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Mineralogy and Sourcing of a Stone Bead Industry Found in Communal Cemeteries Associated with Eastern Africa's First Pastoralists, ca. 5000 B.P.

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ABSTRACT
This article describes the mineralogy and sources for a spectacular stone bead industry associated with the first pastoralists in eastern Africa ca. 5000–4000 CAL B.P. Around Lake Turkana, northwest Kenya, early pastoralists constructed at least seven mortuary monuments with platforms, pillars, cairns, and stone circles. Three sites—Lothagam North, Manemanya, and Jarigole—have yielded assemblages of stone and ostrich eggshell beads that adorned interred individuals. Mineralogical identification of the stone beads reveals patterns of material selection, including notable differences among the pillar sites. Geological sourcing indicates use of many local raw materials and two (amazonite and fluorite) whose known sources lie > 200 km away. The data suggest that bead-making represented a significant investment by early pastoralists in personal ornamentation. New sociopolitical factors emerged, such as access to grazing grounds and water, and definitions of self and society manifested in novel mortuary traditions as people coped with a drying, cooling climate.

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beads; mineralogy; sourcing; geoarchaeology; Africa; archaeometry; pastoralism

Introduction

The following article describes the archaeomineralogy of strikingly colorful and mineralogically diverse stone bead assemblages in northwest Kenya where, ca. 5000–4000 CAL B.P., a novel tradition of personal adornment occurs in tandem with new monumental mortuary traditions. Beads constitute material evidence for social and economic relationships at a variety of geographic scales (Klumpp and Kratz 1993; Leach and Leach 1983; Malinowski 1922; Marshall 1976; Trubitt 2003; Wiessner 1977, 1982). The provenience, size, shape, color, hardness, and toughness of stone beads and pendants reflect choices and reveal an understanding of distinct areas within an environment shaped by geological forces (Rapp 2009). Analysis and sourcing of the stone bead collection provide a unique glimpse into material culture and human behaviors linked to the spread of pastoralism in eastern Africa.

By the term "stone bead," we mean a bead or pendant composed predominantly or solely of a single mineral or of rock. The stone beads are associated with burials from three communal cemeteries ("pillar sites") built by early pastoralists along Lake Turkana's paleoshoreline (Figure 1). Assemblages from Lothagam North (GeJi9: Hildebrand et al. 2018), Manemanya (GcJh 5: Hildebrand, Shea, and Grillo 2011; Sawchuk et al. 2019), and Jarigole (GbJj1: Nelson 1995; Sawchuk et al. 2022) are compelling because of the breadth of the mineral and rock types represented and the specific mortuary context in which they are found. As the first constructed public spaces in the region, pillar sites are estimated to have accommodated hundreds of burials and represent the earliest known evidence for pastoralism in eastern Africa. Because only three early pastoral habitation sites have seen significant excavation (Ashley et al. 2011, 2017; Barthelme 1985, 135–223; Ndiema 2011; Ndiema, Dillian, and Braun 2010; Ndiema et al. 2011), pillar sites are currently our most substantial data sources for a wide range of questions about material culture, aesthetics, social networks, and mobility. As people wear, gift, exchange, and/or are buried with stone beads, they can shed light onto complex pictures of craft production, consumption, and discard, and on landscape use, in basin-wide mortuary contexts during the mid-Holocene.

As the first comprehensive archaeomineralogical analysis of stone bead assemblages in eastern Africa, this study includes: 1) the identification of 806 stone beads, 2) the designation of type specimens representing groups that define the breadth of materials present, and 3) observations of visible characteristics and properties used to classify the materials into six mineral and seven rock categories. Among these 13 distinct bead materials, we conclusively identify four of the more challenging categories using Micro-Raman Spectroscopy (MR), X-ray Diffraction (XRD), and Scanning Electron Microscopy Energy Dispersive Spectrometry (SEM-EDS) (Supplemental Material 1). Through a preliminary survey of areas west of Lake Turkana and search of the literature on the geology of the region, we identify potential source areas for many of these materials. We also consider mineralogical variability within and between pillar sites to understand local variation in choice of, and perhaps access to, raw materials.

This study contributes a geographic counterpoint to the growing literature on stone bead assemblages from Middle Holocene pastoralist sites in the Sudanese and Egyptian Nile Valley (e.g., Kobusiewicz et al. 2009; Peressinotto et al. 2004; Salvatori and Usai 2008; Usai 2016; Zerboni et al.

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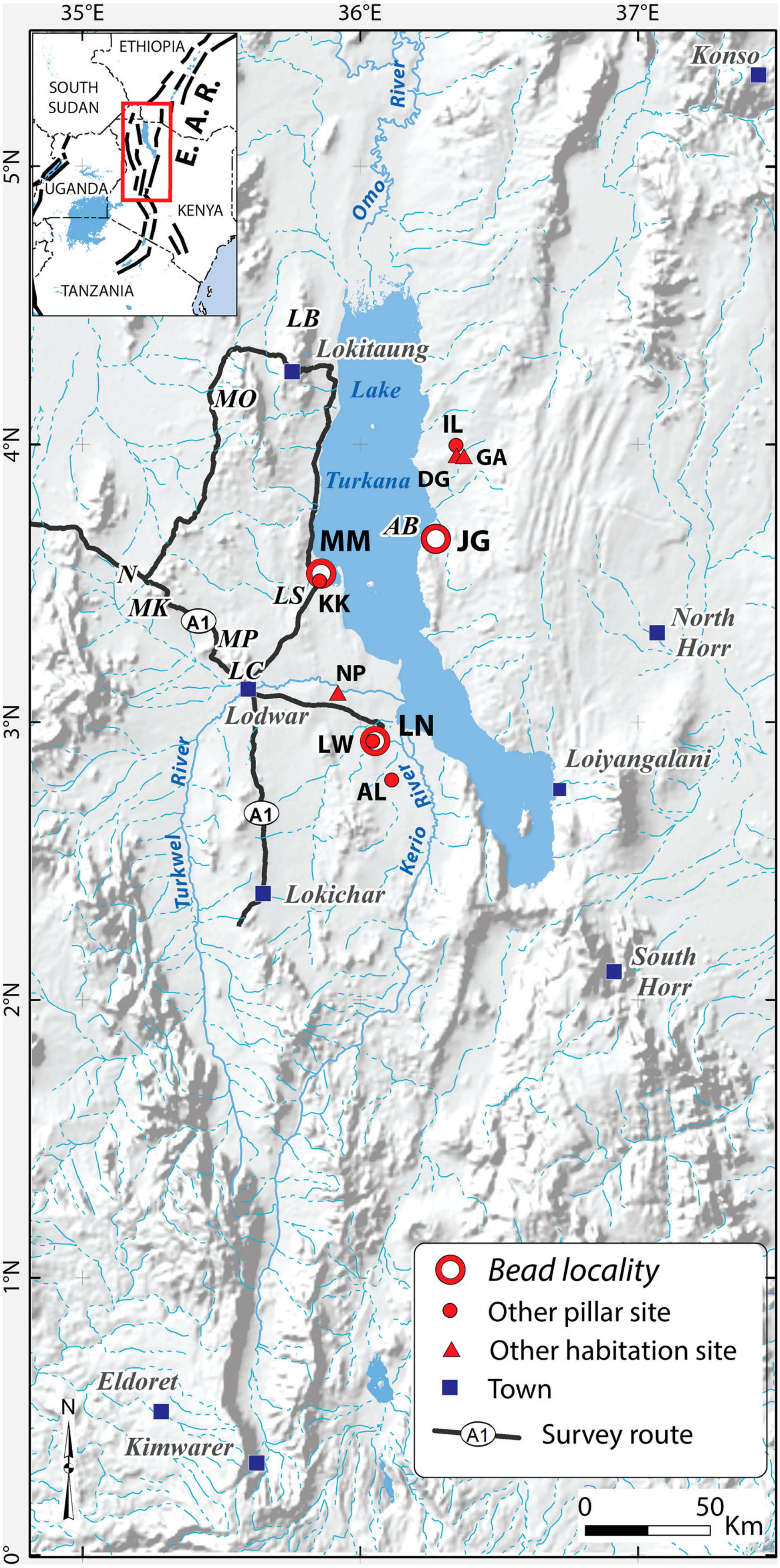

Figure 1. Map of the greater Turkana Basin showing locations of archaeological sites and other notable geographic features. Archaeological sites are (clockwise from north) Il Lokeridede (IL), Dongodien (DG), GaJi2 (GA), Jarigole (JG), Aliel (AL), Lothagam West (LW), Lothagam North (LN), Nakwaperit (NP), Kalokol (KK), and Manemanya (MM). Other important natural features are (clockwise from north) Alia Bay (AB), Lodwar Cone (LC), Muruangapoi Hills (MP), Losedok Hills (LS), Labur Hills (LB), Moruerith Hills (MO), Nadwat (N), and Murianachok Hills (MK). Gray lines are roads traversed during the sourcing study. Inset shows the location (red box) of the map area within the East African Rift (E.A.R.), shown schematically by its bounding faults (thick black lines).

2017, 2018) and the Njoro River Cave assemblage from central Kenya (Leakey and Leakey 1950). The pillar sites are located > 1500 km south of the Nile Valley examples. Although some minerals such as amazonite and chalcedony overlap with materials found in the Nile-region collections, assemblages from around Lake Turkana collectively encompass a greater diversity in materials within and between sites. In comparison to the Njoro River Cave assemblage, ca. 3000 B.P. (Leakey and Leakey 1950), the pillar site assemblages differ in having a greater diversity of materials represented and in shape and other aspects of manufacture.

Specifically, we examine whether beads worn by pillar site peoples were produced from local sources (within a few days' walk) or acquired through long-distance journeys, trade, or exchange. Previous work on pastoralist bead production in the Nile Valley and Turkana Basin has emphasized the possibility of long-distance trade and exchange of amazonite (Zerboni et al. 2018) and shell (Nelson 1993, 1995). Our study gives equal attention to beads that may be locally derived and discusses the role that both geological and social landscapes played in the moving frontier (Lane 2004; Sawchuk et al. 2018) of early pastoralist expansion into the Turkana Basin.

Geological, Environmental, Economic, and Social Context

On both the western and eastern shores of Lake Turkana, Kenya, eastern Africa's earliest herders, ca. 5200–4300 CAL B.P., constructed monumental places known as "pillar sites," which are typically communal cemeteries featuring large platforms with low mounds, columnar basalt pillars, stone circles, and cairns (Hildebrand and Grillo 2012; Hildebrand, Shea, and Grillo 2011; Hildebrand et al. 2018; Klehm 2021; Sawchuk et al. 2019). These sites demonstrate group investments in labor to create shared, common spaces dedicated to ritual and mortuary purposes during a period of major environmental and economic change. During the mid-Holocene, lake levels were dropping dramatically and herding activities largely supplanted fishing and foraging. The interplay of geology, climate change, and economic transformation manifested in monumental structures and material elaboration, including the stone beads that are the focus of this article.

