Magnetostratigraphy of Hominid Fossil Bearing Formations in Sangiran and Mojokerto, Java

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Abstract Paleomagnetic investigation of Plio-Pleistocene formations in Sangiran and Mojokerto, Java was carried out to date stratigraphic levels of *Pithecanthropus* fossils. Secular variation records of paleomagnetic field direction from the two areas show very consistent changes with some prominent features. The record for the past 3 million years obtained in Sangiran revises the magnetostratigraphy of earlier investigations and reveals stratigraphic levels of polarity boundaries and events. Based on correlation of the secular variation record of Mojokerto with that of Sangiran, magnetostratigraphy of Pleistocene formations in Mojokerto was established. The stratigraphic zone of *Pithecanthropus* in Sangiran ranges from the lower boundary of Jaramillo event to the Brunhes/Matuyama boundary, and the stratigraphic level of *Homo modjokertensis* lies at the lower border of Jaramillo event. Magnetostratigraphically it dates from about 0.73–0.97 m.y. for Sangiran and about 0.97 m.y. for Mojokerto.

Key Words: magnetostratigraphy, Plio-Pleistocene, age of *Pithecanthropus*, Sangiran and Mojokerto, Java

1. INTRODUCTION

The *Pithecanthropus* fossils found by E. Dubois in 1891 and 1892 at Trinil, East Java, furnished the first fossil evidence of early human evolution in the world. In the 1930s, a number of hominid fossils were discovered at Ngandong and Mojokerto in East Java and Sangiran in Central Java. Particularly, new *Pithecanthropus* finds from Sangiran together with *Sinanthropus* fossils found in China led to the realization that both *Pithecanthropus* and *Sinanthropus* could be regarded as belonging to a distinct stage of human evolution. Sangiran continued yielding plenty of *Pithecanthropus* and *Meganthropus* fossils thenceforth, and Sambungmacan, Central Java, added a hominid skull in 1973.

Along with the anthropological studies of these hominid fossils, their geological background, in particular their geological age, has long been discussed based on

the framework of Plio-Pleistocene stratigraphy and chronology established in the 1930s. Thanks to the development of new research methods, the hominid fossil-bearing formations in Java came to be reexamined and dated in terms of the absolute age. As one of these attempts, paleomagnetic studies were carried out twice in 1977–1978 and 1986–1988 by respective Japan-Indonesia joint research teams. The result of the former study has been published by Shimizu *et al.* (1985), and the present paper deals with that of the latter.

The aim of the paleomagnetic study in 1986–1988 was not only to clarify the magnetostratigraphy for dating hominid fossils, but also to obtain a secular variation record of paleomagnetic field directions of geophysical interest. The fields of study are Sangiran and Mojokerto (Fig. 1), of which the former is the main source area of *Pithecanthropus* as mentioned above, and the latter is the locality where an infant skull of *Homo modjokertensis* was unearthed in 1936. Sangiran was subjected to a systematic study by the above-mentioned Shimizu and his team, but ambiguities remained in the magnetostratigraphy obtained. In this respect, the present study aimed at and achieved the establishment of a much clearer sequence. In Mojokerto, the present study elucidated the magnetostratigraphy of the area for the first time and revealed the absolute age of *Homo modjokertensis*.

The results of studies are presented below with discussions about the absolute age of hominid fossils in both areas, but specific geophysical discussions have recently been published in another paper (Hyodo *et al.*, 1992).

Fig. 1 Location of Sangiran and Mojokerto, the investigated areas, and Trinil, the discovery site of *Pithecanthropus* fossils by Dubois.

2. GEOLOGICAL SETTING

[Sangiran]

The Sangiran area is located 12 km north of Surakarta City, Central Java, at about 7.5°S latitude and 110.8°E longitude. The area, which extends 8 km from north to south and 4 km from east to west, is characterized by a dome structure which was truncated by erosion (van Es, 1931; Duyfjes, 1936; von Koenigswald, 1940). Because of the structure caused by mud volcanic activity, strata are exposed concentrically on the truncated surface, older strata surrounding the central depression of the dome. The exposed sediments are subdivided into four main stratigraphic units by three marker beds (von Koenigswald, 1940; Sartono, 1975; Itihara *et al.*, 1985a).

The Kalibeng (Puren) Formation is at the bottom and consists mainly of bluish grey clay and silty clay with an intercalation of limestone including fossils of *Balanus* in the uppermost part. Molluscs and foraminifera in this formation indicate marine to brackish water depositional environment. The Kalibeng (Puren) Formation is overlain by the Pucangan (Sangiran) Formation which consists of the Lower Lahar, a volcanic mud flow, at the base and black clays. Depositional environment of this formation gradually changed from shallow marine to lagoonal and then to lacustrine. The Pucangan (Sangiran) Formation is overlain by the Kabuh (Bapang) Formation, which is overlain by the Notopuro (Pohjajar) Formation. The Kabuh (Bapang) and Notopuro (Pohjajar) Formations mainly consist of clays, silts, sands and gravels of fresh water origin. The base of the Kabuh (Bapang) Formation is placed at the lower limit of Grenzbank zone (von Koenigswald, 1940), a calcareous pebbly sand bed with interbeds of hard sands and pebbles (Sudijono, 1985). The Upper Lahar lies on the base of the Notopuro (Pohjajar) Formation. Hominid and mammalian fossils are contained in the Kabuh (Bapang) Formation as well as in the Pucangan (Sangiran) Formation. The formation names in parentheses are proposed for lithostratigraphic units in Sangiran to avoid confusion in correlation between the formations in Sangiran and those in East Java (Itihara *et al.*, 1985b).

[Mojokerto]

The find place of the hominid skull is located 3 km north of Perning and 15 km north-east of Mojokerto City, East Java, at about 7.4°S latitude and 112.5°E longitude. The fossil-bearing formations are situated on the Kedungwaru Anticline, the axis of which trends approximately in the east-west direction. The inclination of the strata is about 6° to 11° near the ridge and 15° to 20° about 1 km away from the ridge. Strata are exposed by erosion of the ridge crest in the north and south wings of the anticline, older one being located at the axis. Two formations are distinguished in this area, namely the Pucangan and the Kabuh (Duyfjes, 1936; von Koenigswald, 1940).

The Pucangan Formation mainly consists of clay and tuffaceous sand layers with intercalations of clay and conglomerate. The depositional environment of this formation changes from marine to fluvial. The Pucangan Formation in this area is divided into volcanic facies in the upper part and marine clay facies at the bottom. An infant skull cap was found in the volcanic facies (von Koenigswald, 1936; Duyfjes, 1936). The Pucangan Formation is overlain by the Kabuh Formation which is formed by sands and tuffaceous sands with intercalations of conglomerate. This formation mainly shows depositional environment of fluvial condition. The stratigraphic boundary between the Kabuh and Pucangan Formations has not been allocated exactly in this area. It is due to the fact that a breccia which was assigned to the basis of the Kabuh Formation in the region west of this area could hardly be traced in this area (Duyfjes, 1936).

