African equatorial hunter-gathers (Ambrose, 2012; McBrearty and Brooks, 2000). Merrick et al. (1994) grant the possibility of 100 to 130 km site to source obsidian transport distances as the products of very mobile hunter-gatherer groups in the Late Pleistocene at Lukenya Hill. However, not a single study of Pleistocene eastern African raw material transport argues for direct procurement of raw materials at distances of ≥ 166 km as seen at the SSRS. If the SSRS obsidians are argued to be evidence of high mobility, they would likely represent embedded procurement of a very mobile hunter-gatherer group curating raw materials over days or weeks as they move about the landscape (Binford, 1979; Gould and Saggers, 1985). Just as much credence is given to intergroup exchange in the existing eastern African obsidian sourcing literature. Merrick et al. (1994) state that 100 to 130 km obsidian transport distances at Lukenya Hill GvJm-16 are as likely to represent intergroup exchange as mobility. In the late MSA levels of Prolonged Drift 90% of the obsidian is from 45-50 km away, just beyond the ~40 km maximum supply zone radius (Merrick et al., 1994). Here, where the farthest

source is the most abundant, Ambrose (2012: 65) suggests “intensive, perhaps even obligate intergroup exchange rather than down-the-line-exchange,” based on an inverse distance decay curve. If this logic is correct then the SSRS fits the standard of proof for intensive or obligate intergroup exchange in the Middle Pleistocene, ~170 kyr earlier than previously documented at Prolonged Drift. Conversely, McBrearty and Brooks (2000: 515) suggest an alternate explanation for Late Pleistocene long-distance obsidian transport patterns such as those seen at Prolonged Drift. In this scenario, MSA hominin groups controlled access to territories (including obsidian sources) and prevented collection in these areas by other groups. The result of this is an archaeological signature in which serviceable obsidians from more proximate sources are passed up in favor of obsidians from more distant sources. For the South African Late Pleistocene MSA record, Ambrose and Lorenz (1990) argue the relatively high proportions (~30%) of fine grained, non-local silcretes and quartz in MSA Howieson’s Poort layers are evidence of both increased mobility and increased intergroup interaction.

These alternative and complimentary interpretations for long-distance raw material transport in the MSA illustrate an important common theme underlying Pleistocene raw material sourcing studies. Whether long-distance raw material transport represents increases in mobility, intergroup exchange or some combination of the above is largely beside the point. Any patterns of increased raw material transport distances would yield some substantial increase in hominin interactions with a wider array of environments and resources as well as with other hominin groups. Increases in hominin group interactions, be these collaborative or contentious, would inevitably impose new and important social,

technological, and biological pressures on hominin populations as they interacted over greater social and geographical spheres. This is something not documented in Acheulean contexts of the Early or Middle Pleistocene or previously recognized in the MSA of the Middle Pleistocene.

The SSRS shows prior conclusions drawn about increased hominin intergroup interactions and/ or ecological responses from long-distance raw material transport in the Late Pleistocene MSA may logically be applied to later Middle Pleistocene hominins ~200 ka. Ambrose and Lorenz (1990: 27) state that increases in raw material transport distances in the Howieson's Poort ~60 ka, "marks the first time in human history when there was a significant change in human territorial organization". Of the Howieson's Poort evidence Ambrose (2006: 366), further states, "the difference in lithic source use reflected fundamental changes in behavior in response to environmental changes that were unlike any seen in response to similar environmental changes over the previous eight glacial-interglacial cycles of the last million years". The SSRS does not directly contradict any previous social or ecological assertions of the importance of long-distance obsidian transport, nor does it necessarily contradict the trends of increasing use and longer transport distances of raw materials observed through time in Africa. Interpretation of the SSRS obsidian data do, however, strongly suggest that the important interpretations of these previous studies, including expansion of home ranges and social networks, logically be revised earlier in time to ~200 ka, the period in which *H. sapiens* first appears.

It could be argued that the SSRS represents a single aberrant data point not indicative of larger trends in hominin behavior. If the sample size of well-dated Middle Pleistocene MSA sites in East Africa were larger and more representative this argument would warrant more consideration. However, the sample size of Middle Pleistocene East African MSA sites currently remains extremely limited. The SSRS represents one of only six or seven such sites (Fig. 1A). At least one of these Middle Pleistocene MSA sites, Gademotta GDM7, is on top of an obsidian raw material quarry, which, for the purposes of raw material sourcing, would likely produce a local signature (Sahle et al., 2014). Thus, while only a single site, the behaviors documented at the SSRS are likely to represent a more common, and until now undiscovered, aspect of hominin behavior in the later Middle Pleistocene. Such behaviors have previously gone unnoticed or underappreciated simply because of the paucity of well-dated later Middle Pleistocene sites. I predict that more and older sites showing evidence of long distance obsidian transport and other important features of hominin behavior will be discovered by excavation of new sites as well as chronological refinement of existing ones.

