M. BARBETTI, J. D. CLARK, F. M. WILLIAMS and M. A. J. WILLIAMS

PALAEOMAGNETISM AND THE SEARCH FOR VERY ANCIENT FIREPLACES IN AFRICA

Results from a million-year-old Acheulian site in Ethiopia

Identifying the traces of ancient fires used by man is not always a simple matter. Field evidence such as the presence of ash or charcoal, the reddening and hardening of sediments, and the reddening or fracturing of rocks may not be obvious, particularly in the case of very ancient sites.

Palaeomagnetic techniques are well suited for determining whether sediments or rocks have been heated in antiquity and it is surprising that they have not yet been applied to a wide range of archaeological problems. The technique for determining ancient magnetic field strengths which was developed more than twenty years ago by E. and O. Thellier (1959) is particularly appropriate. It is true that the Thelliers' studies were made primarily for geophysical reasons, but they used many archaeological materials. They even made measurements many years ago on samples of highly reddened sediment from the Grotte de l'Escale near Marseille, which is dated to about 0.7 m.y. B.P. and is claimed to be one of the earliest known archaeological sites at which fire was used by man; their results indeed confirmed that those sediments had been baked in antiquity (E. Thellier, personal communication). Essentially the same technique has recently been applied to sediments which may have been baked about 1.5 m.y. ago in the Koobi Fora Formation of northern Kenya, with encouraging but as yet inconclusive results (Barbetti, Wintle, and Flude, 1978). Here we present new results from a ~ 1 m.y. year old site in the Ethiopian highlands.

SITE LOCATION

The plain of Gadeb (*Fig. 1)* is situated on the western edge of the South-Eastern Plateau of Ethiopia, and near the eastern escarpment of the Galla Lakes section of the Ethiopian Rift Valley. At elevations of 2300—2400 m the Webi Shebele river meanders across a series of lacustrine and fluvio-lacustrine sediments of Plio-Pleistocene age and, in the process, has exposed a number of archaeological horizons with artifacts belonging to the Developed Oldowan and Acheulian traditions. The artifacts occur within, or at the base of, sequences of fluvial sands and gravels which from a complex system of channel scours and fills within lacustrine diatomaceous clays. The diatomaceous clays themselves occupy a basin some 150 km^2 in area within Tertiary basalts which have yielded K-Ar ages of 4.35—2.51 m.y. (G. Curtis, personal communication). The sands and gravels represent channel fills, alluvial fans and gravel trains resulting from the influx of rivers during the final stages of desiccation of an extensive Plio-Pleistocene lake (M. A. J. Williams, F. M. Williams, Curtis, Gasse, Adamson — 1979). Early tool-making hominids occupied the area at that time.

ARCHAEOLOGY, AGE AND PETROGRAPHY

At archaeological site 8E (*Fig. 1)*, excavation in January to March 1977 of a gravel horizon immediately overlying diatomaceous clays exposed

