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Pre-Columbian mural paintings from Mesoamerica as geomagnetic field recorders

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[1] This paper reports a reconnaissance archeomagnetic study of mural paintings in various pre-Columbian sites in Mexico. The magnetic measurements of the pigments show that at least four murals (sites: Cacaxtla, Cholula and Templo Mayor) retain a remanent magnetization carried by a mixture of magnetite and minor hematite grains. In most specimens, a characteristic remanent magnetization is successfully isolated by alternating field demagnetization. The mean directions are reasonably well determined for each mural and within the range of secular variation during the last centuries. Studied Mesoamerican murals apparently retain the direction of the magnetic field at the time they were painted and therefore are an invaluable source of information concerning its secular variation. The archeomagnetic study of pre-Columbian mural paintings opens new alternatives to drawing a reliable reference master curve for the region and may largely contribute to the Mesoamerican absolute chronology. *INDEX TERMS:* 1503 Geomagnetism and Paleomagnetism: Archeomagnetism; 1519 Geomagnetism and Paleomagnetism: Magnetic mineralogy and petrology; 1522 Geomagnetism and Paleomagnetism: Paleomagnetic secular variation; 1532 Geomagnetism and Paleomagnetism: Reference fields (regional, global); 1540 Geomagnetism and Paleomagnetism: Rock and mineral magnetism. **Citation:** Goguitchaichvili, A., A. M. Soler, E. Zanella, G. Chiari, R. Lanza, J. Urrutia-Fucugauchi, and T. Gonzales (2004), Pre-Columbian mural paintings from Mesoamerica as geomagnetic field recorders, *Geophys. Res. Lett.*, *31*, L12607, doi:10.1029/2004GL020065.

1. Introduction

[2] Since most archaeological materials contain magnetic particles, their magnetic properties can be used in a variety of ways [*Lanos et al.*, 2000]. One of the main properties is that they may acquire a remanent magnetization at some specific time. As the geomagnetic field changes direction and intensity in time (secular variation - SV), the time of remanence acquisition of an archaeological artefact can be determined by comparing the values of its magnetic parameters with known records of the past geomagnetic field. In those regions in which the secular variation curves are well established, archeomagnetic dating can be as precise as the more expensive radiometric dating. The variation of the geomagnetic field elements (declination, inclination and intensity) is now particularly well established for Western Europe for the last 4000 years [e.g., *Schnepp et al.*, 2004]. These studies most frequently used conventional archeomagnetic material carrying thermoremanent magnetization (TRM) such as ceramics, kilns, burned floors.

[3] Despite a rich cultural heritage, only a few reliable archeomagnetic studies are available for Mesoamerica. The most detailed work was carried out by *Wolfman* [1981, 1990] who reported the preliminary results of an archeomagnetic project directed to reassess the Mesoamerican relative and absolute chronology in a period from the year AD 0 to 1200. The value of the reference curve, however, is limited, since the specimens were not demagnetized and the magnetic mineralogy was not investigated. Moreover, in most cases ages were estimated only on the grounds of archeological stratigraphy.

[4] An alternative way to improve the reference curve for Mesoamerica may come from investigation of mural paintings. *Chiari and Lanza* [1997] and *Zanella et al.* [2000] demonstrated that the red colour of many Italian mural paintings contains hematite grains as pigment. When this pigment is applied to a wall, the grains are free to move and align their magnetic moment with the Earth's magnetic field before the paint dries. The mean directions derived from these paintings carrying the pictorial remanent magnetization (PiRM) were consistent with that of the geomagnetic field at the time of painting, known from either historical direct measurements or archeomagnetic studies of well-dated volcanic deposits.

[5] Because pre-Columbian mural paintings are abundant in all of Mesoamerica [*de la Fuente*, 2001], the main goal of this study is to estimate their potential use to derive the secular variation of the Earth's magnetic field.