Taken together, the diverse MSA technologies and long obsidian transport distances shown at the SSRS and the limited sample of East African Middle Pleistocene MSA archaeological sites reviewed here suggests that by ~200 ka hominins were significantly modifying their behavior, including their technologies and spheres of interaction, to suit a wider set of social, biological and/or environmental problems. This broad theme underlies many explanations of modern human behavior in the archaeology of Late Pleistocene MSA and LSA (Ambrose and Lorenz, 1990; McBrearty and Brooks, 2000).

The SSRS thus provides an important data point to a small but steadily increasing body of archaeological work in the later Middle Pleistocene of Africa demonstrating antiquity for several aspects of modern human behavior equaling or exceeding that of the first appearance of *H. sapiens*.

Conclusion

Excavations and artifact analyses at the ~200 ka SSRS from the Bedded Tuff Member of the Kapthurin Formation, Baringo provides new evidence of long- distance transport of obsidian in a well-dated later Middle Pleistocene MSA context. Tephrostratigraphic work at the site and in the Bedded Tuff Member provides a robust minimum age estimate of ~200 ka for the SSRS. Geochemical sourcing of SSRS obsidians show acquisition of these raw materials from at least three sources with the majority of obsidian deriving from the source at Olagirasha, 166 km south of the site and on the opposite (western) side of the Mau escarpment. Thus, despite the limited availability of later Middle Pleistocene MSA archaeological sites in East Africa, long-distance transport of high quality raw materials and the increases in hominin intergroup interactions that this behavior entails were important parts of the hominin behavioral repertoire in East Africa ~200 ka, at or before the time *H. sapiens* first appears in the region.

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Figure captions

Figure 1: A) Physical map of the eastern African Gregory Rift showing sites discussed. B) Physical map of Kenya showing Acheulean and Middle Stone Age sites discussed in this study.

Figure 2: A) Map of Baringo showing extent of Kapthurin Formation exposures as well as locations of archaeological sites in the Kapthurin Formation (longitude and latitude in WGS 84 decimal degrees). B) Schematic stratigraphic section of the Kapthurin Formation with chronometric dates.

Figure 3: A) Bivariate plot (after Tryon and McBrearty, 2006) for all Bedded Tuff Member glass analyses ($n = 272$) data from Tryon (2003) and showing a single compositionally evolving trend among basaltic and trachytic samples of common local volcanic origin. Inset B) All analyses of siliceous glass from $^{40}\text{Ar}/^{39}\text{Ar}$ dated samples at JLC and NRS (Tryon, 2003). Axes are inverted for both bivariate plots. C) Relative stratigraphic relationships of Bedded Tuff Member tuff groups, tuffs dated by the $^{40}\text{Ar}/^{39}\text{Ar}$ method and Kapthurin archaeological sites. Compositionally less evolved glass is found stratigraphically lower and compositionally more evolved basaltic through trachytic glass found stratigraphically higher.

Figure 4: A) The SSRS under excavation. This photo taken when standing at intersection of dirt road and drainage looking east. B) Coarse pumiceous tuff (SSRS Unit #3) capping

the local stratigraphic section of the site (~1.4m total station and tripod for scale). C) One of several dense concentrations of local lava artifacts in SSRS Unit #1 under excavation. D) Local SSRS schematic stratigraphic section. E) The main trench (east of the ~N-S dirt road visible in the top right) under excavation in January 2014 as viewed looking south from vantage of total station during excavation. F) Photograph of one of three dense concentrations of obsidian artifacts in SSRS Unit #1 under excavation. G) SSRS Unit #3 coarse pumiceous tuff dipping ~9° north as viewed looking west in SSRS geotrench. Scale for C, F, G = 10cm.