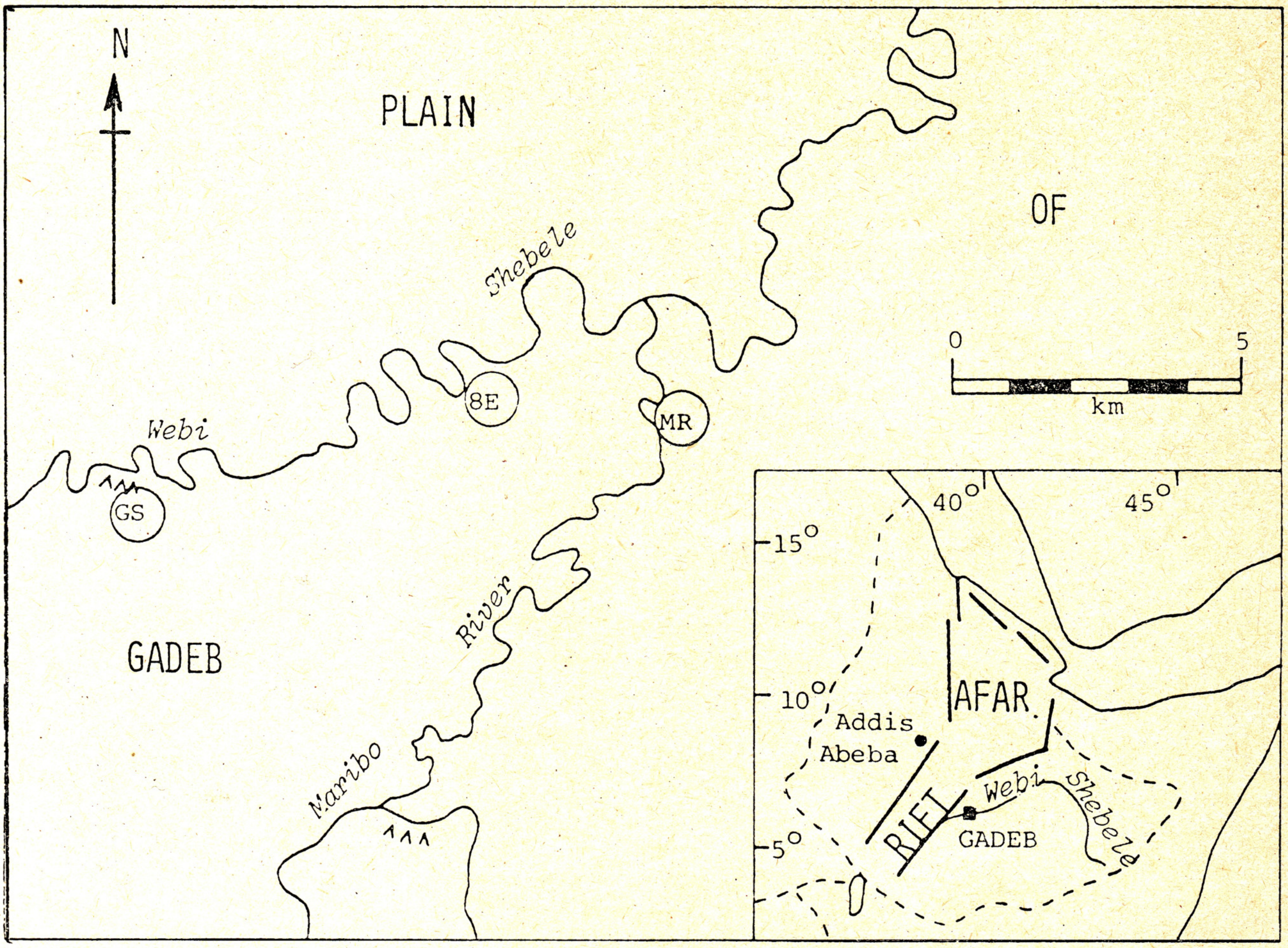

FIGURE 1. *Location map showing sites of samples analysed. 8E: Acheulian/Developed Oldowan archaeological site; MR: Maribo River Iron-Age site; GS: geological sample; ∧ ∧ ∧ : outcrops of welded tuff closest to archaeological sites.*

90 m^2 of a surface rich in Acheulian artifacts together with some bone. This activity area was situated on the bank and in the bed of a shallow stream, and the horizon was probably exposed for only a short time before being sealed by gravelly sands and silty clays. Some rearrangement of artifacts by stream action is believed to have taken place but it was not sufficient to produce any preferred orientation or imbrication of the larger tools. The archaeological horizon has been tentatively dated by K-Ar and palaeomagnetic reversal evidence to between > 0.7 and 1.4 m.y. (G. Curtis and A. Cox, personal communication).

Many of the Acheulian tools are made of welded tuff, the nearest outcrops of which are 6 km or more from the site, and it seems probable that all the welded tuff was carried in by man. In fresh sections the tuff is light brown in colour and, on exposure, becomes patinated to a light grey. Other raw materials for the artifacts include basalt, trachybasalt and trachyte, the most probable source of which was boulders from the ancient stream bed. As excavation proceeded, several weathered but angular fragments of these materials were found that showed differential dark grey and red discolouration such as would not have been inconsistent with their having been burned in a fire. This became apparent only in the closing stages of the excavation so that it was only the later examples to be found that were retained for examination. They mostly occurred singly (samples 8E—H, A, B, D, F and K, *Table 1*), but in the 1 m grid square H4 a group of four such fragments was found (samples 8E—G, J, E and C, *Table 1*), such as might have been associated with a hearth.