Geological context

As part of the East African Rift System (EAR; see Figure 1), the Turkana Basin contains a wide variety of Precambrian through Quaternary sedimentary, igneous, and metamorphic rocks. The topographically high, fault-bounded EAR rift shoulders and some intra-rift highs expose a Precambrian to early Paleozoic metamorphic and igneous basement that elsewhere has been buried by younger volcanic and sedimentary strata (Feibel 2011). In general terms and for the purpose of this study, this younger sedimentary and volcanic cover can be divided by age and lithology (Figure 2) into: 1) pre-rift, Mesozoic sedimentary rock, including Jurassic and Cretaceous limestone and sandstone; 2) rift-related Upper Oligocene to Pleistocene volcanic rocks; 3) Neogene sediments with lesser volcanic interbeds; and, 4) Quaternary alluvium, colluvium, dune sands, lacustrine deposits, paleosols, and pebble sheets derived from erosion or modification of all of the older units listed above and from deposition associated with Pleistocene to Holocene highstands and regressions of Lake Turkana (Bloszies, Forman, and Wright 2015). Each of these geologic units contains potential sources for rock or mineral bead materials.

Changing climate, environment, economy, and society

During the African Humid Period (AHP), which began between 14,800 and 12,000 CAL B.P. and ended between 5500 and 5000 CAL B.P. (reviewed by Costa et al. 2014; deMenocal et al. 2000), strong monsoons led to increased rainfall in many parts of Africa. Lake Turkana underwent a major transgression just after 12,000 CAL B.P., covering twice its present area and flowing over a sill into the Nile Basin. Aside from a brief, deep regression ca. 8200 CAL B.P., lake levels remained high until about 5300 CAL B.P. (Garcin et al. 2012; Owen et al. 1982). AHP archaeological sites show a fishing-hunting-gathering economy emphasizing aquatic fauna; barbed bone points ("harpoons") and pottery suggest that subsistence and material culture may have been shared across extended geographic areas. Human remains recovered from AHP contexts show no signs of individual ornamentation: to date, no beads made of rock, mineral, or ostrich eggshell have been found in early Holocene sites around Lake Turkana (Barthelme 1985; Beyin et al. 2017; Keding 2017; Mirazón Lahr et al. 2016; Phillipson 1977; Robbins 1972, 1974; Yellen 1998).

As the AHP ended, regional aridification caused Lake Turkana to drop and shorelines to retreat between 5300 and 3900 CAL B.P., opening new grassy plains along the shore and altering local vegetation and herbivore diets (Chritz et al. 2019; Garcin et al. 2012; Grillo and Hildebrand 2013). Livestock remains from the habitation sites of GaJi4 (Dongodien) and GaJi2 attest to the advent of herding by 4000 CAL B.P., around the time of these climatic shifts (Ashley et al. 2017; Barthelme 1985, 136–192; Marshall, Stewart, and Barthelme 1984). Remains of fish and other wild fauna from these sites indicate that people practiced a generalized form of multi-resource pastoralism (following Marshall, Grillo, and Arco 2011; Marshall, Stewart, and Barthelme 1984). Early pastoral sites on the western side of the lake are not well studied, but two have recently been recorded at Nakwaperit near the Turkwel River. The lowlands surrounding Lake Turkana likely served as a corridor through which pastoralists could have passed from either the southern Sahel or the Ethiopian Rift into eastern Africa (Grillo and Hildebrand 2013).

Dates from six pillar sites (Lothagam North, Manemanya, Jarigole, Kalokol, Lothagam West, and Il Lokeridede; see Figure 1) suggest that their construction sequences likewise coincide with Lake Turkana's dramatic regression at 5300–3900 CAL B.P. (Hildebrand and Grillo 2012; Hildebrand et al. 2018); the seventh, Aliel, is unexcavated but has a single surface sample dated to 5300–4980 CAL B.P. (Wilshaw et al. 2016). Four seasons of fieldwork at Lothagam North have revealed that it was a communal cemetery with a mortuary cavity that accommodated hundreds of individuals, buried together with thousands of ostrich eggshell beads, hundreds of stone beads, and organic ornaments made from ivory, teeth, and other animal bones (Hildebrand et al. 2018). The mortuary cavity also included a substantial assemblage of

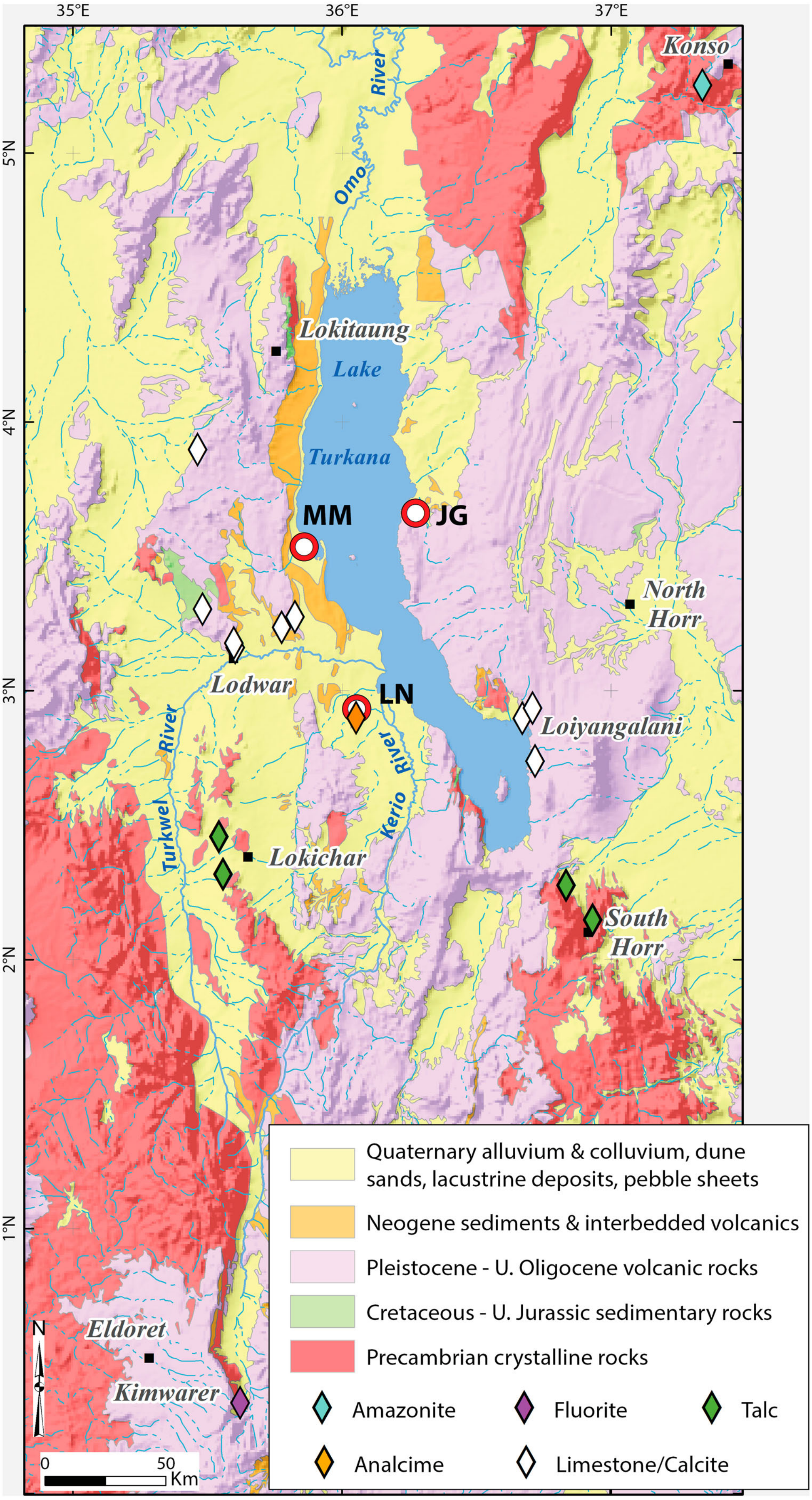

Figure 2. Geological map of the Turkana Basin area, Kenya, simplified after the Geological Map of Kenya (1987), indicating putative raw material locations within the Turkana basin for stone beads of this study, based on a field sourcing and literature survey (see text), that are most proximal to the three mortuary pillar sites. As noted in the text, possible limestone/calcite sources are more numerous than indicated here. Abbreviations: JG—Jarigole, LN—Lothigam North, and MM—Manemanya.

fragmentary Nderit tradition pottery (Grillo, McKeeby, and Hildebrand 2022) and an obsidian-based lithic assemblage (Goldstein 2019). Jarigole also had a mortuary cavity accommodating numerous burials and similar material culture, including a large assemblage of ostrich eggshell beads and stone beads (Nelson 1995; Sawchuk et al. 2022). Other pillar sites have not seen as much research and may or may not have such extensive mortuary components, although a single burial found at Manemanya was accompanied by elaborate ornamentation (Sawchuk et al. 2019).

Stone beads from pillar sites: recovery and significance

Of the six excavated pillar sites, three have yielded substantial assemblages of stone beads: Lothagam North and Manemanya, both on the western side of the lake, and Jarigole, located on the eastern side (see Figure 1). Radiocarbon dates from the pillar sites suggest use durations may have ranged from 312 (4853–4541 CAL B.P.) to 770 years (5270 to ca. 4500 CAL B.P.), with definite chronological overlap among Jarigole, Manemanya, Lothagam North, and Lothagam West (a ca. 1 km walk from Lothagam North); however, these sites may have had a more constrained series of Interment events (4856–4575 CAL B.P.) (Hildebrand and Grillo 2012; Hildebrand et al. 2018; Sawchuk et al. 2019).

Lothagam North (GeJi9) was excavated by the Later Prehistory of Lake Turkana (LPWT) project from 2009–2014 (Hildebrand and Grillo 2012; Hildebrand, Shea, and Grillo 2011; Hildebrand et al. 2018). The site sits between two prominent volcanic ridges that would have formed a peninsula jutting into Lake Turkana at the start of construction, before the lake retreated. More than two dozen pillars of basalt and sandstone cluster on the eastern side of the 30 m platform; nine other stone circles and six cairns lie to the east. Excavations focused on the platform's center (2 × 2 m unit) and its eastern (1 × 1.4 m unit) and western edges (1 × 5 m unit). Ground-penetrating radar showed a mortuary cavity in the center of the platform that would have accommodated an estimated minimum of 580 burials; 36 burials in total were recovered by LPWT (Hildebrand et al. 2018; Sawchuk et al. 2019). Personal ornamentation was common, with hundreds of ostrich eggshell beads accompanying ivory bangles, ivory plackets, ochre, and teeth from wild fauna such as lion (Hildebrand et al. 2018). Included among these burial goods were 303 stone beads and pendants, 173 of which were directly associated with burials (Hildebrand et al. 2018).