Figure 5: A) Bivariate plot (weight percent element oxides) showing all basaltic Bedded Tuff Member glass analyses (dark gray squares) from Tryon (2003) as well as new tephra analyses of SSRS Units #1 and #3 and reanalyses of JLC and NRS pumiceous trachytic newly reported in this study (light gray squares). New SSRS analyses clearly fit the compositional trendline of an evolving magma chamber showing they belong to the Bedded Tuff Member. B, C, D). Expanded bivariate plots of SSRS samples and a single KyS sample newly analyzed here (open icons in legend) with reanalysis of McB97-01 and McB97-02 $^{40}\text{Ar}/^{39}\text{Ar}$ dated to 235 and 284 ka (closed icons in legend). SSRS tephras are indistinguishable from chemical continuum with NRS and JLC samples. Purple 'X's are the Pumice Tuff $^{40}\text{Ar}/^{39}\text{Ar}$ dated to 543 ± 3 ka shown as a chemical 'out-group' for comparison. Note in all bivariate plots both axes are inverted. E) Relative stratigraphic relationships of Bedded Tuff Member tuff groups, tuffs dated by the $^{40}\text{Ar}/^{39}\text{Ar}$ method and Kapthurin archaeological sites at or immediately below the base of the Bedded Tuff Member.

Figure 6: A) Map of Baringo showing extent of Bedded Tuff Member exposures as well as locations of archaeological sites in the Kapthurin Formation. B) Schematic stratigraphic sections for relevant archaeological sites and $^{40}\text{Ar}/^{39}\text{Ar}$ dated units (in rectangular boxes) from the Bedded Tuff Member of the Kapthurin Formation. Tuffs of unique colors corresponding to chemically defined tephras or groups of tephras (after Tryon and McBrearty, 2002, 2006; Tryon, 2003). White area represents non-volcaniclastic sediments not used for correlation. C) Composite stratigraphy of the Bedded Tuff Member showing relative stratigraphic position of tuffs, archaeological sites and chronometric dates.

Figure 7: A) Plan map of SSRS excavation with piece-plotted lithic artifacts of local raw materials, obsidians, fossil bones/teeth, and natural rock color-coded by category. B) Cross sectional view (looking north) of the SSRS excavations with piece-plotted materials (as above) color coded (as above). C) Rose diagram of fossils and artifacts from the SSRS main trench, east of the road, with a long axis showing no preferred directional orientation of these pieces (Rayleigh's R : 0.08371, $\text{Chi}^2 = 52.99$, $p = 0.02616$, Rao's $U = 136$, $p = 0.2957$, Watson's $U_2 = 0.02701$, $p > 0.5$). D) Rose diagram of fossils and artifacts from SSRS west trench showing pieces with minor preferred directional orientation aligned with or perpendicular to northeast-southwest flow of this small channel feature (Rayleigh's $R = 0.05$, $p = 0.85$, $\text{Chi}^2 = 5.901$, $p = 0.1165$; Rao's $U = 144.4$, $p = 0.1444$; Watson's $U_2 = 0.06756$, $p = 0.025 < p < 0.05$).

Figure 8: Size class distributions of artifacts by raw material category.

Figure 9: Raw material categories by A) individual pieces as percentages of total piece count and B) weight (g) as percentages of total. Ylw = yellow.

Figure 10: Levallois points and pointed pieces recovered in situ from the excavations of the main trench. A-D) Levallois points made of the light lava raw material similar to Tryon #3 phonolite (Tryon, 2003). E-G) Levallois points made on dark lava raw material similar to the Lake Baringo Trachyte. H-I) Levallois points made on yellow welded tuff. J) Pointed blade made of obsidian (same lithic artifact concentration as sourced pieces of trachytic SSRS obsidian type #3). K) Obsidian blade made on SSRS obsidian type #3. L) Distal point fragment, dark lava. M) Two blades made on dark lava with technological refit. N) Blade on dark lava with distal tip broken. O) Curved blade (overshot?) on light lava. P) Curved blade (overshot?) on dark lava. Q) Blade on dark lava. All points (A-J and L) except 'J' exhibit tip damage. Four points (D, G, H, K) exhibit proximal-distal breaks. Conjoins of these were found during analysis ('C' is a fresh break during excavation).

Figure 11: A) Levallois cores (preferential) made on yellow welded tuff recovered from the surface near the western edge of the main trench. B) Levallois core (preferential and overshoot) found in situ. C) Levallois point core made on dark lava (found in situ).

