Available online at www.sciencedirect.com
ScienceDirect
Quaternary Research 69 (2008) 91–96
QUATERNARY RESEARCH
www.elsevier.com/locate/yqres

Short Paper

# New paleomagnetic data from the hominin bearing Dmanisi paleo-anthropologic site (southern Georgia, Caucasus)

M. Calvo-Rathert [a,*], A. Goguitchaichvili [b], D. Sologashvili [c], J.J. Villalaín [a], M.F. Bógalo [a], A. Carrancho [a], G. Maissuradze [d]

[a] Dpto. Física, Escuela Politécnica Superior, Univ. Burgos, Av. Cantabria, s/n, 09006 Burgos, Spain
[b] Lab. Interinstitucional de Magnetismo Natural, Inst. Geofisica, Sede Michoacan, UNAM, Morelia, Mexico
[c] Department of Geophysics, Ivane Javakhishvili Sate University of Tbilisi, Georgia
[d] Geological Institute, Georgian Academy of Sciences, M. Alexidze Str. 1, 380093 Tbilisi, Georgia

Received 10 October 2006
Available online 24 October 2007

**Abstract**

The Dmanisi site has yielded human remains and lithic industry associated with Late Pliocene–early Pleistocene fauna. The site is composed of volcanogenic sediments overlying basaltic lava flows. The lithostratigraphic sequence comprises two basic depositional units: Unit A, overlying the basalt flows, and Unit B on top. A paleomagnetic and rock-magnetic study has been carried out on 106 specimens from Units A and B and the uppermost basalt flow. The lava and Unit A provide normal polarities, while reversed polarities and anomalous directions are observed in Unit B, the latter probably due to overlapping of a secondary and a primary reversed polarity component. The lower part of the section shows a clear correlation with the Olduvai subchron, and the upper levels could be as young as 1.07 Ma. As human remains were found both in units with normal and reversed polarity, different non-contemporaneous human occupations might have been possible.


*Keywords:* Paleomagnetism; Pliocene; Pleistocene; Dmanisi; Human evolution; Caucasus

## Introduction

Although a general consensus exists about Africa being the cradle of mankind, the timing of the first habitation and stone technology in different regions of the world remains a topic of debate (e.g., Gabunia et al., 2000; Zhu et al., 2003). During Late Pliocene or early Pleistocene time, hominins started to spread out of Africa and several Plio-Pleistocene and lower Pleistocene Eurasian sites yield direct or indirect evidence of human presence (e.g., Gabunia et al., 2001; Parés et al., 2006). These discoveries have provided new insight about the pattern of human evolution and dispersal, a topic in which age determinations possess capital importance. Paleomagnetic methods are widely used for dating purposes and have proved to be a very useful tool in order to establish a temporal control of sites yielding hominin remains or artifacts (e.g., Zhu et al., 2003).

The Dmanisi paleo-anthropologic site is located in southern Georgia (Caucasus) (41.34°N, 44.34°E), 85 km SW of Tbilisi. Over the course of the last two decades, the site has yielded several hominin fossils, thousands of vertebrate remains and more than one thousand stone tools (Gabunia et al., 2001; Rightmire et al., 2006). K/Ar and $^{40}Ar/^{39}Ar$ dating of the lava flows underlying the site yielded ages of 2.0 Ma (Schmincke and van den Bogaard, 1996), 1.8 Ma (Maissuradze et al., 1991) and 1.85 Ma (Gabunia et al., 2000), and $^{40}Ar/^{39}Ar$ dating of volcanogenic ashes in which a hominin mandible was found gave an age of 1.81 Ma (Lumley et al., 2002), making the Dmanisi findings the most ancient human fossils outside Africa so far.

Dmanisi is located near the confluence of the Masavera and Pinezaouri rivers, on top of an erosional spur of the Masavera basalt, 80 m above present-day water levels. The Late Pliocene Masavera basalt, a thick sequence of lava flows, filled the

* Corresponding author.
*E-mail address:* mcalvo@ubu.es (M. Calvo-Rathert).

