

Wolfe-Visser (6) technique. To obtain an indexing with a high figure of merit required the unacceptable deletion of several reflections. A review of the literature revealed that the x-ray pattern did not correspond to other reports on black sulfur (7). However, in an in situ diamond anvil study Block and Piermarini have corroborated that  $S_4N_4$  decomposes to a black substance which they believe is sulfur (8). In some of our experiments, apparently because of heating or pressurization rates that were too rapid or anvils that were nonuniform, the  $S_4N_4$  exploded upon increasing pressure and temperature. When a sample residue was present in the product after an explosion, it was usually a black, somewhat viscous material having a characteristic x-ray pattern different from that of the black sulfur reported in Table 1.

It seems likely that the decomposition of  $S_4N_4$  at high pressure proceeds by way of the breaking of a cage or ring bond and hence the formation of probably a temporary fragmented chain structure. The black sulfur may form from a transitory chain phase by the release of nitrogen. The possible evolution of a sulfur-nitrogen chain structure from  $S_4N_4$  is illustrated in the inset of Fig. 1.

Since the black form of sulfur is insoluble in  $CS_2$  and since the molecular decomposition of  $S_4N_4$  involves the bond scission of a ring molecule, we suggest that the parent species of the black material is a chain-structured sulfur-nitrogen configuration akin to metallic  $(SN)_x$ . This interpretation is in accord with the high-conductance transient behavior and the positive temperature coefficient of resistance during decomposition and with the electron delocalization and weak sulfur-sulfur bonding in  $S_4N_4$ ; this interpretation is also analogous to the known polymorphic transformation from  $S_8$  rings to fibrous  $S_x$  chains, both of which are identified in and above the decomposition zone of Fig. 1. Since all known sulfur ring molecules exhibit yellow hues (9), and because of the insolubility of the black phase in  $CS_2$ , we believe that the black material is itself also a chain structure.

The only material of which we are aware that has a phase equilibrium behavior somewhat similar to  $S_4N_4$  is  $CS_2$ . The high-pressure phase diagram of  $CS_2$  also shows a zone where a black metallic phase is formed, the zone being between the fields of the starting material  $CS_2$  and the decomposition field of sulfur plus carbon (10). As in  $S_4N_4$ , this zone is wide in pressure and narrow in temperature.

To determine the structure of the suspected quasi-metallic parent phase of the

Table 1. X-ray pattern experimentally obtained for black sulfur and its possible precursor;  $d$  = interplanar spacing;  $I$  = intensity. Sample A was recovered from the  $S_4N_4$  decomposition boundary in synthesis experiments (23 kbar, 298°C, 3 hours). There was no suggestion of any reflections due to the nickel gasket ring, the platinum protective foil, PtS,  $PtS_2$ , or NiS. Sample B was the black and white material from electrical experiments to 310°C with known reflections deleted (37 kbar, 310°C, ¼ hour). Known reflections include any that could be due to residual  $S_4N_4$ , rhombic  $S_8$ , fibrous  $S_x$ , or any impurity from the mica gasketing ring (3). No reflections due to platinum electrodes, PtS, or  $PtS_2$  were observed. Sample C consisted of isolated black particles derived from electrical experiments to 360°C with possible rhombic  $S_8$  reflections deleted (37 kbar, 360°C, ½ hour). Lines in rows 2 through 5 for samples B and C have not yet been identified but may be due to a precursor or transitory phase.

Sample A		Sample B		Sample C	
$d$ (Å)	$I$ (%)	$d$ (Å)	$I$ (%)	$d$ (Å)	$I$ (%)
3.36	100	3.33	50	3.33	20
		3.09	100	3.10	100
		2.76	10	2.77	50
		2.69	10	2.71	50
1.82	10	1.82	30	1.84	10
		1.80	5	1.799	35
1.71	5	1.71	10	1.709	25
1.56	10	1.55	60	1.582	30
1.41	10	1.41	10	1.543	30
				1.410	15

black sulfur material, in situ x-ray diffraction studies will be needed. The pressure and temperature of the formation zone are easily within the capability of diamond anvil systems (adaptable to both x-ray and electrical experiments).

However, the explosiveness of  $S_4N_4$ , which at times can be violent, seriously jeopardizes the diamonds and their alignment, and thus these experiments must be carried out with caution.

