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# Oldowan behavior and raw material transport: perspectives from the Kanjera Formation

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ABSTRACT

The archaeological record of Oldowan hominins represents a diverse behavioral system. It has been suggested that exploitation of lithic resources by Oldowan hominins was simplistic and represented mostly use of local sources of stone. Here we investigate the raw material selection and transport behaviors of Oldowan hominins reflected in the stone artifact assemblages from the Kanjera South Formation, South Rachuonyo District, Kenya. Using geochemical methods (ED-XRF) artifacts are linked to primary and secondary source outcrops throughout southwestern Kenya. These data show that hominins selected raw materials for transport at frequencies that are significantly different from their availability on ancient landscapes. Furthermore, a substantial proportion of the assemblage represents transport over relatively long distances (>10 km). Our study further suggests that in the early stages of stone tool use hominins used a wide variety of raw materials and selected these materials at some distance from their eventual discard locations. Early hominin behavior may have incorporated an understanding of raw material source distributions across a more extensive landscape than has been previously documented. This supports the growing perspective that Oldowan technology represents a more complex behavioral pattern than is usually associated with the beginnings of hominin tool use.

## 1. Introduction

Studies of Oldowan hominin behavior have suggested that transport of resources was a major component of early stone tool use (de Heinzelin et al., 1999; Negash et al., 2005; Potts, 1984, 1991, 1994; Potts et al., 1999; Schick, 1987). The distribution of resources has been shown to affect material culture in modern hunter-gatherers (Binford, 1973; Binford, 1977, 1979; Shott, 1986) and in non-human primates (Boesch and Boesch, 1984; Sugiyama, 1993). Archaeologically, the distribution of raw materials impacts artifact composition and form (Bamforth, 1986, 1990; Dibble, 1995a,b; Kimura, 1999, 2002; Marks et al., 1991; Marks, 1988; Noll, 2000; Potts, 1994; Rogers et al., 1994; Roth and Dibble, 1998; Stiles, 1979, 1991, 1998). There is a continuous relationship between the level of raw material availability and assemblage composition even when technological attributes remain constant (Marks, 1988). The dynamics behind transfer of stone from source to site (Isaac, 1984) seems to be effected over relatively short distances (i.e. 1–5 km) in the Early Stone Age (Potts, 1994; Potts et al., 1999; Toth, 1982) and later technologies (Marks et al., 1991; Marks, 1988). Even within the same toolkit variation in technological behavior may appear to be represented by different raw materials based on their proximity and overall availability (Freeman, 1994; Geneste, 1988; Kuhn, 1991; Meignen, 1988; Tavoso, 1984).

Here we investigate the effect of raw material availability on Oldowan artifact assemblages from the Kanjera South Formation. The Kanjera South Formation is located in South Rachuonyo District, Kenya, and has been investigated since 1995 under the auspices of the Homa Peninsula Paleoanthropology Project (Behrensmeyer et al., 1995; Plummer et al., 1999; Plummer, 2004). Magnetostratigraphy and biostratigraphy have securely dated the site between 1.95 and 2.3 (Plummer, 2004).

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Artifacts and fossils were recovered in three beds, from oldest to youngest KS-1 to KS-3 (Behrensmeyer et al., 1995; Ditchfield et al., 1999). KS-1 has a lower part consisting of coarse grained agglomerate and upper layers consisting of interbedded sandy silts and fine sands with occasional pebbles and granule lenses. KS-2 has two components, a fine pebbly clay rich sand (KS-2 PS) and a thin, patchy conglomerate (KS-2 CP). KS-3 is a sandy silt that also has patchy conglomerate components (KS-3 CP). KS-1 deposition seems to have occurred under mudflat or floodplain conditions, while KS-2 and KS-3 represent fluvial deposits from intermittently flowing, braided streams at the edge of a lake. Stable land surfaces (as evidenced by weak to moderate paleosol formation) were present during depositional hiatuses and the predominant habitat type during deposition of the sequence appears to have been a wooded grassland (Plummer et al., 1999). Recurrent visitation of the site locales combined with relatively rapid sedimentation led to a thick (~1.5 m) sequence with archeological material. Assessment of site formation processes indicates that hominins accumulated artifact and faunal remains in the non-conglomerate levels (Plummer et al., 1999; Plummer, 2004). Excavations so far have recovered 4474 artifacts, making it one of the largest Oldowan assemblages known.

The high integrity of the site and the associated faunal remains make inferences derived from analyses of the archaeology of the Kanjera South Formation an important part of our understanding of early hominin behavior. This study focuses on the provenience of artifacts to investigate stone transport and raw material selectivity among early hominins. We investigate possible raw material selectivity by testing the difference between the frequencies of raw materials in the artifact collection with those raw materials available as conglomerates in various parts of the Winam Gulf. If Pliocene hominins only selected materials based on their local availability in the ancient landscape there should be a strong relationship between the frequency lithologies in local conglomerates and the archaeological collection. First, using geochemical methods we provide a link between artifacts and probable primary and secondary sources. These links suggest that nearly one third of the artifact collection at Kanjera South represents transport of raw materials over relatively long distances for this time period. Second, we suggest that transport selectivity reflected a more complex behavioral pattern of raw material use than previously documented for Oldowan hominins. Certain rock types appear at higher frequencies in the Kanjera South archaeological assemblage than would be expected based on their frequency in conglomerates that are separated by greater than 10 km from the site. Furthermore transport of certain raw materials to Kanjera South is limited to select lithologies. Oldowan hominin behavior at Kanjera South depended on stone artifacts to some degree as evidenced by the use of distant sources and the extensive energy thus probably invested in the transport of certain lithic materials to the Kanjera South locality. The relationships between transport decisions, raw material quality, and artifact manufacture techniques are described elsewhere (Braun, 2006).

## 2. Raw material sourcing

A concise understanding of the geospatial distribution of raw material availability is clearly necessary for a comprehensive artifact provenance study. Identification of raw material sources is a complex process that involves the integration of geochemical, geomorphological, sedimentological, and archaeological data (Church, 1996; Negash et al., 2005; Noll, 2000; Shackley, 1998). Shackley (1998) emphasizes the need to analytically separate primary and secondary sources of raw material. Visual inspections of raw material lithology can be very useful for determining archaeologically relevant lithological categories (Stout et al., 2005). However, several studies have suggested that hand sample identifications can misclassify sources within major raw material groups (Calogero, 1992; Lanier and Dodd, 1985; Moholy-Nagy and Nelson, 1990; Perry, 1992). Even across major raw material groups misidentifications are common in assemblages of fine grained rocks (Hermes et al., 2001). Hence, this study uses the combination of geochemical characterization with macroscopic identification as part of a large secondary and primary source sampling study to produce a model of toolstone availability on the southern side of the Winam Basin in western Kenya.

Although extensive sampling was conducted to determine the locations of primary and secondary sources of rock this study, like many raw material provenance projects, is largely probabilistic (Eerkens and Rosenthal, 2004; Shackley, 1998). Therefore, we can never say with absolute certainty the exact locations of raw material sources because of the multitude of problems associated with assigning an artifact to a specific primary source (i.e. intra-source variability (Shackley, 1998); secondary source transport (Church, 2000; Reid, 1997)). Furthermore identification to an exact primary source location is not a useful behavioral variable at Kanjera South because most artifacts are produced on river cobbles (Braun et al., in press). Documenting transport over a limited geographic scale to a particular primary source is therefore not pertinent for the Kanjera South Oldowan assemblage. Rather we intend to develop ecological models of hominin behavior that suggest general trends of artifact transport through space and time over larger areas of the ancient landscape.

Therefore, this study aims to create broad trends in the geographic distribution of certain raw materials. Inferences of the paleogeography of southwestern Kenya (Kent, 1942; Le Bas, 1977; Saggerson, 1952) allow the determination of broad landscape scale availability of certain raw material types, usually associated with the bed load of particular river systems that can be distinguished temporally and geographically.

## 3. Methodology

The great variety of raw materials incorporated into the technological repertoire of hominins at Kanjera South is affected by the extremely heterogeneous geology of southwestern Kenya. Raw material sourcing studies must incorporate a comprehensive understanding of the primary source geology so that variation within source can be understood. Furthermore, paleogeographical inferences are necessary in order predict the location of secondary sources in antiquity. This framework must accommodate variation specific to the archaeological sample, such as diagenetic modification (e.g. phenocrysts weathering, secondary mineral replacement) and behavioral selection (e.g. the fracture mechanics of fine grained stone is more predictable so hominins are more likely to select the finest grained variety of a rock source despite the diversity of grain sizes within a primary source). The archaeological and modern data sets, moreover, need to be integrated to allow behavioral interpretations of the influence of raw material variation on technological behavior.

Using this framework a study of raw material sources on the Homa Peninsula was conducted over five years in four phases, which are summarized in the next four sections.

### *3.1. Artifact hand sample identification*

Major rock types used by early hominins were identified through visual inspection of artifacts under low magnification. This first phase of work provided a baseline framework for raw material variation in the artifact collection.

### 3.2. Primary source identification

The variation in artifact lithology was used to inform initial investigations of primary source rock outcrops on and around the Homa Peninsula. Sample collections of rock types were collected during surveys from almost every primary source that had been previously mapped (Le Bas, 1977; Saggerson, 1952). A database of 232 separate rock outcrops and 513 separate primary source samples was developed. Outcrops were sampled multiple times to determine the geochemical variation in specific rock types. This extensive coverage allowed us to isolate outcrops that were used to make artifacts as well as those rock types that were not utilized by early hominins. Variation in major rock types was documented using destructive and non-destructive X-ray fluorescence (XRF) techniques.

### 3.3. Artifact geochemistry

Variation within the artifact sample was investigated using destructive and non-destructive techniques. Non-destructive techniques can accurately provide only semi-quantitative information about the trace element chemistry of artifacts. However, ratios of trace elements have proved very useful for accurately characterizing specific groups of raw materials (Latham et al., 1992). Previous analyses suggests that this technique is accurate for assessing provenance within a single data set (Plummer et al., 1994). Non-destructive data cannot be compared to elemental concentrations gathered from other studies. Yet a comparison of the relative concentrations of trace elements within the data set (i.e., from one sample to another) is possible. In this study the non-destructive technique was applied to 4346 artifacts. A small sub-sample of artifacts (1 artifact per major raw material group) was analyzed destructively to determine if the major element characterizations could be linked with a trace element signature in a way that represents meaningful lithological groups. Trace element signatures were used to link artifacts and primary sources.

### 3.4. Secondary source identification

The next phase of the study was to understand the relationship between primary (outcrop) source of stone and secondary sources (conglomerates). Several conglomerates were identified along the gully systems that intersect the southern shores of the Winam Gulf. These conglomerates were sampled and destructive XRF analyses were conducted to match these samples to primary source rock outcrops. This procedure provided a generalized picture of where rock types were available on past landscapes. Geological descriptions of the sedimentary context of deposits on the southern shores of the Winam basin suggest that the river systems are restricted by major structural aspects of the Winam Basin. Major river systems (such as the Awach River) appear to be controlled by major faults in the region (Kent, 1942; McCall, 1958; Saggerson, 1952).

## 4. Geochemical techniques

This study employed non-destructive and destructive forms of energy dispersive X-ray fluorescence (ED-XRF).