0033-5894/$ - see front matter © 2007 University of Washington. All rights reserved.
doi:10.1016/j.yqres.2007.09.001

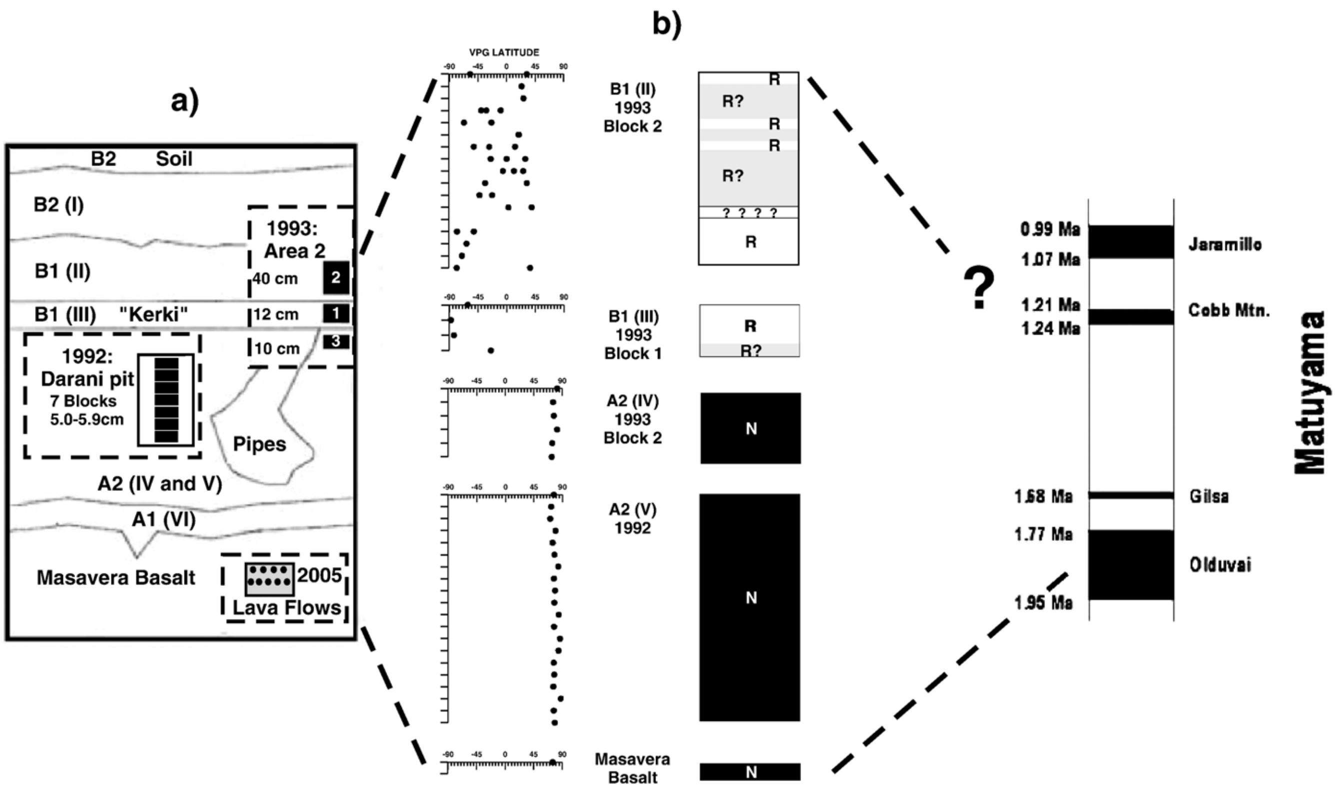


Figure 1. (a) Schematic stratigraphic section of the Dmanisi site (modified from Gabunia et al., 2001). Main depositional Units A1, A2, B1 and B2 (after Gabunia et al., 2001). In brackets, old stratigraphic classification (Dzaparidze et al., 1991). Sampled units (see text) are shown with black (sedimentary samples) and grey (volcanic samples) rectangles. (b) Latitudes of virtual geomagnetic poles and magnetic polarities of studied levels in all units. In grey, samples with anomalous directions, interpreted as reversed polarity directions (see text). Comparison with the Geomagnetic Polarity Time Scale (Gradstein et al., 2004).

Pinezaouri paleo-valley, creating a basin filled by a lake which allowed sediment deposition until both rivers started to excavate the present-day Masavera and Pinezaouri valleys (Dzaparidze et al., 1991). Overlying the lava flows, a 4- to 5-m-thick sequence of volcanoclastic alluvium that is homogeneous in composition, proportions and texture can be found at the site. The basic mineral components are unsorted sand-sized basaltic shards, pumice and glass in a variable matrix of undifferentiated clay, with secondary carbonates in varying proportions (Mallol, 2004).

Dzaparidze et al. (1991) proposed a first stratigraphic classification of the Dmanisi Plio-Pleistocene sequence which comprised six relatively horizontally bedded depositional units. From top to bottom, they are gray clays with limestone blocks (I), yellow brown loam (II), limestone crust (III), brown loam (IV), blackish-brown loam and blackish sand (V) and volcanic ash (VI). A more recent and currently accepted interpretation of the stratigraphic sequence includes only two main depositional units (Gabunia et al., 2000, Fig. 1): the basalt floor is overlain by fallout ash layer Unit A, which is formed by subunits A1 (former layer VI) and A2 (former layers IV and V), the latter conformably overlying A1. The transition between A1 and A2 is gradual, and it has been hypothesized that both units might represent consecutive ash-falls from a single eruption (Mallol, 2004). The upper surface of A2 is an erosional surface and fallout ash layer Unit B unconformably overlies A. Unit B is formed by subunits B1 (former layer II) and B2 (former layer I), which unconformably overlies B1.