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11. We thank Dr. E. G. Sharkoff for suggesting and supporting this work; V. Siele for preparing the  $S_4N_4$ ; Dr. Z. Iqbal for valuable discussions; and Prof. F. Datchille of Pennsylvania State University for the loan of the opposed anvil apparatus. We also thank Dr. J. Sharma for the ESCA studies, Dr. D. Downs for crystal growth work, and Dr. H. Fair for discussions.

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## Namoratunga: The First Archeoastronomical Evidence in Sub-Saharan Africa

**Abstract.** *Namoratunga, a megalithic site in northwestern Kenya, has an alignment of 19 basalt pillars that are nonrandomly oriented toward certain stars and constellations. The same stars and constellations are used by modern eastern Cushitic peoples to calculate an accurate calendar. The fact that Namoratunga dates to about 300 B.C. suggests that a prehistoric calendar based on detailed astronomical knowledge was in use in eastern Africa.*

In recent years there has been a growing interest among archeologists and astronomers in the possible relationships between megaliths erected by prehistoric peoples and the positions of constellations and other solar phenomena (1). Much of this work has centered on European sites such as Stonehenge. In Africa, especially in Ethiopia, megaliths are known that are believed to have been

associated with Cushitic speakers (2); but, as far as we are aware, none of them have been related to astronomical evidence.

Our recent research in northwestern Kenya has resulted in the discovery of evidence warranting archeoastronomical investigation which probably dates from about 300 B.C. Lynch was excavating the site of Namoratunga I (2°0'5"N,

36°6'50"E) located along the Kerio River valley, southwest of Lake Turkana (Fig. 1). This is a large cemetery and rock art site where the graves are surrounded by massive standing stones which have been engraved with cattle brand symbols (3). The burial practices at Namoratunga I closely parallel customs practiced recently by the Konso of southern Ethiopia, a Cushitic-speaking group (4). Namoratunga I has recently been radiocarbon-dated to  $2285 \pm 165$  years before present (B.P.) (5). The name Namoratunga means "stone people" in the language of the local Turkana tribe: the Turkana believe that a malevolent spirit had the power to turn people who mocked the spirit to stone. Namoratunga I was so striking in its isolation from similar sites with massive upright stones that we thought that any other similar sites would surely be known by the people, who are nomadic and possess a great knowledge of the area they inhabit. Local elders informed us of another site with the same name located 210 km to the north near the Ferguson's Gulf area of Lake Turkana (3°24'N, 35°50'E) (Fig. 1). Namoratunga II is located on the eastern edge of the Losidok range overlooking the Lake Turkana basin with an unobstructed view of the entire horizon. Central Island, in the middle of the lake, is due east and can be clearly seen from the site.

We investigated this site and found that it was definitely related to the Namoratunga I site. There was at least one grave marked by upright slabs, and other upright basalt columns were faintly engraved with the same brand symbols. Although Namoratunga II has not been dated, it is clearly part of the same cultural complex and probably dates to the same general period (300 B.C.) as Namoratunga I. Yet Namoratunga II contrasted significantly with Namoratunga I because the large stone columns were in an unusual alignment (Fig. 2). At Namoratunga I, standing stones were only found circling graves. In addition to the standing stones circling the one grave at Namoratunga II, 19 large stone columns were arranged in rows that were not part of any grave. Because the distribution of these stones appeared to be markedly nonrandom (6), we decided to examine the possibility that their arrangement was correlated with certain astronomical events, especially since present-day Eastern Cushites have a sophisticated calendar which uses the rising of seven stars or constellations in conjunction with various phases of the moon to calculate a 12-month, 354-day year. The seven stars or constellations include Tri-

Table 1. Present azimuths and azimuths in 300 B.C. of seven stars used in conjunction with the stone pillars at Namoratunga II to calculate a calendar.

