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Author(s)	NAKAJIMA, Tadashi; TORII, Masayuki
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PALEOMAGNETISM OF MIOCENE ROCKS IN THE WESTERN AREA OF BARAGOI, NORTHERN KENYA

Tadashi NAKAJIMA
Faculty of Education, Fukui University
Masayuki TORII
Faculty of Science, Kyoto University

ABSTRACT A total of 22 reliable paleomagnetic data has been obtained from Miocene rocks in this area. The magnetic polarity sequence is divided into six magneto-zones, which are tentatively correlated with the geomagnetic reversal time scale. The *Kenyapithecus* horizon is assigned to a normal epoch in the period between 14 Ma and 12 Ma. The VGPs obtained from this area show the deviations in the direction of the "far-sided and right-handed" effect from the geographical pole.

INTRODUCTION

Field surveys focusing on discoveries of Miocene hominoids and geological and paleontological analyses of the paleoenvironments of the hominoids have been conducted in Kenya since 1980 (Ishida *et al.*, 1982 ; Ishida, 1984). In 1984 the field survey of the third Japan-Kenya expedition was carried out in the Samburu Hills, the Nachola area, and the middle reaches of the Baragoi River, west of Baragoi, Kenya, where Miocene hominoid fossils were discovered during the second expedition in 1982 (Ishida *et al.*, 1984). During the 1984 field season Miocene volcanic rocks were intensively collected for paleomagnetic measurements and K-Ar age determinations. This area is underlain by Miocene and Pliocene volcanic rocks composed of basalt, trachyte and alkali rhyolite, intercalated with sedimentary rocks, unconformably overlying rocks of the Precambrian metamorphic complex. The Miocene rocks are divided into the Nachola, the Aka Aiteputh, and the Namurungule Formations in ascending order, the stratigraphy of which was studied in detail by Makinouchi *et al.* (1984) and Sawada *et al.* (1987). In this paper we describe preliminary paleomagnetic results obtained from the Nachola and the Aka Aiteputh Formations.

SAMPLES

Paleomagnetic samples were collected by hand sampling, and were independently oriented using a magnetic compass. Strike and dip of the strata were also measured in the field to allow tilt corrections of the remanent magnetic direction. Figure 1 shows the sampling localities, where rock

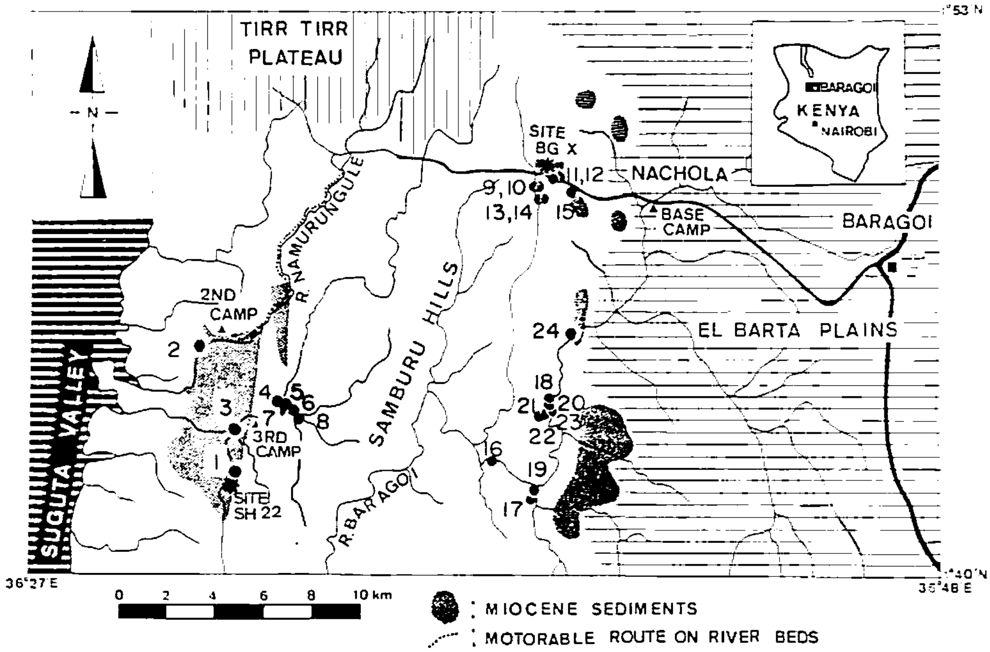

Fig. 1 Investigated area (modified from Ishida, 1984). Solid dots show sampling localities. Numbers correspond to Site Nos. in Table 1. Miocene hominoid fossils were discovered from sites SH 22 and BG X.

samples for K-Ar age determinations were also collected by Itaya (1987). These rock types, K-Ar ages and tiltings of the strata are listed in Table 1. The K-Ar ages of the Nachola and the Aka Aiteputh Formations range from 20 Ma to 14 Ma and from 15 Ma to 11 Ma, respectively. These formations dip gently west at angles of less than 30°.