Figure 12: SSRS cores made on obsidian. A) Single platform core with two unidirectional removals, made on SSRS obsidian type #1, phonolitic composition, from Karau,

presumably abandoned because of large inclusion. B) Discoid core flaked all over on both surfaces. Covered in matte patina, and made on SSRS obsidian type #1 phonolite. C) Levallois preferential flake core with cortex on lower surface, made on SSRS obsidian type #3 trachytic composition.

Figure 13: SSRS core exhibiting refits. A) A recurrent centripetal core (N08E02-4) on light lava with sequential pictures of five refitting flake removals from the same recurrent centripetal debitage surface (arrows point in direction of sequential removals). B) Recurrent centripetal Levallois core (N08E02-12) on light lava with two refitting preparation flakes. C) A preferential Levallois flake core (N09E02-20) on obsidian type #3, trachytic composition, (also pictured in Fig. 11C).with three refitting pieces constituting two preparatory flakes from the right margin of debitage surface (arrows point in direction of sequential removals).

Figure 14: A) Total alkali silica graph (after Le Bas et al., 1986) showing three SSRS obsidian composition categories. B) Cl versus TiO_2 bivariate plot showing difference between SSRS obsidian compositions and similarities between SSRS obsidian types #1, #2 and #3 with their geological sources at Karau and Eburru, Ilkek and Olagirasha respectively. C) Al_2O_3 versus FeO bivariate plot showing difference between SSRS obsidian compositions and similarities between SSRS obsidians #1, #2 and #3 with their geological sources at Karau and Eburru, Ilkek and Olagirasha respectively. (For figure 14 B and C Eburru, Ilkek and Olagirasha source means published in Brown et al., 2013 and their supplementary information; individual analyses donated by F.H. Brown.) D) Map of

central Kenyan rift showing some prominent volcanoes and obsidian sources (after Brown et al., 2013) as well as the SSRS and distances from this site to correlated sources of chemically characterized obsidian artifacts on the site.

Table 1: Mean major and minor element oxides by weight percent ^a.

Samples	No.	SiO ₂	TiO ₂	ZrO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	F	Cl	Sum	less O	Sum	H ₂ O	Total
JLC Pumices 235 ± 2 ka																		
McB97-01	30	61.82	0.32	0.06	15.33	4.25	0.15	0.09	1.08	4.94	5.03	0.25	0.14	93.48	0.14	93.34	5.47	98.81
		0.75	0.06	0.05	0.50	0.61	0.04	0.02	0.10	1.17	0.17	0.07	0.03	0.95	0.03	0.97	1.02	0.82
KyS Pumices																		
NTB2010-1	16	57.03	0.95	0.04	16.19	7.28	0.21	1.06	3.24	5.15	3.20	0.18	0.12	94.65	0.10	94.55	3.86	98.41
		1.37	0.15	0.05	0.51	0.65	0.03	0.13	0.29	0.83	0.12	0.04	0.01	1.84	0.02	1.85	1.37	0.74
NtB2010-1.1	15	56.39	0.94	0.02	16.03	7.19	0.22	1.12	3.40	5.79	3.31	0.27	0.13	94.82	0.14	94.67	4.56	99.23
		1.27	0.05	0.03	0.38	0.23	0.03	0.06	0.14	0.31	0.12	0.14	0.02	2.25	0.06	2.24	1.17	1.47
SSRS Unit 1 Tuff																		
NTB2014-308	8	58.64	0.91	0.10	15.80	7.41	0.21	1.06	3.19	4.73	3.19	0.27	0.11	95.63	0.14	95.49	5.28	100.77
		0.50	0.14	0.08	2.23	1.06	0.03	0.14	0.41	0.77	0.49	0.12	0.02	3.00	0.05	2.99	1.48	1.76
SSRS Unit 3 Tuff																		
NTB2011-1	32	60.09	0.95	0.04	16.19	7.28	0.21	1.06	3.24	5.15	3.20	0.18	0.12	94.65	0.10	94.55	3.86	98.41
		3.07	0.56	0.05	0.61	2.20	0.05	0.75	1.33	0.31	0.86	0.05	0.05	1.66	0.02	1.67	1.89	0.53
NRS Tuff 284 ± 12 ka																		
McB97-02	29	61.57	0.39	0.06	14.77	4.34	0.13	0.22	1.12	4.89	4.37	0.34	0.18	92.37	0.18	92.19	7.59	99.78
		1.84	0.17	0.04	0.27	0.98	0.04	0.16	0.40	0.62	0.38	0.05	0.04	2.09	0.02	2.08	0.81	1.68
CAT97-74	32	61.38	0.53	0.04	15.19	5.22	0.18	0.39	1.65	5.58	4.30	0.37	0.15	94.97	0.19	94.78	7.10	101.88
		1.94	0.18	0.04	0.28	0.95	0.03	0.20	0.53	0.46	0.47	0.04	0.04	0.80	0.02	0.80	0.62	0.51
Pumice Tuff 543 ± 3 ka																		
CAT97-11a	20	58.76	0.64	0.05	12.94	9.34	0.40	0.11	1.34	2.37	3.90	0.58	0.19	90.61	0.29	90.32	9.08	99.40
		0.38	0.04	0.04	0.11	0.12	0.02	0.01	0.02	1.44	0.61	0.03	0.01	2.05	0.01	2.06	1.49	0.69