Two other archaelogical samples (MR-A and B), which showed more obvious evidence of burning, were collected as controls from an Iron Age site on the Maribo River, a right bank tributary of the Webi Shebele, approximately 3 km from 8E (*Fig. 1*). This is the site of a large fortified village which commanded a ford across the Maribo. The age of this and similar sites is uncertain but they are probably no younger than the 13th century since oral tradition is silent as to their associations.

As another control a fresh sample of the welded tuff (the "geological sample" GS) which provided the raw material for many of the artifacts was collected from the nearest present-day outcrop to 8E,

TABLE 1. *Provenance of Samples and Results of archaeomagnetic Analyses*

FEATURE	AGE	SAMPLE	DESCRIPTION (Maximum Dimension)	ARCHAEOMAGNETIC RESULT			
				Component	Temperature (°C)	Ancient field strength ± 95 % confidence limits (µT)	Dipole moment (10^{22} A.m^2)
Archaeological site on Maribo River, GADEB. Stones from fireplace	Iron Age (possibly 12th or 13th century A. D.)	MR-A	friable tuff, bright red throughout (120 mm)		> 650	35 ± 1	
		B	welded tuff, yellow to orange interior (130 mm)		> 600	35 ± 1	
					weighted mean:	35 ± 1	8.8
Geological sample, GADEB	Pliocene (2.35 ± ± 0.2 m.y.)	GS	welded tuff, grey with yellowish tinge (90 mm)		> 600	31 ± 2	7.8
Archaeological site GADEB 8-E. Stones from later Acheulian living floor.	Middle Pleistocene (~1 m.y.	8E-G*	welded tuff, pale pinkish grey throughout (80 mm)		> 650	40 ± 4	
		H	welded tuff, similar to G (80 mm)		> 650	38 ± 5	
		J	welded tuff, yellowish-grey with black surface, otherwise similar to G and H (90 mm)		> 650	38 ± 2	
		E	olivine basalt, pinkish grey (90 mm)		> 650	36 ± 2	
					Mean:	38 ± 3	9.6
		A	vesicular trachybasalt, purplish-pink with yelowish coating, in vesicles near weathered surface, fractured (70 mm)	1	> 650	46 ± 5	
				2	500	44 ± 12	
		B	vesicular trachybasalt, similar to A (50 mm)	1	> 650	n.e.	
				2	500	26 ± 3	
		C	vesicular trachybasalt, dark red with yellow-stained surface (40 mm)		> 650	30 ± 1	
		D	vesicular trachybasalt, similar to A and B, but slightly darker (though not as dark as C) (30 mm)		> 650	22 ± 1	
		F	trachyte, grey with yellow-stained surface (60 mm)		> 650	n.e.	
		K	aegirine trachyte, light grey with yellow-stained surface (40 mm)		> 650	n.e.	

Ancient field strength estimates were obtained from 15 mm cubes cut from each sample. All the NRM sare thermoremanent in origin and the maximum temperature at which each was observed is given. n.e. indicates that no estimate of ancient field strength was possible, because the NRM-TRM diagrams were highly non-linear. Dipole moments listed are the strengths cf hypothetical sources at the Earth's centre which, if aligned with the Earth's rotational axis, would yield the observed ancient field strength at the site. They may be compared with the present-day dipole moment of 8×10^{22} A.m^2.

*) *This sample was roughly oriented from photographs, and the direction of magnetisation (declination 5°, inclination +45°) was found to be more or less consistent with that expected for the region during a time of normal polarity (0°, +14°).*

about 6 km upstream *(Fig. 1)*. This welded tuff has been K-Ar dated at 2.35 m.y. (G. Curtis, personal communication).

The samples were examined petrographically; lithologies and provenances are summarized *in Table 1.* Samples 8E-G, H, J and GS are all welded tuffs and are petrographically similar; 8E-A, B, C and D are trachybasalts, very similar to each other in composition and differing only very slightly in vesicularity. The other samples are all different; 8E-E is a non-vesicular olivine basalt, 8E-F a trachyte and 8E-K a highly aegirine-rich trachyte.