Star or constellation	Present azimuths	Azimuths in 300 B.C.	Namoratunga II	
			Stone alignment	Error
Triangulum (Beta)	35° N of E	23° N of E	1-7	0°
Pleiades	24° N of E	14° N of E	1-8-12	0°
Aldebaran	17° N of E	9° N of E	1-2-9	0°
			5-13	0°
Bellatrix	6° N of E	1° N of E	1-3-4	1°+
			17-18	0°
Central Orion	2° S of E	10° S of E	5-10	1°
			16-18	1°
Saiph (Kappa Orionis)	10° S of E	13° S of E	5-6-7	0°
			14-18	0°
Sirius	17° S of E	17° S of E	5-6-9	0°
			15-18	0°

angulum, Pleiades, Aldebaran, Bellatrix, Central Orion, Saiph (Kappa Orionis), and Sirius (7). For half of the year they identify months by the rising of each of the seven stars or constellations in relation to the new moon. Each star or constellation appears successively in conjunction with the new moon in the order Triangulum, Pleiades, Aldebaran, Bellatrix, Central Orion, Saiph, and Sirius.

Only Triangulum is utilized for the second half of the year beginning when Triangulum rises in conjunction with a full moon. Each successive month is identified by Triangulum's relation to progressively declining phases of the waning moon. Such months are approximately 29.5 days long (7). Since the site was Cushitic in origin, we checked the rising of these seven stars or constellations against the possible stone alignments at Namoratunga II (8).

Because of gradual changes in the earth's axis of rotation, called precession, it was necessary to determine the azimuths of these constellations for the year 300 B.C. (9). In some cases these stars exhibited a difference of as much as 12° in their present azimuths as compared with those of 300 B.C. (Table 1).

We first assumed that if the stone "pillars" at Namoratunga II did indeed align with these stars, the stones in the far west of the site would be the most obvious stones to initially sight from since the rising of the stars was the phenomenon of calendric importance. This would allow the observer maximum use of all the stone pillars. Despite the fact that many of the stones were placed in the ground at angles, we considered only the tops of the stones when checking for possible alignments. The angling of the stones was apparently intentional since present-day Eastern Cushites also place both wooden and stone pillars into the ground at angles. The first position that we examined was stone 18 (see Fig. 3 for all alignments). From this vantage point it was possible to align other stones with the rising of four stars: Bellatrix with stone 17, Orion with stone 16, Saiph with stone 14, and Sirius with stone 15. Only the alignment with stone 16 yielded a 1° error.

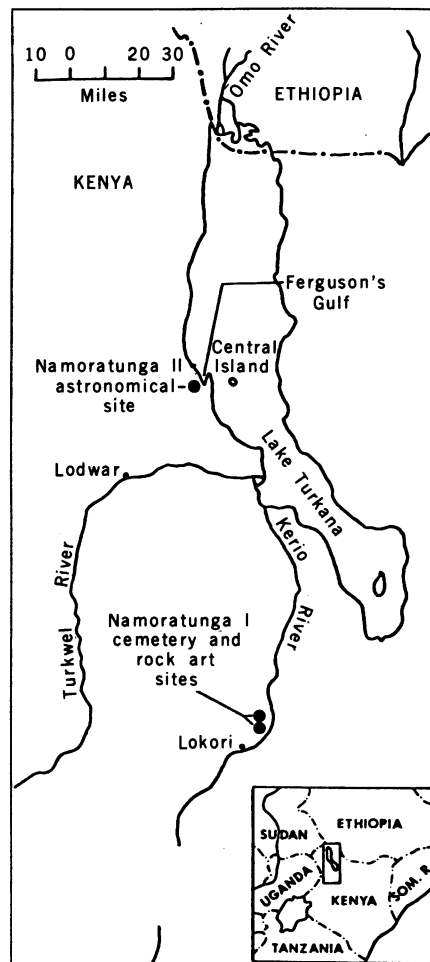


Fig. 1. Location of Namoratunga sites.

From stone 1 alignments were found with Triangulum (1-7), Pleiades (1-8-12), Aldebaran (1-2-9), and Bellatrix (1-3-4). Only the alignment with Bellatrix displayed any error, slightly more than 1°. Three of the four alignments from stone 1 consisted of a row of three stones. In view of the close proximity of these stones, a three-stone alignment would allow for more accurate sightings. This was not necessary for the alignments taken of stone 18 since the stones the particular constellations would rise over were as much as 12 m away.

Alignments were also noted for stone 5. From here, alignments could be formed with Aldebaran (5-13), Orion (5-10), Saiph (5-6-7), and Sirius (5-6-9). The Orion alignment was off by approximate-

ly 1°. Like three of the four alignments from stone 1, the Saiph alignment and possibly the Sirius alignment were formed by a row of three stones. Stones 1 and 5 were oriented exactly true north.