Within Unit A, numerous lens-to-tunnel shaped sedimentary structures cross-cut horizontally bedded strata, and most of the vertebrate fossils, including the hominins, come from these features (Gabunia et al., 2001). Their structure, composition and geomagnetic polarity, which was determined in a previous paleomagnetic study (Gabunia et al., 2000), suggest that they formed during erosion of Unit A before deposition of Unit B. On the other hand, one of the mandibles (D2600) was found in ash layer A1 (Lumley et al., 2002). A post-depositional unit of pedogenic calcrete is also recognized, forming a caliche layer on top and a calcrete layer at the bottom of B1, called "Kerki" in the bibliography. This feature has been interpreted as a non-pedogenic calcrete possibly related to groundwater fluctuation in a semi-arid environment (Mallol, 2004).

The site has been subject of previous paleomagnetic work. Sologashvili et al. (1995) obtained normal polarities in all lithostratigraphic units and an anomalous direction in the basal lava, correlating the section with the Olduvai subchron. Most of the samples, however, were not fully demagnetized. Goguitchaichvili and Parès (2000) analyzed 8 cores from the basalt lava and 27 samples from the overlying sediments. The basalt flow yielded an intermediate polarity direction and the sedimentary samples provided reverse polarity directions. These results did not support an Olduvai age for the human remains but suggested an age between 1.77 Ma (Olduvai/Matuyama boundary) and 1.07 Ma (Matuyama/Jaramillo boundary). Gabunia et al. (2000) obtained normal polarities in samples from Unit A and

Table 1
Paleomagnetic results

| UNIT | Levels | $N$ | DEC | INC | $\alpha_{95}$ | $k$ |
|---|---|---|---|---|---|---|
| B1 (II) | 18 | 46 | No mean calculated | | | |
| B1 (III) "Kerki" | 3 | 3 | 171.0 | −56.9 | 22.3 | 31.8 |
| A2 (IV) | 6 | 11 | 15.4 | 62.3 | 4.3 | 244.7 |
| A2 (V) | 20 | 37 | 0.5 | 52.5 | 3.1 | 112.0 |
| Masavera Basalt | 1 | 8(9) | 352.1 | 69.8 | 9.4 | 36.1 |

Levels: Number of stratigraphic levels in each unit. $N$: number of specimens analyzed (9 specimens, 8 cores in the Masavera basalt). DEC: declination. INC: inclination. $\alpha_{95}$: radius of 95% confidence circle. $k$: precision parameter.

the underlying basalt flow as well as reversed polarities in Unit B and the infills of the aforementioned features cross-cutting Unit A, which therefore proved to be non-contemporaneous to Unit A sediments. Unfortunately, almost no technical details (position of the studied cores, demagnetization temperatures and fields) nor Zijderveld plots were provided in their study, although this kind of information is essential for reliable paleomagnetic results. Mean paleomagnetic directions of samples from Unit A and the infills showed good clustering, while scatter in Unit B was considerable ($k$=3.2), casting doubts about the interpretation of the latter directions and their polarity. In a recent study, (Garcia, 2004) obtained coherent results only from samples of the lava flows and the lowermost parts of Unit A, all yielding normal polarities.

As previous investigations have provided rather contradictory results, the present study was started in order to try to obtain a clearer magnetostratigraphic picture of the Dmanisi paleoanthropologic site. Samples were obtained in three different samplings (Fig. 1). In 1992, samples belonging to Unit A (seven 5–5.9 cm horizontally cut continuously sampled blocks) were taken from the so-called *Darani pit*, and in 1993 three horizontally cut 10 to 40 cm block samples belonging to both Units B (blocks 1 and 2, the former taken in the "Kerki" calcrete crust) and A (block 3) were collected in the so called *Area 2* of the excavation (see description in Sologashvili et al., 1995). Non-magnetic glue was applied every day during 1 month to the blocks to be consolidated for sampling, and the same procedure was repeated once a week during a whole year to preserve them during storage. In 2005, the underlying lava flows were sampled. Sedimentary samples from the 1992 and 1993 samplings were oriented only with a magnetic compass, and volcanic samples also by means of a solar compass.