^a Sample listed on left (No. = number of analyses). One standard deviation from the mean listed below each element oxide mean. Voltage = 15 keV, beam current = 25 nA, spot size = 10 µm

Table 2: Summary of assemblage composition for SSRS lithic artifacts.

	<i>n</i> (subtotal)	% without debris	light lava	dark lava	yellow welded tuff	obsidian
<i>Cores</i>	23	2.39	7	10	3	3
Casual	8	0.83	1	5	1	1
Multiplatform	3	0.31	1	1	1	
Levallois preferential	3	0.31		1	1	1
Levallois point	1	0.10		1		
Levallois recurrent	3	0.31	2			1
Blade	2	0.21	2			
Core on flake	1	0.10	1			
Core fragment	2	0.21		2		
<i>Flakes</i>	407	42.35	173	157	13	64
Whole flakes	389	40.48	160	154	11	64
Levallois flake	6	0.62	5	1		
Levallois point	12	1.25	8	2	2	
% Cortical flakes			10.98	11.47	30.77	12.5
<i>Flake Fragments</i>	523	54.42	134	228	21	140
Flake fragment proximal	184	19.15	54	78	10	42
Flake fragment other	339	35.28	80	150	11	98
% Cortical flake fragments			2.99	6.58	4.76	1.43
<i>Debris</i>	1583	0.00	247	460	20	856
<i>Tools</i>	8	0.83				
side scraper	4	0.42	3	1		
end scraper	2	0.21	1	1		
chopper	1	0.10	1			
biface	1	0.10		1		
<i>TOTAL</i>	2544	100.00	561	855	57	1063
<i>n without debirs</i>	961					

Table 3: Statistics for SSRS debitage and debris sorted by raw material.

Raw Material type	Whole flakes	Mean flake length (mm)	Mean flake width (mm)	Mean flake thickness (mm)	Mean flake platform width (mm)	Mean flake platform thickness (mm)	Flake frags	Debris	Total number debitage & debris	Total weight debitage & debris (g)	Total weight (g)
Light lava	173	32.62	27.47	8.77	17.8	6.8	134	247	554	1810.74	2223.53
± 1 SD		18.33	14.84	5.67	12.04	4.4					
Dark lava	157	35.65	32.41	10.51	22.49	9.16	228	460	845	3521.92	4590.32
± 1 SD		21.75	18.18	6.11	13.17	110.93					
Yellow welded tuff	13	52.1	37.98	15.26	28.76	12.31	21	20	54	820.5	864.6
± 1 SD		21.23	14.16	6.14	10.92	5.08					
Obsidian	64	15.88	15.85	4.84	11.63	3.98	140	856	1060	351.32	471.39
± 1 SD		7.01	7.73	2.67	7.02	2.34					
TOTAL	407						523	1583	2513		8149.84

Table 4: Statistics for SSRS cores by raw material.

Cores	<i>n</i>	Mean length (mm), ± 1 SD	Mean width (mm), ± 1 SD	Mean thickness (mm), ± 1 SD	Total weight (g)
Light lava	7	47.68	38.53	31.5	412.79
± 1 SD		7.14	6.51	14.79	
Dark lava	8	62.74	57.1	38.02	1068.4
± 1 SD		29.38	14.73	11.95	
yellow welded tuff	3	72.14	91.66	44.1	514.52
± 1 SD		22.43	33.01	2.69	
obsidian	3	43.58	40.47	20.24	120.07
± 1 SD		15.04	11.58	4.9	
Total	21				6362.56

Table 5: SSRS lithic artifact size classes listed by macroscopically identified raw material. ^a