MEASUREMENTS

Remanent magnetization was measured with an astatic magnetometer at Fukui University and with a Schonstedt SSM-1 A spinner magnetometer at Toyama University. Three to four pilot samples from each site were first tested by a progressive demagnetization method in alternating field (AF) in steps of 50 or 100 Oe up to a maximum field of 500 Oe. Results of the progressive AF demagnetization of typical samples are illustrated in Figs. 2 and 3. Most samples showed considerable changes in magnetic direction at the beginning of the AF treatment, such as in peak fields of 50 or 100 Oe. The soft component of remanent magnetization which was cleaned by the AF up to 100 Oe can be interpreted as a secondary overprint of viscous remanent magnetization. No remarkable change, however, is observed in magnetic direction by AF demagnetization in fields above 100 Oe. The stable directions with respect to the AF can be regarded as showing those of the primary magnetization. The optimum demagnetization field (ODF) was selected from the

Table 1. Rock type, K-Ar ages and tilting (strike and dip) of paleomagnetic sampling site in area west of Baragoi, Kenya.

Site	Rock Type	K-Ar age (Ma) (Itaya, 1987) (*: Matsuda *et al.*, 1984)		Strike (°)	Dip (°)
AKA AITEPUTH FORMATION					
(Samburu Hills)					
1) 84091501	basalt	10.7,	10.8	N 03 E	30 W
2) D (82100113)	basalt	12.0*		N 20 E	20 W
3) 84091703	basalt	14.5,	14.4	N 30 E	30 W
4) 84091801	basalt	14.3,	14.1	N 05 W	18 W
5) 84091802	sodalite trachyte			N 20 E	20 W
6) 84091805	basalt	14.5,	14.5	N 25 E	20 W
7) E	basalt			N 20 E	20 W
8) 84091807	basalt	15.1,	14.8	N 25 E	20 W
(Nachola Area)					
9) 84082802	basalt	11.6,	11.9	N 90 W	10 S
10) 84082801	welded tuff			N 90 W	10 S
11) 84082903	basalt	13.0,	12.6	N 12 W	13 W
12) 84082902	sandstone			N-S	5 W
13) 84082803 a	tuff			N-S	5 W
14) 84082803 b	tuff			N-S	5 W
NACHOLA FORMATION					
(Nachola Area)					
15) 84082901	trachyte	14.9,	15.9	N 42 E	12 N
(Middle Reaches of the Baragoi River)					
16) 84082701 A	trachyte	14.8,	15.1	N 25 E	15 W
17) 84082601	aphiric trachyte	13.5,	14.0	N 33 E	12 W
18) 84082104	welded tuff			N-S	15 W
19) 84082603	tuff	18.7,	18.6	N 30 E	20 W
20) 84082201	basalt			N 10 W	5 W
21) 84082202 C	basalt	19.0,	18.4	N 10 W	5 W
22) 84082202 B	basalt	18.7,	19.3	N 10 W	5 W
23) 84082202 A	basalt	19.6,	18.8	N 10 W	5 W
24) 84082103	porphyritic basalt	17.7,	17.6	N 30 E	8 W