2. Field and Laboratory Techniques

[6] Mesoamerica is defined as an area in central and southern Mexico, Guatemala, Belize and El Salvador where civilization was developed between 2500 B.C. and 1521 A.D. [*Clark*, 1994; *Marcus and Flannery*, 1996]. The oldest known high civilization is attributed to the Olmecas located at the Gulf of Mexico (1300–400 B.C.). Before their disappearance, they gave birth to other famous civilizations such as the Maya and the Teotihuacan among many others. For this study, we chose four mural paintings from Central Mexico: Templo de Venus (Cacaxtla culture), Templo Rojo (Templo Mayor of Tenochtitlan), Chapulines and Estrellas (both belonging to the Cholula complex). These sites correspond to the Classic and early post-Classic period in Mesoamerican chronology (approx. 200 to

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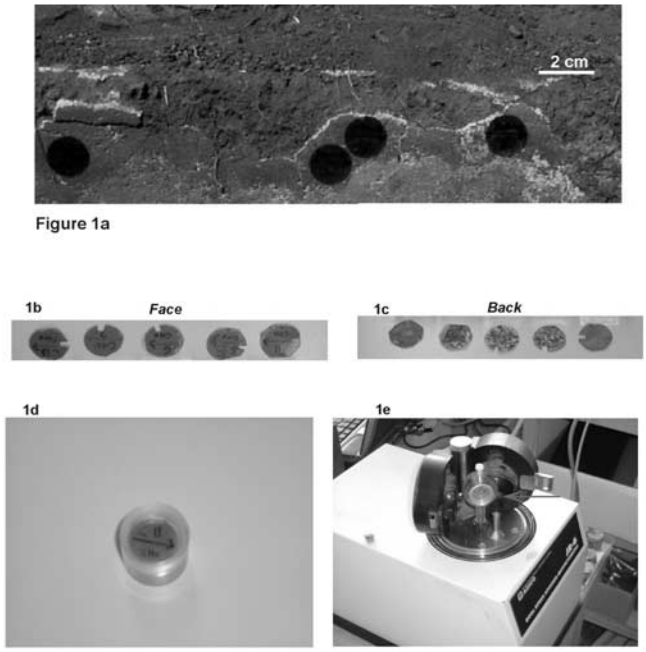

Figure 1. Sampling of mural paintings and measurement procedure. A strip of double-face adhesive tape is stuck onto a small flexible plastic disk (radiographic film is particularly adapted - diamater $\varphi = 18$ mm). The disk acts as stiff support and is applied to the painting with a light finger pressure. Only plain red fields, possibly near *lacunae* are sampled, in order to minimize the sampling impact (Figure 1a). A horizontal orientation line is marked on the plastic support and oriented according to usual archeomagnetic methods. The disk is then removed together with the paint sample (1b - front and 1c - back). The specimen is inserted in the middle of the sample holder, a cylinder made of perspex and of the same dimensions as rock-specimens used in paleomagnetism (diameter 25 mm, height 22 m) (1d) and divided in two halves which can be screwed together. The whole is measured in the spinner magnetometer (1e). See color version of this figure in the HTML.

1200 A.D. following the catalogue of Tiempo Mesoamericano (2500 A.C.–1521 D.C.) (*Arqueologia Mexicana*, *XI*(E11), Special Edition, 83 pp., 2003) and *Carlos de Mendez* [1990]. The technique to get and measure the samples is summarized in Figure 1.

[7] Selected samples from each mural were analyzed by X-ray powder diffraction to determine the type and quality of the pigments using a SIEMENS D5000 diffractometer. The only red pigment found consisted of antiferromagnetic hematite (Figure 2a) and there is no evidence for a "spinel" ferrimagnetic phase. On the contrary, the hysteresis loops obtained using a Micromag-AGFM on micro-samples yielded evidence for a ferrimagnetic phase, most probably magnetite or maghemite, as do isothermal remanence (IRM) measurements, which show that saturation is reached at moderate fields of the order of 150–200 mT. The discrepancy between the results of X-ray and magnetic analyses is discussed in the next section.

[8] The remanent magnetization measurements were carried in accordance to routine paleomagnetic techniques, using the AGICO JR5 and JR6 spinner magnetometers (at the University of Torino and at the UNAM paleomagnetic laboratory respectively). The magnetization intensity (A/m) cannot be precisely determined because the sampling technique [see, e.g., *Zanella et al.*, 2000] does not control the amount of paint taken from the wall. It depends on the layer strength and adhesion to the tape, which vary from one mural to another and even from one point to another of the same mural (Figure 1c). Intensities are therefore reported as magnetic moment (Am^2). Nominal sensitivity of AGICO spinner is $\approx 3 \times 10^{-11}$ Am^2. Working on plasterboards painted in laboratory controlled magnetic field, *Saudino* [1999] has shown that JR5 measurements are repeatable within an error of ±1% to ±3% for samples with magnetic moment as low as 2.5×10^{-9} Am^2. We therefore stopped the alternating field (AF) demagnetization procedure as the sample moment fell below 1×10^{-9} Am^2. This usually occurred after demagnetizing at 50 to 70 mT peak-field.