### 4.1. Non-destructive trace element analyses

Non-destructive ED-XRF analyses can accurately determine trace element composition in a wide array of sample types (e.g. silicate rocks, fossils) (Borkhodoev, 2002; D'Angelo et al., 2002; Hermes and Ritchie, 1997; Hermes et al., 2001; Latham et al., 1992; Plummer et al., 1994). Non-destructive ED-XRF analysis of fine grained rocks has been proven especially effective for the semi-quantitative assessment of artifact geochemistry (Hermes and Ritchie, 1997; Hermes et al., 2001). The non-destructive semi-quantitative dataset was applied to whole rock samples (artifacts, primary source blocks and secondary source cobbles). Semi-quantitative analyses provide data that is useful for comparisons within the dataset but are unlikely to provide enough accuracy for comparison across different instruments. In other words semi-quantitative data may lack some accuracy while precision of elemental values remains high. Weathering processes have a substantial affect on intra-source variation and was considered when analyzing elements with concentrations near detection limits, however these affects are ameliorated by the penetration of primary X-rays beyond the surface of whole rock samples (Davis et al., 1998). The non-destructive technique followed protocols outlined by Hermes and Ritchie (1997) to increase precision and accuracy. Whole rock samples were cleaned in an ultrasonic bath for 3 min to remove adhering matrix. Samples from archaeological assemblages were selected based on the absence of adhering sedimentary matrix under 10× hand lens inspection. Whole rock samples were exposed directly to the primary X-ray beam. Analyzed surfaces were selected so that only those surfaces with minimum relief were exposed to the primary X-ray beam (Hermes and Ritchie, 1997). For each sample three separate surfaces of each artifact were analyzed. This reduced the possibility of data being influenced by uneven concentrations of trace elements in phenocrysts or the matrix of the rocks (i.e. the "nugget" effect"; Dello-Russo, 2004).For whole rock samples spectra were acquired for 500 live count seconds. Analysis from these methods is limited to trace elements Rb, Zr, Sr, Y.

### 4.2. Destructive analyses

Samples for destructive ED-XRF analysis were pulverized to less than 50 μm, homogenized, and pressed into a pellet. This type of sample preparation allowed for rapid and precise determination of major, minor, a trace elemental composition (Saini et al., 2000). Prepared samples were analyzed for 500 lives seconds. Both destructive and non-destructive trace element analyses were conducted at the University of Nairobi, Institute of Nuclear Science ED-XRF facility. This facility uses a Cd-109 radioisotope source with a Si(Li) detector across a beryllium window. Spectra were collected using a Canberra multi-channel analyzer through a Canberra 2020 signal amplifier. Problems of overprint from overlapping $K_\alpha$ and $K_\beta$ peaks were resolved using Axil-QXAS software developed by the International Atomic Energy Association (IAEA). Major element chemistry was conducted on a Phillips MiniPal with an Rh X-Ray tube and a Si(Li) detector. Secondary filters of the primary X-rays were used to provide optimum sensitivity for particular elements. A Kapton filter was used for Si. An Al filter was used for K and Mn. A Mo filter was used for Fe. No filter was used for the analysis of Ca and Na. All spectra were captured for 500 live seconds and were repeated at least twice to ensure the precision of the results. Elemental concentrations were calculated using 12 USGS standards (W-2; BHVO-1; SCO-1; QLO-1; BIR-1; RGM-1; GSP-2; AGV-2; (Lemberge et al., 2000; Potts, 1987)). Known standard samples were run throughout all analyses to maintain the accuracy of the results.

### 4.3. Methodological results: comparison of destructive and non-destructive trace element analysis

Since we apply this technique to a variety of igneous and metamorphic rock types, it was necessary to determine if this type of analysis could produce consistent trace element signatures for a variety of rock types. Thirty-three samples of various rock

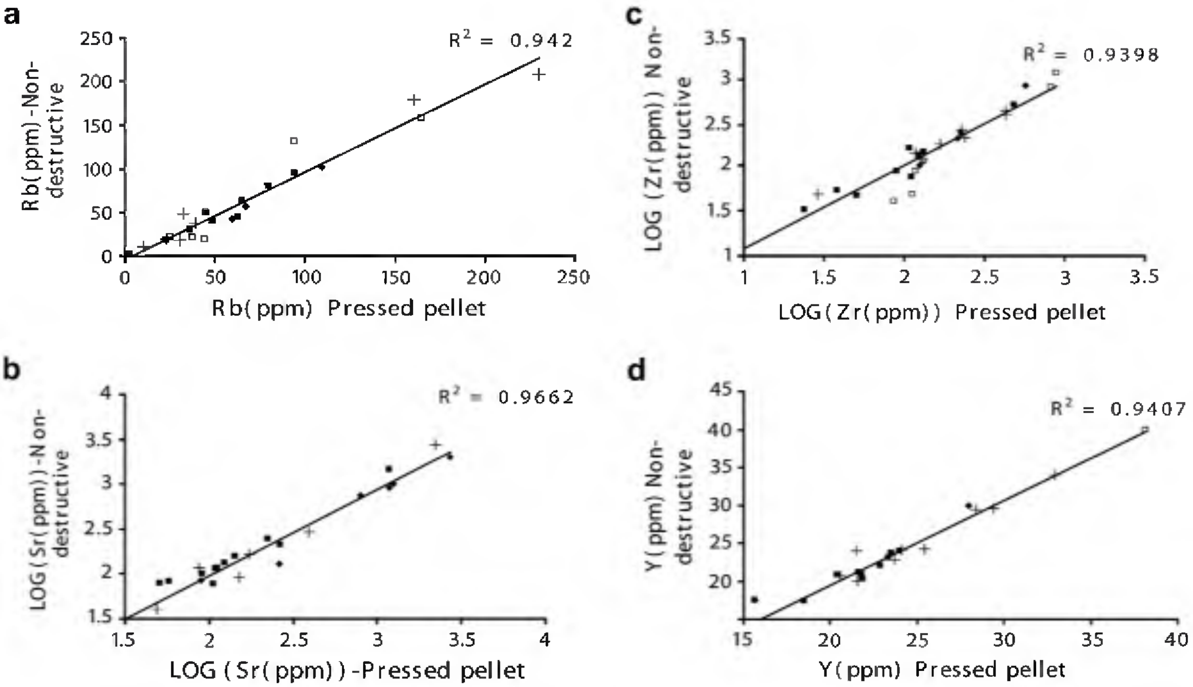

**Fig. 1.** Comparison of trace element analysis from non-destructive and destructive techniques on various rock types. Four trace elements are investigated: (a) rubidium; (b) strontium; (c) zirconium; (d) yttrium. Five different rock types are used in this analysis. Closed rectangles, basalt; closed diamonds, granite; open squares, quartzite; crosses, rhyolite.

types (basalt, granite, quartzite, rhyolite) from this study were analyzed using both the destructive and non-destructive techniques. Five trace elements were selected to determine the ability of the non-destructive technique (semi-quantitative) to produce similar data as the destructive technique (quantitative). The trace elements selected in this study (Rb, Sr, Zr, Y) are sometimes referred to as "incompatible" elements and are particularly useful for geochemical characterization (Potts, 1987). These elements are often good for the characterization of rock types because they will enter only into certain crystalline phases (Hall and Kimura, 2002, p. 260). Comparison of destructive and non-destructive techniques shows good correlation between these two techniques (Fig. 1). All correlations between destructive and non-destructive data sets are significant to the $p < 0.001$ level and therefore support the use of the non-destructive data set for the analysis of trace element concentration.

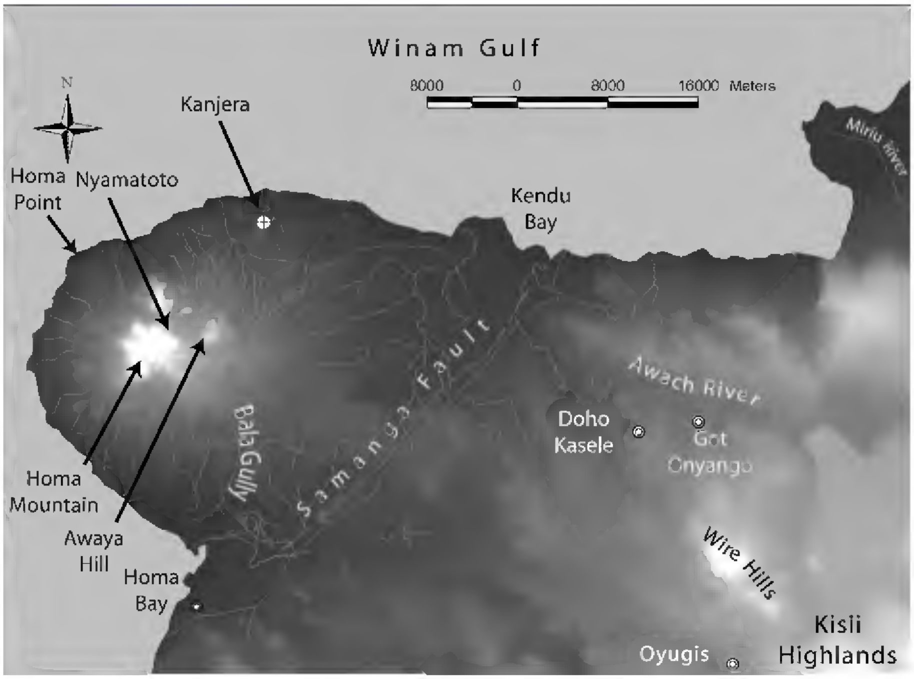

**Fig. 2.** Map of major features of the Winam Basin that are mentioned in the text.

## 5. Geological background to the study area

The basement geology of the Kisii Highlands and South Nyanza areas of western Kenya is very complex. Rocks of Precambrian to Tertiary age crop out throughout this area. A brief review of different regions and their underlying geology is necessary to contextualize the samples used in the artifact provenance study. Features referred to in this review can be found on the map in Fig. 2.

### 5.1. The Homa Mountain carbonatite center

Located at the far western end of the Winam Gulf, Homa Mountain is the product of carbonatite volcanism that is relatively young compared to the rocks surrounding it. This area was originally surveyed by Saggerson (1952) as part of the Kenya Geological Survey. The vast majority of our understanding of this region comes from the work of LeBas (1977) in the area. The most abundant rock types in this region are from the Nyanzian System. These rocks were largely rhyolites and dacites emplaced over a large area that had become peneplained prior to the doming of the Homa Mountain carbonatite edifice (Le Bas, 1977). The lateral equivalents of these Nyanzian Rocks can be found at the foothills of the Kisii Highlands and near the Samanga Fault region. These rocks can be found in this relatively unaltered state in a broad 9 km arc to the south and east of Homa Mountain carbonatite center. These unaffected rocks are fine grained and sometimes glassy rocks with numerous phenocrysts. Dacites can have microphenocrysts with interlocking feldspar laths. Rhyolites can be distinguished by their sub-hedral quartz phenocrysts set in a fine grained matrix of quartz and orthoclase (McCall, 1958; Saggerson, 1952).