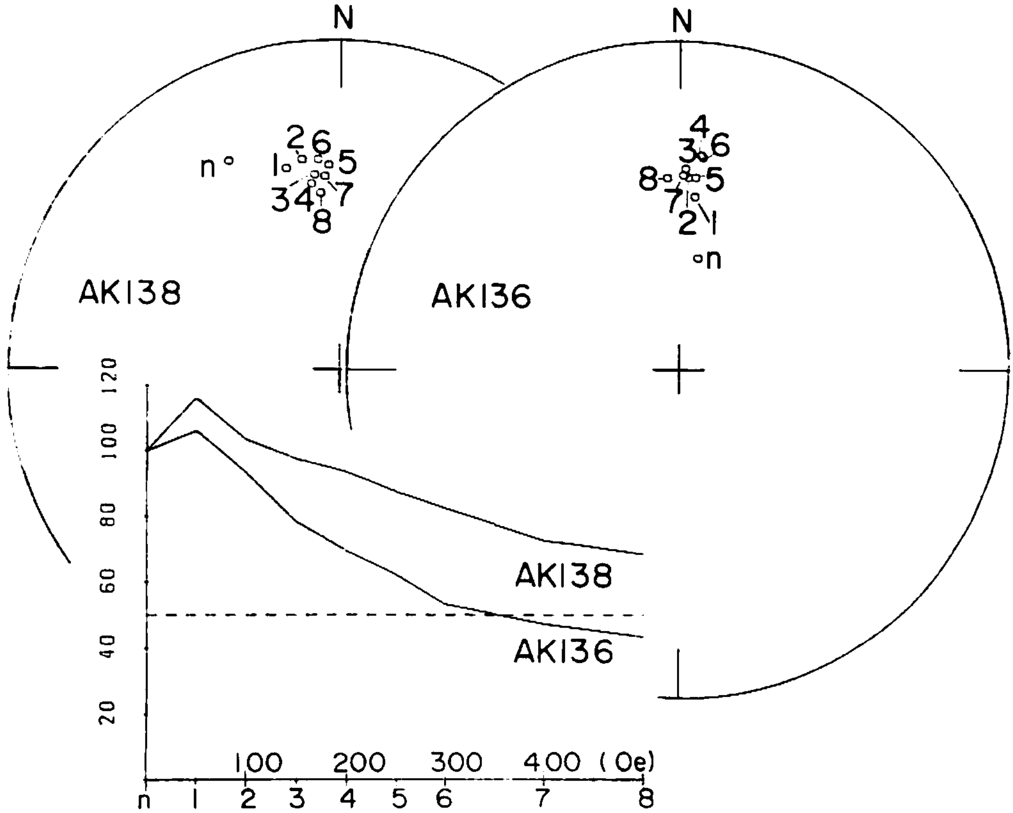

Fig. 2 AF demagnetization plots for typical samples (AK 136 and AK 138) showing decay of normalized remanent intensity and changes in direction on equal area projection of upper hemisphere. n : 0 Oe, 1 : 50 Oe, 2 : 100 Oe, 3 : 150 Oe, 4 : 200 Oe, 5 : 250 Oe, 6 : 300 Oe, 7 : 400 Oe, 8 : 500 Oe.

results of the AF cleaning at 100 to 500 Oe on the basis of the smallest value of α_{95} (Fisher, 1953). The rest of samples for each site was demagnetized at the ODF. Table 2 shows site mean directions cleaned by the ODF and corrected for the tiltings of strata. We could not obtain reliable paleomagnetic data from sites 5 and 12 because intensities of remanent magnetization of the samples were too weak to be measured after the AF demagnetization. The table includes the data of sites 2 and 7 reported by Matsuda *et al.* (1984). Their samples, of which magnetic stabilities were confirmed as being stable by the progressive thermal demagnetization method, were collected from the Aka Aiteputh Formation during the 1982 field season of the second Japan-Kenya expedition.

MAGNETOSTRATIGRAPHY

The site mean directions together with their α_{95} values are plotted on the equal area projection