3. SAMPLING AND EXPERIMENTS

Fine clay, tuff and tuffaceous clay were preferentially sampled, but when they were unobtainable, silty clay was sampled. From each sampling level, at least five small cubic specimens or one large block sample were collected by hand sampling and in laboratory seven small cubic specimens were cut from each block sample. Specimens were put in acrylic cubic capsules 2.5 cm on a side.

In Sangiran sampling sites were selected from those localities where the lithostratigraphy and correlation of strata are well-documented on the geological columnar sections made in 1976–1979 by Itihara *et al.* (1985a). Field guidance was made by Sudijono and Aziz who had taken part in the field survey of the area in 1976–1979. Samples were obtained from fourteen outcrops along the rivers of Brangkal, Puren, Pb stream, Pucung and Pohjar, and near the villages of Bapang and Pondok (Fig. 2). Sampling horizons are shown on columnar sections in Figs. 3 and 4, and their details are described in Table 1 with levels from key beds. Six specimens per level on average were prepared from 109 horizons.

In Mojokerto geological field guidance on the sampling sites and horizons was given by Kumai who had surveyed the area in 1976–1979 (Kumai *et al.*, 1985). Sampling was made mainly on the northern wing of the anticline (Fig. 5). The samples along the road near the anticline axis are mostly tuffaceous clay or tuffaceous silty clay. Few outcrops were found to the north of Sumbertengah. Map of sampling sites and sampling horizons on columnar section are represented in Fig. 5. Stratigraphic levels from key beds are listed in Table 2. Five specimens per level on average were prepared from 38 horizons.

Natural remanent magnetization (NRM) was measured using a spinner magnetometer of 10^{-10} Am² sensitivity. All the specimens were progressively demagnetized in alternating fields (AF) up to 80–100 mT at intervals of 5–20 mT

to examine the stability of magnetization and consistency of magnetization decay patterns in the same horizon. Low field susceptibility was measured on one specimen per level using a superconducting magnetometer of 10^{-11} Am² sensitivity.

Fig. 2 Map of the Sangiran area. Open circles show locations of columnar sections for sampling sites in Figs. 3 and 4. Locality numbers are after Itihara *et al.* (1985a). Solid squares show villages.

Fig. 3 Columnar sections for sampling sites for the Notopuro (Pohjajar) and Kabuh (Bapang) Formations in Sangiran. The columnar sections are after Itihara *et al.* (1985a). The formation names in parentheses are the names proposed by Itihara *et al.* (1985b) for specifying the Formations in Sangiran.

Fig. 4 Columnar sections for sampling sites for the Pucangan (Sangiran) and Kalibeng (Puren) Formations in Sangiran. The columnar sections are after Itihara *et al.* (1985a). The formation names in parentheses are the names proposed by Itihara *et al.* (1985b) for specifying the Formations in Sangiran.

4. RESULTS

4.1 Magnetic properties

The progressive AF demagnetizations show that fine clay and unaltered fine tuff usually possess stable NRM. They represent stable normal or reverse remanence directions throughout the progressive demagnetization in AFs up to 60-80 mT. Such a remanence is found in some fine clays from the Kalibeng (Puren) Formation, most of fine clays and tuffs from the Pucangan (Sangiran) Formation, and some tuffs from the Kabuh (Bapang) and Notopuro (Pohjajar) Formations in Sangiran.

Some NRMs are intensively affected by secondary viscous remanent magnetization (VRM). The VRM component often consists of more than 90 % of total NRM and

Fig. 5 Map of the Mojokerto area and a columnar section for sampling sites. The dashed line in the map shows the Kedungwaru Anticline. The columnar section is after Kumai *et al.* (1985).

sometimes remains unremoved even by the demagnetization in AF of 50 mT. Such a high-coercivity secondary component may be ascribed to thermoviscous magnetization (Pullaiah *et al.*, 1975; Kent, 1985). The NRM affected by a large VRM is often found in fine clays and silty clays from the Kabuh (Bapang) Formation in Sangiran and fine clays and tuffaceous clays in Mojokerto. Typical results of AF-demagnetization of sediment samples from Sangiran and Mojokerto are shown in the Appendix.

NRM intensities of silty clay are larger by one or two orders of magnitude than those of fine clays. Such different magnetic property can be explained by different size of magnetic grains. The silty clay possibly contains coarser grains, which have lower coercivity and easily acquire a large VRM. Magnetization vectors sometimes converged at two or more directions in the course of progressive AF demagnetization. It is explained by multi-component due to wide lock-in zone in post depositional magnetization process (Hyodo, 1984; Hyodo and Yaskawa, 1986).

Horizon-average values for NRM intensities before AF-demagnetization (J_0) for samples from Sangiran are shown in Fig. 6 compared with those after demagnetization in an AF 60 mT (J_{60}) and low field susceptibilities (χ). Magnetization intensity variations have a sharp boundary in the uppermost part of the Pucangan (Sangiran) Formation. Intensities of J_0 , J_{60} and χ for sediments above the tuff T11 exhibit high values as a whole with large fluctuations. Although many of strong intensities are ascribed to silty clays, even fine clays from some horizons have high intensity. This indicates inhomogeneity of sediments in addition to large quantity of magnetic minerals in accordance with the fact that the Kabuh (Bapang) and Notopuro (Pohjajar) Formations consist of fluvial deposits. The large fluctuations in the uppermost part of the Pucangan (Sangiran) Formation above T11 may be due to a transitional environment from lacustrine to fluvial.

The NRM intensities below T11 are low with smooth change representing homogeneity of marine, lagoonal and lacustrine sediments. The only exception is in the thin layer just below the Balanus Limestone in the Kalibeng (Puren) Formation which shows large fluctuations in magnetization intensity. This part mainly consists of silty clay so that the large values of J_0 and χ may be partly due to multi-domain grains. The high peaks just below the Balanus Limestone in the J_0 and χ logs (Fig. 6) are smoothed in the J_{60} log (Fig. 6) suggesting an existence of multi-domain grains.

Sediments in Mojokerto exhibit intensity patterns similar to those of Sangiran with respect to lithofacies. Fluvial sediments, which are marked by the emergence of vertebrate fossils, show high values with large fluctuations in magnetization intensities of J_0 , J_{60} and χ as in Fig. 7, while marine tuffaceous sediments have small intensities below the boundary fluvial/marine in the long sequence of alteration of sands and tuffaceous sands. The wide range of intensity changes in the Molluscan

Horizon II (Fig. 7) is similar to that of sediments just below the Balanus Limestone layer in Sangiran.

The converged directions of remanence after demagnetization in higher AFs were adopted for calculation of a horizon average in later discussion. We omitted magnetization of samples from fifteen horizons in Sangiran and three horizons in Mojokerto indicating neither consistent pattern of demagnetization nor convergent stable direction within a same horizon. The observation of fresh outcrops after the rainy season revealed that some of those horizons had been disturbed by slumping. At present, we have no clear explanation for the others. Chemical alteration of magnetic minerals or disturbance of grain alignment during diagenesis possibly cause such unstable NRM.