In areas closer to the carbonatite magma chamber these rocks underwent intense metasomatism (Le Bas, 1977). These metasomatized rocks are termed fenites and are largely brecciated and shattered with secondary minerals forming along the resulting joint surfaces. Veinlets of secondary minerals cutting through the rock are common. This diagenetic process grades into more severe metasomatism where the entire fabric of the rock is replaced. Feldspar laths are often completely replaced by dark minerals. Aegerine and amphibole form in veins that cross-cut the fabric of the rock. As the fenitization process becomes more intense the largely brownish-black rock can be wholly replaced by potassium feldspars working out from the veins and resulting in extensive penetration of the rock by amphibole and aegerine (Le Bas, 1977). The result is a bluish-green rock that weathers very rapidly. Those rocks that received the least metasomatism are associated with the Awaya Hill center. As these rocks are mechanically weathered they usually form angular blocks.

A separate part of the fenitization process results from pyroclastic carbonatite volcanism through the Nyanzian country rock. As the carbonatite magma erupts through the Nyanzian rock it shatters it and recrystallizes as a breccia-like rock. The result is a rock with a carbonatite matrix with small xenoliths of heavily fenitized Nyanzian rhyolites and dacites. The percentage of these xenoliths varies and many of these carbonatite breccias can be found with only a few Nyanzian xenoliths. These extrusive carbonatite rocks outcrop from various small vents throughout the Homa Peninsula. They are more infrequent away from the carbonatite center, however they can be found upwards of 9–12 km away from the Homa Mountain edifice (Le Bas, 1977).

By far the most abundant carbonatite rocks are ijolites. Ijolites are plutonic rocks made from mostly aegerine-augite (40%) and nepheline (58%). Almost the entirety of the Homa Peninsula is underlain by large masses of this rock type. It can vary in grain size depending on the depth of emplacement. However, because of its shear abundance of sub-surface, almost every extrusive rock outcropping on the Homa Peninsula carries with it large blocks of ijolite wall rock. Alkaline lavas can have blocks of ijolite upwards of 15 cm in maximum dimension.

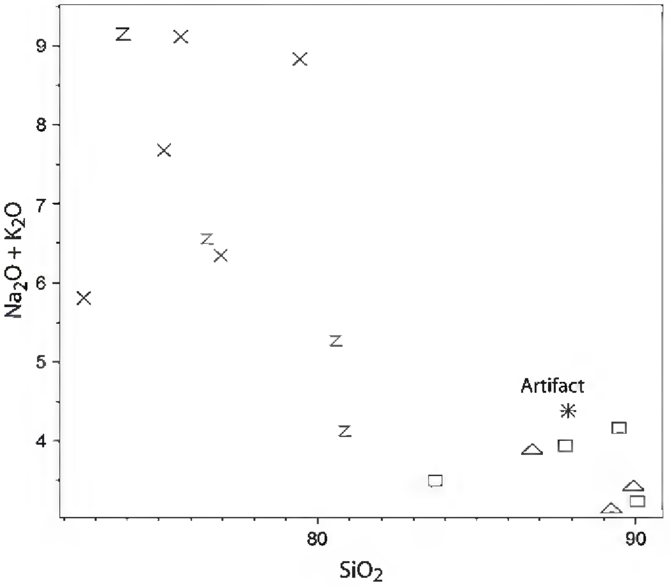

**Fig. 3.** Comparison of total alkali versus silica value for several quartzite samples. Quartzite primary source samples are depicted as boxes. Quartzite secondary samples are depicted as triangles. Quartzite artifact depicted as a star. Bukoban felsite primary source samples are depicted as "x"s. Nyanzian rhyolites are depicted as "z"s. Only one quartzite artifact was analyzed using the destructive technique.

Around 2.5 Ma, carbonatite volcanism reached a peak and began to subside. This is recorded in the subsidence of the Homa Mountain center which today appears as a large ring structure with a depressed center. During this stage several large phonolite plugs were emplaced in various areas around the Homa Mountain complex. All of these phonolitic plugs have various levels of alkali feldspar. Depending on the frequency of these minerals, these rocks are termed nephelinites, phonolites or nephelinitic phonolites. Because these rocks can differ in appearance and sometimes differ

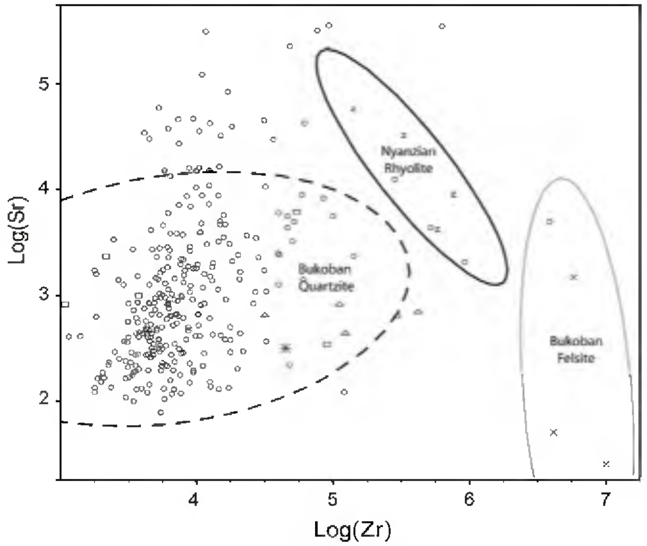

**Fig. 4.** Comparison of logarithmic transformations of zirconium ppm and strontium ppm values for quartzite samples and other primary source samples. Ellipses represent 3 sigma intervals. Quartzite primary source samples are depicted as boxes. Quartzite secondary samples are depicted as triangles. Bukoban felsite primary source samples are depicted as "x"s. Nyanzian rhyolite primary source samples are depicted as "z"s. Bukoban quartzite artifact samples are depicted as open circles.

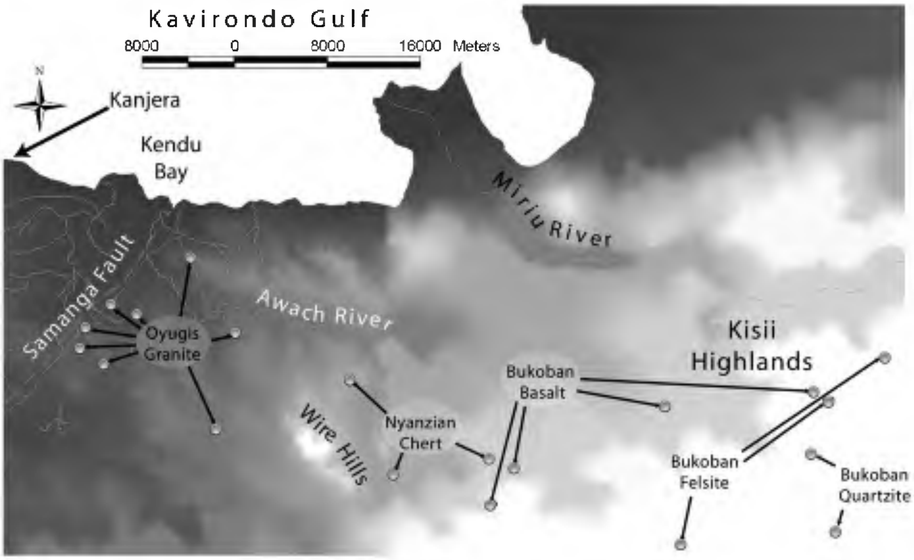

**Fig. 5.** Map of primary sources of artifacts near the Samanga Fault and Kisii Highlands areas.

in their physical properties, those rocks with less than 46% silica will be referred to as nephelinites following the TAS system of Le Bas (1977). Other alkali extrusive lavas will be considered phonolites (even if terms such as tephriphonolite or phonotephrite are a more accurate description of their actual chemical composition). In the field these rocks can be distinguished by their bluish-green color and fine grained groundmass. Biotites are infrequently observed in phonolite outcrops at Homa Point and at Nyamatoto. Phonolitic rocks are abundant throughout the Homa Mountain region and are similar to rocks found in the Samanga Fault region.

The outer radius of the Homa Mountain carbonatite center is covered in a thick mantle of Plio-Pleistocene sediments. These sediments are largely fluvial and lacustrine deposits with intercalated limestone beds (Ditchfield et al., 1999; Saggerson, 1952). These limestone beds appear to be somewhat homogenous throughout the southern shores of the Winam basin. Some of these beds vary in the degree of secondary silicification, and others appear to have higher magnesium content. This variation appears to be continuous as opposed to geographically distinct types of limestone beds.

### *5.2. Plutonic and extrusive rocks of the Kendu Fault region*

Parallel to the road that passes from Kendu Bay on the southern shores of the Winam Gulf to Homa Bay is the large and ancient Samanga fault. The fault marks an important lithological division. All of the rocks to the west of this fault are associated with Homa Mountain and the country rocks affected (fenetized) by it. It appears that the fault represents a point of weakness that allowed for the emplacement of phonolitic and nephelinite lavas that cover a 5 km wide swath across the whole length of the fault (15 km). It seems likely that the small phonolite plugs and surrounding lavas were emplaced at a similar time as the alkali lavas near Homa Mountain because of their geochemical similarity (Le Bas, 1977). To the southwest of the Samanga fault near Homa Bay a series of dark Nyanzian acid igneous rocks have largely escaped secondary alteration and form a large block of fine grained rhyolitic lava in this region. Further to the east a large area approximately 9 km wide (east–west) and 15 km long (north–south) is covered by a granitic mass known as the Oyugis granite. This plutonic mass is relatively homogenous, although it grades from a more leucocratic type in the north to a darker variety in the south with higher percentages of orthoclase feldspars. This granite has not been heavily affected by the intense faulting that has modified the rocks in the north near Kendu Bay. The granite cuts through Nyanzian rocks near Doho Kasele and the resulting rock is more microgranitic. Interactions between the granite and Nyanzian rocks throughout the area have resulted in various degrees of fine and coarse grained granites. The granitic body was likely uplifted by the Samanga fault, and is exposed at the surface today. The granite probably extends beneath the full length of the Homa Peninsula given that pyroclastic rocks near the Homa Mountain center include fragments of fenitized granite (Le Bas, 1977). Along the shore of the Winam Gulf to the northeast is a very large granodiorite body that forms a prominent ridge associated with the Kendu Fault which is the southern boundary of the Winam Rift system.

Three other rock types in this region are of note because of their appearance in the archaeological materials at Kanjera South.

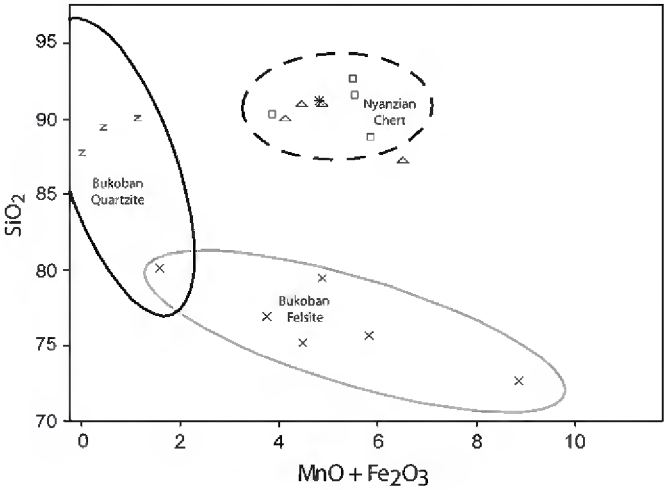

**Fig. 6.** Comparison of SiO % and (MnO % + $Fe_2O_3$ %) for Nyanzian chert samples and other primary source samples. Ellipses represent 3 sigma intervals. Bukoban quartzite primary source samples are depicted as "z"s. Nyanzian chert secondary samples are depicted as triangles. Bukoban felsite primary source samples are depicted as "x"s. Nyanzian chert primary source samples are depicted as boxes. Nyanzian chert artifact sample is depicted as a star. Only one Nyanzian chert artifact was analyzed using destructive techniques.