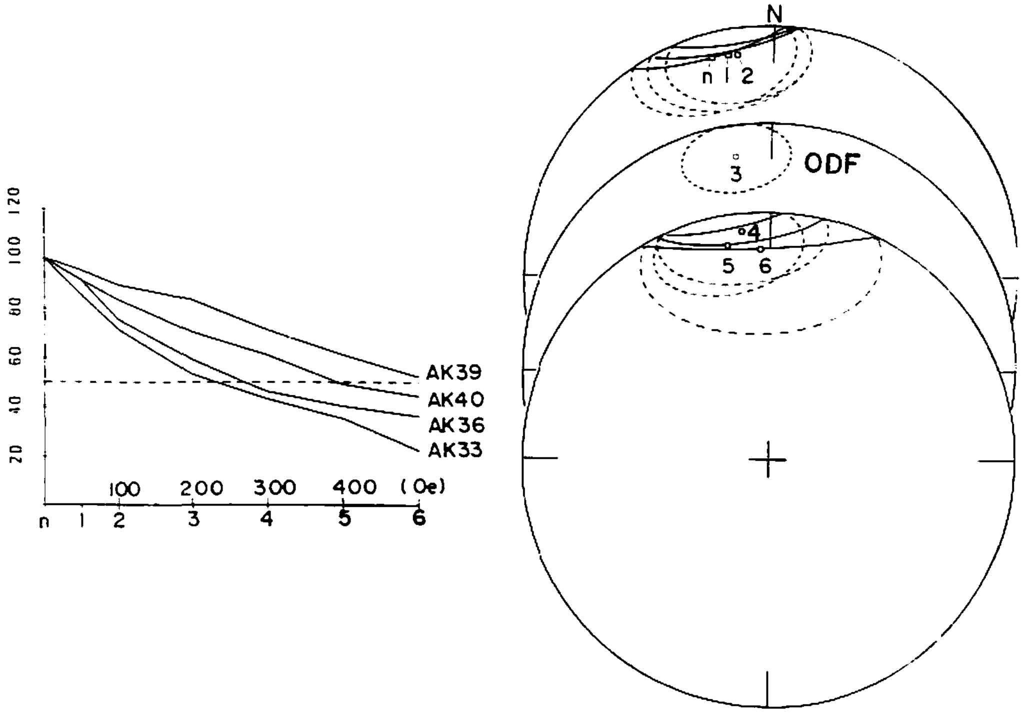

Fig. 3 AF demagnetization plots for pilot samples from site 18 showing decay of normalized remanent intensity for each sample in left-hand figure and mean directions for the pilot samples on equal area projection of upper hemisphere in right-hand figure. Ellipses indicate α_{95} values. The smallest α_{95} is 14.1° after AF demagnetization at 200 Oe, which is selected for ODF. n : 0 Oe, 1 : 50 Oe, 2 : 100 Oe, 3 : 200 Oe, 4 : 300 Oe, 5 : 400 Oe, 6 : 500 Oe.

diagram in Fig. 4. These directions are grouped into two separate clusters in antipodal directions, which are regarded as of normal and reversed polarity, respectively. The stratigraphic distribution of the normal and reversed polarity sites is illustrated in Fig. 5. The Nachola and the Aka Aiteputh Formations are magnetostratigraphically divided into two and four zones, respectively, which are called magneto-zones and numbered from I to VI in ascending order as shown in Fig. 6. Magneto-zones I, III and V are typified by a dominance of normal polarity sites, whereas Magneto-zones II, IV and VI are composed of reversed polarity sites. Figure 6 also shows the tentative correlation of the Magneto-zones with the geomagnetic reversal time scale (GRTS) (Harland *et al.*, 1982) based on the K-Ar ages (Table 1). The K-Ar ages of Magneto-zone I (except site 24) are well concentrated in a period between 19.6 Ma and 18.4 Ma. Therefore, the normal polarity part of the zone is assigned to the polarity chron 5 E of the GRTS ranging from 19.12 Ma to 18.59 Ma. The ages of Magneto-zones II, III and IV range in a short period from 15.9 Ma to 13.5 Ma. Although significant difference in the three zones are not found in the ages, Magneto-zones II, III and IV are assigned to the polarity chrons 5 Br (16.20—15.23 Ma), 5 AD (14.63—14.16 Ma) and 5 ACr (14.16—14.04 Ma), respectively, from the stratigraphic relation. On

Table 2. Paleomagnetic site mean directions from the Nachola and Aka Aiteputh Formations.

Site	ODF (Oe)	N	Dc (°E)	Ic (°down)	α_{95} (°)	k
AKA AITEPUTH FORMATION						
(Samburu Hills)						
1) 84091501	150	6	214.9	−16.2	5.0	181.6
2) D	(570°C)	3	187.0	0.2	14.2	76.7
3) 84091703	150	7	180.8	−1.6	3.7	263.9
4) 84091801	350	3	196.4	−10.1	39.3	10.9
5) 84091802						
6) 84091805	200	8	357.5	−17.9	9.1	37.8
7) E	(520−570°C)	6	356.3	9.6	8.7	24.0
8) 84091807	300	4	244.4	−44.1	21.6	18.9
(Nachola Area)						
9) 84082802	100	9	13.2	4.6	7.3	50.7
10) 84082801	100	10	12.9	4.3	4.3	126.9
11) 84082903	100	8	3.1	0.0	5.1	119.3
12) 84082902						
13) 84082803 a	100	5	10.3	−17.8	9.6	64.2
14) 84082803 b	400	4	3.9	−44.0	5.0	342.0
NACHOLA FORMATION						
(Nachola Area)						
15) 84082901	500	7	192.4	23.3	30.7	4.8
(Middle Reaches of the Baragoi River)						
16) 84082701 A	350	9	204.8	56.4	14.3	13.9
17) 84082601	500	7	200.4	52.3	17.1	13.3
18) 84082104	200	10	354.0	−13.1	5.3	84.0
19) 84082603	100	10	0.2	−13.0	16.2	9.9
20) 84082201	300	8	315.4	−22.4	14.4	15.8
21) 84082202 C	100	7	335.1	−15.3	11.7	27.4
22) 84082202 B	100	7	355.1	−36.2	4.3	193.6
23) 84082202 A	500	5	188.8	−28.9	33.4	6.2
24) 84082103	100	10	356.1	−31.6	11.4	18.8