4.2 Magnetostratigraphy

Average magnetization of each horizon was calculated using the characteristic higher coercivity magnetizations obtained after demagnetization usually in AFs of 50–100 mT. The remanence was classified as normal, reverse or intermediate. The intermediate was defined as a direction which departed from the geocentric axial dipole field by more than 50°. Polarity of each horizon is distinguished on the columnar sections in Figs. 3, 4 and 5.

[Sangiran]

Stable component of NRM isolated by demagnetization in higher AFs clearly defines the boundary of the geomagnetic polarity change. The following polarity zones were identified: (1) normal, (2) reverse, (3) intermediate, (4) normal mixed with intermediate and (5) reverse mixed with intermediate (Fig. 8).

The polarity change just below the Upper Tuff in the Kabuh (Bapang) Formation should be the Brunhes/Matuyama boundary at age 0.73 m.y. (Mankinen and Dalrymple, 1979). At three localities in the southern part, the boundary was identified in zones <1 m thick below the Upper Tuff. The Jaramillo event, which ranges in age between 0.90 and 0.97 m.y., is correlated with the normal zone mixed with intermediate magnetic vectors between the Grenzbank zone and the tuff layer T11. The second normal zone also with intermediate directions around the Balanus Limestone in the Kalibeng (Puren) Formation can be correlated with the Olduvai event, between 1.67 and 1.87 m.y. This event ranges in level between 1–3 m above and 7–10 m below the Balanus Limestone near Pablengan. The succession of normal polarity below the nodule layer in the Kalibeng (Puren) Formation would belong to the Gauss normal chron. The Gauss/Matuyama boundary at 2.48 m.y. in age may be situated somewhere between the Upper Tuff and the nodule layer. No paleomagnetic sample was available in the range due to the lack of good outcrop. Below the Lower Tuff 3 in the Kalibeng (Puren) Formation are two mixed zones of reverse and

intermediate, separated by a stable normal layer just below the Lower Tuff 1. The Kaena event, between 2.92 and 3.01 m.y., may be correlated to the Upper zone and the Mammoth event, between 3.05 and 3.15 m.y., to the lower zone.

The present result of magnetostatigraphy is more consistent with recently published fission-track ages (Suzuki, 1985; Suzuki *et al.*, 1985) than those reported previously (Nishimura *et al.*, 1980). For example, Nishimura *et al.* (1980) obtained 0.69 and 0.58 m.y. just above the diatom bed in the Pucangan (Sangiran) Formation, around which Suzuki *et al.* (1985) obtained 1.51 and 1.49 m.y. from the tuffs T5 and T6, respectively. Since these horizons are between the Olduvai and Jaramillo events, the former dates are clearly too young. Other fission-track datings by Nishimura *et al.* (1980) also tend to give younger ages.

A noticeable feature of the geomagnetic secular variation is the westerly rotated directions over a 40 m thick zone, above the Lower Lahar and below the tuff T2 in the Pucangan (Sangiran) Formation (Fig. 6). The fission-track ages of the tuff T5 and T6 and the upper boundary of the Olduvai event suggest that the time span of the deflection is more than 10^5 years. The behavior of the geomagnetic field is regarded as an excursion which can be explained by a model with an eccentric radial dipole source persisting for a long time (Hyodo *et al.*, 1992).

[Mojokerto]

Reverse or intermediate magnetizations were obtained in most of horizons in Mojokerto (Fig. 7). The polarity zones characterized by dominance of easterly intermediate magnetizations were recognized around the sand and gravel beds SG1 and SG2, and at the base. The upper zone ranges between 3.2–5.0 m above the sand and gravel layer SG2 and the base of the sand and gravel layer SG1. The lower zone is in the basal marine clay and silt with molluscan fossils below a tuffaceous silt. These two intermediate zones sandwich a reverse zone in which there is the succession of westerly deflected directions. This pattern of zonation is well correlated with that of polarity zones between the Jaramillo and Olduvai events in Sangiran as compared in Fig. 8. Consequently the upper zone should be correlated to the Jaramillo event and the lower zone to the Olduvai event. Although the lower zone includes no horizon of complete normal polarity, the dominance of easterly intermediate direction is consistent with that of the Olduvai event in Sangiran. In addition, the lowermost two horizons have almost normal directions. This shows that the intermediate field directions are transitional from normal to reverse.

The Brunhes/Matuyama boundary may be situated between the uppermost normal and reverse polarity horizons. The normal horizon which may be in the Brunhes chron is below the gravel bed with vertebrate and molluscan fossils at the top and the reverse horizon is in a tuffaceous silt below the thick sands and gravel layer SG4 at Sumbertengah.

Fig. 6 Vertical plots of magnetization intensities and paleomagnetic directions from Sangiran. NRM intensities before and after demagnetization are averages in each horizon. Susceptibility is a value for a single specimen per horizon, plotted on a relative scale. Declination and inclination are of horizon averages of higher coercivity stable magnetizations.

Fig. 7 Vertical plots of magnetization intensities and paleomagnetic directions from Mojokerto. NRM intensities before and after demagnetization are averages in each horizon. Susceptibility is a value for a single specimen per horizon, plotted on a relative scale. Declination and inclination are of horizon averages of higher coercivity stable magnetizations.