## Laboratory measurements and rock-magnetic results

### *Paleomagnetic experiments*

Paleomagnetic measurements were performed in the University of Burgos. Blocks were cut into cubic or prismatic specimens of 1.5 to 2.0 cm height with a non-magnetic saw, so that specimens from 47 different stratigraphic levels were available together with specimens from the uppermost lava flow. Although most blocks had enough consistency to be used for subsequent thermal or alternating field demagnetization experiments, some had to be put into plaster moulds in order to resist thermal demagnetization without breaking up. All of the latter samples belonged to Unit B. Magnetization of the plaster moulds was negligible (normally less than 1% and less than 4% in the worst case) compared to magnetization of the specimens.

Remanent magnetization was measured with a 2-G cryogenic magnetometer, thermal demagnetization was performed with a Schonstedt TSD-1 furnace and AF demagnetization with a degausser included in the 2-G cryogenic magnetometer equipment. Directions of remanent magnetization components were determined in all cases by means of principal component analysis (Kirschvink, 1980).

Specimens were subjected either to thermal or AF demagnetization. In almost all cases, each stratigraphic level was represented by at least a thermal and an AF demagnetized specimen. In a few cases in Unit B, a combined thermal and AF

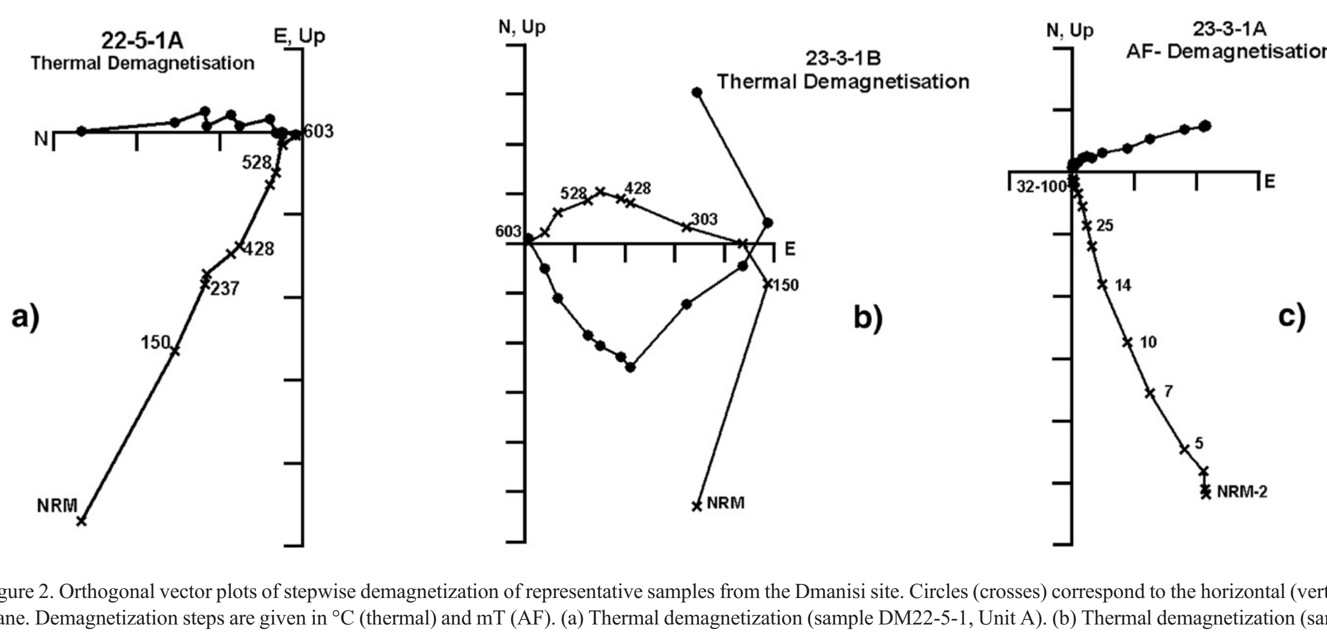


Figure 2. Orthogonal vector plots of stepwise demagnetization of representative samples from the Dmanisi site. Circles (crosses) correspond to the horizontal (vertical) plane. Demagnetization steps are given in °C (thermal) and mT (AF). (a) Thermal demagnetization (sample DM22-5-1, Unit A). (b) Thermal demagnetization (sample DM23-3-1, Unit B). (c) AF demagnetization (sample DM23-8-2, Unit B).

https://doi.org/10.1016/j.yqres.2007.09.001 Published online by Cambridge University Press

