An updated catalog of pre-hispanic archaeomagnetic data for north and central Mesoamerica: Implications for the regional paleosecular variation reference curve

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ABSTRACT

Despite the immense cultural heritage of Mesoamerica, there is still no reference archaeomagnetic curve available for Central Mexico and adjacent areas. The present research has two simultaneous objectives: to obtain finer characteristics of the geomagnetic field elements over archaeological past, and to build up a reliable regional archaeomagnetic dating tool for the time span of 350 BC. to 1500 AD. For these purposes, 72 previous were compiled and analyzed with 40 new data selected from unpublished reports and theses performed in the paleomagnetic laboratories of the Geophysics Institute of UNAM (CDMX and Morelia). Most of the samples carry thermo-remanent magnetization, 31 cases were unburned stuccos, and 3 mural paintings carrying detrital or pictorial remanent magnetization. A total of 112 archaeomagnetic directions constitute the core of the updated catalogue. Special effort should be paid for to the time intervals of 500 BC.—AD. 200 and AD. 1200–325 where there is a major lack of reliable archaeomagnetic results. The present paleosecular variation curve agrees reasonably well with the fluctuation observed in the SW United States area. The differences in the intervals between AD. 600–720, AD. 850 and 1000 and AD. 1200–1325 may be rather attributed to the lack of reliable data than to local non-dipole field. It is urgent to gather a greater number of high-quality data supported by radiometric ages to improve the reference curve in both regions.

Keywords: Archaeomagnetic dating, geomagnetic field, paleosecular variation, central Mexico.

RESUMEN

Aunque el patrimonio cultural de Mesoamérica es cuantioso, aún no se cuenta con una curva de variación secular del campo geomagnético mediante datos arqueomagnéticos para el centro de México y áreas adyacentes. La presente investigación persiguió dos objetivos: obtener características más precisas de los elementos del campo geomagnético en el pasado arqueológico para el lapso 350 aC. a 1500 dC., además de construir una herramienta de datación arqueomagnética confiable para el centro y Sur de México, región que corresponde con la porción central y norte de Mesoamérica. Para ello se compilaron y seleccionaron 72 resultados previamente publicados en revistas arbitradas junto con 40 datos provenientes de informes de proyectos o tesis. La mayoría de las muestras portan magnetización termo-remanente, únicamente 31 son estucos no quemados con magnetización remanente detrítica y 3 pinturas murales con magnetización remanente pictórica. Un total de 112 direcciones arqueomagnéticas constituyen el núcleo del catálogo actualizado. Es necesario un mayor número de datos respaldados por edades radiométricas y de mayor calidad para mejorar la curva de referencia en México, en particular para los lapsos entre 500 aC. y 200 dC. y entre 1200 dC y 1325 dC. La curva de variación paleosecular que se presenta muestra buena correlación con la fluctuación observada en el área SO de Estados Unidos. Las grandes diferencias entre ambas áreas para los lapsos 600–650 dC., 850–1000 dC. y 1200–1325 dC. pueden ser mayormente atribuidas a la falta de datos confiables más que al campo no dipolar local.

Palabras clave: Datación arqueomagnética, campo geomagnético, variación paleosecular, centro de México.

1. Introduction

The variation of the geomagnetic field in the archaeological past can be obtained from the well dated burned archaeological artifacts, bearing some spinels like titanomagnetites, as principal carriers. Archaeomagnetic data retrieved from thermoremanent magnetization are considered the most accurate and reliable compared to the data from lakes and sediments which may be smoothed and/or offset due to their magnetization acquisition process. These data are used to draw up regional PSV reference-curves or global prediction models building upon the knowledge of the geomagnetic field variations for the periods covering the last few millennia. Reference PSV curves can also be used for dating purposes by comparing the archaeomagnetic field information (direction and/or intensity) of archaeological material within a region with the known PSV curve of the Earth's magnetic field for the corresponding region (Lanos and Dufresne, 2008; Pavón-Carrasco *et al.*, 2011).Well-defined PSV curves in southwest USA are scarce (Sternberg and McGuire, 1990; Eighmy *et al.*,1990; Wolfman, 1990a) in contrast to Europe, where several well-defined PSV curves are available for different regions (Gómez-Paccard *et al.*, 2006; Schnepp and Lanos, 2005; Gallet *et al.*, 2002).