ODF: optimum demagnetization field (1 Oe=0.1 mT), N: number of samples,
Dc: declination after tilt correction, Ic: inclination after tilt correction, α_{95} and k: Fisher's statistic parameters. Data of sites 2 and 7 are referred to Matsuda *et al.* (1984).

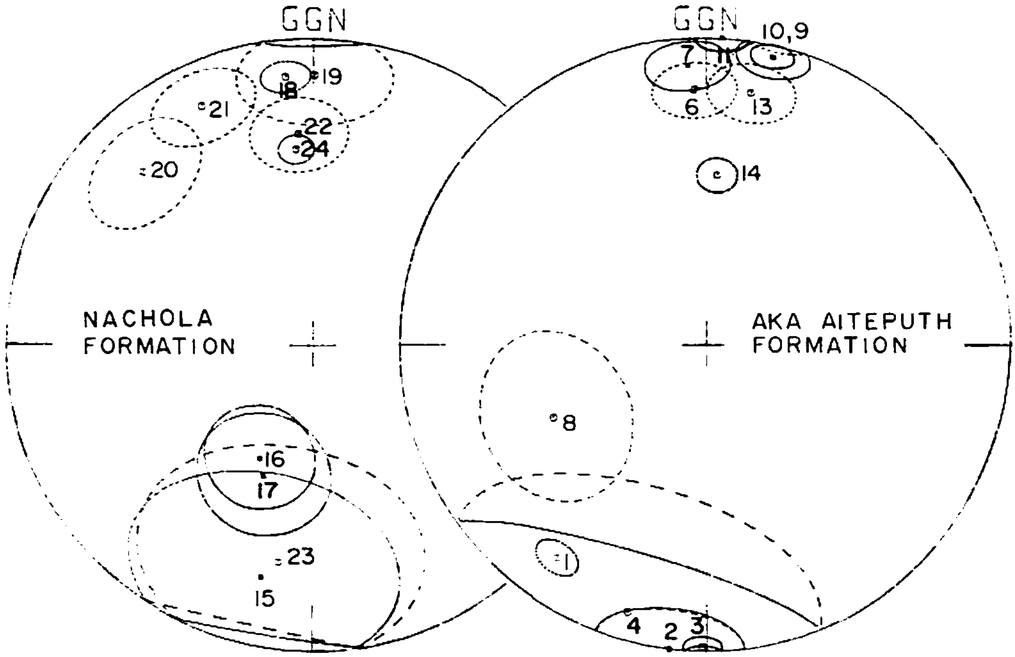

Fig. 4 Site mean directions with α_{95} values plotted on equal area projection. Solid symbols and solid lines are on lower hemisphere, and open symbols and dashed lines on upper hemisphere. Numbers correspond to Site Nos. in Table 1.

the other hand, the periods of Magneto-zones V and VI estimated from the K-Ar ages are more than two million years. The periods are too long to correlate the zones with the specific polarity chrons.

The horizon of the hominoid fossil : *Kenyapithecus* which was discovered in the 1982 Japan-Kenya expedition (Ishida *et al.*, 1984) is assigned to Magneto-zone V of the normal polarity as can be observed in Figs. 5 and 6. Unfortunately, it is impossible to date the zone with the correlation to the GRTS. However, Magneto-zone IV is assigned to the chron 5 ACr (14.16−14.04 Ma), and the horizon of site 11, which is upper than the *Kenyapithecus* horizon, is dated to be 13.0±0.6 Ma or 12.6±0.5 Ma by Itaya (1987). This suggests that the horizon of the hominoid fossil is in a normal epoch between 14 Ma to 12 Ma.