PALAEOMAGNETIC RESULTS

Measurements were conducted on several cubic specimens (15 mm edges) cut from each of the parent samples, using a 'Digico' magnetometer (Molyneux 1971) at the Australian National University. Directions of magnetisation were compared and were generally found to be uniform across a given sample, although the variation was greater in some samples (MR-B, GS, 8E-A and B) than it was in others. We were able to relate the mean direction for sample 8E-G (which was roughly oriented) to the field direction *(Table 1)*.

We then proceeded to measure ancient geomagnetic field strengths on one specimen from each sample, using a standard laboratory procedure known as the modified Thelliers' method (E. and O. Thellier 1959, Nagata, Arai, Momose 1963, Coe 1967). Specimens were subjected to a large number of heating cycles, performed twice at each of a series of progressively higher temperatures. Heating was carried out in air, using a large laboratory furnace with good temperature control and reproducibility. The first of each pair of cycles was performed in zero magnetic field (McElhinny, Luck, Edwards 1971), and the partial Natural Remanent Magnetisation (NRM) remaining after that treatment was measured. The specimens were then reheated to the same temperature in a laboratory magnetic field of 60 μT, cooled and remeasured; vector subtraction of the partial NRM gave values for the partial Thermoremanent Magnetisation (TRM) acquired during the second cooling. Specimens were placed in the furnace so that their partial TRMs were roughly parallel to their partial NRMs. Four of the lower-temperature partial TRM steps were repeated after the first heating at 590 °C, and reproducible values were found for all samples except MR-B and 8E-K.

Ancient field strengths were determined in the usual manner by constructing NRM-TRM diagrams (Nagata, Arai, Momose 1963, Coe 1967) and fitting lines to appropriate sets of points using the "maximum likelihood" method (Kendal, Stuart 1973).

The slopes of the lines are an estimate of the ratio of NRM to TRM which is assumed to be the same as the ratio of the ancient and laboratory magnetic field strengths. The results are listed in *Table 1* and illustrated in *Fig. 2.* Decisions about which points to include in the line-fitting analysis were made in the following way. The (total) NRM was omitted because of the probable presence of viscous magnetisation acquired during transport and laboratory handling. All other points for MR-A lie near a well defined straight line whose slope indicates an ancient field strength of 35 ± 1 μT. This type of behaviour is typical of young, well-fired and oxidised materials, and linearity over such a wide temperature range is strong evidence for a reliable result. But the points for MR-B (a welded tuff undoubtedly baked in antiquity at the same time as MR-A) do not all lie on a line. Deviations from linearity at high temperatures are common for materials with ancient TRM and are generally attributed to physical or chemical changes induced by weathering and/or the laboratory reheatings. Our usual procedure is to discard the high-temperature points until the calculated 95 % confidence limits approach a minimum width; in the case of this specimen, however, we were forced to discard also the points below 230 °C in order to obtain a result in accord with that for MR-A. We adopted the same procedure for the remaining specimens.

All thirteen samples analysed including the fresh welded tuff GS, have NRMs which are clearly thermoremanent in origin and, interestingly, 8E-A and B each had two components of magnetisation. Samples 8E-G, H, J and E gave very similar values of ancient field strength, despite the fact that 8E-E differed petrographically. There is no sensible way in which these NRM-TRM diagrams could be "interpreted" to give the same results as GS (which is petrographically similar to 8E-G, H and J). The mean results and a corresponding estimate for the Earth's dipole moment is given in *Table 1.*

INTERPRETATION

Using the results as evidence for or against the presence of fire is complicated by the fact that all the stones have possessed TRM from the time they were originally formed as volcanic rocks. With sediments, TRM acquired by firing can be distinguished readily since any original magnetisation would be of another type and probably very much weaker than TRM. Criteria for making such distinctions are discussed in Barbetti et al. 1978 and examples are given in Barbetti 1976. In the present case, however, it is necessary to make a more subtle distinction between TRM which is geological and TRM which is archaeological. The following conditions may be used as a guide.