Manemanya (GcJh5) saw more limited excavations by LPWT: two test units in 2008 and 2009, one of which was expanded in 2012 (Hildebrand and Grillo 2012; Hildebrand, Shea, and Grillo 2011). Located ca. 70 km north of Lothagam, Manemanya lies on a plain 1 km east of the Losedok Hills, roughly halfway between a natural pass through the Losedok Hills and a spring at their base farther north. Its nine pillars cluster in two different areas. The surface is fairly flat, without a visible platform mound, but cobbles in a central area have a distinct size range that helps differentiate the site visually from the surrounding natural surface. The 2009 and 2012 excavations revealed more than a meter of upper fill that included pottery, ostrich eggshell beads, lithics, and (at the base) a burial. The individual was accompanied by teeth from wild fauna, 330 stone beads, and thousands of ostrich eggshell beads (Sawchuk et al. 2019).

The Jarigole Pillar Site (GbJj1) saw research by the Koobi Fora Field School (KFFS) from 1986 through the early 1990s. Jarigole Pillar Site is located near both Alia Bay and a permanent spring. The site has a low, mounded central area, with several emplaced and fallen pillars in various positions in and around the mound. KFFS excavations included a 5 × 2 m area from the center of the mound towards the northern edge and other extensions and test units (Nelson 1995). KFFS removed over 8 m^3 of mound fill, but excavations generally stopped short of deposits that may have contained primary burials. One primary burial was reported from an excavation unit on the northern side of the mound (Nelson 1995). We examined the 173 stone beads that KFFS recovered from Jarigole, which came from fill and were not in direct association with the primary burial (Nelson 1995). LPWT returned to Jarigole in July 2019 for renewed excavations and profiling (Sawchuk et al. 2022); beads recovered during the 2019 field season are not included in this analysis.

Three other contemporaneous pillar sites have seen more limited excavations. Lothagam West (GeJi10) and Kalokol (GcJh3) on the western side of Lake Turkana have not yielded stone beads (Grillo and Hildebrand 2013; Hildebrand and Grillo 2012; Hildebrand, Shea, and Grillo 2011). While the absence of stone beads so far is notable, more excavations are needed to determine whether it is due to sampling bias or a true difference. Excavations during the 1990s at Il Lokeridede (GaJi23), located on the eastern side of the lake, yielded three green stone beads (Githinji 1994; Koch et al. 2002). Finally, Aliel, a mound with a single monolith, has been surveyed and dated via surface material but not excavated (Wilshaw et al. 2016).

Pillar sites are architecturally diverse and demonstrate a range of mid-Holocene mortuary behaviors along the ancient shorelines of Lake Turkana (Hildebrand and Grillo 2012, 2022). They also contain variable types and distributions of material culture, which have thus far been little explored. Analysis of stone beads from Lothagam North, Manemanya, and Jarigole can shed light on one type of craft production that would have held social significance for pastoralists. Here, we demonstrate the breadth of mineral and rock types that early herders used to make adornments, evaluate potential sources, and discuss the implications of these data for understanding the mobility patterns of and/or social connections among pillar site builders.

Methods

This work represents the first mineralogical analysis of stone beads from Lothagam North and Manemanya. Cataloging and primary identification were done at the Turkana Basin Institute's Turkwel Research Station, Kenya, where these assemblages are curated. For Jarigole's stone bead assemblage, which is curated at the Nairobi National Museum, Nelson (1995) reported numerous raw materials, but some of the classifications were uncertain or entirely unknown, with counts being at times estimates. To ensure comparability between sites, we applied uniform classification procedures and groupings to all three assemblages.

Beads were photographed with a stand-mounted Dino-Lite digital microscope and a digital SLR camera with a CameraTrax™ color card in view for color correction. Rock and mineral identification relied primarily upon characteristics visible to the unaided eye and at up to

40X magnification with an optical microscope: color, texture, grain size, luster, cleavage, fractures, relative toughness, and hardness from abrasion and wear. Visual characteristics were supplemented with response to a hand magnet, reaction to long- and short-wavelength ultraviolet (UV) light, and, for select, representative beads, measurement of specific gravity. These procedures, which are non-destructive and could be accomplished with minimal handling, resulted in the designation of 13 raw mineral and rock types, described below and in Table 1. Some mineral types were given additional sub-classifications when significant variations (e.g., in color, texture, or mineralogy) were present, as they 1) may indicate a different source or 2) could have played a factor in selection. Cryptocrystalline quartz, for example, included a range of chalcedony, including carnelian (red chalcedony) and agate (banded chalcedony), as well as chert. As another example, limestone ranged in grain size and coloring and was therefore recorded with multiple subtypes (see Table 1).

Specific gravity (SG) can be a particularly effective, rapidly determined, property for separating, and in some cases identifying, materials with strong visual resemblance. Once fashioned into beads or ornaments, materials such as white calcite, zeolites, and ivory can look quite similar but have significantly different SGs. It is not as useful for distinguishing among or identifying polymineralic (i.e., rock or altered mineral) materials, in which slight modal mineral differences can produce significant differences in SG. Even so, it can prove useful as a gauge of differences among otherwise visually similar polymineralic materials.

Specific gravities were determined with an Ohaus SPE 123 Scout Pro portable balance, precise to 0.003 grams, by hydrostatic weighing. The SG apparatus (see Supplemental Material 1) is simple and well-suited for field use. To expedite analysis, SG was measured for one to four type specimens of each bead raw material type. Restricting SG analysis to a few specimens per material type or subtype minimized exposure and handling, limiting contamination and possible removal of residues that could be analyzed in the future. Accuracy, assessed by SG mineral standards with volumes and weights similar to those of tested beads and monitored during the measuring period, is 0.5–1%. SG errors reported in Table 1 are one standard deviation, derived from four or more replicate measurements if from a single specimen or derived from five or more measurements if from two or more specimens of the same type. SG measurements for small specimens like the beads of this study can be strongly affected by air trapped during the water immersion weighing process. This problem is particularly acute for beads with roughly textured surfaces and drill holes and for beads of small volume in general. Care was taken to dislodge adhering bubbles, and averages of replicate measurements are reported, but some SG results may be skewed to higher values for this reason. Specific gravity was measured for Lothagam North and Manemanya assemblages, when meaningful, but we were unable to measure SG for all of the Jarigole collections.

Of the 13 rock and mineral types observed, four could not be confidently identified by the above techniques, and three warranted further study: LPWT ID Codes A1, A2, and A3; R1 and R2; D; and, Z. Accordingly, seven beads were loaned to the University of Texas at Austin for nondestructive laboratory analysis (XRD, MR, and SEM-EDS) by M. H. Results are incorporated into the classifications below, with descriptions of these techniques and more detailed analytical results included in Supplemental Material 1.

To scout potential sources for bead materials, we conducted a pilot survey immediately following bead field identification and classification. In this remote area west of Lake Turkana, our survey efforts focused on rock and alluvial sediment exposures that were accessible from roads and short off-road driving and foot journeys and which—based on published geologic maps and reports (Dodson 1971; Joubert 1966; Ochieng et al. 1988; Walsh and Dodson 1969)—warranted examination as potential source materials. The 2015 survey covered four main routes across a total of 780 km in seven days (see Figure 1). First, we visited Lothagam to identify rocks and minerals within a day's walk of Lothagam North Pillar Site. Second, we made a two-day counterclockwise loop north of Lodwar, first heading northeast to visit volcanic outcrops and Neogene sediments on the eastern and western flanks of the Losedok Hills, in order to examine raw materials in the vicinity of Manemanya; we then headed north to Lokitaung and crossed nearby Mesozoic formations and Cenozoic volcanics; finally, we traveled southwest back to Lodwar, passing through volcanics of various ages, plus remnant outcrops of Cretaceous and Precambrian rocks. A third sourcing excursion headed west out of Lodwar toward the Ugandan border, and a fourth (multiday) journey explored areas near Lokichar. Geological specimens were collected for comparison of some of the more challenging specimen classes to identify.

Results

Bead mineralogy

We examined 806 stone beads from Lothagam North (303), Manemanya (330), and Jarigole (173). These numbers vary slightly from Nelson (1995), Sawchuk and colleagues (2019), and Klehm (2021) but represent the most accurate assessment after 1) reexamination of the Jarigole assemblage by the authors and 2) further scrutiny of the Lothagam North and Manemanya data and mineralogical classifications. Classification yielded 13 primary rock or mineral types, with additional secondary types where warranted by unique mineralogical or textural characteristics.

Characteristic type specimens, identified by LPWT catalog numbers (for Lothagam North and Manemanya) and National Museums of Kenya (NMK) collection accession number (for Jarigole), were designated for all types (see Table 1). From most to least abundant, the primary bead types, described in Table 1 and counted by locality in Table 2, are calcite, microcline (amazonite), zeolite (principally analcime), volcanic rock, limestone (discussed below with calcite), cryptocrystalline quartz (especially chalcedony, with one chert), fluorite, and talc (schist). Hematite-cemented sandstone, arkosic sandstone, an iron precipitate, and gypsum and/or dolomite each number as singular artifacts and are not elaborated upon below, but are described in Table 1 and included in Table 2. One bead from Lothagam North and seven from Jarigole could not be mineralogically identified due to poor preservation and are marked as Unknown in Table 2. Subtypes were identified in several categories where additional visible and/or mineralogical characteristics warranted division (e.g., would have come from distinct sources or may have been intentional in selection).

Table 1. Table of the 13 mineral and rock types of the stone beads from the Turkana pillar sites of Lothagam North, Manemanya, and Jarigole. Each mineral identification (and, as relevant, subtype) includes a description of color, visible characteristics, specific gravity (as relevant), type specimens for future comparison, and the specific ID code used in the LPWT database and on the collection bags.