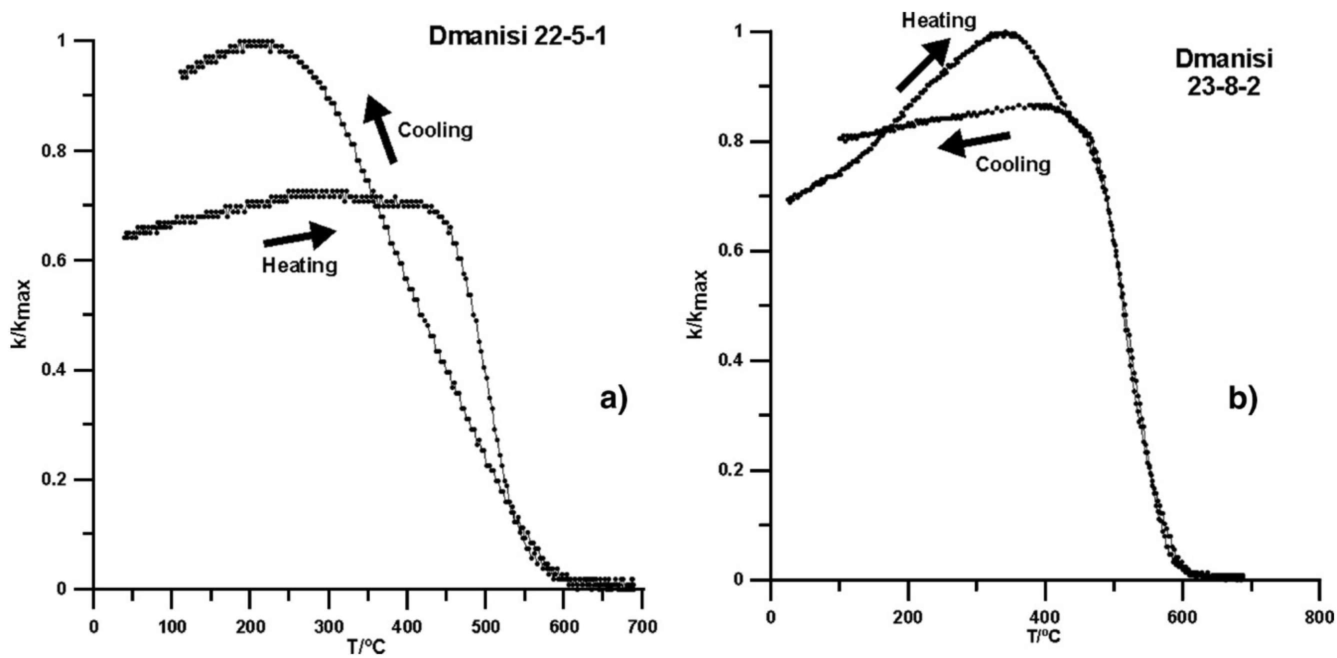


Figure 3. Susceptibility-versus-temperature curves. (a) Sample DM22-5-1 (Unit A). (b) Sample DM23-8-2 (Unit B).

demagnetization was also carried out. Thermal demagnetization was performed in 11 to 20 steps up to maximum temperatures of 574 to 640°C; AF demagnetization in 16 to 20 steps up to maximum peak fields of 90 to 140 mT; and, in combined demagnetization experiments, samples were thermally demagnetized up to 236°C before being AF-cleaned. During thermal demagnetization, room temperature bulk susceptibility was measured after each heating step in order to check possible alteration of the carriers of remanence. Unit A samples showed a 50–60% increase in susceptibility at room temperature after 428°C, with susceptibility starting to rise mainly after heating at 237°C. Unit B samples displayed a steady but only slight increase of susceptibility during demagnetization.

Thermal demagnetization of samples from the basalt flow yielded almost complete demagnetization at 575°C, although most specimens were subjected to AF demagnetization. A normal polarity component partially overlapped by a more or less intense secondary component could be isolated in all studied cases (Table 1).

Unit A specimens displayed a rather simple paleomagnetic behavior (Fig. 2a), both in thermal and in AF-demagnetized samples, showing a single paleomagnetic component. Only in a few cases orthogonal demagnetization plots of samples from some of the upper-lying Unit A levels showed a more complex behavior, apparently related to the partial overlapping of a primary normal polarity component and a secondary one, although the characteristic component could also be easily isolated. Characteristic remanence (ChRM) could be isolated at temperatures above 150 to 237°C (in a few cases above 428°C) or fields above 10 to 20 mT. All analyzed 48 specimens from Unit A, which belonged to 26 different stratigraphic levels, provided normal polarity directions, and thermal and AF-demagnetized sister specimens from the same level showed good agreement in their paleomagnetic directions. ChRM is probably a post-depositional remanence (pDRM), as Dmanisi sediments show signs of intense bioturbation (Mallol, 2004).