If we were dealing simply with an agglomeration of igneous rocks we would expect to find:

1. the magnetisation across a given sample to have (a) a uniform direction which is (b) stable during demagnetisation at high temperature,
2. if (1b) holds, cleaned directions of magnetisation which are random between samples (this is a variation of the "conglomerate test" used in palaeomagnetism (McElhinny 1973), and
3. identical ancient field strengths for stones derived originally from the same rock unit, and probably different results for stones from other rock units.

On the other hand, we could be reasonably certain that fire was present if a high proportion of stones possessed either:

4. stable directions of magnetisation consistent between samples (and probably reasonably close to the normal or reversed directions for the site), or
5. identical ancient field strengths regardless of several different rock types (but note that condition [5] would not be found if the stones were used over periods of centuries while the geomagnetic strength was changing).

Note that, if the stones were only partially baked (300 to 500 °C) in antiquity, they would have two components of TRM (and probably non-uniform directions across individual stones); conditions (4) or (5) would apply to the secondary components (as observed for some Magdalenian hearths in Fran-

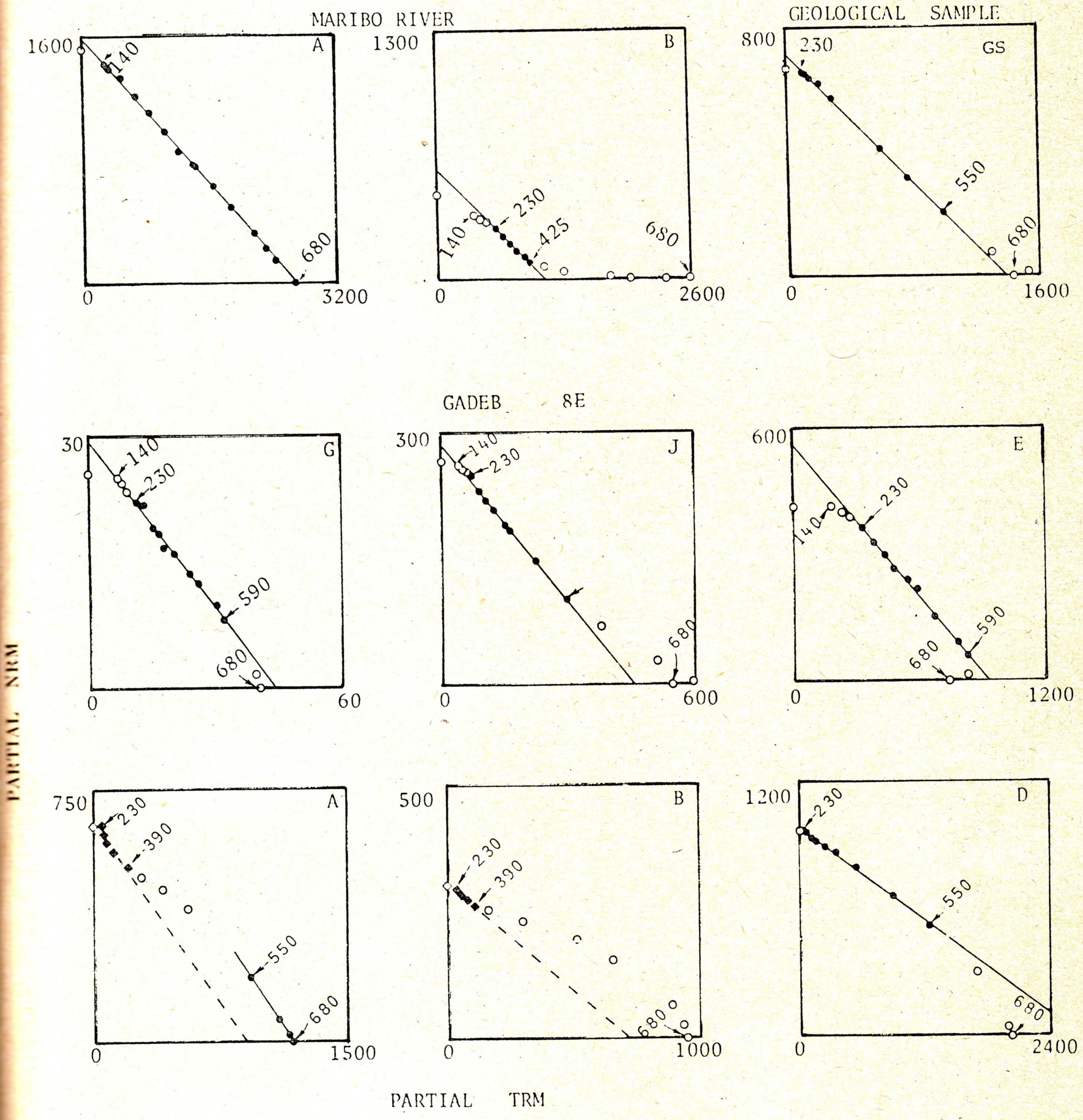

FIGURE 2. *NRM-TRM diagrams for 9 of the 13 specimens studied. Values are in* $\mu A\ m^2\ kg^{-1}$*, numbers near some of the points are heating temperatures in °C, and lines have been fitted to those points represented by solid symbols. Vertical scales are half the horizontal ones. Results for Gadeb 8E-A and B had to be corrected (using Method II of Barbetti in press) because in each case the NRM consisted of two components with different directions; corrected values are indicated by diamonds and fitted lines are dashed (note that these lines are poorly constrained). Open symbols on the ordinates are the (total) NRM and the three points below 230 °C are sometimes omitted for clarity. Diagrams for samples 8E-H and C resembled those for 8E-G and the fresh tuff GS, respectively.*

ce [B a r b e t t i, T a b o r i n, S c h m i d e r, F l u d e — in press]). Whatever the degree of heating, it would of course be necessary to rule out the possibility that the baking resulted from causes other than fire (e.g. a stratigraphically younger lava flow).