Each of the three sighting points (1, 5, 18) produced four alignments. Five and possibly six of these alignments were formed by three stones (six if the 5-11-10 alignment is included). In no case were any of these alignments off by more than 1°. In addition, with one exception all of the 19 stones at the site were used in forming the alignments. Stone 11, which had fallen down, would most likely have fallen on the 5-10 Orion alignment. Only stone 19 was not used, but this stone was the smallest at the site, only 15 cm above the surface, and as such would have

been of questionable value as a line of sight. Since Central Island, the only geographical feature readily visible from the site, is due east of Namoratunga II, it seems likely that some of the alignments may have used Central Island as an additional distant line of sight.

We followed the same procedure to check for alignments, using the present azimuths of these seven stars. Only four of them matched the stone alignments at Namoratunga II. In the case of Sirius, for example, there was no difference between the present azimuth and that of 300 B.C. This information adds further support to the idea that the Namoratunga II alignments are nonrandom and gives weight to the idea that the stones were used in calendric reckoning in 300 B.C.

The archaeoastronomical information described for Namoratunga II adds significantly to the growing body of evidence attesting to the complexity of prehistoric cultural developments in sub-Saharan Africa. It strongly suggests that an accurate and complex calendar system based on astronomical reckoning was developed by the first millennium B.C. in eastern Africa. Furthermore, it raises the possibility that other megalithic sites will be found that will have astronomical implications.

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6. The mean height of the portion of the stones visible above the ground was 55 cm. The stones are estimated to weigh between 45 and 270 kg each.
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9. All alignments at the site were determined with the aid of a transit and as such are accurate to within 1°.
10. Fieldwork was generously supported by the National Science Foundation. We are grateful to the Government of Kenya for permission to do this research. We thank R. E. F. Leakey and J. C. Onyango-Abuje of the National Museums of Kenya and N. Chittick and D. W. Phillipson of the British Institute of Eastern Africa for facilitating our research. We are grateful to S. E. Tlengoi for leading us to the site. We thank P. Uland for her excellent drawings. We are especially grateful to R. Victor of the Michigan State University Planetarium and Department of Astrophysics for his advice and calculation of the azimuths of the stars used in the analysis.

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Fig. 2. Pattern of stones at Namoratunga II.

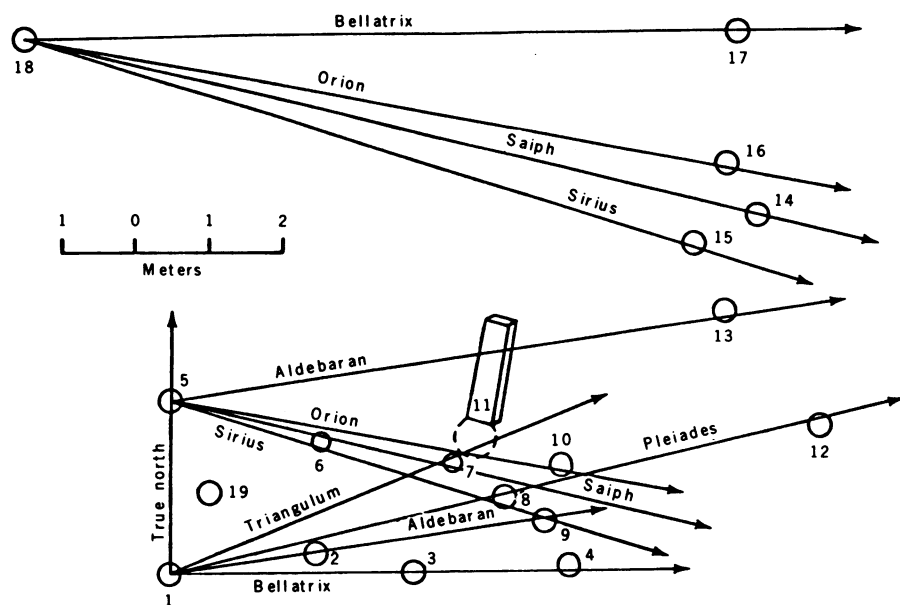


Fig. 3. Stone alignments relative to the seven stars at Namoratunga II.