Mesoamerican culture in Mexico had great development, since the Olmec civilization, which left strong evidence of numerous big cities with trade networks that covered all of Mexico and Central America. Many investigations headed by the INAH (Instituto Nacional de Antropología e Historia) were carried out in the XX century elaborating regional sequences with ceramics and architectonic styles as chronological controls. The chronology was divided into three broad periods: The Formative or Preclassic from 2000 BC. to AD. 300, the Classic from AD. 300 to 950 and the Postclassic from AD. 950 to the contact with the Spaniard in AD. 1521. A period denominated Epiclassic between AD. 800–1200 corresponds to a brief flowering of secondary-states that grew with the collapse of great cities such as Teotihuacan and Monte Albán (López-Austin & López-Luján, 2014). By 1960 the radiocarbon method began to be employed, but due to the relatively high cost, the poorly constrained laboratory techniques or the lack of a rigorous sampling methodology, some aberrant dates were obtained and consequently unreliable sequences were developed. Wolfman (1990b) visualized the archaeomagnetic dating as a great tool to provide an unattainable precision for the chronometric results solving cultural-historical problems. He then published the first directional secular variation for Mesoamerica with samples of twelve sites in Mexico, two in Guatemala, one of Honduras and six in El Salvador. A total of 81 burned samples were measured in the Wolfman research and only one directly related to a radiocarbon date.

A compilation of previously available results for Mexico is here reported, 35 of Wolfman, 39 published in refereed journals, 12 of them unburned samples that includes 4 of pictorial origin. 38 samples complete the catalog of 112 archaeomagnetic directions to build upon a reliable PSV curve for central and southem Mexico. For each individual study, the main information has been detailed, including the field sampling procedures, laboratory treatment and archaeological and chronological information. Rock magnetic studies have been carried out to identify the main magnetic minerals and their thermal stability. In addition, these data may largely contribute to better constraining the variation of the Earth's magnetic field in the North and Central Mesoamerica during the last two millennia.

2. Archaeomagnetic studies in Mexico

The directional component of the geomagnetic field from Preclassic to Postclassic (AD. 1–1200) recorded in burned materials of 12 sites of Me xico were reported by Wolfman (1990b). The site locations are mentioned in Table 1 and Figure 1.

Table 1. Magnetic parameters of each sample. 1st State of sampling, 2nd archaeological site, 3rd name of sample and location, 4th and 5th geographic coordinates of site (Latitude, longitude). 6th if it is burned or unburned (b/ub), 7th the number of specimens employed to the calculus of media n and the total number of the specimens of the sample N. 8th Demag: NRM if the samples were not demagnetized or the AF field in mT until the sample were demagnetized. 9th ,10th and 11th Parameters of the media direction of the sample Dec, Inc and α_{95} of the Fisher statistic. 12th and 13th PLat (North Latitude) and PLong (East Longitude) of the VGP. 14th Estimated date 15th method of date estimation st - stylistic of ceramics or stratigraphy and rc - related to a radiocarbon date. 16th Archaeomagnetic date obtained by Rendate software (--see Tula text). 17th Reference: thesis or paper that reported the data and a key to identify if the data was Published in Referee Journals (PRJr) or in a thesis or internals reports (uPRr unPublised in Referree Journals) (*continued in next page*).