The results from Gadeb 8E show elements of both categories. Unfortunately, we did not orient the stones before collection and we are therefore unable to say whether condition (2) or condition (4) applies. The approximate NRM direction for sample 8E-G (which satisfied condition [1]) is close to the normal direction for the site, but this could be interpreted either as evidence for baking or as a fluke (since only one stone is involved). Ancient field strengths appear to differ for samples 8E- A, B, C and D even though petrographic analyses suggest they are probably derived from the same rock unit; the variability might be due to differences in magnetic mineralogy or weathering or it might arise from archaeological heating of some but not all of the stones. The most interesting observation, however, is that condition (5) appears to be met by samples 8E- G, H, J and E and, moreover, that ancient field strengths for 8E- G, H and J differ from that of the fresh tuff GS. That, together with the directional result for sample G and the fact that samples 8E-A and B have secondary thermal components (with ancient field strengths perhaps not significantly different) puts the weight of evidence marginally in favour of fire.

CONCLUSION

Unequivocal evidence for the use of fire by Lower Palaeolithic man is at present no older than 0.5 m.y. and more probably the age is between 0.4 and 0.1 m.y. from sites such as Vértesszöllos (Hungary), (C h e r d y n t s e v 1965); Choukoutien (China), (V a r i o u s a u t h o r s 1964); Kalambo Falls (Zambia), (L e e, B a d a, P a t t e r s o n 1976); Cave of Hearths (South Africa), (M a s o n 1962); Terra Amata, Nice (France), (d e L u m l e y 1976) and others. The evidence at Gadeb is suggestive, though certainly not conclusive, that the makers of the Acheulian tool-kits there may have been using controlled fire, even if they were not already making fire, as early as a million years ago in the high plains of east central Ethiopia. We hope that our results will serve to draw attention to the potential of palaeomagnetic techniques for detection of the prehistoric use of fire and to the requirements for future sampling.

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Mike Barbetti,
Radiocarbon Laboratory,
Department of Physical Chemistry,
University of Sydney,
Sydney, N.S.W. 2006,
Australia.

J. D. Clark
Department of Anthropology
University of California
Berkeley
California 94720
USA

F. M. Williams and M. A. J. Williams
School of Earth Sciences
Macquarie University,
N. Ryde
N.S.W. 2113
Australia