Table 1. Listing of paleomagnetic measurements in Sangiran

Site Name	Site	Level from Key bed (m)	Facies	NRM intensity		Mean direction of stable NRM				
				J0 (mA/m)	J60 (mA/m)	N	DEC (°)	INC (°)	α-95 (°)	k
SF39	S43A	SK18 + 1.6	Silty C.	47.34	3.08	7	14.6	-24.5	25.6	9.2
S239	S43A	SK18 + 1.55	Silty C.	34.38	3.79	5	-43.3	27.5	36.0	5.5
SH17	S43A	SK17 + 6.3	Fine C.	16.45	2.29	4	35.3	24.2	14.7	40.2
SH28	S16	SK17 - 0.25	Silty C.	2.07	0.78	4	-27.9	-2.7	29.7	10.6
SJ48	S16	SK17 - 1.9	Fine C.	99.37	3.90	7	-25.7	-22.3	12.4	24.6
SH15	S48	SK16 + 7.2	Silty C.	4.89	0.99	4	-17.1	35.2	37.0	31.7
SH29	S16	SK17 - 4.7	Silty C.	20.10	1.76	4	7.3	25.6	25.9	13.6
SF36	S48	SK16 + 1.4	Silty C.	5.18	1.79	7	4.7	17.0	25.1	6.7
BB01	S48	Sk16 + 0.25	Fine C.	8.67	0.61	4	-3.2	-17.2	13.3	48.8
BB03	S48	Sk16 + 0.15	Fine C.	6.86	0.93	5	-2.3	-19.6	16.9	21.4
SO15	S42	SK16	Fine T.	8.65	0.90	7	Indeterminable			
S215	S42	SK16	Fine T.	9.43	0.92	5	Indeterminable			
SS05	S59	SK16	Fine T.	8.36	1.55	7	Indeterminable			
SS11	S42	SK16 - 0.01	Silty C.	90.48	1.38	7	12.6	-8.7	18.6	11.5
S211	S42	SK16 - 0.06	Silty C.	52.53	4.20	6	0.7	24.8	23.7	9.0
SS06	S5	SK16 - 1.9	Silty C.	134.0	2.11	7	Indeterminable			
SS04	S59	SK16 - 0.55	Silty C.	6.74	2.36	6	-30.7	-47.1	23.8	8.9
S204	S59	SK16 - 0.60	Silty C.	6.61	0.81	3	208.6	68.7	24.8	25.8
SS08	S5	SK16 - 2.9	Fine C.	33.54	0.71	4	Indeterminable			
SO17	S42	SK16 - 0.63	Fine C.	44.47	0.91	7	176.2	-9.3	21.8	8.6
S217	S36	SK16 - 0.68	Fine C.	75.44	0.68	7	62.6	-26.5	22.0	8.5
SO23	S42	SK16 - 0.9	Fine C.	6.85	0.54	7	176.6	-29.8	21.9	8.5
SO24	S42	SK16 - 1.5	Fine C.	10.40	0.67	5	181.9	6.1	30.6	7.2
SS03	S59	SK15 + 2.55	Fine C.	205.9	2.66	7	191.8	4.5	21.0	9.2
SS12	S42	SK16 - 3.2	Fine C.	36.65	7.29	7	183.6	5.2	6.4	89.3
SS07	S5	SK15 + 2.0	Fine C.	187.5	1.25	7	179.7	-30.4	20.9	9.3
SS13	S42	SK16 - 5.8	Silty C.	319.0	1.42	5	208.5	-3.1	29.9	7.5
SS02	S59	SK15	Fine T.	12.54	0.65	7	182.6	-5.7	22.0	8.5
SS09	S6	SK15 - 1.2	Fine C.	17.27	1.08	6	203.3	12.4	21.7	10.5
SO20	S36	SK15 - 0.62	Fine C.	0.36	0.22	7	159.4	-12.6	15.3	16.6

Fig. 8 (left page) Magnetostratigraphy and declination plot for Sangiran and Mojokerto. Shaded portions in the declination plot show mixed polarity zones and a long sequence of westerly rotated fields. On the polarity column of Sangiran, fission track ages with an asterisk are after Suzuki (1985) and those without asterisk after Suzuki *et al.* (1985). On the geological column of Mojokerto, A and B indicate the find level of *Homo modjokertensis*: A after Kumai *et al.* (1985) and B after Jacob (personal communication), see text. Two arrows at the extreme right indicate the levels paleomagnetically correlating to the Formation boundaries in Sangiran: upper arrow shows the Pucangan (Sangiran)/Kabuh (Bapang) boundary and lower arrow the Kalibeng (Puren)/Pucangan (Sangiran) boundary.

Table 1. (cont'd)

Site Name	Site	Level from Key bed (m)	Facies	NRM intensity		N	Mean direction of stable NRM			
				J0 (mA/m)	J60 (mA/m)		DEC (°)	INC (°)	α-95 (°)	k
SS10	S9	SK15 – 8.7	Silty C.	117.3	2.46	5	208.6	–20.4	16.4	22.6
SO22	S48	SK14 + 0.1	Silty C.	0.95	0.38	7	Indeterminable			
SO21	S48	SK14	Fine C.	0.98	0.82	7	173.0	11.2	11.6	28.2
SH30	S15	SK14 – 2.2	Silty C.	33.11	1.47	4	157.4	48.5	33.4	8.5
SH34	S36	SK14 – 1.33	Silty C.	2.01	0.33	5	160.2	–14.4	15.9	24.2
SO19	S36	SK14 – 1.85	Silty C.	0.91	0.30	7	Indeterminable			
SJ50	S15	SK14 – 10.0	Silty C.	134.9	3.61	4	169.9	28.3	31.3	9.6
SF37	S48	SK13 + 3.3	Fine C.	14.83	4.58	7	182.6	19.3	4.3	196.3
SF38	S48	SK13 + 0.9	Fine C.	0.35	0.36	7	176.2	8.4	10.4	34.8
SH35	S36	SK13 – 0.10	Fine C.	2.72	0.46	4	–23.3	14.5	8.2	126.0
SH16	S48	SK13 – 0.5	Fine C.	0.71	0.29	5	261.1	–15.0	25.5	9.9
SH27	V-5	SK12 + 5.5	Silty C.	0.45	0.17	5	Indeterminable			
SH39	S36	SK13 – 3.0	Silty C.	5.49	1.14	5	175.3	77.1	30.8	7.1
SH38	S36	SK13 – 9.5	Silty C.	21.63	1.06	4	110.8	–11.9	11.3	67.2
SO18	S36	SK13 – 4.0	Silty C.	9.11	1.81	7	23.3	29.5	15.7	15.7
SH26	V-5	SK12 + 2.4	Silty C.	0.15	0.02	5	Indeterminable			
SH36	S36	SK13 – 4.4	Silty C.	13.67	1.22	5	95.6	55.3	22.4	12.7
SH37	S36	SK13 – 6.9	Silty C.	11.87	1.24	5	32.2	–4.7	20.8	14.5
SJ47	V-5	SK12 + 4.5	Fine C.	0.14	0.03	6	–1.3	17.3	28.1	6.6
SH25	V-5	SK12 + 0.05	Fine C.	1.19	0.60	5	179.5	13.7	2.7	832.1
SJ46	V-5	SK11	Fine T.	0.21	0.11	5	190.3	35.4	8.9	74.4
SJ45	V-2	SK10 + 0.1	Fine C.	1.16	0.69	6	172.9	–9.3	6.4	112.2
SH24	V-3	SK10 + 12.5	Fine C.	1.40	0.67	5	179.3	3.1	3.8	412.0
SH22	V-2	SK10	Silty T.	5.76	3.65	5	171.2	–8.1	7.7	100.1
SH23	V-2	SK10 – 2.6	Fine C.	0.57	0.02	5	Indeterminable			
SF35	IV	SK9 – 2.0	Fine C.	0.66	0.43	6	176.3	56.7	11.6	35.8
SF34	IV	SK8 – 4.71	Fine C.	0.11	0.05	7	184.7	1.4	15.0	17.2
SF30	III-2	SK7 + 33.5	Fine C.	0.99	0.20	7	264.9	17.0	6.4	89.7
SH01	III-3	SK7 + 2.6	Fine C.	1.00	0.18	4	262.1	3.9	12.7	53.0
SJ43	III-2	SK7 + 27.8	Fine C.	0.66	0.23	7	226.9	8.7	4.8	161.7
SF29	III-2	SK7 + 26.5	Fine C.	0.33	0.11	7	214.9	0.9	10.9	31.5
S229	III-2	SK7 + 26.45	Fine C.	0.34	0.12	5	230.5	16.2	16.8	21.7
SF28	III-2	SK7 + 15.5	Fine C.	0.56	0.26	7	208.9	3.2	5.2	136.2
S228	III-2	SK7 + 14.45	Fine C.	0.56	0.24	5	211.2	4.7	6.7	131.2
S227	III-2	SK7 + 9.70	Fine C.	0.24	0.15	5	187.9	5.9	24.7	10.5
S327	III-2	SK7 + 9.65	Fine C.	0.28	0.26	4	205.0	7.4	18.4	26.0
SF26	III-1	SK7 – 1.28	Fine C.	0.27	0.03	5	169.1	0.9	24.4	10.8
S226	III-1	SK7 – 1.33	Fine C.	0.22	0.15	6	183.4	–14.8	22.9	9.5
SJ42	III-1	SK6 – 5.0	Fine C.	0.30	0.11	7	195.1	10.2	13.0	22.4
SJ41	III-1	SK6 – 6.2	Fine C.	0.41	0.08	7	62.5	–60.8	22.8	7.9