Raw Material	SC 1	%	SC 2	%	SC 3	%	SC 4	%	SC 5	%	SC 6	%	SC 7	%	SC 8	%	SC 9	%	SC 10+	%
All	811	0.32	1010	0.40	310	0.12	159	0.06	92	0.04	49	0.02	23	0.01	21	0.01	6	0.00	11	0.00
Light basalt	65	0.12	237	0.45	95	0.18	66	0.13	36	0.07	12	0.02	5	0.01	6	0.01	1	0.00	3	0.01
Dark basalt	116	0.14	381	0.45	154	0.18	75	0.09	51	0.06	32	0.04	16	0.02	12	0.01	4	0.00	7	0.01
Obsidian	624	0.59	369	0.35	54	0.05	13	0.01	0	0.00	2	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Yellow welded tuff	3	0.07	16	0.36	6	0.14	4	0.09	5	0.11	3	0.07	2	0.05	3	0.07	1	0.02	1	0.02

^a SC= size class.

Table 6: Individual obsidian artifacts analyzed for sourcing. ^a

SSRS Obsidian Samples	No.	SiO ₂	TiO ₂	ZrO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	F	Cl	Sum
SSRS type #1														
NTB2014-348tuff Karau	source	58.70	0.61	0.12	16.46	7.42	0.38	0.36	1.11	7.33	5.40	0.50	0.24	98.63
	15	0.82	0.06	0.03	0.57	0.29	0.04	0.02	0.04	3.38	0.55	0.06	0.02	4.46
NTB2014-351tuff Karau	source	57.31	0.55	0.10	15.80	7.06	0.34	0.35	1.05	1.89	5.38	0.44	0.24	90.50
	12	2.44	0.06	0.04	0.65	0.26	0.04	0.01	0.12	3.15	0.67	0.06	0.06	5.64
NTB2014-354 Karau	source	59.66	0.57	0.11	15.57	7.77	0.31	0.30	1.17	7.14	4.68	0.45	0.24	97.98
	19	0.75	0.12	0.03	0.28	0.54	0.03	0.03	0.07	1.42	0.16	0.04	0.02	2.50
NTB2014-348obs Karau	source	59.99	0.61	0.11	16.91	7.74	0.40	0.38	1.10	9.39	5.14	0.52	0.23	102.52
	5	0.17	0.06	0.04	0.10	0.04	0.03	0.02	0.04	0.23	0.07	0.01	0.02	0.36
NTB2014-380 N09E07-1 core	artifact	57.11	0.60	0.12	15.66	7.23	0.38	0.34	1.09	9.71	5.26	0.56	0.24	98.31
	6	0.24	0.08	0.04	0.07	0.24	0.02	0.01	0.03	0.34	0.10	0.02	0.01	0.49
NTB2014-381 N12E01-1 core	artifact	57.57	0.61	0.11	15.87	7.22	0.36	0.34	1.09	9.09	5.31	0.60	0.24	98.42
	6	0.30	0.04	0.02	0.15	0.20	0.02	0.01	0.04	0.46	0.08	0.03	0.01	0.64
NTB2015-583 N08E02	artifact	58.08	0.62	0.13	15.41	7.49	0.38	0.65	1.07	9.67	5.43	0.36	0.20	101.79
	5	0.93	0.03	0.02	0.20	0.12	0.01	0.04	0.02	0.20	0.04	0.05	0.02	0.78