APPARENT POLAR WANDER

Virtual geomagnetic poles (VGP) calculated from the site mean directions of Table 2 are listed in Table 3, and plotted on the polar equal area net of the Northern Hemisphere in Fig. 7. Most of the VGPs deviate somewhat from the present geographic pole, and cluster in the Arctic Ocean between longitudes 110°E and 260°E. The deviations are almost all in the direction of the "farsided and right-handed" effect first noted by Wilson (1970), whereby inclinations are systematically lower

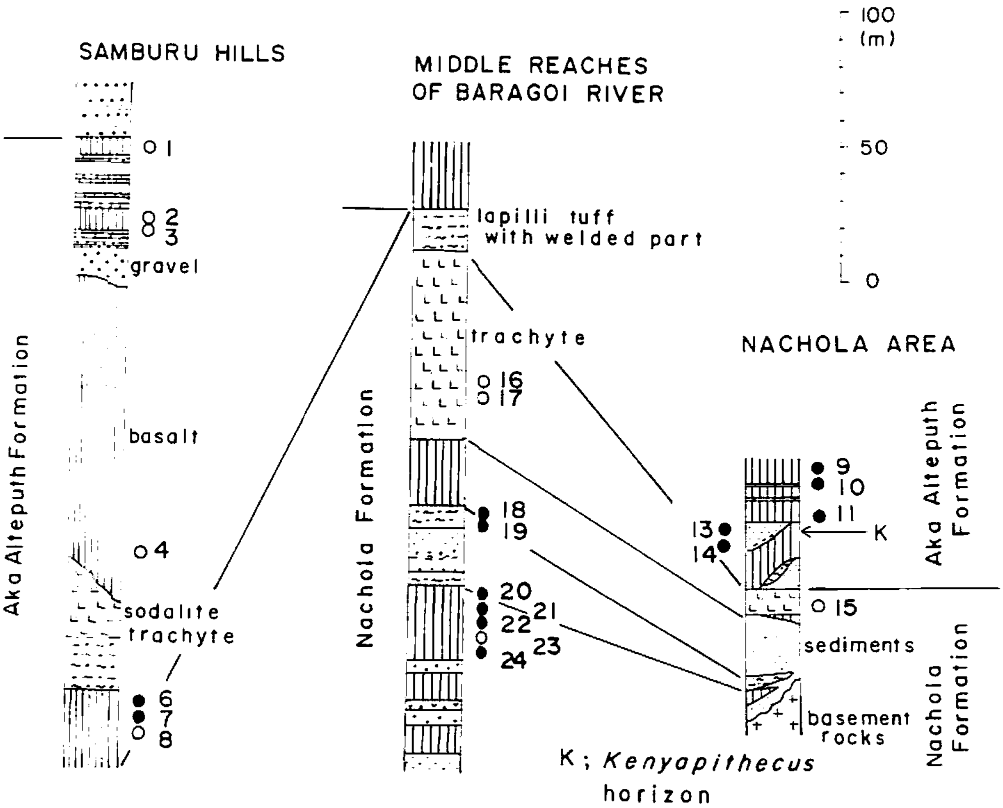

Fig. 5 Stratigraphic distribution of normal and reversed polarity sites for the Nachola and Aka Aiteputh Formations. Columnar sections are simplified from Sawada *et al.,* 1987. Solid and open circle symbols show normal and reversed polarities, respectively. Numbers correspond to Site Nos. in Table 1.

and declinations systematically eastward of what would be expected for a simply geocentric axial dipole model of the geomagnetic field. The similar shift of the VGPs was observed in the paleomagnetic study of the Miocene rocks in the Kirimun district, central Kenya (Ishida *et al.,* 1982).

Most of the Cenozoic paleomagnetic poles from Africa summarized by Irving and Irving (1982) and Brock (1981) are close to the geographical pole, and the latitudes are almost similar to or slightly higher than those of our VGPs. It is impossible to trace the apparent polar wander (APW) from the paleopoles, partly because of uncertainties of their ages and the effect of the above mentioned dipole offsets. If APW took place in Miocene time, the amount of its drift was presumably very small. In order to know whether or not APW occurred during Miocene time, the mean paleopoles were separately computed for the Nachola and the Aka Aiteputh Formations, of