Table 1. (cont'd)

Site Name	Site	Level from Key bed (m)	Facies	NRM intensity		N	Mean direction of stable NRM			
				J0 (mA/m)	J60 (mA/m)		DEC (°)	INC (°)	α -95 (°)	k
SA61	III-1	SK6 – 7.1	Fine C.	0.54	0.09	7	92.4	–13.0	11.3	29.5
SF25	III-1	SK6 – 7.6	Fine C.	1.83	0.30	6	32.2	–39.0	20.3	11.8
S225	III-1	SK6 – 7.65	Fine C.	2.97	0.68	6	18.5	–37.7	21.0	11.1
SH41	III-1	SK5 – 1.7	Silty C.	0.84	0.15	4	5.2	–12.2	21.5	13.6
SA59	III-1	SK5 – 2.30	Silty C.	3.18	0.36	6	199.5	8.1	19.3	13.0
S259	III-1	SK5 – 2.35	Silty C.	1.71	0.46	5	88.9	56.5	26.7	9.1
SH40	III-1	SK5 – 3.8	Silty C.	9.81	1.10	4	26.8	–30.2	7.2	163.6
SJ40	III-1	SK5 – 4.6	Silty C.	11.34	1.67	6	17.9	23.0	11.6	34.5
SA60	III-1	SK5 – 5.55	Silty C.	32.47	1.74	7	12.1	–2.8	18.3	11.8
SA58	III-1	SK5 – 6.8	Silty C.	12.56	0.83	7	13.2	12.8	20.5	9.6
SH21	III-1	SK5 – 10.0	Silty C.	1.78	0.19	4	145.1	16.4	22.2	18.1
SH20	II	SK4 + 5.0	Fine C.	0.65	0.14	4	171.0	–22.8	27.6	12.1
SH14	II	SK4 + 3.7	Fine C.	0.62	1.08	5	–5.9	–17.5	12.8	36.5
SH19	II	SK4 + 1.0	Fine C.	0.36	0.22	5	98.6	–1.9	19.2	16.8
SH32	II	SK4 – 0.05	Fine C.	0.47	0.13	4	2.0	–2.5	10.9	71.5
SH18	II	SK4 – 1.0	Fine C.	0.56	0.14	5	12.6	–45.4	19.9	15.7
SH33	II	SK4 – 1.93	Fine C.	0.52	0.05	4	69.6	27.8	22.1	18.2
SH13	II	SK3 – 1.5	Fine C.	2.31	1.01	5	–23.6	–32.3	19.2	16.8
SJ53	II	SK3 – 0.9	Fine C.	1.96	0.50	5	–2.9	–32.3	18.1	18.7
SJ55	II	SK3 – 2.5	Fine C.	0.63	0.11	5	81.7	–5.9	9.2	69.8
SH12	II	SK3 – 2.2	Fine C.	0.90	0.34	5	–14.7	20.7	25.4	10.1
SH11	II	SK2 + 21.5	Silty C.	0.72	0.24	5	Indeterminable			
SH10	II	SK2 + 18.7	Fine C.	0.63	0.27	5	Indeterminable			
SF33	II	SK2 + 14.5	Fine C.	0.51	0.22	7	–14.0	–1.4	12.1	26.0
S233	II	SK2 + 14.45	Fine C.	0.66	0.26	5	–6.6	6.9	26.6	9.2
SH09	II	SK2 + 12.5	Fine C.	2.86	0.73	3	–23.9	11.5	14.0	78.1
SF32	II	SK2 + 8.0	Fine C.	0.97	0.32	7	–7.9	12.1	15.2	16.8
SH08	II	SK2 + 7.0	Fine C.	0.61	0.16	4	24.7	11.0	7.0	171.0
SF31	II	SK2 + 6.5	Fine C.	0.51	0.21	5	12.1	–22.7	35.0	5.7
SH07	II	SK2 + 6.0	Fine C.	0.75	0.14	5	23.3	–51.1	42.9	4.1
SH06	II	SK2 – 5.5	Fine C.	0.78	0.29	5	–35.4	–20.0	31.7	6.8
SH05	I-1	SK1 + 23.9	Fine C.	0.44	0.14	5	–18.3	–0.2	47.7	3.5
SH04	I-1	SK1 + 13.9	Fine C.	1.48	1.08	5	56.7	–14.3	33.6	6.1
SJ52	I-1	SK1 + 8.00	Fine C.	0.43	0.11	4	79.6	6.8	15.7	35.3
S252	II	SK1 + 7.95	Fine C.	0.80	0.13	5	152.8	–15.5	22.0	13.0
SH02	I-1	SK1 – 1.2	Fine C.	5.26	2.68	5	14.3	–43.7	12.1	40.7
SH03	I-1	SK1 – 11.1	Fine C.	0.44	0.14	5	149.2	–18.4	47.2	3.6
SJ51	I-1	SK1 – 13.5	Fine C.	0.86	0.31	5	93.3	–29.4	16.3	23.1
SH31	I-1	SK1 – 15.5	Fine C.	2.41	0.22	4	115.1	–37.0	18.8	24.7

Table 1. (cont'd)

Site:	Sampling sites in Fig. 2	N:	Number of specimens
α -95:	Radius of 95% - confidence circle	k:	Precision parameter
J0:	Mean intensity of NRM before AFD	J60:	Mean intensity of NRM after 6mT-AFD
C.:	Clay	T:	Tuff

[Key beds]

Kalibeng (Puren) F. SK1: Lower Tuff 1. SK2: Lower Tuff 4. SK3: Nobule layer. SK4: Upper Tuff. SK5: Bottom of Balanus Limestone. SK6: Bottom of Corbicula Bed.

Pucangan (Sangiran) F. SK7: Bottom of Lower Lahar. SK8: T5. SK9: T8. SK10: T9. SK11: T10. SK12: T11.

Kabuh (Bapang) F. SK13: Bottom of Grenzbank Zone. SK14: Lower Tuff. SK15: Middle Tuff. SK16: Upper Tuff.

Notopuro (Pohjajar) F. SK17: Bottom of Upper Lahar. SK18: Base of Uppermost Lahar.