Mineral/Rock ID	Subtype	Sites	Color	Visible Characteristics/Comments	Specific Gravity	Type Specimen(s)	LPWT ID Code
Microcline (Amazonite)	N/A	Lothagam North, Jarigole	Light blue to turquoise blue	Light to medium blue to greenish blue with off-white perthitic lamellae that range from fine to coarse in width and sparse to dense in number; examined by Micro-Raman and XRD	2.56 ± 0.01	4674	Z
Zeolite	Analcime	Lothagam North, Jarigole	Orange pink to light pink, with variably developed white surface coating and some with white interior regions	Identified by x-ray diffraction, Micro-Raman, and SEM-EDS; pale pink-orange, variably covered by a white exterior coating; white coating is porous; translucent to opaque, brittle, with conchoidal fractures; beads are commonly broken or fragmented	2.28 ± 0.0078	4221.01.01, 7026.01.01, 5430.06.01, 6150.03.01, 4595.01.01, 7252.05.03	A1
	Analcime with phillipsite	Lothagam North	Creamy white with some orange or pinkish material exposed at the surface	Identified by x-ray diffraction, Micro-Raman, and SEM-EDS; opaque to weakly translucent, creamy white, weakly to moderately lustrous; appears to be quite soft, but has good polish; white analcime represents one end of the color spectrum with orange, with mixed orange and white between; white analcime bead coatings suggest that at least some white analcime was produced authigenically from orange analcime upon burial; some of these beads may once have been entirely orange	2.2	4512.01.01, 4782.01.01	A2
	Scolecite/mesolite	Lothagam North	Creamy white	Identified by x-ray diffraction, Micro-Raman, and SEM-EDS; white, smooth, lustrous, uniform in texture and color	2.2	4782.01.01	A3
Talc	N/A	Lothagam North	Yellow-green brownish, with black flecks	Examined by x-ray diffraction, Micro-Raman, and SEM-EDS; yellow-green to brownish, coarsely crystalline with metallic, black granular clots, and small single crystals (rare) of magnetite; greasy luster; contain disseminated small whitish spheres visible at 10x magnification	TS2, 2.78 ± 0.008	5546.01.01, 7287.06.01, 4846.01.01	D
Limestone	Stromatolitic limestone	Lothagam North, Jarigole	Rough textured white and gray or white-gray and brown banding	Highly porous, deeply weathered and etched banded carbonate; gray and white, deeply etched to reveal the bladed habit of the carbonate; looks like palisades of carbonate sheaves in mm scale layers; texture and banding strongly resemble stromatolitic layering	Not measured	4815.01.01, 4674.01.01	J1
	Fine-grained white limestone	Jarigole	Beige-white to creamy white	Smooth textured, slightly etched	TS1, 2.56–2.74	41156, 41920, 18032, 50992	J2
	Medium-grained limestone	Jarigole	Orange-pink to orange-yellow	Medium grained, light tone, orange pink to orange-yellow, bladed to fibrous, often without a coating; interiors have vitreous luster; rarely granular	TS1, 2.70 ± 0.005	60908	J4
	Pisolitic limestone	Jarigole	Creamy white with black patches	Pisolitic limestone with MnO crust variably developed; pisolites variably zoned, with concentric calcite exterior and coarse fibrous calcite interior; outer fine-grained calcite is deeply weathered, inner less so and stands out in relief; inner calcite fibers radially arranged	Not measured	22857	J5
	Fine-grained orange-brown limestone	Jarigole	Rusty orange-brown	Rusty orange-brown carbonate with patchy developed drusy calcite crust and drusy calcite-lined mm-scale vugs; interior nowhere exposed, but softness suggests carbonate	Not measured	42237	J6
	Granular limestone	Jarigole	Soft pink	Porous orange-pink, vitreous, granular with 1 mm and smaller pores coated with chalky-red substance; looks vesicular and dull chalky red, salmon pink to naked eye; variably coated with honey brown granular fine-grained crystals; chalky, porous exterior distinguishes from J4	2.61 ± 0.02	11343	J8

(*Continued*)

Table 1. Continued.

Mineral/Rock ID	Subtype	Sites	Color	Visible Characteristics/Comments	Specific Gravity	Type Specimen(s)	LPWT ID Code
Calcite	Pedogenic calcite	Manemanya	Chalky mottled pink with black and white coating	Identified by x-ray diffraction, Micro-Raman, and SEM-EDS; porous, soft, microcrystalline calcite, containing sparse dark red angular patches that are 250–500 microns in size and contain rare very fine grains of white tabular feldspar and dark rock fragments; most material is pale red to pink; most have a variably developed 100–150 micron thick white crust that coats the bead; black pyrolusite dendrites, a product of weathering, are prominent on bead surfaces, rendering some nearly black	2.505 ± 0.007	3251.01.01, 3247.01.04	N1
	Pedogenic calcite	Manemanya	White chalky with spotty black and white coating	Porous, microcrystalline, weathered to chalky white; has pores up to 1 mm in diameter, spherical to elliptical to less regular in shape; not crystal-lined; black pyrolusite dendrites, a product of weathering, are prominent on bead surfaces	TS1, 2.453 ± 0.002; TS2, 2.465; TS3 2.407 ± 0.007; TS4 2.5 ± 0.006; range due to variable porosity	3239.01.01, 3239.01.03, 3233.01.02, 3251.01.01, 3233.01.03	N2
	Vein calcite	Manemanya	Yellowish-white to brown	Slightly rough texture; weakly etched and weathered; rough texture, but not porous; pink long-wave UV fluorescence, dull red in short wave; black pyrolusite dendrites on outer surface, product of weathering, although less abundant than on pedogenic beads; some have microveins of the same material as the host that stands out in relief on the weathered outer surfaces of the beads; beads that are more obviously etched show fibrous, bladed, and columnar calcite crystal habits, with fibers aligned subparallel to the bead holes	TS1, 2.693 ± .01; TS2, 2.719 ± 0.004; TS3, 2.58 ± 0.01; TS4, 2.834 ± 0.001 (variation due to MnO)	3239.01.05, 2810.01.01, 2740.01.01, 3251.01.02	R1
	High-magnesium vein calcite	Manemanya	Mottled beige and white	Identified by x-ray diffraction; opaque, rough textured, with sub-mm, fibrous calcite aligned parallel to the bead hole	Not taken	3203S.01.01, 3239.01.07	R2, initially labelled J1 or Ivory
	Granular calcite	Jarigole	Honey yellow	Massive honey-yellow granular vitreous calcite; no appreciable coating; hardness approximately 4	2.71 ± 0.002	46235	R3 (J7)
	Medium-grain, arkosic calcite	Manemanya	White and gray with black staining	Chalky white feldspar, glassy gray quartz grains floating in calcite cement; fine black particles that may be biotite grains or from soil; surface very rough, carbonate cement partially dissolved; distinguished from N2 by abundance of mineral grains	TS1, 2.635 ± 0.013	3239.01.06	P
Chalcedony	Generic chalcedony	Lothagam North	Pale yellow, white, pink-orange, orange	Smooth exterior with crescentic percussion marks consistent with natural shaping and wind-polishing (sand-blasting); ranges to pink-orange hues	TS1, 2.597 ± 0.003	6141.01.01	G1
	Carnelian	Lothagam North, Jarigole	Red to deep red	Smooth, slightly translucent with percussion marks on external surfaces consistent with natural shaping and polishing; one sample has a fine-grained drusy quartz crystal interior parallel to the drill hole	TS1, 2.597 ± 0.004	4773.01.01, 2202.01.01	G2
	Agate	Jarigole, Lothagam North	White with gray-blue or black banding	Banded chalcedony of botryoidal habit; one has mm-scale, crystal-lined vugs	Not measured	4154.01.01, 40508, 58942	G3
Fluorite	Generic fluorite	Lothagam North, Jarigole	Faint purple, pink, pale yellow	Translucent, purple to pink hues of light tone; outer surface grainy, not well-polished, roughness shows small flats that glitter; microcleavage plane flashes; fluoresces purple (moderate to weak) in long-wave UV light	TS1, 3.175 ± 0.003	4347.04.04, 4347.04.01, 6526.001.02	F1
	Fluorite with cloudy white matrix	Lothagam North	Light purple with opaque white calcite matrix	62–88 micron, weakly translucent, light purple fluorite grains in cloudy white (calcite) matrix; not highly polished, with surface irregularities	TS1, 3.153 ± 0.007; TS2, 3.146 ± 0.11	4906X.03.02, 4906X.02.01, 4812.01.03	F2
Volcanic	Andesite or phonolite		Gray with white-veined material		Not measured		C1

(*Continued*)

Table 1. Continued.

Mineral/Rock ID	Subtype	Sites	Color	Visible Characteristics/Comments	Specific Gravity	Type Specimen(s)	LPWT ID Code
		Lothagam North		Gray with white vein material or chalcedony; at 16x magnification, vitreous lathes of groundmass plagioclase and larger square to rectangular 1–2 mm phenocrysts of feldspar and square- or diamond-shaped phenocrysts of black cpx or hbl (sparse, about 0.5 mm); encrusting white patina was there before bead was made, maybe vein material, calcite? Not coated due to weathering		7239.01.04, 7239.01.01, 7227.01.01	
	Rhyolite	Lothagam North	White and gray	Microporphyry composed of crystal clots of white feldspar and gray quartz and weathered grey-brown groundmass; feldspars are white to glassy-colorless, with cores typically whitish and rims transparent; likely from lava flow; contains no lithic clasts or pumice (cf. ash flow tuff)	Not measured (too fragile)	6259.01.02	C2
	Amygdaloidal basalt with quartz phenocrysts	Lothagam North	Bluish gray and spotted with quartz phenocrysts	Blue-gray, amygdaloidal; amygdule fill is crystals of white calcite (?) or zeolite (?); bladed, fan-like habit; chalcedony in some amygdules; white amydules give a spotted appearance on dark background; xenocrysts (?) of quartz (rounded, gray, vitreous blebs) and phenocrysts of feldspar (white rectangles and squares)	Not measured	5406.01.01	C3
	Amygdaloidal basalt with chalcedony	Lothagam North	Black with white spots	Amygdaloidal basalt; amygdules filled with white chalcedony, some with drusy centers; black basalt has weathered pits that were likely once filled with olivine and/or augite phenocrysts	Not measured	5489.01.01	C4
	Microdiorite or holocrystalline andesite or phonolite with white vein quartz	Lothagam North	Black with brownish-red rims, with white veins	Gray to white microporphyry with black prismatic hornblende; relict (?) black, less euhedral phenocrysts of pyroxene with brownish-red fibrous rims (ilmenite going to rutile?); gray to white groundmass nearly entirely crystalline plagioclase and quartz with flecks of very fine biotite (?)	Not measured	4812.01.01	C5
	Phonolite with prominent chalcedony blobs	Lothagam North	Two-tone whitish-pink and blue-gray	Blue-gray, nearly aphanitic; plagioclase lathes visible at high magnification comprise ground mass but not phenocrysts; white irregular blobs of chalcedony, some with outer megaquartz rinds	Not measured	4906.03X.01	C6
	Vesicular basalt	Jarigole	Blackish gray	Unfilled vesicles are mm scale	Not measured	13151	C7
Chlorite	N/A	Lothagam North	Dark green	Fine-grained chlorite schist, with greater than or equal to ca. 80% chlorite	Not measured	7042.01.01	H
Sandstone	Arkosic sandstone	Lothagam North	White and black	Medium-grained sandstone with black staining; also likely calciche sourced	Not measured	3239.01.06	P
	Hematite	Lothagam North	Black, silvery	Weak silvery metallic luster on black body color; hematite cemented or replaced sedimentary rock—fine-grained sandstone or siltstone; at 40x mag, can see red-stained vitreous quartz grains; non-magnetic	3.917 ± 0.019	5458X.01.01	I
Chert	N/A	Jarigole	White with yellow staining	Heavily coated with chalky white crust, variably stained yellows; containing mm-scale cavities	Not measured	13970	Q

Table 2. Comparison of stone bead types and quantities from the Turkana pillar sites of Lothagam North, Manemanya, and Jarigole. Total percentages of mineral types across all sites are also included.