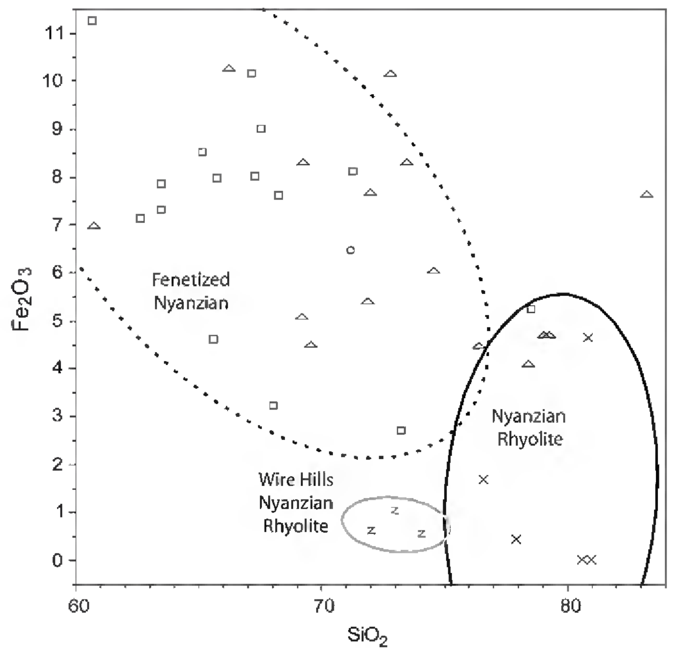

**Fig. 7.** Comparison of SiO % and (Fe$_2$O$_3$ %) for fenetized Nyanzian samples and other primary source samples. Ellipses represent 3 sigma intervals. Wire Hills rhyolite primary source samples are depicted as "z"s. Fenetized Nyanzian secondary samples are depicted as triangles. Nyanza rhyolite primary source samples are depicted as "x"s. Fenetized Nyanzian primary source samples are depicted as boxes. Fenetized Nyanzian artifact sample is depicted as an open circle.

(1) At the tops of some hills south of Kendu Bay are a series of banded ironstone cherts from the Nyanzian system. These are very fine grained rocks that are often brecciated and shattered but sometimes can form very thick bands of fine grained chert that is likely of colloidal origin (Saggerson, 1952; Shackleton, 1952). Some hills (Godnyango) are made entirely of rocks that vary from black waxy cryptocrystalline cherts to more weathered banded ironstones. The durable nature of these stones makes them a prominent feature of some conglomerates in the region.

(2) In the region near Doho Kasele along the southern banks of the Awach river system are large outcrops of Nyanzian Basalts. These rocks become intensely schistose as they get closer to the intersection of the Kendu and Samanga faults. The majority of the outcrops of Nyanzian basalt have been sheared but in the town of Doho Kasele they can be found largely unaltered. These rocks are very fine grained and are blue to black in color. The complete lack of phenocrysts in this rock makes it extremely hard to distinguish from other basic lavas in the Homa Peninsula area in hand sample.

(3) Steep hills along the eastern side of the Oyugis–Kendu road are referred to as the Wire Hills and are made of a light grey to red rhyolitic rock. The outcrops of this rock are variably weathered but are generally coarser grained than the Nyanzian rhyolitic rocks of the Samanga region.

### 5.3. Bukobon System of the Kisii Highlands

To the southeast of the Homa Peninsula is an upland region made of a series of steep ridges that are the product of the Bukoban System sometimes known as the Kisii Series (Huddelston, 1951). This group of rocks is made of a series of lavas and metamorphosed sediments. The base of the Bukoban Series is composed of porphyritic basalts that are not widely exposed. They are dark green in color with large (15 mm) pale green feldspar phenocrysts. Non-porphyritic varieties are more widely exposed and are distinguished by large vesicles (5–8 cm) that are often infilled with chalcedonic silica. The middle of the Bukoban Series is dominated by upwards of 70-m high scarps of banded quartzites. These rocks are very fine grained grey to dark red and are made up of almost entirely silica. Microscopic analysis by Huddelston (1951) suggested these rocks were derived from very mature quartz beach deposits

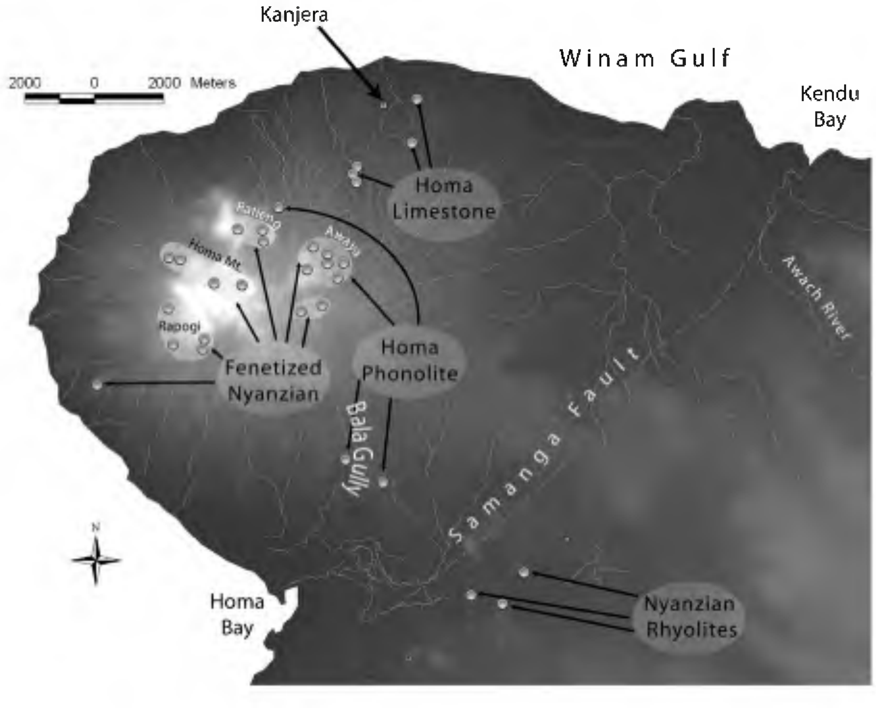

**Fig. 8.** Map of the primary sources in the Homa Mountain area.

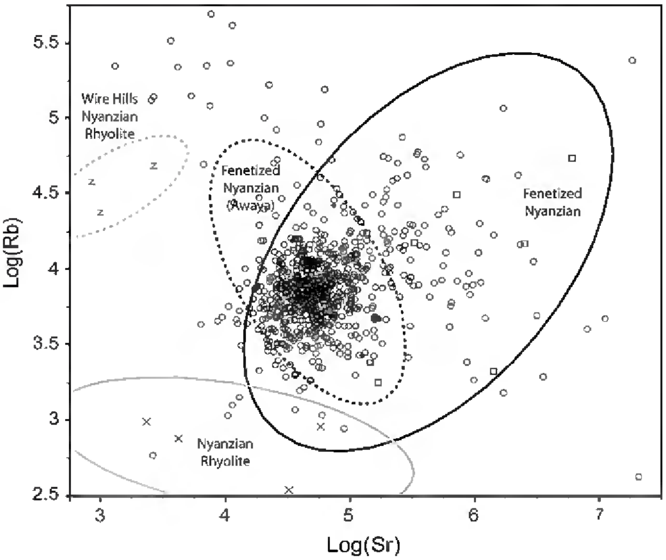

**Fig. 9.** Comparison of the logarithmic transformation of strontium ppm and rubidium ppm concentrations for fenetized Nyanzian samples and other primary source samples. Ellipses represent 3 sigma intervals. Wire Hills rhyolite primary source samples are depicted as "z"s. Nyanzian rhyolite primary source samples are depicted as "x"s. Fenetized Nyanzian primary source samples are depicted as boxes. Fenetized Nyanzian primary source subgroup from Awaya Hill is depicted as diamonds. Fenetized Nyanzian artifacts are depicted as open circles.

because of the complete lack of other minerals. The microcrystalline quartz grains are set in a siliceous fine grained cement. Immediately overlying the quartzites in the Kisii Highlands are a series of fine grained felsic volcanic rocks. These rocks are usually described as "felsites" because they are very fine grained and usually lack distinguishing phenocrysts. The groundmass is a fine grained intergrowth of quartz and orthoclase (Huddelston, 1951). The rock is a deep red and is sometime characterized by vesicular bands that are filled with chalcedonic silica. In hand sample the rock is usually described as "fine grained felsic igneous"(McCall, 1958), but chemical studies have shown the rock to range from dacitic to rhyolitic in its composition. For clarity of nomenclature the previously used "felsite" distinction is retained.

## 6. Results: geochemical provenance of artifacts

Artifacts from the Kanjera South assemblages were attributed to lithological groups based on major and trace element concentrations. Trace element chemistry has been utilized here to link artifacts to geographically isolated rock groups. Major element chemistry is limited to the small sub-sample of artifacts that were destroyed for geochemical analysis. Samples from the study of secondary sources (conglomerates) have also been incorporated into these analyses to insure that hand sample identifications for that part of the analyses are accurate. Major element analysis with petrological indices have been used to distinguish different types of volcanic and sedimentary rocks (Le Bas et al., 1986). Previous provenance studies have suggested that a $3\sigma$ ellipse of the variation of a known rock group (i.e., modern rock outcrop) has previously been recognized as a reasonable standard of geochemical group inclusion (Malyk-Selivanova and Ashley, 1998).

Nine major rock types were selected for comprehensive geochemical analysis. This sample of rock types represents 85.7% of the entire archaeological assemblage. The remainder of the assemblage (14.3%) represents diverse groups of rocks that could not be sourced or had very small sample sizes ($n < 10$). We focus on trace element signatures because these elements can be used to pinpoint differences between specific rock outcrops. Often these elements are associated with particular types of rock that are more likely to incorporate one or another of these trace elements (e.g., rocks with calcium-rich plagioclases often have high strontium levels). Ratios of specific trace elements are used to try to characterize specific rock groups.