In Unit B, 49 specimens from 21 stratigraphic levels were analyzed, both AF and thermally demagnetized samples showing two or three components. In several cases, specimens from the same block and stratigraphic level (i.e., the same sample) displayed a rather different demagnetization behavior when subjected to different demagnetization techniques (Figs. 2b and c). In the case shown, thermal demagnetization was able to separate a lower unblocking-temperature normal polarity component and a higher unblocking-temperature reversed-polarity component, while AF demagnetization of the sister specimen did not, providing an anomalous northwest-pointing direction with negative inclination. In other cases AF demagnetization was able to separate components to a certain extent, while thermal demagnetization of sister specimens did not. Some specimens were subjected to combined thermal and AF demagnetization, but in most cases this technique did not supply much new information. The higher unblocking-temper-

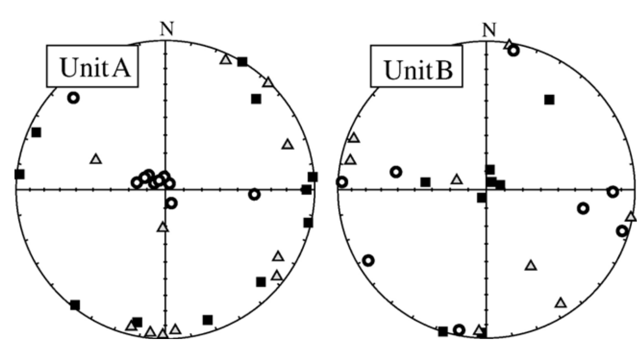


Figure 4. Anisotropy of magnetic susceptibility of representative samples in Unit A and Unit B. Squares: maximum principal axes. Triangles: intermediate principal axes. Circles: minimum principal axes.

ature components could be isolated at temperatures above 350 to 500°C, and the higher unblocking-field components at fields above 20 to 50 mT.

Reversed-polarity ChRM directions could be clearly isolated in block 1 (“Kerki” carbonate layer) and lower stratigraphic levels of block 2 (Fig. 1). In several specimens of Unit B, however, analysis of orthogonal vector plots did not allow determination of a clear ChRM component or, more frequently, provided extremely anomalous directions, such as northward pointing directions with negative inclinations. In some cases, however, analysis of directions during demagnetization showed that there was a tendency of the remaining remanence towards a southward-pointing reversed polarity direction, indicating that the complex behavior observed in Unit B samples could be produced by the overlapping of a normal and a reversed polarity component of similar unblocking-temperature and field spectra, rather than by the presence of anomalous intermediate polarity directions. Due to the aforementioned problems, at higher stratigraphic levels, a more complex picture arose, and while some specimens also provided reversed polarity directions, often rather anomalous directions of intermediate polarity were determined.

### *Rock magnetic experiments*

In order to identify minerals responsible for remanent magnetization, susceptibility-versus-temperature ($\kappa$–$T$) curves were measured on whole rock powdered samples from both Units A and B with a KLY-2 Kappabridge with furnace. Measurements were performed in argon atmosphere, with samples being heated up to temperatures near 700°C and cooled down to room temperature, and Curie points were determined taking inflexion points in $\kappa$–$T$ curves following the drop of susceptibility corresponding to the destruction of ferromagnetic phases.

In Unit A specimens (Fig. 3a), a main component with a Curie temperature $T_C \approx 510$°C (low-Ti titanomagnetite) could be recognized on the heating curve together with a small and almost imperceptible hump at approximately 330°C (perhaps related to the presence of pyrrothite, titanomagnetite or titanomaghemite). The cooling curve showed an increased susceptibility value. In specimens from Unit B (Fig. 3b), two phases could be clearly identified in heating curves, one with a Curie temperature $T_C \approx 520$°C (low-Ti titanomagnetite) and one with $T_C \approx 400$°C, probably also related to the presence of titanomagnetite or titanomaghemite. In Unit B, cooling curves did not show a significant susceptibility increase, but the lower $T_C$ phase had disappeared.

Some Unit A and B specimens were subjected to isothermal remanent magnetization (IRM) acquisition and demagnetization experiments. A weak (0.12 T), intermediate (0.4T) and strong (2T) IRM were imparted to the samples at three perpendicular axes and then thermally demagnetized. The low-Ti titanomagnetite component could be recognized in all cases, but the phase with $T_C \approx 400$°C could be distinguished only in one Unit B specimen. In Unit A specimens, a decrease of IRM was recognized at 300°C in the high and intermediate field axes, probably related to the presence of pyrrothite.