Type	Total %	Lothagam North Count	Lothagam North %	Manemanya Count	Manemanya %	Jarigole Count	Jarigole %
Mineral Beads							
Zeolite							
Analcime	16.9%	136	44.9%			6	3.50%
Scolecite/mesolite	0.12%	1	0.33%				
Microcline (amazonite)	18.2%	97	32.0%			50	28.9%
Fluorite	2.73%	10	3.30%			12	6.93%
Calcite	41.1%	1	0.33%	330	100%		
Gypsum or calcite/dolomite	0.12%	1	0.33%				
Cryptocrystalline quartz							
Chalcedony	3.97%	16	5.28%			16	9.24%
Chert	0.12%					1	0.58%
Rock Beads							
Volcanic	1.61%	12	3.96%			1	0.58%
Metamorphic							
Talc (schist)	2.23%	18	5.94%				
Chlorite schist	0.12%	1	0.33%				
Sedimentary							
Sandstone, arkosic	0.12%	1	0.33%				
Hematite-cemented	0.12%	1	0.33%				
Limestone	10.70%	6	1.98%			80	46.2%
Other							
Iron precipitate	0.12%	1	0.33%				
Unknown	0.99%	1	0.33%			7	4.05%

Subtypes are included for the zeolites, limestones, calcites, chalcedonies, fluorites, volcanic rocks, and sandstones and are identified uniquely in their LPWT ID Code (see Table 1). Collectively, the rock and mineral categories range widely in appearance, offering a strikingly diverse set of beads which vary by site (Figures 3–5; see Table 2). Laboratory analysis permitted distinction of zeolite and calcite subtypes and provided additional information for talc and amazonite beads (see Supplemental Material 1). Although sites show some overlap among rock and mineral categories, each site contains a unique assemblage with distinct materials and representation of mineral and rock types (see Table 2).

Coarse- to medium-grained calcite is the sole or major mineral in six bead subtypes (see Figure 4), and fine- to medium-grained calcite is the main constituent of six subtypes of limestone beads (see Table 1, Figure 6). As described below, calcite bead subtypes differ primarily by combinations of differences in surface texture (rough unpolished vs. smooth, polished), purity (pure calcite vs. calcite enclosing other minerals), grain size and habit (coarse-grained fibrous vs. medium- to fine-grained equant to indistinct), and color (creamy yellow white to pale pink to mottled and speckled pink or white). Limestone beads are distinctive in being uniformly finer-grained and mineralogically homogeneous and in some subtypes preserve primary depositional features. Calcite beads are found almost exclusively, and abundantly, at Manemanya, with limestone beads a common occurrence at Jarigole (see Table 2). Only a few limestone beads and only one calcite bead were identified within the Lothagam North assemblage. Specific gravity of the calcite and limestone beads vary by subtype and by other factors (e.g., calcite was variably pure), but average 2.41–2.72 depending on the subtype of calcite and 2.51–2.74 for various limestone subtypes.

Amazonite is a color-based varietal name for alkali feldspar that is blue to green microcline or, more rarely, green

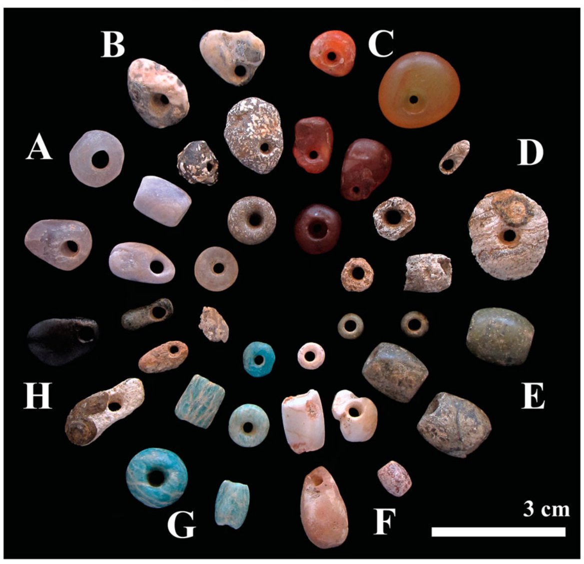

Figure 3. Range of minerals and rock types of the stone beads from Lothagam North. These include: A) fluorite, B) volcanics, C) chalcedony, D) stromatolitic limestone, E) talc, F) analcime, G) amazonite, and H) assorted other bead types, including hematite, chlorite, limestone, iron precipitate, and an unknown sedimentary rock. Scolecite, not pictured here, is shown in Figure 8.

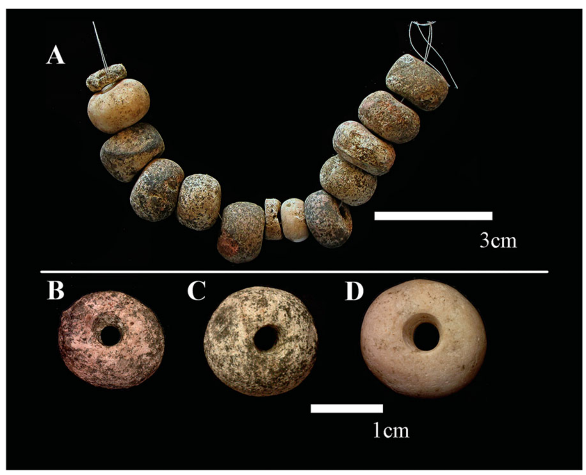

Figure 4. Stone beads from Manemanya. A) A bead strand found in situ, B) pink pedogenic calcite (N1), C) white pedogenic calcite (N2), and D) yellowish-white vein calcite (R).

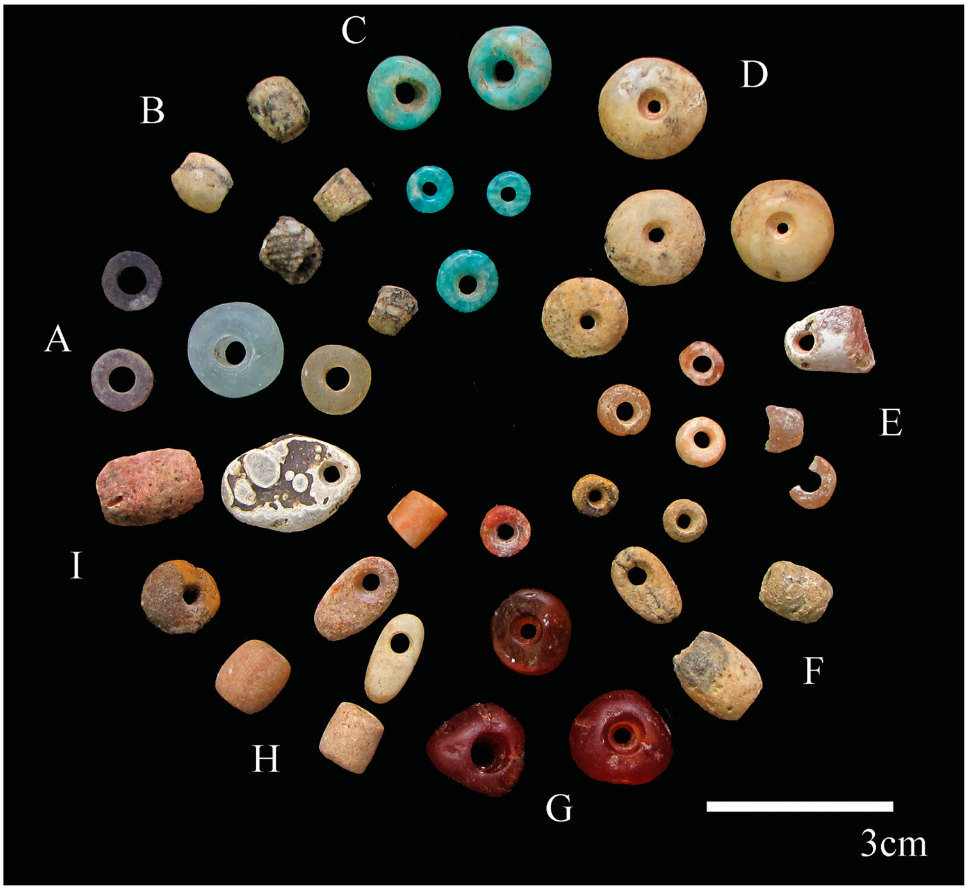

Figure 5. Range of minerals and rock types of the stone beads from Jarigole. This includes: A) fluorite, B) agate, C) amazonite, D) fine-grained limestone, E) analcime, F) fine-grained orange-brown limestone, G) carnelian, H) medium-grained orange-pink limestone, and I) assorted beads (i.e., fine-grained, pisolitic, and granular limestone).

orthoclase (Hofmeister and Rossman 1985; Figure 7). It is the second most common bead type at Lothagam North and Jarigole but notably absent from the assemblage at Manemanya (see Table 2). It is the most distinctive and easily recognizable material in the bead assemblages. Probably because of its hardness and toughness, nearly all amazonite beads retain a high luster and show little to no signs of chemical weathering or alteration. All amazonite beads are perthitic, composed of blue to blue-green microcline with millimeter to submillimeter, wormy to patchy white perthite intergrowths. The rich blue-green tone of the microcline diminishes as the abundance and size of the white perthite increases (see Figure 7). Perthite is produced during crystallization by unmixing of a single alkali feldspar into sodium

Figure 6. Limestone disks, pendants, and beads from Jarigole. A) Fine-grained white limestone (J2) ear disks, B) soft pink to orange-pink granular limestone (J8) crescent-shaped pendants, and C) other limestone beads. Note that calcites are pictured in Figure 4.

Figure 7. Amazonite stone beads and pendants from Lothagam North. These are arranged by hue, with beads with the least number and thinnest perthites in the upper left corner and the densest and thickest perthites in the lower right corner.

(albite perthite)-rich and potassium (microcline or orthoclase)-rich phases (Deer, Howie, and Zussman 1992, 402–405) during cooling. Macroscopic perthite is indicative of crystallization during slow cooling (Deer, Howie, and Zussman 1992), and perthite is a common if not ubiquitous feature in microcline amazonite (Hofmeister and Rossman 1985). The abundance, size, and shape of perthites is equally diverse in amazonite from both the Jarigole and Lothagam North bead assemblages, producing similar ranges of hues and tones for both localities. Such variation is not uncommon within a single source (Ostrooumov 2016) so need not be indicative of multiple sources. The SG of a single amazonite bead is 2.56 ± 0.01, with greater variation expected with greater or lesser amounts of perthite.

Zeolites are a large group of relatively soft, low density, hydrous silicate minerals that have in common an aluminosilicate framework containing loosely bonded alkali and/or alkaline earth cations. Individual zeolite minerals can be challenging to identify, often having similar physical and optical properties and occurring together with other zeolites as intergrown crystal clusters. Positive identification of analcime and mesolite/scolecite beads relied upon XRD and/or MR to characterize the framework geometry. When necessary, SEM-EDS provided supplemental compositional information to further narrow or identify specific zeolites (see Supplemental Material 1), as noted below. Pale orange analcime beads with variably developed white coatings are the most common beads in the assemblage at Lothagam North and occur with much less frequency at Jarigole (Figure 8; see Table 2). They are absent at Manemanya. They are a distinctive vitreous, pale orange color and are the least durable of all beads in the assemblages: ca. 60% of analcime beads at Lothagam North are broken or exist as bead fragments. Specific gravity, determined from 11 measurements of two beads, is 2.28 ± 0.078. Nearly all analcime beads have an opaque, rind-like matte white coating that partially or entirely obscures a pale orange interior (Figure 8A). The coating mimics the bead shape and is of nearly uniform thickness on many beads, indicating it most likely formed by alteration or replacement of the pale orange analcime after the beads were constructed and is not a primary aspect of the bead mineralogy. This is a natural (i.e., non-anthropogenic) post-manufacture alteration. Partial dehydration of analcime is known to produce this whitening effect (Tschernich 1992, 31), but whether in this case it occurred during use or after burial cannot be determined. Orange bead interiors exposed in broken beads also often display less lustrous opaque white material in irregular patches that, when surface-reaching, are similarly coated (Figure 8B, 8E). Laboratory analyses of the orange inner portion and white outer coating of two analcime bead fragments indicate that, despite the difference in color, both are composed of analcime; however, the interior white portions have MR spectra and SEM-EDS compositions more consistent with phillipsite (see Supplemental Material 1). A lustrous opaque white crescentic bead from Lothagam North (Figure 8C) is also composed of zeolite minerals. Resembling polished ivory but with a specific gravity of 2.2, this bead is the sole example of this material type. A bead composed of a cryptocrystalline fibrous aggregate of ca. 2/3 scolecite and 1/3 mesolite best satisfies the joint SEM-EDS, MR, and XRD results (see Supplemental Material 1).