### 6.1. Bukobon quartzite (BQu)

This rock type is found in the Kisii System most notably along the Manga Escarpment. A comparison between quartzite samples from primary and secondary sources, on the one hand, and igneous samples, on the other, shows that the former are distinguished by

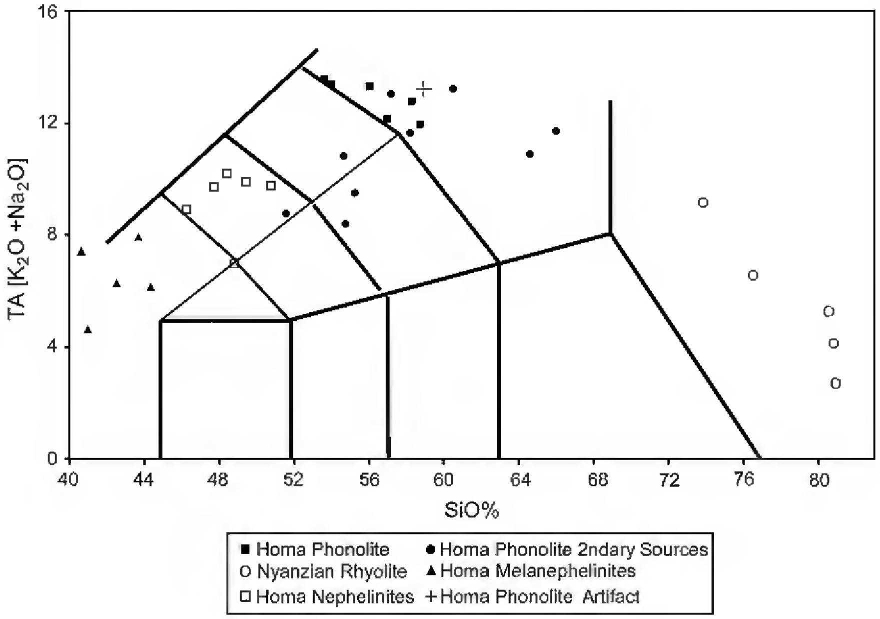

**Fig. 10.** Comparison of SiO (%) and total alkali [$Na_2O + K_2O$] for Homa phonolite and various alkaline lavas in the vicinity of the Homa carbonatite center. Homa phonolite secondary sources derive from various conglomerates.

extremely high silica values (>87%) and very low amounts of alkali minerals (Fig. 3). The artifact sample has similar major element chemistry as the primary source samples of quartzite. A more specific investigation of these rock types shows that the vast majority of the artifacts assigned to quartzite based on visual inspection, have a similar trace element (strontium and zirconium) chemistry to quartzite primary sources found in the Kisii Highlands (Fig. 4). However, a population of artifacts initially classified as quartzite through visual inspection has very high strontium values. These artifact samples actually have a greater resemblance to the population of rhyolite samples and were likely misclassified during the initial round of visual inspection. The quartzite rock is very fine grained and the rhyolites can sometimes be porphyritic so that it is possible to misclassify rhyolites as quartzites. The primary source samples of Bukoban quartzite (BQu) derive from outcrops approximately 63 km away from the Kanjera South site in the Kisii Highlands, south of the Miriu River (Fig. 5). Artifacts from this group often show signs of well rounded cortical surfaces suggesting that fluvial transport had a significant role in transporting the quartzite at least part of the way from the Kisii Highlands to the Kanjera South site.

### 6.2. *Nyanzian chert (NyC)*

The varying levels of oxidation and reduction that occurred during the formation of these rocks resulted in cherts with a varied geochemical composition. These rocks have high concentrations of iron, manganese, and silica. Shackleton (1952) has suggested that these cherts were formed in shallow pools that were oversaturated with silica, and that intense periodic oxidation caused the formation of ironstone bands in the siliceous matrix. Secondary and artifactual samples attributed to this rock group have similarly high concentrations of silica, manganese and iron (Fig. 6). Trace element chemistry was not conducted on the sample of artifacts attributed to this group because trace element concentrations in cherts are tightly linked to prevailing oxidation levels during deposition (Luedtke, 1992). Since the chert outcrops in this study were subject to rapid and intense fluctuations in oxidation levels (as seen by the presence of ironstone and limonite), the trace element chemistry is unlikely to be diagnostic of specific outcrops or groups of outcrops. The location of these silica rich Nyanzian cherts is restricted to a few hills at the foot of the Kisii Highlands (Fig. 5), and therefore the closest primary source outcrop to Kanjera South is approximately 35 km from the archaeological site.

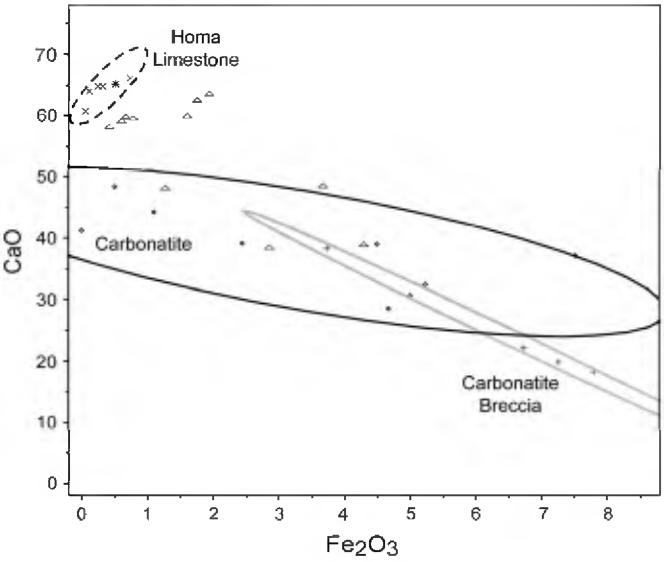

**Fig. 12.** Comparison of CaO % and $Fe_2O_3$ % for Homa limestone samples and other primary source samples. Ellipses represent 3 sigma intervals. Carbonatite breccia primary source samples are depicted as crosses. Carbonatite primary source samples are depicted as diamonds. Homa limestone primary source samples are depicted as "x"s. Homa limestone artifact depicted as a star. Homa limestone secondary samples are depicted as open triangles.

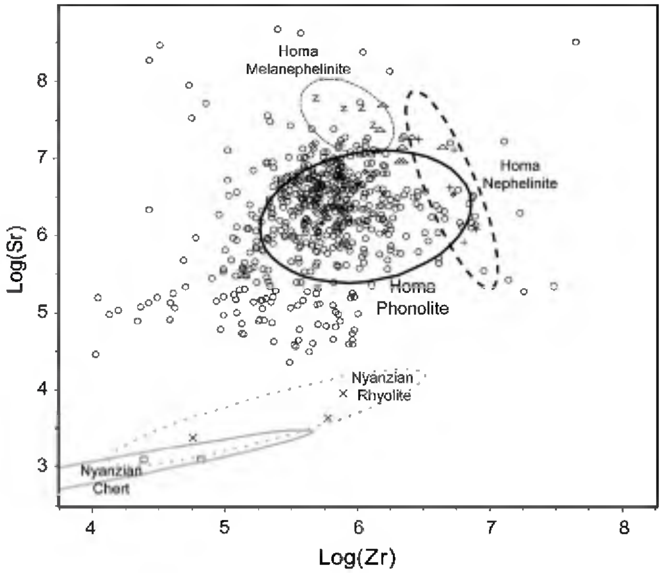

**Fig. 11.** Comparison of the logarithmic transformation of Sr (strontium ppm) and Rb (rubidium ppm) concentrations for Homa phonolite samples and other primary source samples. Ellipses represent 3 sigma intervals. Homa melanephelinite primary source samples are depicted as "z"s. Nyanzian chert primary source samples are depicted as open squares. Homa nephelinite primary source samples are depicted as crosses. Homa phonolite primary source samples are depicted as diamonds. Homa phonolite artifacts are depicted as open circles. Homa phonolite secondary samples are depicted as open triangles.

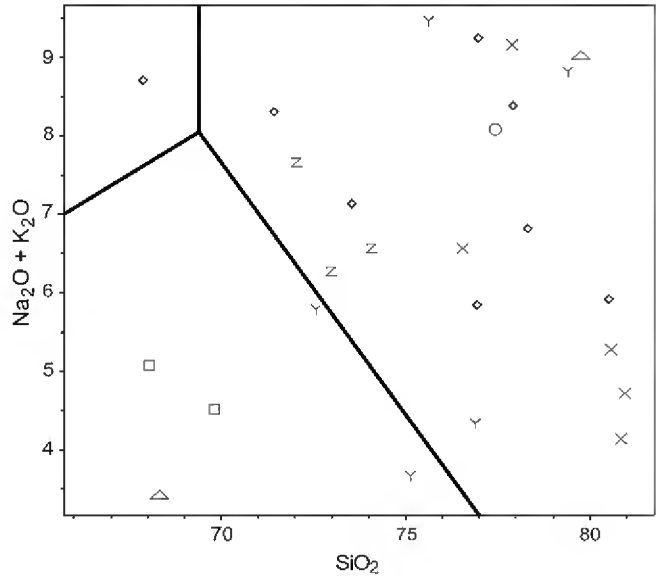

**Fig. 13.** Comparison of total alkali ($K_2O+Na_2$) and silicon (SiO) in Oyugis granite primary source samples and other primary source samples. Nyanzian rhyolite primary source samples are depicted as "x"s. Wire Hills rhyolite primary samples are depicted as "z"s. Bukoban felsite primary source samples are depicted as "y"s. Oyugis granite primary samples are depicted as diamonds. Miriu granodiorite primary samples are depicted as boxes. Oyugis granite secondary samples are depicted as open triangles. Oyugis granite artifact sample is depicted as an open circle.

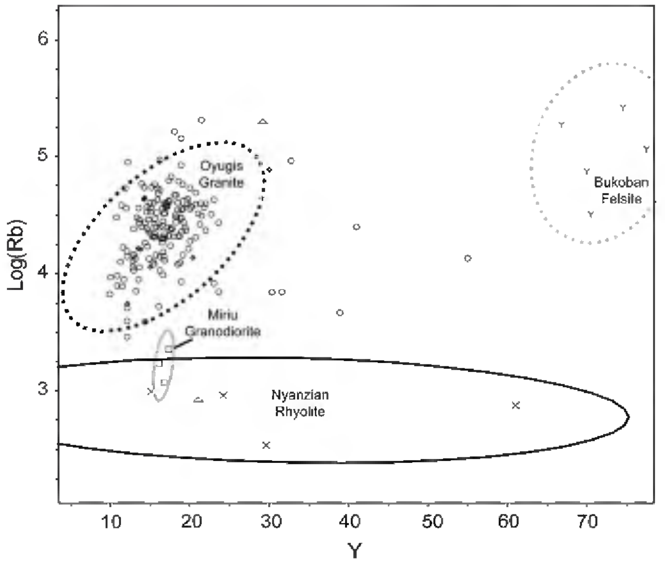

Fig. 14. Comparison of yttrium ppm and the logarithmic transformation of rubidium ppm values for Oyugis granite primary source samples and other primary source samples. Ellipses represent 3 sigma intervals. Nyanzian rhyolite primary source samples are depicted as "x"s. Bukoban felsite primary source samples are depicted as "y"s. Oyugis granite primary samples are depicted as diamonds. Miriu granodiorite primary samples are depicted as boxes. Oyugis granite secondary samples are depicted as open triangles. Oyugis granite artifact samples are depicted as open circles.