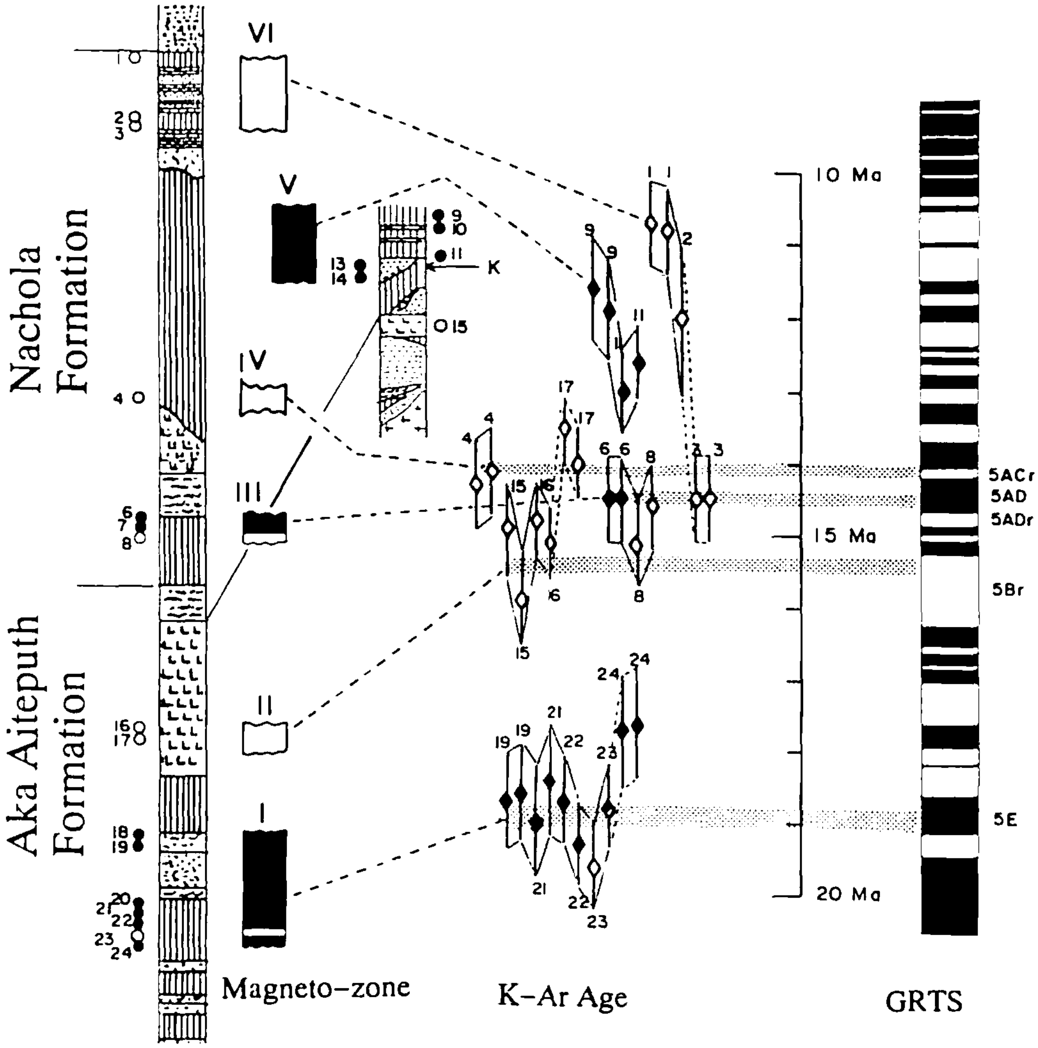

Fig. 6 Correlation of polarity sequence from the Nachola and Aka Aiteputh Formations with the geomagnetic reversal time scale (Harland *et al.*, 1982). Solid and open symbols show normal and reversed polarities, respectively. Numbers correspond to Site Nos. in Table 1.

which ages are well-known to about 20—15 Ma and about 15—11 Ma, respectively. The latitude, longitude, and α_{95} of the mean paleopole for the Nachola Formation are 73.6°N, 224.7°E and 15.2° respectively, and those for the Aka Aiteputh Formation are 77.4°N, 132.4°E and 13.9°. The difference between the mean paleopoles suggests that APW towards the north occurred during the Miocene period.