Measurements of anisotropy of magnetic susceptibility (AMS) were carried out on 11 samples from Unit A and 8 samples from Unit B with a KLY-4 Kappabridge. Anisotropy factor P was characterized by very low values, with a maximum $P = 1.006$. Analysis of anisotropy parameters, however, showed that in Unit A samples foliation (F) dominates over lineation ($L$), with $F = 1.0020$; $L = 1.0012$, while the opposite occurs in Unit B samples ($F = 1.0009$; $L = 1.0020$). In Unit A, a sedimentary fabric with nearly vertical minima was observed, but in Unit B the sedimentary fabric could no longer be recognized, a secondary fabric probably being superposed to the latter (Fig. 4).

## Discussion and conclusions

In Figure 1, paleolatitudes of virtual geomagnetic poles (VGP) corresponding to directions from all sequence levels are shown. A cut-off angle of 45° has been chosen to distinguish between intermediate and reverse or normal geomagnetic field (McElhinny and McFadden, 1997). Where specimens belonging to the same stratigraphic level displayed coherent directions, as occurred in Unit A, their mean direction was used to calculate the VGP. Elsewhere, VGPs from each specimen were calculated, providing more than one at a single stratigraphic level. Only in those cases in which a characteristic remanence could unmistakably not be isolated (e.g., Fig. 2c), a VPG was not determined.

In Unit A, samples from all 26 stratigraphic levels displayed well-clustered normal polarity directions (Table 1 and Fig. 1), in most cases obtained from the mean value of thermally and AF demagnetized specimens, which showed excellent agreement. The underlying lava flow also yielded a normal polarity direction. Unit B samples belonging to the “Kerki” calcrete layer (block 2, Fig. 1) also provided coherent results (Table 1). Three of four analyzed levels displayed reversed polarity, and the lowermost one, where no thermally demagnetized specimen was available, had an intermediate polarity. Analysis of remanence directions during demagnetization showed a tendency towards a southward-pointing reversed polarity direction. Remaining Unit B samples (block 1, Fig. 1) showed a more heterogeneous behavior. Only the lowermost stratigraphic levels clearly yielded reversed polarity directions, but the remaining ones were characterized by the occurrence of anomalous intermediate polarity directions together with some reversed polarity directions.

If demagnetization characteristics of samples with the kind of behavior described in the previous section is taken into account (i.e., contradictory behavior of AF and thermally demagnetized specimens belonging to the same stratigraphic level, tendency towards reversed polarity directions of paleomagnetic remanence vectors during demagnetization), it seems reasonable to suppose that the anomalous intermediate polarity directions observed in Unit B actually have no geomagnetic significance but are produced by the coexistence of a secondary normal and a primary reversed polarity component of similar unblocking temperature and field spectra. This interpretation is supported by AMS results, insofar as Unit B (as opposed to Unit A) clearly shows a secondary, non-sedimentary fabric. Therefore, upper-lying Unit B samples are also interpreted as possessing reversed polarities.

If the results from the present study are compared with the geomagnetic polarity scale, and available radiometric data (1.8 to 2.0 Ma for the underlying lavas and the volcanic ash level) are considered, the lower part of the section shows a clear correlation with the Olduvai subchron (Fig. 1). If considered reversed, the upper levels cannot be correlated with any specific point and could be as young as 1.07 Ma (age of Jaramillo) because the whole section is not continuous and so the smaller events might not be recorded, even though the data set from this study is composed of continuous subsections. If directions of the upper-lying Unit B samples are considered intermediate, those data might correspond to a polarity change between Olduvai and any of the normal polarity subchrons shown, although because of the reasons outlined before we do not favor that interpretation.

Despite the morphologic differences observed between mandible D2600 found in layer A1 and the remaining hominin findings (Rightmire et al., 2006), different data sources (i.e., stratigraphic and sedimentological) suggest that the time frame spanning the Dmanisi lithostratigraphic section is not long (e.g., Gabunia et al., 2001). On the other hand, human remains and artifacts have been found in volcanic ashes (Unit A, normal polarity), pipe features (reversed polarity) and Unit B (reversed polarity), and the Olduvai/Matuyama reversal is not recorded in the discontinuous sequence presented in this study. A conservative analysis of these observations suggests that the age of the Dmanisi site could at least span several ten thousands of years, although a much wider period of hundreds of thousands of years cannot be excluded. All this might point to more than one human population occupying the studied area.

## Acknowledgments

We wish to thank two anonymous reviewers and Jaime Urrutia Fucugauchi for their comments on the manuscript. This research was supported by projects BU16/03 and BU028A06 (Junta de Castilla y León, Spain) and *Fundación del Patrimonio Histórico de Castilla y León*. Profiles described in the study were exposed thanks to an excavation of Middle Palaeolithic sites by the Laboratory of Prehistory, Katholieke Universiteit Leuven.