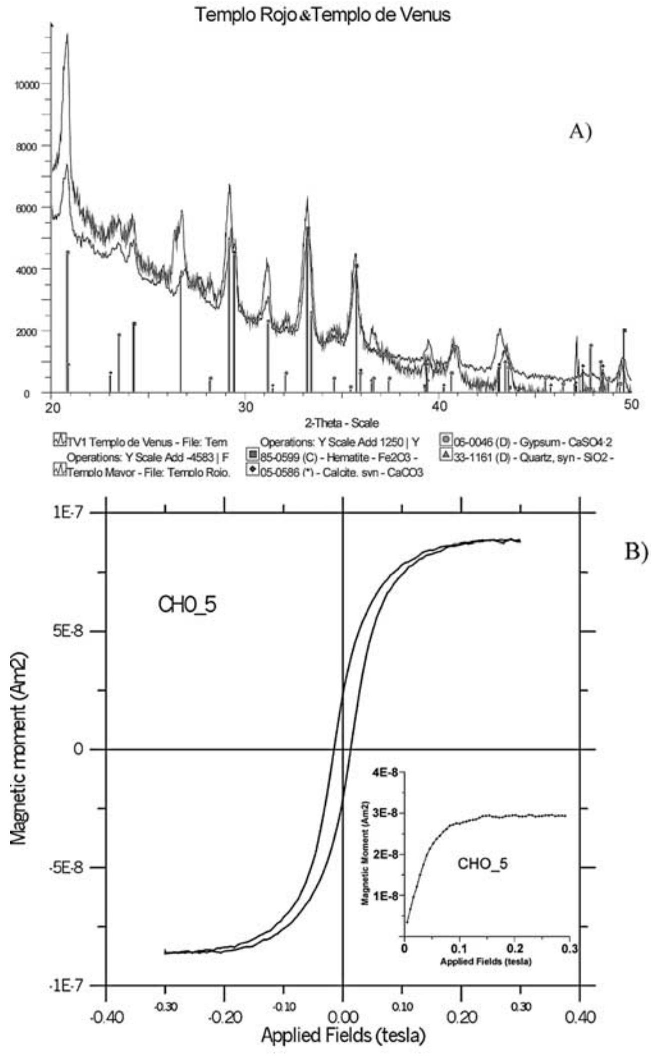

Figure 2. a) X-ray powder diffraction spectrum for Templo Rojo and Templo de Venus samples. The only red pigment found consists of antiferromagnetic hematite (see text for further explanation). b) Typical examples of hysteresis loops (uncorrected) and associated isothermal remanence (IRM) acquisition curves. See color version of this figure in the HTML.

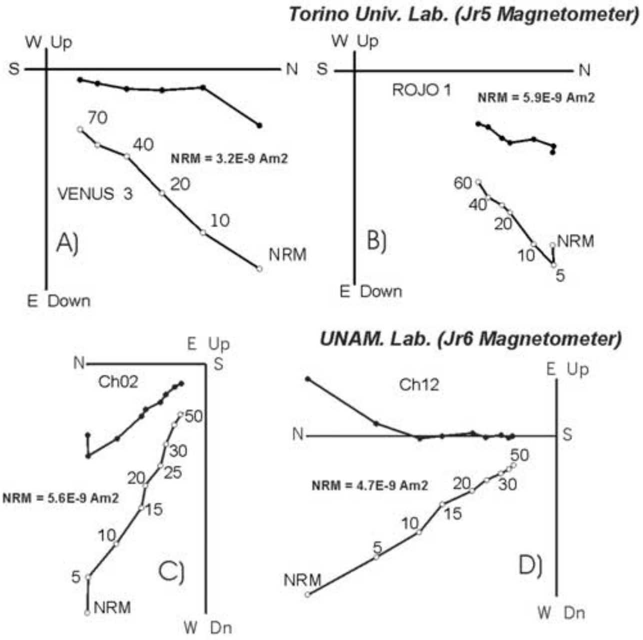

Figure 3. Orthogonal vector plots of stepwise AF demagnetization of representative samples (geographic coordinates). Symbols: full/open dot = projection onto the horizontal/vertical plane; figures = peak-field in mT. NRM is given as magnetic moment (Am^2).