Table 2. Listing of paleomagnetic measurements in Mojokerto

Site Name	Site	Level from Key bed (m)	Facies	NRM intensity		Mean direction of stable NRM				
				J0 (mA/m)	J60 (mA/m)	N	DEC (°)	INC (°)	α -95 (°)	k
MH13	S1	SG5 +	Silty C.	3.31	0.34	5	49.6	-31.4	29.0	7.9
MN10	S2	SG4 -	Silty C.	18.82	0.65	5	193.8	7.2	25.2	10.2
MH23	S2	SG3 - 4	Silty TC	225.5	0.92	4	86.3	-52.5	28.4	11.4
MH22	S2	SG3 - 0.3	Silty TC	21.95	0.61	3	135.3	-29.0	21.7	33.4
MH21	S3	ML3 +	Fine TC	4.08	0.74	5	162.4	11.0	16.4	22.7
MH03	S6	SP -	Silty TC	2.33	0.13	5	Indeterminable			
MH02	S7	SP -	Silty TC	0.90	0.16	5	119.2	-21.3	29.0	7.9
MH01	S5	SG2 + 5	Silty TC	1.08	0.16	3	182.8	-28.3	51.2	6.9
MH04	S8	SG2 + 5	Silty TC	9.20	0.42	4	181.6	-23.7	16.1	33.7
MH20	S9	SG2 + 3.2	Silty TC	81.30	1.89	6	63.6	-7.1	13.9	24.1
MA01	S9	SG2 - 0.2	Fine C.	14.02	0.56	6	-14.1	-48.0	3.7	321.1
M201	S9	SG2 - 0.3	Fine C.	10.84	0.40	7	-17.8	-32.9	8.9	46.7
MN07	S9	SG2 - 1.8	Silty TC	25.53	0.69	5	105.1	57.6	23.8	11.3
MN08	S9	SG2 - 2.4	Silty TC	140.6	2.89	5	83.8	-1.8	20.9	14.3
MA02	S9	SG2 - 8	Fine C.	1.71	0.12	6	50.4	-6.4	16.9	16.7
M202	S9	SG2 - 8.1	Fine C.	1.54	0.11	6	125.3	50.9	22.6	9.7
MH07	S10	SG1 + 5.1	Fine TC	1.43	0.21	5	Indeterminable			
MH05	S6	SG1 + 6	Fine TC	0.29	0.23	4	178.9	68.4	16.4	32.5
MH06	S6	SG1 - 0.5	Fine TC	1.26	0.72	5	187.2	32.1	12.5	38.2
MH08	S6	SG1 - 9	Silty TC	323.5	3.97	5	176.6	15.0	20.1	15.5
MH09	S6	SG1 - 13	Fine TC	19.52	0.98	4	191.5	0.5	50.6	4.3
MH10	S6	SG1 - 16.6	Fine TC	3.27	0.46	4	217.7	8.4	9.6	93.1
MH11	S6	SG1 - 18.5	Silty TC	1.34	0.35	6	249.8	-35.1	26.1	7.6
MH12	S6	SG1 - 23	Silty TC	14.11	0.59	5	250.3	10.5	23.5	11.5

Table 2. (cont'd)

Site Name	Site	Level from Key bed (m)	Facies	NRM intensity		N	Mean direction of stable NRM			
				J0 (mA/m)	J60 (mA/m)		DEC (°)	INC (°)	α -95 (°)	k
MH24	S6	SG1 – 33.5	Fine TC	0.58	0.23	5	218.1	18.3	13.5	32.9
MH25	S6	SG1 – 36.5	Fine TC	0.61	0.34	4	208.5	24.9	13.5	47.3
MH26	S6	SG1 – 47	Fine TC	1.88	0.23	3	180.9	24.5	8.0	240.8
MA03	S11	ML2 + 0.35	Fine TC	38.38	3.95	7	221.7	4.4	2.5	574.1
MN06	S11	ML2 + 0.11	Fine TC	86.38	3.04	5	200.9	2.9	6.5	138.3
MN05	S11	ML2 – 0.48	Fine C.	1.71	0.36	5	144.1	–1.6	16.4	22.8
MA04	S11	ML2 – 0.68	Fine C.	1.48	0.39	7	91.0	0.9	10.3	35.6
MH14	S11	ML2 – 0.75	Fine C.	1.52	0.28	5	79.8	6.9	22.7	12.3
MN11	S6	SG1 – 50	Silty TC	79.50	5.49	5	164.0	9.6	12.9	36.0
MH15	S11	ML2 – 0.85	Fine C.	2.09	0.45	5	113.4	13.2	16.9	21.5
MH16	S11	ML2 – 0.95	Fine C.	1.80	0.63	5	124.4	2.9	15.5	25.2
MH17	S11	ML2 – 1.05	Fine C.	3.66	0.47	5	137.0	–10.6	18.9	17.3
MH18	S11	ML2 – 1.15	Silty C.	23.60	0.58	5	30.9	4.1	17.7	19.7
MH19	S11	ML2 – 3.5	Fine C.	3.52	0.67	5	45.5	33.7	11.3	46.8

Site: Sampling sites in Fig. 5

N: Number of specimens

 α -95: Radius of 95% - confidence circle

k: Precision parameter

J0: Mean intensity of NRM before AFD

J60: Mean intensity of NRM after 60mT-AFD

Only +/-: just above/below

C.: Clay TC: Tuffaceous clay

[Key beds]

SG1: Lower boundary of the thick sand and gravel layer just above the alteration of sand and tuffaceous sand.

SG2: Lower boundary of the thin sand and gravel layer with vertebrate fossils below the sand pipe layer.

SG3: Upper boundary of the sand and gravel layer just above the Molluscan horizon III.

SG4: Lower boundary of the second top sand and gravel layer.

SG5: Upper boundary of the topmost sand and gravel layer.

ML2: Lower boundary of the tuffaceous silty clay just above the Molluscan horizon II.

ML3: Clay just above tuffaceous silt in the Molluscan horizon III.

SP: Sand pipe layer.

5. DISCUSSION

The present paleomagnetic study revises the magnetostratigraphy of earlier investigations in Sangiran. The stratigraphic position of Brunhes/Matuyama boundary is considerably higher than reported by earlier investigators who located it in the Pucangan (Sangiran) Formation (Yokoyama *et al.*, 1980; Semah, 1982) or between the Upper Middle and Middle Tuffs (Shimizu *et al.*, 1985). It seems that earlier studies failed to obtain the succession of reverse polarity in the lower part of the Kabuh (Bapang) Formation, because of insufficient removal of high-coercivity VRM. The stratigraphic level of the Jaramillo event was first determined by clear paleomagnetic evidence. Shimizu *et al.* (1985) obtained several normal layers in the lower part of the Kabuh (Bapang) Formation and suggested that they might be the Jaramillo or some other events. However, all the layers are included in a reverse zone in our data. Only the position of Olduvai event is consistent with the suggestion by the earlier investigations (Semah, 1982; Shimizu *et al.*, 1985). Stratigraphic positions of the polarity boundaries below the Olduvai event have never been discussed in detail in the earlier investigations.