SSRS type #2														
MER 70 Eburru, Ilkek	source	71.24	0.34	0.41	8.33	7.93	0.23	0.01	0.30	6.42	4.62	0.76	0.42	101.00
	5	0.19	0.03	0.05	0.03	0.07	0.03	0.01	0.02	0.12	0.07	0.02	0.02	0.28
K80-403 Eburru, Ilkek	source	70.69	0.27	0.49	8.25	7.70	0.23	0.01	0.25	6.68	4.57	0.76	0.41	100.30
	5	0.13	0.05	0.03	0.09	0.08	0.04	0.01	0.01	0.20	0.07	0.04	0.02	0.36
MER 71 Eburru, Ilkek	source	71.26	0.30	0.45	8.39	7.70	0.21	0.01	0.30	6.27	4.60	0.78	0.40	100.66
	5	0.23	0.03	0.06	0.07	0.12	0.02	0.01	0.01	0.05	0.07	0.03	0.03	0.32
NTB2014-313 N14W19	artifact	72.64	0.30	0.38	8.20	7.49	0.25	0.03	0.26	6.44	4.67	0.94	0.40	102.00
	7	0.35	0.04	0.02	1.13	0.09	0.03	0.03	0.02	0.14	0.09	0.13	0.01	1.22
SSRS type #3														
MER 59 Olagirasha	source	63.97	0.41	0.16	10.36	9.70	0.36	0.02	0.73	8.57	4.53	0.45	0.29	100.63
	4	0.40	0.05	0.03	0.08	0.16	0.05	0.01	0.02	0.11	0.07	0.03	0.02	0.69
NTB2013-314 N08E05	artifact	66.24	0.43	0.20	10.33	9.82	0.38	0.05	0.74	8.23	4.40	0.66	0.29	101.77
	7	0.56	0.06	0.09	1.48	0.10	0.03	0.01	0.02	1.66	0.15	0.11	0.01	2.42
NTB2013-315 N08E05	artifact	66.58	0.43	0.19	10.95	9.78	0.38	0.05	0.74	8.47	4.39	0.63	0.27	102.87
	8	0.13	0.06	0.04	0.06	0.10	0.04	0.01	0.02	0.33	0.08	0.10	0.01	0.43
NTB2013-316 N11E03	artifact	66.62	0.40	0.16	10.78	9.78	0.37	0.05	0.71	8.89	4.37	0.62	0.27	103.03
	7	0.24	0.05	0.06	0.79	0.10	0.02	0.01	0.03	0.44	0.09	0.08	0.01	0.78
NTB2014-379 N15W16	artifact	63.88	0.44	0.16	10.30	9.46	0.36	0.04	0.76	8.59	4.42	0.63	0.33	99.37
	5	0.11	0.04	0.03	0.29	0.26	0.02	0.01	0.02	0.29	0.05	0.06	0.02	0.48
NTB2014-382 N09E02-20 core	artifact	63.08	0.39	0.17	10.00	9.58	0.40	0.04	0.76	8.69	4.39	0.64	0.33	98.47
	6	0.87	0.05	0.04	0.19	0.15	0.02	0.02	0.05	0.52	0.09	0.05	0.01	0.96
NTB2015-565 N11W02	artifact	63.44	0.42	0.19	9.74	10.54	0.41	0.05	0.73	8.72	4.58	0.56	0.31	99.70
	5	0.11	0.04	0.03	0.17	0.25	0.02	0.01	0.02	0.26	0.11	0.06	0.00	0.34