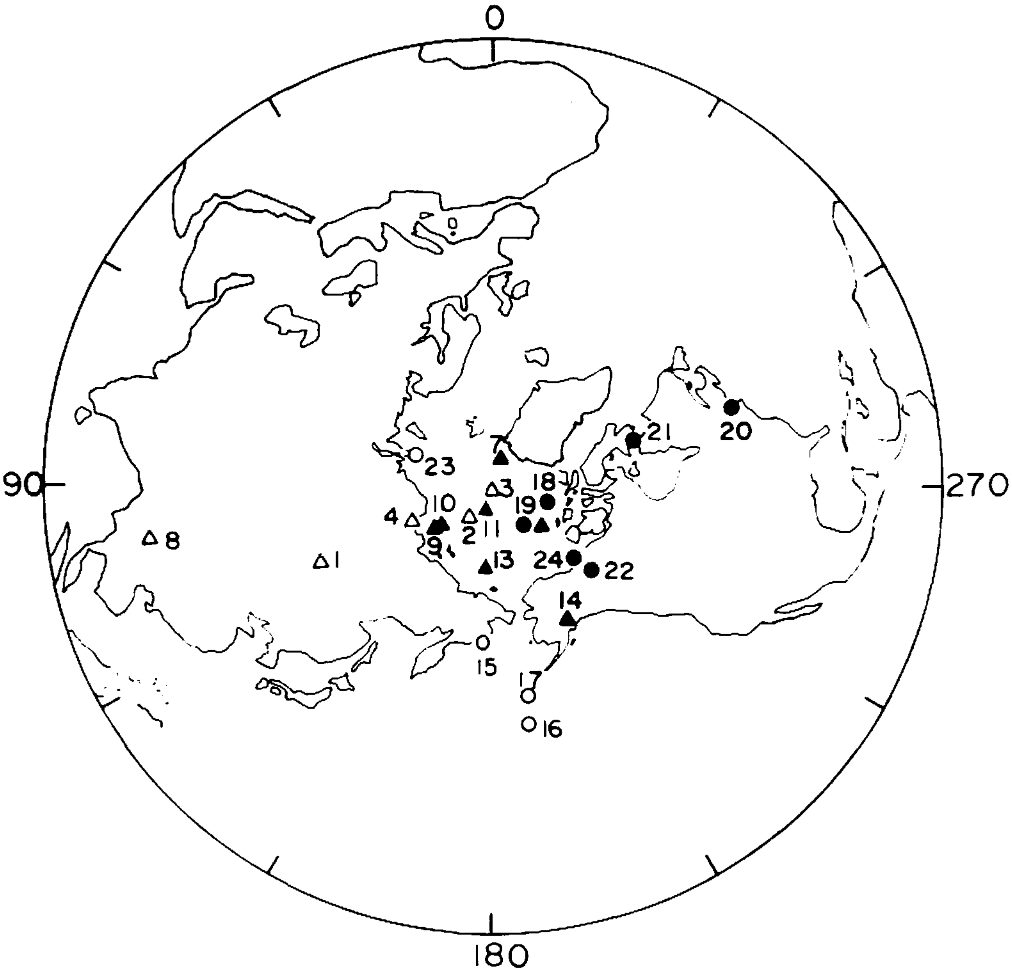

Fig. 7 VGPs plotted on polar equal area projection of Northern Hemisphere. Triangle and circle symbols are from the Nachola and Aka Aiteputh Formations, respectively. Numbers indicate Site Nos. in Table 1. Solid symbols correspond to north poles, and open symbols to south poles.

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Table 3. VGPs from the Nachola and Aka Aiteputh Formations.

Site	Lat (°N)	Lon (°E)	dp (°)	dm (°)
AKA AITEPUTH FORMATION				
(Samburu Hills)				
1) 84091501	−54.6	294.6	2.7	5.2
2) D (82100113)	−82.8	321.4	7.1	14.2
3) 84091703	−88.8	355.7	1.9	3.7
4) 84091801	−73.3	294.6	20.1	39.8
5) 84091802				
6) 84091805	78.8	229.3	4.9	9.4
7) E	85.2	346.6	4.4	8.8
8) 84091807	−23.7	279.0	17.0	27.1
(Nachola Area)				
9) 84082802	76.8	124.3	3.7	7.3
10) 84082801	77.1	125.0	2.2	4.3
11) 84082903	86.4	157.0	2.6	5.1
12) 84082902				
13) 84082803 a	75.0	173.6	5.2	10.0
14) 84082803 b	62.1	209.1	3.9	6.3
NACHOLA FORMATION				
(Nachola Area)				
15) 84082901	−71.4	355.6	17.4	32.7
(Middle Reaches of the Baragoi River)				
16) 84082701 A	−45.0	8.3	14.9	20.6
17) 84082601	−50.4	9.3	16.1	23.5
18) 84082104	79.7	252.2	2.8	5.4
19) 84082603	81.7	215.3	8.4	16.5
20) 84082201	43.7	288.7	8.1	15.3
21) 84082202 C	63.4	285.4	6.2	12.0
22) 84082202 B	67.6	228.8	2.9	5.0
23) 84082202 A	−73.8	248.5	20.2	36.8
24) 84082103	70.8	228.0	7.2	12.8

Lat and Lon: latitude and longitude of VGP, dp and dm: error angles of VGP.

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