Only AF demagnetization is practicable in the case of paintings, since thermal experiments would destroy the sample.

[9] Weak (Figures 3a, 3b, and 3c) to moderate (Figure 3d) soft components probably of viscous origin were easily removed at fields of 5 to 10 mT, which noticeably reduced the dispersion of the natural remanent magnetization (NRM). The characteristic magnetization direction (ChRM) was determined by the least squares method using the principal component analysis (PCA). The maximum angular deviation (MAD) was always less than 3°, which corresponds to the high quality individual determinations [*Kirschvink*, 1980]. In most cases, the major part of remanence was removed applying 50 mT peak-field (Figure 3, samples Ch02 and Ch12). The median destructive field (MDF) range mostly from 25 to 35 mT, suggesting pseudo-single domain grains as remanent magnetization carriers [*Dunlop and Özdemir*, 1997].

3. Discussion and Conclusion

[10] Although diffraction patterns clearly identified hematite as the major component of the red pigment in the studied Mesoamerican murals, its contribution to the remanence is minor. Hysteresis and associated IRM acquisition curves point to ferrimagnetic phases as remanence carriers, most probably titano-magnetites or -maghemites. This hypothesis is substantiated by AF demagnetization, since the major part of remanence is removed within 50 to 70 mT peak fields (Figure 3). The murals probably contain a mixture of abundant antiferromagnetic (hematite) and minor ferrimagnetic (most probably magnetite) phases. The largest peaks of these phases (at about d = 2.95 and d = 2.50 Å) strongly overlap with each other, making it almost impossible to distinguish a small amount of magnetite and/or maghemite in the presence of abundant hematite. As the intensity of remanence for magnetite/maghemite is at least two orders of magnitude higher than for hematite [*Dunlop and Özdemir*, 1997], even a very low content of magnetite/maghemite not detectable by X-ray analysis is enough to screen the hematite contribution to the magnetic signal.

Table 1. Mean Archeomagnetic Directions From Studied Murals[a]

Mural	N	Dec (°)	Inc (°)	α_{95} (°)	k
Chapulines	7	339.8	47.1	7.5	65
Estrellas	10	351.8	48.3	10.4	63
Templo Rojo	5	16.8	44.1	5.3	209
Templo Venus	6	348.7	35.1	10	46

[a]Mean directions of AF cleaned remanence. Symbols: N, number of specimens used for calculation; Dec, Declination; Inc, Inclination; k and α_{95}: precision parameter and semi-angle of 95% confidence cone of Fisher's statistics.

[11] The mean characteristic remanent magnetization (ChRM) was obtained from almost all of the samples. The within site dispersion is reasonably low since all α_{95} semi-angle of confidence are less than 10.4° (Figure 4 and Table 1). The best quality determination was obtained from the murals Templo Rojo and Chapulines yielding α_{95} equal to 5.3° and 7.5° respectively. As far as the origin of the remanence is concerned, we can reasonably assume that the ChRM is a primary, pictorial remanent magnetization. The hypothesis of viscous magnetization (VRM) is hardly tenable, because secondary components are minor and ChRM is stable against AF treatment up to 50 to 70 mT. Moreover, the capability of samples to acquire a VRM is limited, as shown by the low values (usually less than 8%) of the viscosity indexes, evaluated according the method of *Prévot et al.* [1983]. Lastly, there is no evidence for a secondary, chemical magnetization since the studied murals show sign neither of weathering nor of other kind of alteration.