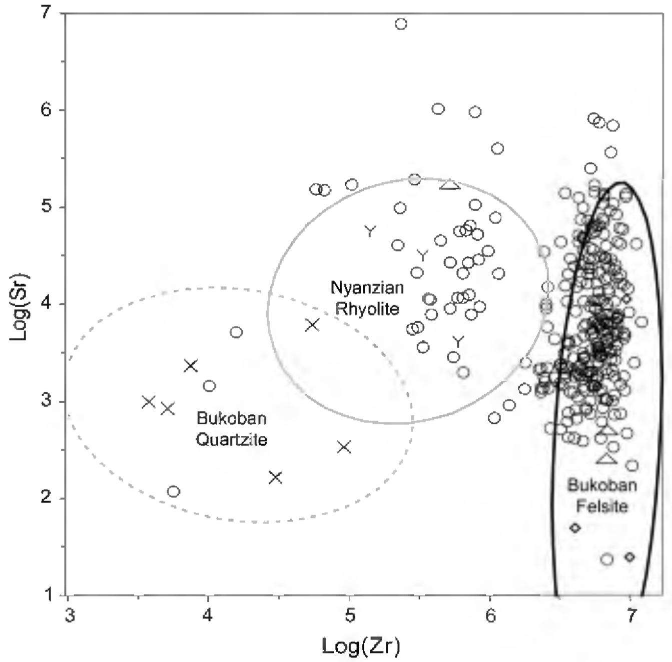

Fig. 16. Comparison of the logarithmic transformation of strontium (ppm) and zirconium (ppm) values for Bukoban felsite primary source samples and other primary source samples. Ellipses represent 3 sigma intervals. Bukoban quartzite primary source samples are depicted as "x"s. Nyanzian rhyolite primary source samples are depicted as "y"s. Bukoban felsite primary source samples are depicted as diamonds. Bukoban felsite secondary samples are depicted as open triangles. The Bukoban felsite artifact sample is depicted as open circles.

### 6.3. Fenetized Nyanzian (FNy)

This group of rocks is highly diverse but their location relative to the site of Kanjera South makes them a coherent analytical unit for the study of stone transport. This sample is composed of rhyolitic and dacitic rocks that were metasomatized into rocks that are highly fractured with numerous secondary minerals replacing the original constituents of the rock. Varying levels of low grade metamorphism (fenitization) that occurred locally in this rock type has resulted in a large amount of geochemical variation. Comparison of total iron and silica values (Fig. 7) shows that sometimes these rocks retain silica concentrations near to their original dacitic or rhyolitic composition. However, the secondary formation of mafic minerals along joint surfaces and through the rock fabric

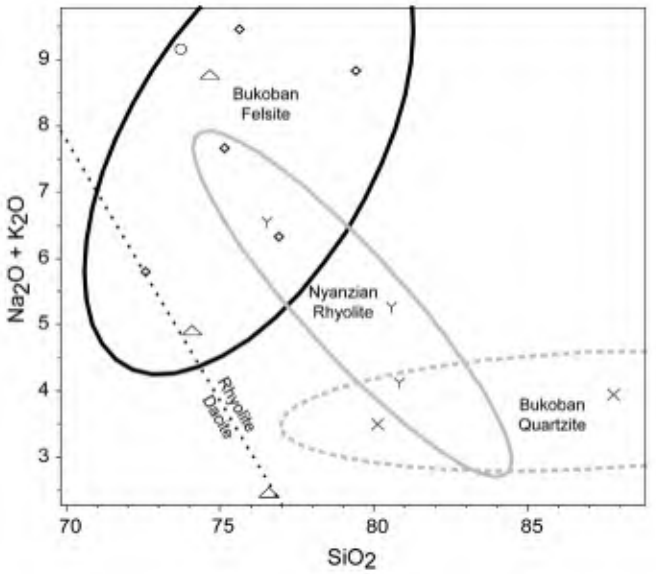

Fig. 15. Comparison of total alkali ($K_2O$ % + $Na_2O$ %) and silica SiO % for Bukoban felsite primary source samples and other primary source samples. Ellipses represent 3 sigma intervals. Bukoban quartzite primary source samples are depicted as "x"s. Nyanzian rhyolite primary source samples are depicted as "y"s. Bukoban felsite primary source samples are depicted as diamonds. Bukoban felsite secondary samples are depicted as open triangles. The Bukoban felsite artifact sample is depicted as an open circle.

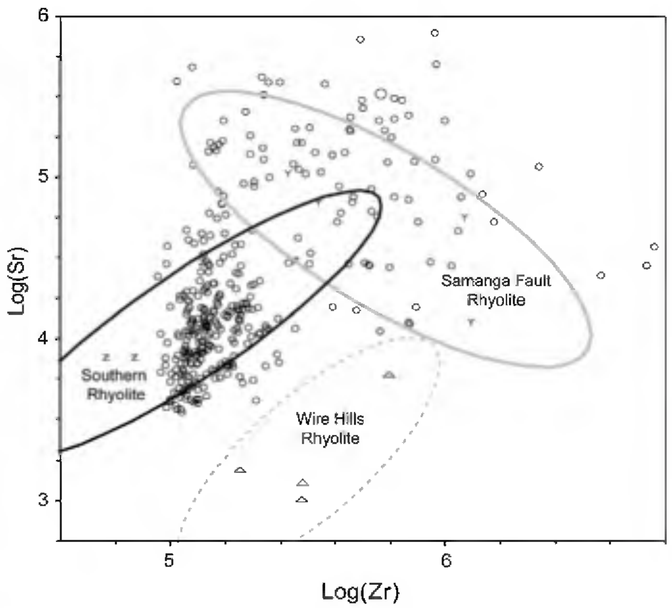

Fig. 17. Comparison of logarithmic transformation of strontium (ppm) and zirconium (ppm) values for Nyanzian rhyolite primary source samples and other primary source samples. Ellipses represent 3 sigma intervals. Wire Hills rhyolite primary source samples are depicted as open triangles. Samanga Fault rhyolite primary source samples are depicted as "y"s. Southern rhyolite primary source samples are depicted as "z"s. Nyanzian rhyolite artifact samples are depicted as open circles.

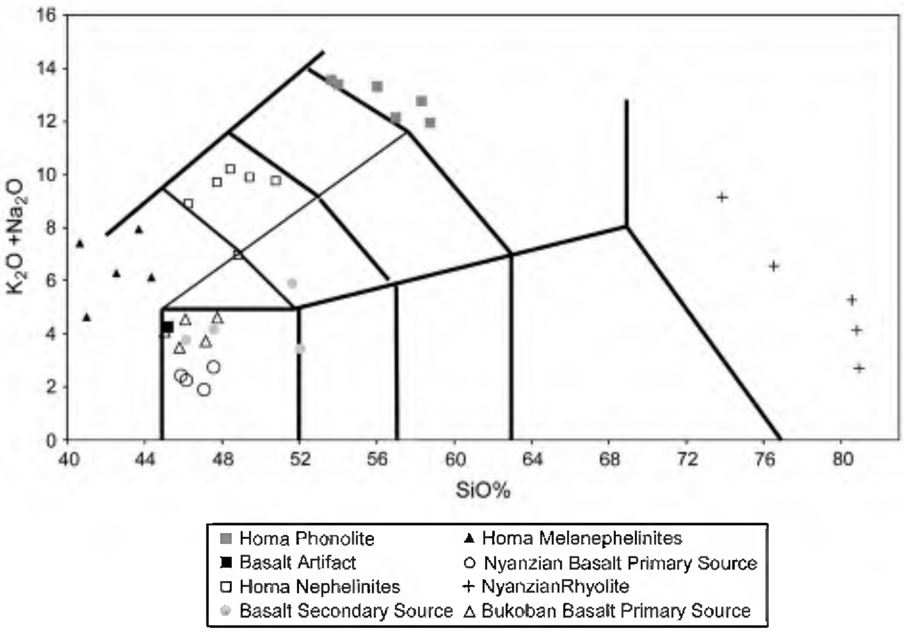

**Fig. 18.** Comparison of SiO and total alkali ($Na_2O + K_2O$) for Nyanzian and Bukoban basalt primary source samples. Other igneous primary source samples are included for comparison. A Bukoban basalt artifact sample is also included as well as secondary samples from conglomerates.

creates a rock with much higher iron percentages than is seen in the original Nyanzian rock (although the ellipses overlap slightly). Two secondary source samples have a signature similar to the original Nyanzian rock. These two samples derive from conglomerates near Kendu Bay and probably represent rocks that were only partially fenetized. While the rocks in this FNy sample do have similar trace element chemistries, variation in rubidium and strontium is large and overlaps the values of these elements in other primary source samples. The distribution of these samples shows that fenetized Nyanzian rocks can be found upwards of 7 km away from the Homa Mountain center (Fig. 8). However, the vast majority of fenetized Nyanzian rock comes from the hills of Got Awaya and Got Ratieng just south of Kanjera South. By isolating those samples collected on the Awaya Hill (Got Awaya) a group of samples can be distinguished that are similar to the artifact population (Fig. 9).

### 6.4. *Homa phonolite (HPh)*

The youngest volcanic rocks on the Homa Peninsula are a series of alkaline lavas that formed plugs and dykes throughout the peninsula shortly after the cessation of carbonatite volcanism (Le Bas, 1977). This youngest stage of volcanism is genetically associated with a similar stage of alkaline volcanism near the Samanga Fault closer to the present day Homa Bay town. Le Bas (1977) has shown that many types of alkaline lavas represent a continuum from nephelinite to phonolite within one volcanic center. The total alkali versus silica plot (Le Bas et al., 1986) of these samples shows a clear distinction between nephelinites, melanephelinites and phonolites (Fig. 10). Samples from the conglomerates on the southern shores of the Winam Gulf also show some variation along this graph with some rocks previously assigned to phonolites actually being closer to trachytes or nephelinites. The one artifact assigned to the phonolite group based on hand sample identification falls closely with the other primary source phonolite samples. A comparison of trace element chemistry of the artifacts and primary source samples shows a very tight grouping between the three major alkaline rock types (melanephelinite, nephelinite, and phonolite) (Fig. 11). A large majority of artifacts fall into the ellipse that characterizes 90% of the variation in phonolite primary sources. There is some overlap between primary source trace element signatures and some artifacts are more similar to nephelinites or melanephelinites. Similarly some secondary sources were misidentified as phonolite and are actually nephelinite. In this analysis logarithmic transformation of the trace element concentrations

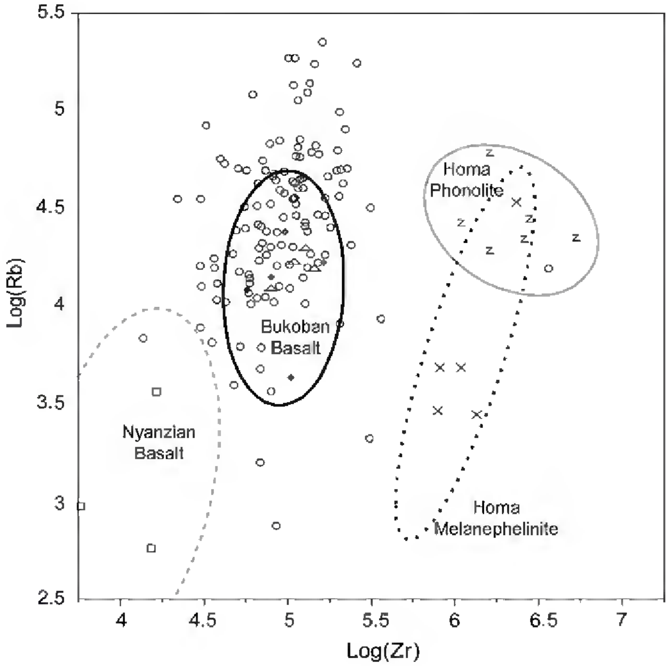

**Fig. 19.** Comparison of the logarithmic transformation of rubidium (ppm) and zirconium (ppm) values for Bukoban basalt primary source samples and other primary source samples. Ellipses represent 3 sigma intervals. Bukoban basalt primary source samples are depicted as diamonds. Nyanzian basalt primary source samples are depicted as boxes. Homa melanephelinite primary source samples are depicted as “x”s. Homa nephelinite primary source samples are depicted as “z”s. Bukoban basalt secondary samples are depicted as triangles. Bukoban basalt artifact samples are depicted as open circles.