The secular variation of field direction shows that the geomagnetic field must have been unstable during the time of geomagnetic events. Magnetization in intermediate easterly direction has frequently been observed in those events. In addition, the normal or reverse magnetic vector deviates from the geocentric axial dipole field. These directions should be true geomagnetic signals because they are similarly observed in different sediments 200 km distant. Such directions can be also explained as a resultant of two or more field vectors due to post depositional magnetization process (Hyodo, 1984). However, rapid field changes or deflected fields are still needed to produce intermediate magnetization direction. Anyway, the geomagnetic field during events seems unstable. Hence, it is likely that the short sequence of normal and intermediate easterly vectors around the Upper Tuff in the Kalibeng (Puren) Formation (see Figs. 6 or 8) may be correlated to the Reunion event, at ages 2.01–2.04 and 2.12–2.14 m.y.

On account of the Jaramillo and Olduvai events recognized in the paleomagnetic secular variation in Sangiran and Mojokerto, chronological correlation of corresponding strata is available between both areas (Fig. 8). Particularly significant is that well-defined formation boundaries in Sangiran can be correlated to the stratigraphy in Mojokerto where the boundaries have been vaguely located.

In Sangiran the Jaramillo event lies just below the Grenzbank zone the base of which is the boundary between the Kabuh (Bapang) and Pucangan (Sangiran) Formations. In Mojokerto the event occupies approximately the sand and gravel beds SG1 and SG2. Accordingly, the Kabuh/Pucangan boundary in Sangiran paleomagnetically corresponds to a level just above the sand and gravel bed SG2

in Mojokerto as shown by an arrow in Fig. 8. Since the Kabuh/Pucangan boundary has been assumed to lie somewhere above the Molluscan Horizon III and the bed SG2 is in the midst of volcanic facies of the Pucangan Formation by Duyfjes, the boundary deduced from paleomagnetism largely contradicts the traditional scheme of stratigraphy in Mojokerto.

On the other hand, the Olduvai event occurs in Sangiran a little below the Lower Lahar the base of which is the boundary between the Pucangan (Sangiran) and Kalibeng (Puren) Formations, while in Mojokerto it lies approximately at the Molluscan Horizon II. Consequently, the Pucangan/Kalibeng boundary in Sangiran is correlated to a level a little above the Molluscan Horizon II in Mojokerto as shown by an arrow in Fig. 8. The Pucangan/Kalibeng boundary has remained unknown in Mojokerto because the marine facies defined by Duyfjes as the lower part of Pucangan Formation beneath the volcanic facies can hardly be observed in the area. Since the Molluscan Horizon II lies in the volcanic facies of Pucangan Formation, the Pucangan/Kalibeng boundary paleomagnetically correlated to that of Sangiran is unexpectedly high in level.

In conclusion, the paleomagnetic correlation indicates the contemporaneity of corresponding strata of Sangiran and Mojokerto, and if the contemporaneity of corresponding formations of both areas is assumed, the formation division in Mojokerto may be worthy of geological and paleontological reexamination.

A noteworthy coincidence in geological events between Mojokerto and Sangiran is a change in depositional environment. At Sangiran the sequence of westerly rotated reverse fields ends around the level where a change of sediments occurs from marine to lagoonal. At Mojokerto on the other hand, the westerly rotation of field directions ends around the level where a change of sediments occurs from marine to fluvial. This coincidence seems to suggest a more or less simultaneous occurrence of upheaval in the two areas.

In Sangiran plenty of hominid fossils have been discovered since 1936, but all of them were obtained from the surface collection by local collectors. During the geological field study of the area in 1976–1979, the find localities of these hominid fossils were surveyed with the aid of information on individual discoveries obtained from literatures as well as directly from the collectors and others concerned. Consequently, the most probable provenance levels were assumed with regard to the *Pithecanthropus* skulls II–VIII (PII–VIII) or Sangiran 2–4, 10, 12 and 17 in code by Jacob (1975a), *Pithecanthropus* jaws b–f (Pb–f) or Sangiran 1b, 9, 15a, 21 and 22, *Meganthropus* mandible b (Mb) or Sangiran 8, and four other hominid fossils discovered later (Itihara *et al.*, 1985a, b). The skull named PV by Sartono (1964) and PVI by Jacob (1966) is the same specimen corresponding to Sangiran 10. The jaw Pd was regarded by the research team of 1976–1979 as a maxilla fragment kept at Geological Research and Development Centre in Bandung which corresponds to

Sangiran 15a. "Four other hominid fossils" mentioned above include Sangiran 27, a skull found in 1978 from the central part of Sangiran dome (Jacob, 1980).

Of these specimens, PIV, Pb, Pc, Pd, Pf, Mb, and two other human fossils were reportedly found from black clay of the Pucangan (Sangiran) Formation. They are assumed to have come from the uppermost part of the Formation higher than the Tuff 11, or possibly from the Grenzbank zone with respect to PIV, Pc, Pd, and Mb. The rest of the specimens, PII, PIII, PV/PVI, PVII, PVIII, Pe and two other hominid fossils, were collected from the exposed regions of the Kabuh (Bapang) Formation. Their provenance levels are assigned to various stratigraphic positions between the Grenzbank zone and the Upper Tuff of the Formation. Figure 9 is a schematic presentation of these results, in which the assumed provenance levels of individual specimens are plotted at the relative stratigraphic positions inferred from the detailed geological columnar sections as shown in Fig. 3. In the indication of localities at the top, Loc. S54, S60 and S61 are of the central part of Sangiran dome, and the mark H on the row of S61 indicates the find level of Sangiran 27.

The original levels of hominid fossils in Sangiran deduced from the fluorine content of bone substance are mostly consistent with those mentioned above. In addition, the fluorine content of *Meganthropus* a (Ma) or Sangiran 6 and *Pithecanthropus dubius* or Sangiran 5 suggest their original occurrence in the Grenzbank zone or the upper part of the Pucangan (Sangiran) Formation (Matsu'ura, 1982, 1985).

The provenance of hominid fossils thus assumed falls within the range between the Upper Tuff of the Kabuh (Bapang) Formation as the upper border and the Tuff 11 of the Pucangan (Sangiran) Formation as the lower border. With respect to the upper border of provenance, the present paleomagnetic work indicates that the Brunhes/Matuyama boundary, 0.73 m.y. in age, lies just below the Upper Tuff. Strictly speaking, the uppermost provenance level is approximately comparable to the horizon from which a small fragment of tektite was found in situ by excavation in 1978 (Aziz *et al.*, 1985). The horizon is shown in Fig. 9 and marked by T on the geological column S59 in Fig. 3. The tektite fragment gave a fission track age 0.71 ± 0.10 m.y. (Suzuki *et al.*, 1985). As for the lower border of provenance, the Tuff 11 approximately corresponds to the starting level of the Jaramillo event which dates from 0.97 m.y. As the result, in so far as the above-mentioned specimens are concerned, the absolute age of *Pithecanthropus* and *Meganthropus* in Sangiran can be assumed to be 0.73–0.97 m.y. from the aspect of magnetochronology. It is consistent with the fission track dates (Fig. 8) obtained from the area by Suzuki *et al.* (1985).