[12] In absence of a reliable master curve for Mesoamerica, it is difficult to attempt an archeomagnetic dating. Judging from the preliminary reference curve (Y. Hueda-Tanabe et al., Archaeomagnetic studies in central Mexico—Dating of Mesoamerican lime-plasters, paper presented to *Physics of the Earth and Planetary Intereriors*, 2004), it may be

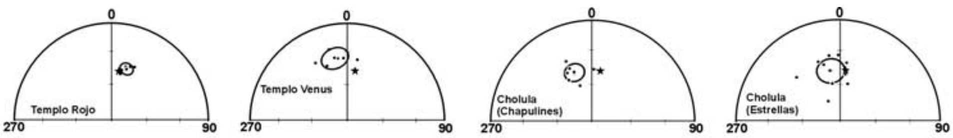

Figure 4. Equal-area projections of the characteristic magnetization directions of studied murals. Symbols: ellipse = α_{95} cone of confidence; star = present day geomagnetic directions at latitude and longitude of Mexico City.

argued that at least the mean ChRM direction from Templo Venus, Estrellas y Chapulines corresponds to the interval between 1000 A.D. and 1200 A.D.

[13] In summary, 28 samples belonging to four Mesoamerican mural paintings were investigated and the direction of their remanent magnetization was successfully determined. A mixture of magnetite and hematite is responsible for the magnetization, contrary to the Italian murals investigated by *Chiari and Lanza* [1997] which only contain hematite. Studied Mesoamerican mural paintings retain the direction of the magnetic field at the time they were painted and are therefore an invaluable source of information concerning secular variation. The archeomagnetic study of pre-Columbian mural paintings opens new alternatives for improving the Mesoamerican absolute chronology.

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References

Carlos de Mendez, A. (1990), *La Epoca Clásica—Nuevos Hallazgos, Nuevas Ideas: Seminario de Arqueología*, Mus. Nac. de Antropología, Inst. Nac. de Antropología e Historia, Mexico City, Mexico.
Chiari, G., and R. Lanza (1997), Pictorial remanent magnetization as an indicator of secular variation of the Earth's magnetic field, *Phys. Earth Planet. Inter.*, *101*, 79–83.
Clark, J. E. (1994), Antecedentes de la cultura Olmeca, in *Los Olmecas en Mesoamerica*, edited by J. E. Clark, pp. 34–42, Citibank, México City, Mexico.
de la Fuente, B., (Ed.) (2001), *La Pintura Mural Prehispanica en Mexico 1: Teotihuacan*, 384 pp., Univ. Nac. Auton. de Mex., Mexico City, Mexico.
Dunlop, D., and Ö. Özdemir (1997), Rock-Magnetism, fundamentals and frontiers, 573 pp., Cambrige Univ. Press, New York.
Kirschvink, J. L. (1980), The least-square line and plane and analysis of palaeomagnetic data, *Geophys. J. R. Astron. Soc.*, *62*, 699–718.
Lanos, P., M. Kovacheva, and A. Chauvin (2000), Archaeomagnetism, methodology and applications: Implementation and practice of the archeaomagnetic meted in France and Bulgaria, *Eur. J. Archaeol.*, *2*, 365–392.
Marcus, J., and K. V. Flannery (1996), *Zapotec Civilization: How Urban Society Evolved in Mexico's Oaxaca Valley*, 255 pp., Thames and Hudson, New York.
Prévot, M., R. S. Mainkinen, S. Grommé, and A. Lecaille (1983), High paleointensity of the geomagnetic field from thermomagnetic studies on rift valley pillow basalts from the middle Atlantic ridge, *J. Geophys. Res.*, *88*, 2316–2326.
Saudino, S. (1999), Studio sperimentale di un nuovo metodo archeomagnetico: L'analisi delle pitture murali, Ph.D. thesis, 158 pp., Univ. of Torino, Torino, Italy.
Schnepp, E., R. Pucher, J. Reinders, U. Hambach, H. Soffel, and I. Hedley (2004), A German catalogue of archeomagnetic data, *Geophys. J. Int.*, *157*, 64–78.
Wolfman, D. (1981), Geomagnetic dating methods in archaeology, *Ark. Archaeol. Surv.*, Russelville.
Wolfman, D. (1990), Mesoamerican chronology and archaeomagnetic dating, AD 1–1200, in *Archaeomagnetic Dating*, edited by J. L. Egihmy and R. S. Sternbeg, Univ. of Ariz. Press, Tucson.
Zanella, E., L. Gurioli, G. Chiari, A. Ciarallo, R. Cioni, E. De Carolis, and R. Lanza (2000), Archaeomagnetic results from mural paintings and pyroclastic rocks in Pompeii and Herculaneum, *Phys. Earth Planet. Inter.*, *118*, 227–240.

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