Chalcedony, the fibrous variety of cryptocrystalline quartz, is present both at Lothagam North and Jarigole (see Table 2, Figure 9). We use chalcedony as the mineral type, despite variations in color, due to its mineralogical uniformity, while noting variation in terminology that the gem and archaeological communities might use (cf. Rapp 2009). We recognize subtypes of red and dark red chalcedony as carnelian and white chalcedony with gray-blue or black banding as agate. Chalcedony is a hard and tough material; notably, most chalcedony beads in the Lothagam North and Jarigole assemblages have microscopic crescentic percussion marks on their surfaces, implying they were wind-polished by sand-blasting and thus likely collected as pebbles (see Figure

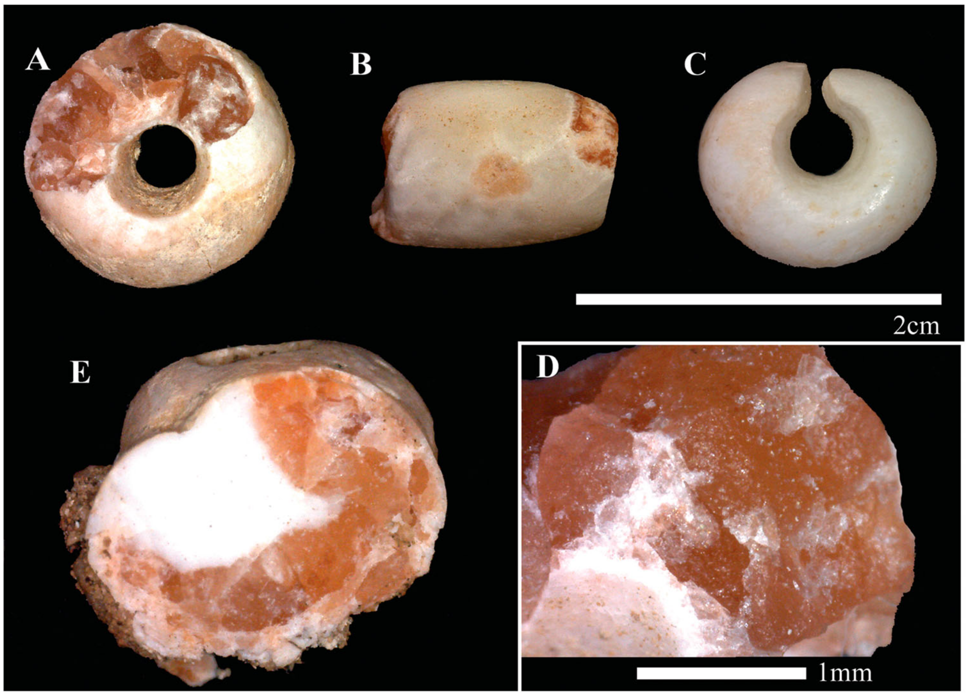

Figure 8. Zeolites from Lothagam North. A) Broken bead with an orange analcime interior and white analcime coating (A1), B) bead of predominantly white analcime (A2), C) crescentic bead of scolecite/mesolite (A3), D) close-up of the interior of a broken orange analcime (A1) bead, and E) broken bead with interior regions of orange analcime and white phillipsite, both coated by a white analcime exterior (A2).

9). Specific gravity for carnelian and other chalcedony (i.e., non-carnelian and non-agate) beads are nearly identical: 2.6 ± 0.003; agate SG was not measured.

Fluorite, another mineral of variable hue and tone, is also only present at Lothagam North and Jarigole (Figure 10). In contrast to chalcedony, fluorite is relatively soft and easily cleaved, and thus quite easy to work. All fluorites from Lothagam North and Jarigole are translucent, with hues ranging from faint purple to pink to pale yellow. Some contain areas of white coarsely crystalline calcite matrix, indicative of a source from recrystallized limestone or marble. Beads without matrix exhibit moderate to weak purple fluorescence in long-wave UV. Outer surfaces of all fluorite beads are rough to the touch and not well-polished. At magnification, roughness can be seen to be the consequence of the intersections of a myriad of small, smooth, flat micro-cleavage planes that glitter and flash when moved beneath a light. Specific gravity ranges from 3.15 ± 0.11 for a type specimen with matrix to 3.18 ± 0.003 for a type specimen without noticeable matrix.

Present only within the Lothagam North assemblage are 18 opaque, dark brownish green to yellowish green beads with a greasy to waxy luster that contains mm to sub-mm grains of a black metallic ferromagnetic mineral (Figure 11). Color, luster, and attraction to a magnet are the most distinctive properties of these beads, which are also notable for numerous, sometimes deep, white scratches on the surface, indicating a soft material. SG for a bead with the fewest metallic grains is 2.78 ± 0.008. Laboratory analyses show the green material in these beads is talc and that the black metallic grains are an oxide composed dominantly of iron but containing ca. 5–7% by weight chromium, consistent with chromium-rich magnetite (see Supplemental Material 1). We note that talc is commonly characterized in archaeological literature as soapstone (Eddy 2013, 15–17; Williams and Rosenthal 1993, 29–30). However, soapstone is a mineralogically ill-defined term that includes materials that are not talc. For example, soapstone deposits near Kisii, Kenya, are

Figure 9. Chalcedony and carnelian pendants from Lothagam North. Carnelian beads from Jarigole are shown in Figure 5G.

Figure 10. Fluorite beads from Lothagam North. Beads at the 12, 1, and 6 o'clock positions contain less translucent areas of dull white coarse calcite matrix. Fluorite colors in the Jarigole collection are shown in Figure 5A.

Figure 11. Small and large talc beads and a single talc pendant from Lothagam North.

composed of kaolinite and sericite (i.e., fine-grained mica). To avoid confusion, talc, rather than soapstone, is preferred and used here.

Raw material sourcing

As noted earlier, identification of the material types helped direct the sourcing survey around Lake Turkana. The nearest bedrock or surficial source locations we were able to identify from our sourcing survey or from published geological studies (e.g., Dodson 1971; Feibel 2011; Joubert 1966; Ochieng et al. 1988; Walsh and Dodson 1969) for some of the most distinctive and abundant materials, including analcime, talc, fluorite, limestone, calcite, and amazonite, are indicated in Figure 2. Although by no means exhaustive in scope, the literature survey shows there are possible sources for most of these materials within ca. 150 km of the archaeological sites where beads were recovered. The most notable exceptions are amazonite and fluorite, for which the closest known sources are respectively > 225 and > 350 km from the pillar sites where these materials were recovered. Alluvial sources for some materials are also likely. Tougher and harder materials (e.g., chalcedony, fine-grained limestone, and volcanic rock of several types) are capable of surviving river or stream transport and could logically be collected as pebbles well removed from their in situ occurrences: their "secondary source" would be alluvial in origin. This might not be the case for softer, more easily abraded, and/or cleaved minerals such as talc, analcime, and perhaps fluorite.

The sourcing survey began near Lothagam North, as zeolites, calcites, and chalcedony are known to be common throughout the basaltic and alkalic volcanic rocks nearby (Dodson 1971; Ochieng et al. 1988; Walsh and Dodson 1969). Of particular note are occurrences of orange analcime suitable for beads within an analcime-rich altered tuff (the so-called "Marker Tuff") at the base of the upper member of the Nawata Formation in the Lothagam Hills (Feibel 2003), described further below. Analcime and other zeolites within volcanic rocks of the Rift are elsewhere commonly colorless, microcrystalline, and intergrown with other minerals, unlike the relatively pure, macrocrystalline bead material from Lothagam North and Jarigole, so these occurrences are rare.

The geological literature for the Turkana Basin suggests a likely presence of coarse-grained analcime and other zeolites in the Pliocene stratigraphy of Lothagam (Feibel 2011). Although these were not examined during our 2015 field survey, previous geological surveys such as Powers (1980) provide clues to sources that should be examined in the future. Approximately 300 m east of the site of Lothagam North, a marker tuff that runs for several kilometers on a north-south axis separates the upper and lower Nawata Formation. Analcime-rich mudstones and replaced tephra are located near the marker tuff. Although much of the tuff and mudstone would likely not have yielded analcime of sufficiently good quality and purity of color for stone beads, the marker tuff located at the "Crystal Palace," an east-west canyon at the upper reach of the Nawata River, contains prominent veins of coarse sparry calcite or analcime within fractures. Here, and especially just south of this location—along the floor of a *laga* (gully) that drains southward from the Galana Boi tombolo—are swarms of mineral veins that are 0.5–1 cm wide (C. Feibel, personal communication 2017). Given its nearby location with respect to Lothagam North and the rarity of macrocrystalline orange analcime, this is a highly likely source for the site's analcime beads.

Farther from Lothagam (≥ 50 km) but still on the western side of the lake, Precambrian metamorphic rocks (see Figure 2) contain talc, chlorite schist, and pegmatites, the last a host for amazonite elsewhere (Hofmeister and Rossman 1985; Joubert 1966; Walsh and Dodson 1969). Along the Kalokol River where it emerges from the Losedok Hills (see Figure 1), river sediment contains abundant chalcedony and amygdaloidal volcanic pebbles and cobbles. Rock outcroppings along the A1 Highway between Lodwar and Nadwat (see Figure 1) include phonolite and rhyolite in the Muruangapoi Hills and Precambrian gneisses, schists, and granitoids in the Murianachok Hills near Nadwat. Phonolite and rhyolite, along with basalt, were noted during a trip north along the western shore of Lake Turkana to Lokitaung (via the Lokitaung Gorge) that returned to Lodwar via the C47 through the Moruerith Hills and points south (see Figure 1).

Substantial areas of Precambrian rocks are present near Lokichar, west of the road between Lokichar and Lodwar (Dodson 1971; Joubert 1966; see Figure 2), and on the eastern side of the lake north of Loiyangalani (Ochieng et al. 1988). These include talc schists, metaserpentinite, and granitoids as potential sources for the green beads. Samples of metaserpentinite and ultramafic rocks were collected from three localities; attempts to examine and collect talc schists were unsuccessful.