**Fig. 20.** Map of conglomerates sampled in this study.

were used because values vary over two orders of magnitude (Fig. 11). The geographic distribution of outcrops assigned to Homa phonolite is widespread. The majority of these outcrops were sampled on the northern side of the Homa Mountain edifice where small alkaline lava plugs are distributed widely (Fig. 8). Homa phonolite outcrops can also be found as far south as Homa Bay in the Bala Gully system.

### 6.5. *Homa limestone (HLi)*

Limestone is found in discontinuous beds throughout the margins of modern Lake Victoria from Homa Point in the west towards Kendu Bay in the east (Fig. 8). A comparison of the major element chemistry of these rocks shows that those sampled as part of this analysis have a very restricted geochemistry with low iron contents and high levels of calcium. Fine grained carbonatite lavas, which can look very similar to limestone in hand sample, have much higher iron levels (Fig. 12). Trace elements have been shown to be useful for discriminating between marine limestones formed during different global climatic conditions (De Vito et al., 2003). As most of the limestone in the Winam Basin was formed as lake levels fluctuated (Ditchfield et al., 1999), it is unlikely that trace element composition will vary relative to geographical location in the basin. Moreover, limestones are present within a few hundred meters of Kanjera South and so were readily available to hominins. Hence geochemistry is simply used to distinguish limestone from the other major rock types, especially fine grained carbonatite lavas.

### 6.6. *Oyugis granite (OyG)*

These intrusive igneous rocks form a boundary between the Tertiary volcanism and sediments of the Homa Peninsula and the older rocks of the Kisii Highlands. These rocks are typical granites but with slightly elevated silica levels. They are sometimes referred to as leucogranites because of their high feldspar content. In some instances the Oyugis granite samples grade toward a granodiorite. This is probably the product of interaction with Nyanzian rocks near the northern extent of this rock mass (Saggerson, 1952). The samples in

**Table 1**
Conglomerates sampled for provenance study

| Conglomerate | Gully system | Geological formation | Distance from Kanjera South (km) | Previous geological description |
|---|---|---|---|---|
| KWESTCON2 | Inland Kanam West | Apoko Fm. | 4.75 | Pickford (1987) |
| KWESTCON1 | Inland Kanam West | H3 (Homa Fm.) | 4.95 | Ditchfield et al. (1999), Pickford (1987) |
| KWESTCON3 | Inland Kanam West | Apoko Fm. | 5.1 | Pickford (1987) |
| KECON1 | Kanam East | Kasibos Fm. | 3.42 | Ditchfield et al. (1999) |
| KECON2 | Kanam East | Apoko Fm. | 3.45 | Ditchfield et al. (1999) |
| KECON3 | Kanam East | Abundu Fm. | 3.56 | Ditchfield et al. (1999) |
| KCENCON1 | Kanam Central | Rawe Fm. | 5.25 | Ditchfield et al. (1999) |
| KECON4 | Kanam East | Kasibos Fm. | 3.39 | Ditchfield et al. (1999) |
| RDRVCON1 | Red River | Rawe Fm. (?), Abundu Fm. (?) | 1.7 | Pickford (1987) |
| RDRVCON2 | Red River | Apoko | 1.9 | Pickford (1987) |
| AWACON1 | Awach River | Pleistocene | 11.6 | Saggerson (1952) |
| AWACON2 | Awach River | Pleistocene | 11.92 | Saggerson (1952) |
| NYAPCON2 | Nyapetho River | Plio-Pleistocene (Under Orio Tuff) | 12.7 | Saggerson (1952) |
| KANJCON2 | Kimera River | Pleistocene | 10.3 | Saggerson (1952) |
| AWACON3 | Awach River | Modern | 13.16 | – |

this study show a clear distinction between granites and granodiorites near the Miriu River drainage system (Fig. 13). Trace element chemistry also distinguishes between artifacts and primary samples attributed to Oyugis granite and other rock types (Fig. 14). Samples for this study derive from a variety of locations in the study area. Oyugis granite outcrops can be found from Doho Kasele to Samanga along an east–west transect and from Kendu Bay to Oyugis in a north–south transect. They are never found west of the Samanga fault (Saggerson, 1952) (Fig. 5). The nearest rock outcrop of the Oyugis granite is likely at least 10 km away from the Kanjera South site.

### 6.7. *Bukoban felsite (BFe)*

These rocks are difficult to identify in hand sample because of their microcrystalline structure and lack of diagnostic phenocrysts (Huddelston, 1951; Saggerson, 1952; Shackleton, 1952). They are siliceous and grade between a rhyolitic and dacitic chemistry (Fig. 15). Bukoban felsites can be distinguished from other siliceous rocks by their zirconium concentrations (Fig. 16). Although most of the artifacts identified via hand sample as Bukoban Felsites appear to have a similar geochemistry as the primary source samples from the Kisii Highlands, some of the artifacts fall into the range of rhyolites and quartzites. Although Bukoban felsite outcrops are widely dispersed throughout the region, the closest outcrops to Kanjera South are in the north–south trending escarpment of Komela and Kisigoro in the Kisii Highlands overlying large bands of Bukoban quartzite (Fig. 5).

### 6.8. *Nyanzian rhyolite (NyR)*

The acid igneous rocks of the Nyanzian System are well documented in the Kisumu and Gwasi areas (McCall, 1958). Despite the antiquity of these rocks they are still geochemically similar to unweathered rhyolites in their major element chemistry (Figs. 3 and 10). In hand sample they can vary from whitish grey rocks to glassy black rocks with numerous quartz phenocrysts. All of these rhyolites belong to the Nyanzian System. These rocks can vary greatly in their appearance based on specific geographic distinctions. Rhyolites from the Wire Hills are Nyanzian in age but have slightly lower silica levels and lower strontium concentrations. There is significant overlap between the rhyolites found in the northern Samanga region and those found in more southerly outcrops near Homa Bay town. The majority of the artifacts from Kanjera South have a trace element chemistry similar to the Nyanzian rocks found at the southern extent of the Samanga Fault, which we refer to as "Southern rhyolite" (Fig. 17). All unfenetized Nyanzian rhyolitic samples were found east of the Samanga Fault (Fig. 8). Nyanzian rhyolite outcrops near the Kendu Bay region are heavily modified at the Kendu Fault and can be identified by their schistose cleavage. Although these rocks are found in the secondary sources, they are only very rarely found in the artifact sample ($n = 1$). None of the artifacts that were attributed to Nyanzian rhyolite on the basis of their hand sample identification have a geochemistry similar to the fenetized Nyanzian rocks or the Wire Hills rhyolites.

### 6.9. *Bukoban basalt (BBa)*

The basaltic rocks of the region are difficult to identify because they are usually very fine grained and have few phenocrysts. Although many of these rocks have infrequent vesicles this is not a diagnostic feature of any one type of basalt. A comparison of total alkali versus silica composition shows that most of the secondary sources identified in hand sample as basalts actually are similar to the Nyanzian or Bukoban basalts (although one secondary source sample appears to be more andesitic in composition) (Fig. 18). The artifact sampled shows geochemical affinities to the Bukoban basalt. It should be noted that this rock is not silica rich but has relatively high alkali concentrations for a basalt. Trace element concentrations distinguish between the Nyanzian and Bukoban basalts. On the basis of this comparison, the majority of the artifacts and secondary source samples fall within the range of variation of Bukoban basalt. A subset of artifacts falls within the range of the Nyanzian basalt, although these artifacts appear to form a gradation with those that fall well within the range of the Bukoban basalt (Fig. 19). Bukoban basalt crop out along the Kisii Highlands below the quartzite scarps. Although these rocks crop out widely, they have not been found northeast of Oyugis (Fig. 5).

## 7. Results: secondary sources and the availability of raw materials

Raw material sourcing studies often focus on identifying the petrography and geochemistry of artifacts and then link this information to surrounding geological outcrops. Other studies focus

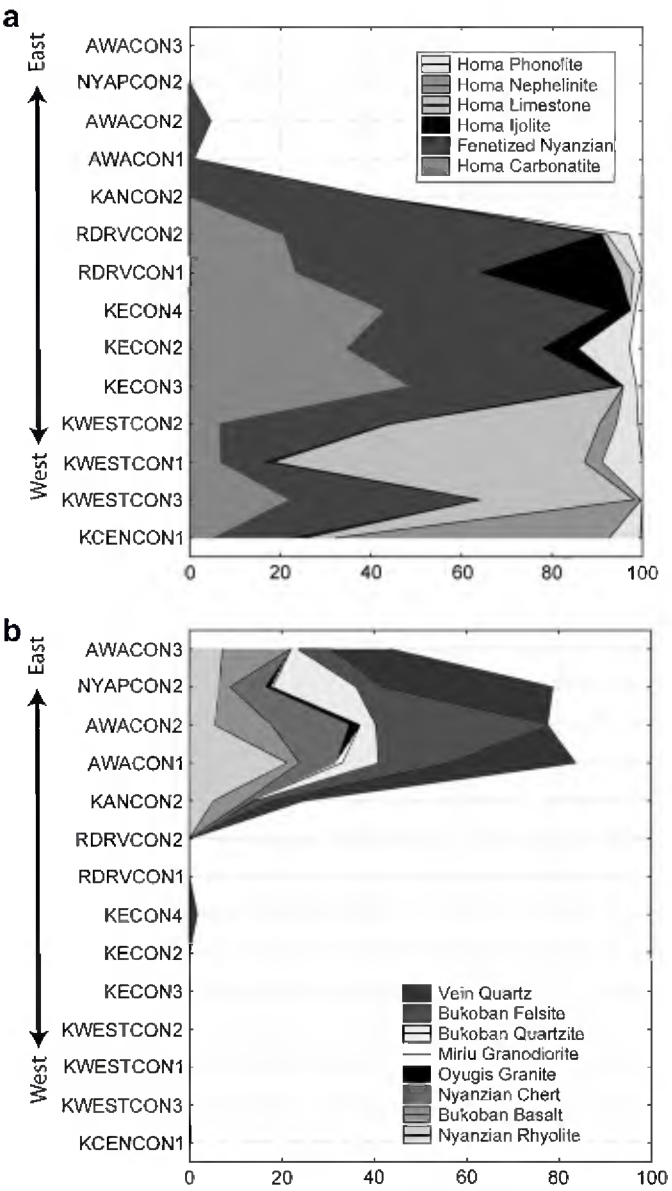

**Fig. 21.** Composition of conglomerates in a transect from east to west. (a) Percentage of conglomerates that derive from primary sources that are found west of the Samanga Fault. (b) Percentage of conglomerates that derive from primary sources that are found east of the Samanga Fault.

on one source area and determine the movement of that one rock type to various regions (Bamforth, 1992; Church, 1994). To understand aspects of raw material variation and availability in a way that allows the testing of hypotheses about artifact manufacture and transport requires the attribution of artifacts to rock outcrops and the documentation of raw material availability across the landscape utilized by the tool makers.