The infant skull of *Homo modjokertensis* was discovered in 1936 from the Pucangan Formation containing Djetis fauna of the Early Pleistocene (Duyfjes, 1936; von Koenigswald, 1936). While taxonomic orientation is difficult due to its

infantile condition, the skull has been regarded as belonging to *Pithecanthropus* or *Homo erectus* (von Koenigswald, 1968; Jacob, 1975b; Sartono *et al.*, 1981).

The skull was obtained by Andoyo who was engaged in collecting vertebrate fossils in the region north of Peking for the former Geological Survey in Bandung.

Horizon Loc.																	
	S19	S20	S39	S23A	S24	S53	S22	S58	V-5	S16	S9	S8	S6	S12	S54	S60	S61
Kabuh (Bapang) Formation	Upper Part																
	Middle Part																
	Lower Part																
	Lowermost Part																
Pucangan (Sangiran) Formation	Pe																
	Pd																
	P1V																
	Mb																
	Pc																
Grenzbank Zone																	
Pb																	
Tuff 11																	
Tuff 10																	

Coming across the fragments of a leptobos skull in a sandstone bed, he excavated the spot to find the skull of *Homo modjokertensis* at about 1 m depth (Duyfjes, 1936; von Koenigswald, 1940, 1956). According to von Koenigswald (1940), a tooth of *Cervus zuwaani* was collected from the same sandstone bed when he visited there accompanied with Teilhard de Chardin and H. de Terra. While the location of find site was described in literatures, the exact spot was forgotten in the course of time.

On the occasion of geological survey of the area in 1976–1979, the find site in literatures was searched in the field, and the sand and gravel bed SG2 on the geological column in Fig. 5 at the locality marked by A on the map in Fig. 10 was assumed as the most probable find site of the skull (Kumai *et al.*, 1985). In 1987 when the area was surveyed again by a group of Japanese and Indonesian geologists, a local villager pointed out another location as the find site of the skull. It is located at the edge of a cliff facing shallow valley as indicated by B on the map in Fig. 10. There is exposed a sand and gravel bed which resembles that of the locality A but contains not so many vertebrate fossils. The bed was correlated by Kumai to that SG1 on the geological column in Fig. 5. Recently, one of the authors (N.W.) was informed by T. Jacob of Gadjah Mada University that the exact find site of the skull had been located by Andojo, the discoverer of the skull, in 1969 when they had visited the site together. The location verified by Andojo corresponds to the above-mentioned locality B.

On the magnetostratigraphy of the area, the exact find site, that is the bed SG1, lies at the lower border of the Jaramillo event. Since the event dates from 0.90–0.97 m.y., the age of *Homo modjokertensis* can be considered as about 0.97 m.y.

In 1969 when Jacob and Andojo visited the find site of the skull, they were accompanied by G.H. Curtis of the University of California, who collected samples for the K-Ar dating. Pumice taken from a few meters below the find site of the skull gave a date 1.9 ± 0.4 m.y. (Jacob, 1972). This was the first absolute age of the Pucangan Formation implying the age of early *Pithecanthropus* in Java. According to Curtis (1981), however, the accuracy of this date is greatly reduced by the very high atmospheric argon content of analyzed samples.

Meanwhile, from geological and paleontological point of view, revisions have been proposed with regard to the prevailing view since the 1930s that the infant skull of *Homo modjokertensis* originated from the Pucangan Formation associated with Djetis fauna which is earlier in age than Trinil fauna characteristic of the Kabuh Formation. Sartono *et al.* (1981) proposed that the deposit which yielded the skull should be regarded as a lower part of Kabuh Formation instead of the Pucangan Formation. As a reason they pointed out that several vertebrate fossils newly collected from the stratigraphic levels lower than that of *Homo modjokertensis* were of Trinil fauna. On the other hand, de Vos *et al.* (1982) presented a new scheme of vertebrate stratigraphy in Java, in which they revised the popular sequence of

Djetis-Trinil-Ngandong faunas to a more detailed succession taking into account the change of environment reflected on the composition of faunal taxa. A drastic revision is that Djetis fauna was defined as Kedung Brubus fauna and given the biostratigraphic position above Trinil fauna in the revised sequence of Ci Saat-Trinil H.K.-Kedung Brubus-Ngandong faunas. In this context, de Vos (1985) concluded that *Homo modjokertensis* should be correlated to Kedung Brubus or Ngandong fauna probably younger than 0.7 m.y. in age. Both of these studies suggest a younger age for *Homo modjokertensis* than previously thought.

The present paleomagnetic investigation clarified the absolute age of *Homo*

Fig. 10 Location of find site of the *Homo modjokertensis* skull. Site A is after Kumai *et al.* (1985) and site B is after Jacob (Personal communication). The map is after Kumai *et al.* (1985).

modjokertensis and its contemporaneity with early fossil hominids of the uppermost part of Pucangan (Sangiran) Formation in Sangiran through paleomagnetic chronology and correlation. The magnetostratigraphy set up in Sangiran, the important area for plenty of hominid fossils and well-exposed sequence of Plio-Pleistocene deposits, will serve as a standard time scale for studies of human evolution in Java and other regions.

6. CONCLUSION

The present investigation established a magnetostratigraphy throughout the exposed sediments in the Sangiran area. Nine polarity boundaries from the upper boundary of the Mammoth event to the Brunhes/Matuyama boundary were obtained in the stratigraphy. By comparison with a detailed paleomagnetic secular variation record from Sangiran, magnetostratigraphy of the sediments in Mojokerto was also determined. The stratigraphic levels of hominid fossils in Sangiran range from the lower boundary of the Jaramillo event at 0.97 m.y. to the Brunhes/Matuyama boundary at 0.73 m.y. and that of *Homo modjokertensis* in Mojokerto lies at the lower border of the Jaramillo event at 0.97 m.y.

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APPENDIX

Vector endpoint diagrams for progressive AF-demagnetization results of sediments from Sangiran and Mojokerto. Open (solid) circles in the orthogonal projections are on the vertical (horizontal) plane. Open (solid) circles in the equal area projection are on the upper (lower) hemisphere. Samples from Sangiran are (a) a tuff just below the Upper Lahar, (b) a fine clay just above the Upper Tuff in the Kabuh (Bapang) Formation, (c) a fine clay just below the Tektite horizon in the Kabuh Formation, (d) a fine black clay just above the tuff T11 in the Pucangan (Sangiran) Formation and (e) a fine clay just below the Lower Tuff 1 in the Kalibeng (Puren) Formation. Samples from Mojokerto are (f) a fine clay just below the sand and gravel bed SG2, (g) a fine black clay in the Molluscan Horizon II and (h) a tuffaceous silty clay in the sand and gravel bed SG2. The samples of c and f are intensively affected by a secondary viscous remanence. The sample of h has a NRM which is characterized by a downward-pointing direction being somewhat fluctuated. Other samples have stable NRMs less affected by a secondary magnetization.

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