The search for amazonite sources included limited Precambrian exposures west of the Losedok Hills north of Lodwar and among exposures south of the Turkana pillar sites. None were discovered. Within the literature, the closest known potential source of amazonite occurs near Konso in southern Ethiopia (Zerboni et al. 2018; see Figure 2), approximately 225 km northeast of the Jarigole pillar site. With vast areas of more proximal Precambrian crystalline rocks along the western rift shoulder and near South Horr not mapped geologically in any detail, it is plausible that a now-defunct amazonite pegmatite source(s) might have existed. It should be noted that the Konso locality has no documented evidence for early quarrying, as is known for sources in southern Egypt (Harrell and Osman 2007) and the Tibesti mountains in northern Chad (Zerboni et al. 2017).

Equally elusive is a proximal source for fluorite. The nearest documented source is at Kimwarer, southern Kerio Valley (Nyambok and Gaciri 1975; see Figure 2), about 40 km east of Eldoret and approximately 300 km south-southwest of Lothagam North. Notably, Kimwarer fluorite occurs within white marble, and fluorite there is pale violet, yellow-brown, dark gray, and colorless. These characteristics align with the white, coarsely crystalline calcite matrix and various colors of some fluorite beads at Lothagam North and Jarigole, suggesting this very well may be the source (see Table 1). If not sourced directly from this distant deposit, then perhaps fluorite from Kimwarer was available more locally in lower Kerio River Valley alluvium. Fluvial transport from the upper to lower Kerio River Valley near Lothagam North (see Figures 1, 2) is plausible, particularly for fluorite attached to calcite matrix, which would render it tougher and better able to survive abrasion than fluorite alone.

Prospective local calcite and limestone sources are, in contrast, numerous. These include Pleistocene–Holocene lacustrine and palustrine carbonates associated with terraces and paleoshorelines of Lake Turkana, alkali spring deposits, pedogenic carbonate (Ochieng et al. 1988; Walsh and Dodson 1969), and limestone interbeds within Upper Oligocene to Pleistocene volcanic and sedimentary rocks (see Figure 2; Feibel 2011). Mineralogical characteristics of the majority of calcite beads from Manemanya (Types N1 and N2; see Table 1)—including their porous texture, low specific gravity, inclusions of other mineral and rock grains, and, for some, their pale pink color—point to a pedogenic origin from calcite duricrust, calcrete, or caliche nodules, of which numerous to near ubiquitous occurrences have been noted within Neogene and Quaternary sediments on both the western and eastern sides of the lake (see Figure 2; Ochieng et al. 1988; Walsh and Dodson 1969). Of particular note with respect to Manemanya beads may be the local accumulations of caliche nodules near the base of Lodwar Cone, the volcanic edifice approximately 6 km north of Lodwar (see Figure 1; Walsh and Dodson 1969). Other local sources for such material, as described by Walsh and Dodson (1969, 30), are " … superficial limestones … flanking the Mruangapoi Hills and on the Lodwar to Lokitaung road … " comprising " … broad flat expanses of nodular pea-sized kunkar limestone of varying shades of off-white and pink, sometimes with heavy admixture of soil and sand (as observed northeast of Lodwar) but more often virtually pure limestone." The vein calcite beads from Manemanya (Type R1; see Table 1, Figure 4D) may also be pedogenic, having formed by recrystallization of pedogenic calcite during repeated wetting and drying cycles (cf. Freytet and Verrecchia 2002). Stromatolitic limestone beads (Type J1; see Table 1, Figure 3D) are distinctive for their layered structure and highly porous texture. Possible sources exist on both sides of the lake within lake terraces at the 50-ft level on the eastern side of the Labur Mountains (Walsh and Dodson 1969) and within Holocene lake deposits of the Galana Boi Formation (Ashley et al. 2017; Ochieng et al. 1988).

Chalcedony, including banded agate and carnelian, is common within amygdules, nodules, and veinlets within lower Miocene basalts of the Losedok and Labur hills on the western side of the lake; it occurs with less frequency in overlying olivine basalt (see Figure 2; Walsh and Dodson 1969). Similar occurrences are known within the vesicular tops of the lowest basalts on the lake's eastern side (Ochieng et al. 1988). Both comprise sources for alluvial pebbles that collect in drainages, alluvial fans, and pebble sheets, all possible bead material sources. As described earlier, many chalcedony beads show percussion marks indicative of polishing by wind abrasion and so were fashioned from pebbles, not shaped from larger pieces.

Beads were also made from a wide spectrum of volcanic rocks, from alkalic phonolite to silicic rhyolite, intermediate andesite, and mafic basalt (see Table 1), the Pleistocene to Upper Oligocene volcanic unit of Figure 2. Most contain a contrasting secondary mineral or minerals, either precipitated upon cooling within amygdules or later as vein or vesicle fill, that provide a unique aesthetic color and/or textural contrast. As suggested by their nonsymmetric baroque shapes, these, too, were likely collected as polished pebbles from an alluvial source or sources. Bedrock sources for such pebbles are numerous on both sides of the lake (Dodson 1971; Nash, Brown, and Merrick 2011; Ndiema 2011; Ndiema, Dillian, and Braun 2010; Ochieng et al. 1988; Walsh and Dodson 1969). Though individually unique, no beads of this type present characteristics that permit precise geographic sourcing.

Discussion

The Lothagam North (N = 303), Manemanya (N = 330), and Jarigole (N = 173) stone bead and ornament collections represent a range of rocks and minerals that span all rock classification categories and contain lithic and mineral materials that range from hard and tough to relatively soft and brittle (see Table 2). Among the pillar sites, minerals and rocks used to make beads and necklaces also vary significantly. We first discuss the potential roles of color and other factors in raw material selection. Lothagam North and Jarigole are discussed first, given their similarities and contrast with Manemanya. Second, we explore the relationship between potential material sources and broader inferences about mobility in early pastoral societies. The variety and at times discrete locations for many bead types suggest an intimate knowledge of and interaction with the local landscape. More potentially distant sources for minerals such as amazonite and fluorite suggest bead material choice went beyond convenience; these were materials that people sought out and incorporated into intentional and meaningful adornment. Lastly, we briefly contrast the three pillar sites with known stone bead collections to the other sites and to the Njoro River Cave (Kenya) assemblage, which is also associated with early pastoralists.

Color and comparison among Lothagam North, Manemanya, and Jarigole

Lothagam North stone beads encompass a wide range of colors: 45% are pale orange analcime, 32% green to blue amazonite, 6% yellow-green talc, 5% orange, yellow, and red chalcedony, and 3% pale purple to colorless fluorite (see Table 2, Figure 3). Singular ornaments also stand out: a shiny black hematite pendant (Figure 3H) and a lustrous white scolecite (see Figure 8C). Lothagam North's color range, and the mineralogical diversity it entails, underline one of the most basic human reasons for choosing one type of mineral over another: visual appeal. Related characteristics such as luminosity, luster, translucence, and others might make a particular mineral valuable within certain societal contexts, be it economic, social, spiritual, or symbolic. Additional factors may include the importance of a specific location on the landscape, availability versus exclusivity (either feature might be desired), the workability (ease of shaping into various forms), and singular characteristics of particular stones (e.g., bi-colored), among others.

The Lothagam North assemblage (see Figure 3) also demonstrates that early pastoralists sought a wide range of minerals and rocks to create beads and pendants. Zeolites and amazonites are most common: of 234 beads, they collectively comprise 77.2% of the assemblage (see Table 2). Talc, chalcedony, fluorite, multiple volcanic rocks, and others complement this blue- and pale orange-dominated palette to make for a colorful assemblage: dark reds from carnelians and pale purple from fluorites; lustrous hematite and scolecite that would have caught light and gleamed. Most of these bead materials are consistent with derivation from local sources. In contrast, amazonite and fluorite, although potentially sourced from within the Rift Valley, may have been acquired from more distant sources, as either raw materials or finished beads, and through trade or exchange (see Figure 2). The number of amazonite beads and their distribution among several different burials and within platform cap deposits suggest either intergenerational curation of beads from an initial period of production, multiple trips to a single source over an extended period, or acquisition from multiple sources over an extended period.

The Jarigole stone bead assemblage (173 beads; see Figure 5) also has a high number of amazonites (50). These, as well as the analcime, fluorite, and chalcedony beads, show strong parallels with Lothagam North in raw material selection (see Table 2). Given the extreme fragility of analcime beads in excavation and laboratory handling, there remains a slight possibility that they may be underrepresented in curated material, as these were collected over multiple field seasons by different teams. Agate is unique to the Jarigole assemblage, as is the singular chert bead (Figure 5B). There are also greater quantities of limestone beads at Jarigole than at Lothagam North, including ear disks (two, ranging from 35–45 cm in width) and hooked and oval-shaped pendants that were distinct and notable for their sizes and shapes (see Figure 6). Although notably different in these regards, the overall similarities of the Jarigole and Lothagam North assemblages are nevertheless striking; there seems to be consistency in what may have been considered appropriate for interment. Whether this similarity is a consequence of similar aesthetic preference, similar access to raw materials (or both), or because of consistently similar notions of what was appropriate for interment cannot currently be resolved but offer a number of interesting possibilities. Additional sourcing research examining both inter- and intra-site variability in bead mineralogy may shed light on the post-production circulation of beads.

The Manemanya bead assemblage (see Figure 4, Table 2) presents a stark contrast to Lothagam North and Jarigole. Composed entirely of two types of pedogenic calcite, the 330 Manemanya beads are, as a group, similar in texture and color—off-white, pale pink, or beige hues and light tones, today partially or entirely obscured by a secondary coating of black pyrolusite dendrites (see Table 1 for further description). With their often porous surfaces, they look somewhat rough in appearance; their muted hues and tones are less visually striking. The beads may have had a more colorful presentation soon after manufacture, with greater differences between the light pinks and near-whites, but the range is far more constrained than the orange analcime and blue to blue-green amazonite assemblages from Lotham North and the fine-grained creamy limestone and amazonite of Jarigole. Collectively, Manemanya beads are made from easily worked, relatively soft materials that have correspondingly poorer polishes. In part due to their workability, but also due to choices by the manufacturer, many of the beads are substantially larger and more uniform in shape than beads and pendants from other mineral types (see Figure 4).

Excavations at Manemanya were limited in scope, oriented primarily around a single burial that was found in one of two test units at the site. As discussed by Sawchuk and colleagues (2019), the skeleton is of a young, tall female with facial and jaw asymmetries that would have impacted both her appearance and her physical abilities. The 330 stone beads recovered with that individual exceeds the entire sum of stone beads recovered at Lothagam North, which represent more than 30 individuals. These stone beads supplement over 10,000 ostrich eggshell (OES) beads also associated with her body. Again, this is in contrast to Lothagam North and Jarigole: proportionally, OES beads are an order of magnitude less prevalent at Lothagam North, and, while burials at Jarigole were not located in the original Koobi Fora field school excavations, the various stages of manufacture of the OES collection suggests on-site production (Momanyi 1988) rather than finished, intentional interment with a particular person. The colors may be muted, but the abundance of white-to-off-white personal adornments would have been striking at the time of burial.