This study investigated ancient conglomerates to develop a model of cobble transport by major river systems along the southern part of the Winam Basin with the goal of understanding raw material selection and transport patterns by hominins at Kanjera South. A large number of artifacts are derived from primary sources that crop out up to 60 km away from the Kanjera South locality. Hence, the conglomerate sampling strategy focused on determining the presence of rock types derived from these distant primary sources. To carry out this strategy, 500 stones were collected from each of 15 conglomerates along the southern shores of the Winam Gulf. All 500 of these stones were identified to raw material category based on visual inspection. A subset of each of these rock groups was subsequently analyzed using XRF methods to determine the accuracy of visual inspection characterizations. The 15 conglomerates were sampled from Neogene sediments exposed in erosional gully systems along the southern shores of the Winam Gulf (Fig. 20). These conglomerates were selected based on their distance from the Kanjera South locality and/or because previous studies had documented a stratigraphic correlation between these sediments and the Kanjera Formation (Ditchfield et al., 1999; Ditchfield et al., in press). The sample names of conglomerates and their geological affiliation can be found in Table 1. These conglomerates range in age from Late Miocene through Late Pleistocene (Ditchfield et al., 1999; Pickford, 1987; Saggerson, 1952). The long time span they sample and their lithologic composition indicates the availability of the different major rock types across the region and through the evolution of the drainage systems. Fig. 21 displays the percentages of rock types found in conglomerates along an east–west transect. It is clear that rock types that have primary sources west of the Samanga Fault are completely absent in conglomerates that are found near the Kanjera South locality. Only conglomerates found east of the Samanga Fault have any clasts from the major rock groups of the Nyanzian and Bukoban system that are found in the archaeological assemblage. In contrast the conglomerates found near Kanjera South are dominated by materials from the Homa Mountain complex and its associated alkaline igneous rocks. These data show that river drainages, mostly the Awach and the Nyapetho rivers, are primarily responsible for the transport of clasts from the Kisii Highlands to a distance within the range accessed by hominins at Kanjera South. These two graphs display the differences between the bed loads of rivers traveling from the Kisii Highlands northwest toward Kendu Bay and those rivers that are part of the radial drainage pattern from Homa Mountain. Fig. 22 provides a model of clast transport that distinguishes between the two major river systems known to transport clasts to different parts of the southern shores of the Winam Basin.

These drainage patterns are consistent throughout the geological record. Even Plio-Pleistocene conglomerates show that very little interaction took place between the two river systems. The Awach River system is likely of great antiquity. Previous research has suggested this river system is bounded by a branch of the Kendu Fault that acts as the southern border of the Winam Rift system (Saggerson, 1952). The only evidence of interaction between these river systems is in the form of fenetized rocks found in conglomerates east of the Samanga Fault. It is very probable that the river drainages that currently radiate out from Homa Mountain had a much higher competence in the past than in the present day. Homa Mountain apparently collapsed after a series of explosive eruptions near the Plio-Pleistocene boundary (Le Bas, 1977). Prior to this collapse the mountain was substantially higher and therefore the river systems traveling outward from it may have been able to push across into the watershed of the Awach and Nyapetho river systems.

## 8. Discussion: raw material availability at Kanjera South

Understanding the composition of conglomerates on the southern shores of the Winam Gulf allows the investigation of the affect of raw material availability on Oldowan technological decisions. We would expect that if hominins at Kanjera showed no selectivity in their procurement of raw materials that the distribution of artifacts would reflect the distribution of available rock

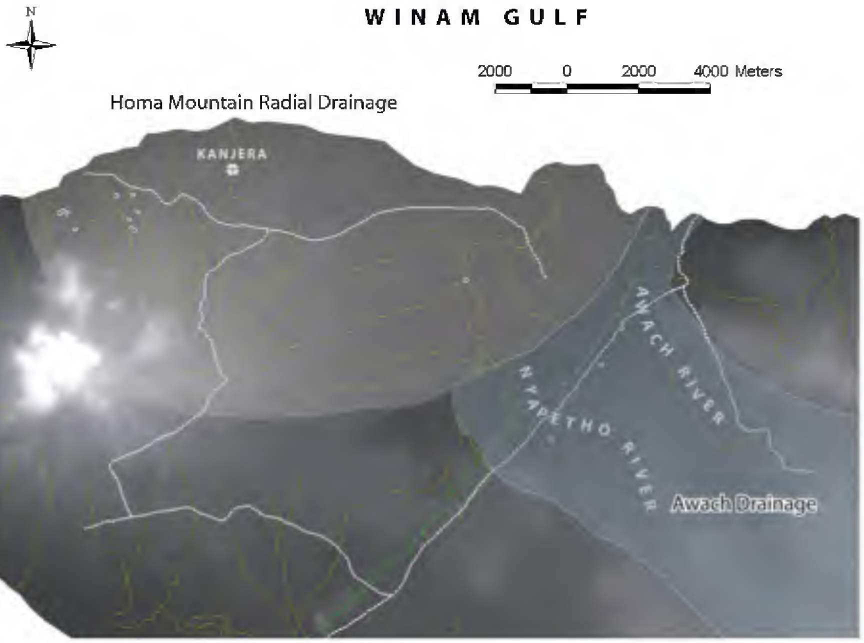

**Fig. 22.** Model of the two major river systems carrying clasts to within procurement distance of Kanjera South.

types in the conglomerates around the site. However, when we compare the archaeological assemblage to an expected assemblage based on the percentage of those raw materials available in conglomerates from the Homa Mountain radial drainage system (Homa carbonatite, fenetized Nyanzian, Homa ijolite, Homa limestone, Homa phonolite, Homa nephelinite) there are consistent differences at the $p < 0.001$ level (Table 2). If Pliocene technology was directly correlated to the availability of raw materials, a very strong relationship would be expected to occur between the availability of raw materials on the ancient landscape and the percentage of these raw materials in the archaeological collection. This is clearly not the case in the Kanjera Formation assemblage. The local raw materials are not incorporated into the archaeological assemblage at a frequency commensurate with their availability.

An even more striking comparison is that between the archaeological assemblage and the Awach drainage system. The provenience data suggest that 27.9% of the archaeological collection is made from raw materials that were only available in the Awach river system. However, a comparison between the expected frequency of those raw materials available in the Awach drainage system and the archaeological collection shows significant differences (Table 2). These comparisons imply that hominin stone transport decisions were governed by strict selection criteria.

Some have suggested that the classic “distance–decay” relationship between distance from source to site and proportion in the archaeological collections may be a product of the length of time a particular unit of raw material (e.g., cobble) stays operative in a toolkit (Brantingham, 2003). However, data from Kanjera South suggest that for Pliocene technology this was not the case. The frequency of certain raw materials in this Oldowan archaeological collection was apparently linked to a decision-making system that, to a certain degree, was independent of the proximity and overall availability of those raw materials. In order to explore other factors that shaped raw material selection it will be necessary to investigate technological decisions based on artifact morphological patterning and other aspects of assemblage variation that go beyond the mere frequency of a raw material in the archaeological collection (Braun, 2006).

## 9. Conclusion: raw material availability at Kanjera South and Oldowan transport

Geochemical provenance analyses of primary and secondary sources provide a rich context for the analysis of the archaeological collection at Kanjera South. This study shows that raw materials from Kanjera South were derived from a wide variety of geographically distinct primary sources of raw materials. Analysis of secondary sources shows that raw material availability from conglomerates also varied across the landscape. Clasts made from the Bukoban and Nyanzian systems were apparently widely available in conglomerates approximately 10–13 km from Kanjera South. Clasts of rocks associated with the Homa Mountain complex were widely available in conglomerates all along the southern shores of the Winam Gulf. Based on the frequency of raw materials in the archaeological collection, it appears that certain raw materials were transported to Kanjera South at higher proportions than can be expected based on their availability in conglomerates. Almost one-third (27.9%) of the entire artifact collection derives from raw materials that were only available in conglomerates deposited by the Awach River system. Selective transport was a major factor shaping the composition of the archaeological collection. Indeed, many raw materials can be found in high frequencies in conglomerates near the Samanga Fault that were *not* transported to Kanjera South. If transport of clasts from the region around Kendu Bay was an important element of the technological behavior represented at Kanjera South, we should expect to see a reflection of this behavior in the manufacture and discard of certain artifact types at this site. Future analyses will focus on the interaction between technological attributes and transport decisions (Stout et al., 2005).

Recent studies of Oldowan sites have suggested that technological decisions were interconnected with the selection of certain raw materials (Harmand, 2006; Stout et al., 2005). In fact, some have suggested that this selection and transport behavior is the hallmark of the Oldowan (Davidson and McGrew, 2005; Potts, 1991). Movements over long distances may have been related to anatomical changes in early *Homo* (Bramble and Lieberman, 2004; Lieberman et al., 2007; Pickering and Bunn, 2007). Here we show that hominins in the Winam basin during the Pliocene exhibited a range of selective transport behaviors that indicate the expenditure of extensive amounts of energy to produce and maintain a stone tool kit. A likely implication is that the benefits accrued from such behavior were commensurate and adaptive. These data support a growing interpretation that, when transport and stone flaking are considered in considerable detail, Oldowan tool behavior was possibly more complex than previously expected (Delagnes and Roche, 2005; Semaw, 2000).

**Table 2**
Results of $\chi^2$ test of the difference between expected frequencies of raw materials versus the known frequency of raw materials in the archaeological collection

| Raw material | Observed | Expected | Freeman–Tukey deviates | $\chi^2$ | $\nu$ | $p$ |
|---|---|---|---|---|---|---|
| *Kanjera Fm. archaeological collection vs. Homa Mountain radial drainage system* | | | | | | |
| Homa carbonatite | 65 | 641.6 | −34.48 | 3084.96 | 5 | <0.001 |
| Fenetized Nyanzian | 1785 | 1068.1 | 19.14 | | | |
| Homa ijolite | 4 | 158.4 | −20.95 | | | |
| Homa limestone | 255 | 488.6 | −12.25 | | | |
| Homa nephelinite | 3 | 210.6 | −25.31 | | | |
| Homa phonolite | 586 | 129.0 | 25.70 | | | |
| *Kanjera Fm. archaeological collection vs. Awach drainage system* | | | | | | |
| Nyanzian rhyolite | 299 | 81.3 | 16.55 | 2776.86 | 8 | <0.001 |
| Bukoban basalt | 131 | 88.1 | 4.14 | | | |
| Schistose rocks | 2 | 451.9 | −39.38 | | | |
| Nyanzian chert | 42 | 90.7 | −6.04 | | | |
| Oyugis granite | 148 | 84.4 | 5.97 | | | |
| Miriu granodiorite | 0 | 78.5 | −16.75 | | | |
| Bukoban quartzite | 248 | 41.2 | 18.64 | | | |
| Bukoban felsite | 290 | 89.8 | 15.10 | | | |
| Vein quartz | 91 | 237.5 | −11.71 | | | |

Expected frequency is derived from a model of raw material frequency in the different river systems based on the average percentage of each lithology for conglomerates falling within that drainage system.

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