NTB2015-566	artifact	63.96	0.43	0.21	10.15	10.89	0.40	0.04	0.74	8.78	4.62	0.45	0.28	100.94
N13E00	3	0.18	0.03	0.07	0.10	0.07	0.01	0.01	0.01	0.21	0.03	0.04	0.02	0.30
NTB2015-567	artifact	63.50	0.45	0.17	9.93	10.84	0.38	0.03	0.73	8.62	4.58	0.62	0.29	100.14
N13E01	5	0.42	0.02	0.03	0.18	0.06	0.02	0.01	0.03	0.29	0.05	0.03	0.02	0.31
NTB2015-568	artifact	65.99	0.45	0.18	10.17	11.04	0.36	0.03	0.74	8.71	4.56	0.50	0.30	103.03
N13E01	4	0.60	0.03	0.07	0.10	0.08	0.03	0.01	0.02	0.23	0.08	0.03	0.00	0.48
NTB2015-569	artifact	63.88	0.45	0.19	9.87	10.80	0.39	0.01	0.71	8.71	4.51	0.50	0.30	100.32
N13E01	3	0.70	0.03	0.06	0.03	0.06	0.02	0.01	0.02	0.12	0.09	0.04	0.02	0.80
NTB2015-570	artifact	64.75	0.44	0.18	10.00	10.93	0.37	0.01	0.74	8.61	4.50	0.50	0.30	101.34
N14E02	3	1.00	0.03	0.06	0.12	0.11	0.02	0.02	0.02	0.18	0.05	0.02	0.01	1.23
NTB2015-571	artifact	64.98	0.41	0.17	10.16	10.93	0.38	0.01	0.73	8.12	4.52	0.41	0.30	101.13
N13E01	4	0.66	0.02	0.04	0.28	0.11	0.02	0.01	0.01	0.38	0.11	0.04	0.01	0.64
NTB2015-572	artifact	62.68	0.44	0.18	9.84	10.80	0.37	0.01	0.75	8.72	4.53	0.51	0.28	99.10
N13E01	5	0.91	0.02	0.04	0.12	0.12	0.02	0.01	0.03	0.21	0.03	0.06	0.01	1.08
NTB2015-573	artifact	63.93	0.42	0.18	9.81	10.79	0.36	0.01	0.73	8.79	4.56	0.52	0.31	100.41
N13E02	5	0.32	0.03	0.05	0.20	0.07	0.03	0.01	0.02	0.14	0.03	0.03	0.02	0.46
NTB2015-574	artifact	64.38	0.47	0.18	9.70	10.90	0.38	0.00	0.73	8.70	4.56	0.49	0.30	100.78
N13E02	3	0.71	0.03	0.02	0.31	0.11	0.02	0.02	0.02	0.14	0.02	0.08	0.01	1.22
NTB2015-575	artifact	64.89	0.47	0.19	10.47	9.84	0.37	0.04	0.77	9.01	4.54	0.42	0.29	101.31
N13E02	7	0.34	0.03	0.05	0.07	0.19	0.02	0.02	0.07	0.18	0.11	0.14	0.02	0.60
NTB2015-576	artifact	64.82	0.44	0.19	10.47	9.85	0.38	0.05	0.73	8.89	4.36	0.49	0.29	100.95
N12E00	7	0.29	0.07	0.05	0.12	0.14	0.03	0.01	0.03	0.25	0.18	0.23	0.02	0.40
NTB2015-577	artifact	64.79	0.40	0.18	10.49	9.99	0.39	0.05	0.75	8.80	4.48	0.53	0.30	101.14
N11W02	7	0.14	0.05	0.06	0.06	0.15	0.02	0.01	0.01	0.24	0.13	0.11	0.01	0.31
NTB2015-578	artifact	64.78	0.48	0.20	10.46	10.05	0.38	0.04	0.77	9.08	4.49	0.62	0.31	101.66
N12E02	7	0.20	0.10	0.05	0.08	0.07	0.04	0.01	0.02	0.25	0.14	0.18	0.01	0.70
NTB2015-579	artifact	64.72	0.41	0.19	10.45	9.99	0.37	0.05	0.76	9.01	4.45	0.51	0.30	101.23
N12W01	7	0.25	0.09	0.02	0.11	0.06	0.02	0.02	0.09	0.37	0.15	0.22	0.01	0.40
NTB2015-580	artifact	65.00	0.45	0.18	10.51	9.97	0.39	0.04	0.73	8.88	4.50	0.55	0.29	101.49
N12W02	7	0.31	0.11	0.04	0.09	0.16	0.05	0.01	0.05	0.31	0.16	0.09	0.03	0.43
NTB2015-581	artifact	64.65	0.41	0.15	10.43	10.06	0.39	0.05	0.76	8.92	4.36	0.48	0.30	100.96
N13E01	7	0.19	0.05	0.05	0.05	0.09	0.02	0.01	0.03	0.26	0.12	0.17	0.02	0.38
NTB2015-582	artifact	64.72	0.47	0.18	10.42	9.88	0.37	0.04	0.74	8.92	4.47	0.54	0.30	101.06
N10W01	7	0.29	0.07	0.05	0.09	0.15	0.03	0.01	0.01	0.32	0.16	0.15	0.02	0.62
NTB2015-585	artifact	64.65	0.45	0.18	10.48	9.56	0.37	0.05	0.73	8.93	4.55	0.51	0.29	100.75
N09E06	7	0.25	0.08	0.07	0.07	0.14	0.03	0.01	0.02	0.32	0.06	0.25	0.01	0.41

^a Source samples in gray. Mean major and minor element oxides by weight percent. Sample listed on left (No . number of analyses). One standard deviation from the mean listed below each element oxide mean. Voltage = 15 keV, beam current = 25 nA, spot size = 10 µm.

Figure 1 East Africa DEM

Figure 2 Baringo Plan Map

Figure 3 K4 Magma Evo Scheme Strat

Figure 4 a-g SSRS photos

Figure 5 K4bslt SSRS trch

Figure 6 K4 and SSRS Scheme Strat

Figure 7 SSRS Piece Plots

Figure 8 SSRS lithic size class

Figure 9 SSRS raw mat pie chart

Figure 10 SSRS Lev points flakes

Figure 11 SSRS Lev cores

Figure 12 SSRS Obsidian cores

Figure 13 SSRS Refits

Figure 14 SSRS Obsidian sourcing