Our stone bead analysis contributes to a growing body of data suggesting material, and possibly cultural, distinctions between Manemanya and other pillar sites. Manemanya lacks some of the visible surface structures seen at other pillar sites, such as stone circles (Lothagam North) and cairns (Lothagam North and West, Jarigole, and Kalokol), although one should note that these structures could have been created subsequent to the main period of use. In addition, the Nderit ceramic assemblage at Manemanya seems to differ in subtle aspects of production and style from those at Jarigole and Lothagam North (Hildebrand, Shea, and Grillo 2011). These differential patterns of bead production, use, and discard at Manemanya reflect site construction and use by a contemporary group that may have been socially or ethnically distinct or had access to, or a preference for, a more limited variety of bead materials. Variability, like commonality, describe the assemblages from each pillar site. The diversity of ornaments and raw materials and their uniqueness as seen from burial to burial are striking and suggest ornamentation may have been highly personal (Klehm 2021).

Raw material sourcing and implications for pastoralist mobility

Overall, there are plausible sources for all bead types from Lothagam North, Manemanya, and Jarigole within the area shown in Figure 2. Our data do not preclude the possibility that beads or source materials may have been transported to our study area from farther away. Additional testing would be necessary to match individual beads with more precisely determined raw material sources and even so may not prove definitive. It remains difficult to confirm if early herders in the Turkana Basin practiced relatively localized forms of craft production and how craft production may have been embedded within long-distance systems of mobility and/or exchange. Complementary evidence from a preliminary clay sourcing study suggests that Nderit tradition ceramics found at Jarigole and Il Lokeridede were made with clay from a limited number of sources (Koch et al. 2002), although the locations of those clay sources are currently unknown.

As Grillo, McKeeby, and Hildebrand (2022) point out, understanding the organization of mid-Holocene craft production in the Turkana Basin will ultimately require concerted effort to reconstruct patterns of pastoralist mobility —which are to date almost wholly unknown (Hildebrand et al. 2022). We also note semantic concerns: in discussing movement of materials and artifact transport, it is all too easy to create categories such as “local,” “far,” or “intermediate distance.” For archaeological settings involving farmers tethered to distinct plots of land for significant portions of each year, such categories may be useful. Multi-scalar types of mobility associated with herding economies (Adriansen 2005; Turner and Schlecht 2019), however, might force confrontation with the potential elasticity of distance concepts and the many possible interpretations that can arise from even a robust dataset such as this one.

Discovering likely potential sources for several of the materials at Lothagam North (see Figure 2) reveals the complex nature of relations between source use, other aspects of landscape use, and more general mobility strategies by early pastoralists. The probable source for analcime near Lothagam (identified in Powers 1980 and Feibel 2011), for example, raises interesting questions: does the prevalence of analcime in the Lothagam North assemblage reflect opportunistic exploitation of a raw material source that people passed in the course of visits to the Lothagam peninsula? Or does it reflect a distinct aesthetic or workability preference, whereby analcime was a main motivating factor for Lothagam visits? Difficult as it is to untangle the primary goals from the secondary opportunities pursued by pastoralists, the changing position of Lothagam in the post-AHP landscape, from jutting peninsula to a conspicuous ridge above emerging fertile pastures, complicates the picture even more.

With the possible exception of fluorite and amazonite, all the sources for stone beads recovered at Lothagam North may have been within a day or two’s walk of the cemetery where they were found. Lothagam North presents an interesting case where most stone beads appear to have local raw material sources, whereas obsidian, the dominant lithic raw material there, could be obtained only from much greater distances (Ndiema 2011; Ndiema, Dillian, and Braun 2010; Ndiema et al. 2011). Thus, people buried at Lothagam North appear to have moved or exchanged for some distant materials (obsidian) but not others (most of the stone bead ornaments) (Hildebrand et al. 2018). At Lothagam West, a contemporaneous pillar site < 1 km away, no stone beads have been found, and obsidian is a minor proportion of the lithic assemblage. This contrast raises two possibilities. First, the builders of Lothagam West may have been a distinct social group who, unlike their neighbors at Lothagam North, were interested in neither obsidian nor the more locally available ornamental materials. Alternatively, the two neighboring pillar sites may have been used by the same group(s) but in slightly different ways, only one of which called for obsidian and stone bead ornaments to be interred with the dead.

The likely analcime source, which is effectively adjacent to Lothagam North, opens additional avenues for speculation or interpretation when considered in a broader geographic context. Was this truly the main analcime source for the entire circum-Turkana region? If so, collecting minerals from this source may have been a way to create connections with specific points on the landscape, as with obsidian (Nash, Brown, and Merrick 2011; Ndiema 2011). In this scenario, the analcime found at Jarigole was likely brought there by the same group of people or exchanged among varying groups communicating across tens or even hundreds of kilometers. Alternatively, if other analcime sources are found near Turkana’s paleoshoreline, it is possible that Jarigole’s analcime beads were made from a different material source. Given the distinctness of the orange marker tuff near Lothagam North, this second scenario is significantly less likely. Further trace element analyses would help clarify this point, but given the many similarities (architectural features, Nderit ceramics, overall set of stone bead materials represented, etc.; e.g., Sawchuk et al. 2019) between Jarigole and Lothagam North, it is reasonable to argue for some degree of communication and interplay between their builders. The lack of analcime beads in the Manemanya mortuary assemblage—and the lack of stone beads altogether at Lothagam West and Kalokol—likewise adds to the increasingly robust literature demonstrating that variability amongst pillar sites is also marked by material cultures. This (apparently idiosyncratic) variability is not, as one might expect, structured by locally- or regionally-specific proximity to raw materials. Rather, it may be due to complex systems of meaning (of sites or of the beads themselves) or variable knowledge of, or access to, sources by different pastoral groups.

Comparison to other pillar sites and beyond

Another important distinction is between pillar sites with or without stone bead assemblages. To date, no stone beads have been recovered from Lothagam West and Kalokol; excavations at these two sites are not extensive but do surpass the volumes of initial excavations that first yielded stone beads at Jarigole, Lothagam North, and Manemanya. Amidst the very tight material cultural connections between Lothagam North and Jarigole, we must also recognize considerable heterogeneity across the entire group of sites, possibly reflecting different ideologies or aesthetic preferences in the circum-Turkana region. Further research at Il Lokeridede, which has only seen very limited excavation, and Aliel, which has not seen excavation at all, could lend additional dimensions of comparison.

Stone bead assemblages from archaeological sites in the region are rare, which is partly why the pillar site beads provide such an exceptional opportunity to examine pastoralist craft production in depth and in tandem with other lines of evidence. The other well-known stone bead assemblage from early pastoralists comes from Njoro River Cave, located over 400 km south of the Turkana pillar sites. Njoro River Cave, excavated by Mary and Louis Leakey in the 1930s and dated to approximately 3000 B.P., includes over 800 stone beads that are described in Leakey and Leakey (1950, 26–33). The 16 beads featured in the Njoro River Cave monograph and the necklaces were examined by C. K. and M. H., as these were the beads that could be located at the NMK. The variety of bead materials and manufacture of the beads are quite different from the pillar sites. As described by Beck in the Leakey and Leakey (1950) publication, most are chalcedony. However, even these appear quite different from those at Lothagam North and Jarigole: they are almost all somewhat uniformly oblate and have smooth, crackled surfaces from exposure to high heat. Leakey and Leakey also mention two additional beads from the Rift Valley area, from the Nakuru Burial Site and around Mount Meru (near Arusha, Tanzania), and a few additional chalcedony (agate and carnelian) beads from Zanzibar, but these were not located nor examined by the authors. These stone bead industries and the pillar sites appear to be distinct; there is also a two millennia time gap between them. However, as noted by Leakey and Leakey, stone beads remain rare in eastern African contexts, with the Turkana pillar sites an important and early exception.

Conclusion

We have described the mineralogy of 806 highly stylized and variable stone beads found with individuals buried in megalithic communal cemeteries surrounding Lake Turkana, which were built by the region's earliest pastoralist communities ca. 5000 CAL B.P. Through a geological and literature survey, we have identified potential source locations for many of the raw materials, including calcite and limestone, talc, and chalcedony, within the Turkana Basin. We likewise believe analcime may have been sourced from a location within a few kilometers of Lothagam North. We were unsuccessful in locating local sources for amazonite and fluorite, although published geological information suggests that those minerals are present within this part of the Rift Valley not much farther afield. Extended sourcing trips, combined with geochemical analyses of minerals sampled from possible sources, would in the future allow for more detailed mapping of both raw mineral procurement and patterns of mobility.

The implication we raise—that all beads found at the pillar sites could have been produced from sources within or very near the Turkana Basin—does provide a compelling counterpoint to much of the existing literature on early pastoralism in northeastern and eastern Africa that emphasizes the importance of long-distance trade and/or mobility. Social networks across vast distances are well-documented by other sourcing studies of amazonite beads (Zerboni et al. 2018), obsidian (Goldstein 2018; Prendergast et al. 2013), and possibly marine shells (Nelson 1993). Although early herders in the Turkana Basin may very well have had long-distance connections, and some of their beads could have come from afar, our sourcing data reveal the great degree to which these herders understood and interacted with local landscapes over the course of their lives.

These data likewise challenge us to consider the role those local landscapes played as settings for "moving frontiers." The "moving frontier" has been invoked as an explanatory model for the initial phase of pastoralist expansions into eastern Africa (see Lane 2004; Sawchuk et al. 2018). As reviewed by Sawchuk and colleagues (2018), moving frontiers are times of flux as groups negotiate both social relationships and land-use strategies in new environments. In the Turkana Basin, herders moved into a new landscape occupied by fisher/hunter/gatherer groups during a time of relatively dramatic climate change. Sawchuk and colleagues (2018) argue that pillar site construction and use demonstrate an investment in cooperative social networks, necessary for the success of herding system(s) in new physical and social contexts. Stone beads, like shell beads and other grave goods, were part of the ritual of interring the deceased at these sites and were often associated directly with individuals (Klehm 2021). Land-use strategies, however, have been much harder to see in the archaeological record. They must have involved establishing grazing regimes, residential settlement patterning, daily and seasonal mobility of herds, and so forth (Marshall, Grillo, and Arco 2011). Land-use extends to the procurement of other raw materials such as rocks and minerals for producing beads and lithics or clays and minerals for ceramics. There remain many unknown factors in the selection of the bead materials. For example, procurement may have been integrated with or separated from daily or seasonal mobility, associated with managing herds, or undertaken during special, specific trips. The materials may have been obtained by some and circulated more widely or collected on an individual basis. They may have been considered related to or representative of particular landscape features or chosen instead for their color or other properties (see Klehm 2021, 140–141). Whether additional data would clarify motivations is unclear, but they remain important considerations for understanding the interplay between early herders and their geological landscapes of the Turkana Basin. As the mineralogy and sourcing of the stone beads demonstrate, even a single dataset can broaden our understanding of the dynamics of early pastoralism in eastern Africa.

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Disclosure Statement

The authors report there are no competing interests to declare.

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Geolocation Information

The study area (e.g., Figures 1, 2) is within a rectangle with opposing corner coordinates of 0.0°N, 37.25°E and 5.5°N, 34.7°E.

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