## References

Dzaparidze, V., Bosinski, G., Bugianishvili, T., Gabunia, L., Justus, A., Klopotovskaya, N., Kvavadze, E., Lordkipanidze, D., Majsuradze, G., Mgeladze, N., Nioradze, M., Pavlenishvili, E., Schmincke, H.U., Sologashvili, D., Tushabramishvili, D., Vekua, A., 1991. Der altpaläolithische Fundplatz Dmanisi in Georgien. Jahrbuch des Römisch-Germanischen Zentralmuseums Mainz 36, 67–116.

Gabunia, L., Vekua, A., Lordkipanidze, D., Swisher III, C., Ferring, R., Justus, A., Nioradze, M., Tvalchrelidze, M., Anton, S., Bosinski, G., Jöris, O., Lumley, M.A., Maisuradze, G., Mouskhelishvili, Aleksander, 2000. Earliest Pleistocene hominid cranial remains from Dmanisi, Republic of Georgia: Taxonomy, geological setting and age. Science 208, 1019–1025.

Gabunia, L., Anton, S., Lordkipanidze, D., Vekua, A., Justus, A., Swisher III, C., 2001. Dmanisi and dispersal. Evolutionary Anthropology 10, 158–170.

Garcia, T., 2004. Cadres stratigraphique, magnetostratigraphique et geochronologique des hominides fósiles du site de Dmanissi en Georgie. PhD Thesis. Museum National d'Histoire Naturelle. 233 pp.

Gradstein, F., Ogg, J., Smith, A. (Eds.), 2004. A Geologic Time Scale. Cambridge University Press (588 pgs).

Goguitchaichvili, A., Parès, J.M., 2000. A recognition paleomagnetic study of volcanic and sedimentary rocks from Dmanisi (Caucasus): Implications for the oldest human occupation in Europe. Comptes Rendus de l'Academie des Sciences de la Terre et des Planètes, Paris 331, 183–186.

Kirschvink, J.L., 1980. The least squares line and plane and the analysis of paleomagnetic data. Geophysical Journal of the Royal Astronomical Society 62, 699–718.

Lumley, H., Lordkipanidze, D., Féraud, G., Garcia, T., Perrenoud, C., Falguères, C., Gagnepain, J., Saos, Th., Voinchet, P., 2002. Datation par la méthode 40Ar/39Ar de la couche de cendres volcaniques (couche VI) de Dmanissi (Géorgie) qui a livré des restes d'hominidés fósiles de 1,81 Ma. Comptes Rendus Palevol 1, 181–189.

Maissuradze, G., Pavlenshvili, E., Schmincke, H.U., Sologashvili, D., 1991. Paläomagnetik und die Datierung der Basaltlava, In: Dzaparidze et al., Der altpaläolithische Fundplatz Dmanisi in Georgien. Jahrbuch des Römisch-Germanischen Zentralmuseums 36, 74–76.

Mallol, C., 2004. Micromorphological observations from the archaeological sediments of Ubeidiya (Israel), Dmanisi (Georgia) and Gran Dolina-TD10 (Spain) for the reconstruction of hominid occupation contexts. PhD Thesis, Harvard University, Cambridge, Massachusetts, 259 pp.

McElhinny, M.W., McFadden, P.L., 1997. Paleosecular variation over the past 5 Ma based on a new generalized database. Geophysical Journal International 131, 240–252.

Parés, J.M., Pérez-González, A., Rosas, Benito, A., de Castro, J.M. Bermúdez, Carbonell, E., Huguet, R., 2006. Matuyama-age lithic tools from the Sima del Elefante site, Atapuerca (northern Spain). Journal of Human Evolution 50, 163–169.

Rightmire, G.P., Lordkipanidze, D., Vekua, A., 2006. Anatomical descriptions, comparative studies and evolutionary significance of the hominin skulls from Dmanisi, Republic of Georgia. Journal of Human Evolution 50, 115–141.

Schmincke, H.U., van den Bogaard, P., 1996. Die Datierung des Masavera Basaltstroms. Jahrbuch des Römisch-Germanischen Zentralmuseums 42, 75–76.

Sologashvili, D., Pavlenshvili, E., Gogichaishvili, A., 1995. Zur Frage der Paläomagnetischen Stratigraphie einiger junger Vulkanite und Sedimentgesteine im Masavera-Becken. Jahrbuch des Römisch-Germanischen Zentralmuseums Mainz 42, 51–74.

Zhu, R., An, Z., Potts, R., Hoffman, K., 2003. Magnetostratigraphic dating of early humans in China. Earth-Science Reviews 61, 341–359.