STATE	Site	Sample	Site lat N	Site long W	b/ub	n/N	Demag	Dec	Inc	a_{95}	PLat	PLon	Estimated Date	Radiocarbon date(rc) Stylistic datw (st)	Archeomagnetic date	Reference
HIDALGO	HUAPALCALCO	539 Feat. 30 Rm.2	20.1	261.6	b	8/8	NRM	358.8	24.2	1.9	82.5	90.4	AD. 750–950	st	AD. 850–880	Wolfman, 1990b PRJr
		563 Feat. 30 Wall 1	20.1	261.6	b	9/9	NRM	1.7	25.9	2.5	83.4	67.1	AD. 750–950	st	AD. 745–785	Wolfman, 1990b PRJr
	TULA	488 Tula70, Test Pit 1	20	260.7	b	8/8	NRM	346.4	40.8	1.9	76.9	188	AD. 950–1200	st	AD. 1095–1140	Wolfman, 1990b PRJr
		598 Tula70, Unit3 Feat3	20	260.7	b	9/9	NRM	344.1	34.6	2.4	74.9	170.2	AD. 950–1200	st	AD. 1140–1190	Wolfman, 1990b PRJr
		415 Palacio Quemado, E Wall s415	20	260.7	b	8/8	NRM	322.4	50.5	3.9	54.5	194.8	AD. 1150–1200	st	-- AD. 1169–1171	Wolfman, 1990b / revised Martínez-Miranda, 2013
		440 Palacio Quemado, E Wall s440	20	260.7	b	8/8	NRM	345.5	30.4	1.5	75.8	158.2	AD. 1150–1200	st	-- AD. 1160–1190	Wolfman, 1990b / revised Martínez-Miranda, 2013
		611 Palacio Quemado, E Wall s611	20	260.7	b	8/8	NRM	345	34.4	1.2	75.8	169.4	AD. 1150–1200	st	-- AD. 1160–1190	Wolfman, 1990b / revised Martínez-Miranda, 2013
		613 Palacio Quemado, E Wall s612	20	260.7	b	8/8	NRM	347.3	36.1	1.1	78	173.5	AD. 1150–1200	st	-- AD. 1160–1190	Wolfman, 1990b / revised Martínez-Miranda, 2013
		612 Palacio Quemado, E Wall s613	20	260.7	b	7/9	NRM	346.4	35.7	2.5	77.2	172.5	AD. 1150–1200	st	-- AD. 1160–1190	Wolfman, 1990b / revised Martínez-Miranda, 2013
	TULA	785 Palacio Quemado, E Wall s613	20	260.7	b	9/9	NRM	342.2	42.4	3.4	72.9	189.4	AD. 1150–1200	st	-- AD. 1068–1098	Wolfman, 1990b / revised Martínez-Miranda, 2013
		TU06 Shire Hall 2	20	260.7	b	5/10	100	351.1	28.1	2.2	80.3	143.5	AD. 1160–1190	st	AD. 1100–1200	Martínez-Miranda, 2013 uPRJ
		TU17 Floor W lobby Unit 5	20	260.7	b	10/12	100	339.8	32.6	8.6	70.8	168.7	AD. 1160–1185	st	AD. 1100–1200	Martínez-Miranda, 2013 uPRJ
		TU22 W floor of R3	20	260.7	ub	7/12	100	346.6	34.4	9.4	77.3	169.8	AD. 1160–1190	st	AD. 900–1150	Martínez-Miranda,2013 uPRJ
		TU23 Floor W lobby	20	260.7	ub	8/15	100	5.1	20.5	14.7	79.7	52.2	AD. 1160–1190	st	AD. 1150–1350	Martínez-Miranda, 2013 uPRJ
		TU27 Floor and Wall S lobby	20	260.7	ub	8/12	100	358.4	51.6	13.45	77.3	254.9	AD. 1450–1480	st	AD. 1100–1350	Martínez-Miranda, 2013 uPRJ
	SIERRA DE LAS NAVAJAS	SNE1 Tamped soil	20.08	261.4	b	5/9	100	353.3	27	9.6	81.4	130.3	AD. 460–545	st	AD. 469–540	Terán-Guerrero, 2016 PRJr Terán-Guerrero, 2013
		SNE2 Tamped soil	20.08	261.4	b	6/8	100	9.6	34.4	8.7	80.9	357.2	AD. 325–550	st	AD. 330–342 AD. 391–550	Terán-Guerrero, 2016 PRJr Terán-Guerrero, 2013

Table 1. Magnetic parameters of each sample *(continued).*

STATE	Site	Sample	Site lat N	Site long W	b/ub	n/N	Demag	Dec	Inc	a_{95}	PLat	PLon	Estimated Date	Radiocarbon date(rc) Stylistic datw (st)	Archeomagnetic date	Reference
CHIAPAS	CHACHI	570 Wall in small md	16.4	267.3	b	8/8	NRM	356.3	10.9	1.9	78.5	105.9	AD. 800–1000	st	AD. 885–930	Wolfman, 1990b PRJr
	PANTEÓN	569 45cm below top of md	16.4	267.3	b	8/8	NRM	356.3	17.9	1.5	81.9	114.3	125 BC.–AD. 1 400–125 BC.	st	25 BC.–AD. 1	Wolfman, 1990b PRJr
	LOS GRIFOS	LG01	16.8	265.6	b	6/17	100	345.8	21.3	9.38	75.1	154.7	AD. 900–1521	st	AD. 1385–1445	Fregoso,2010 uPRJr
		LG02	16.8	265.6	b	6/14	100	352	55.5	5	69.5	246.8	AD. 900–1521	st	AD. 1460–1500	Fregoso,2010 uPRJr
CDMX	TEM-PLO MAYOR	Etapa III	19.44	260.9	ub	8/	100	339.6	36.2	9.6	70.8	176.2	AD. 1427– 1440	st	AD. 1426–1441	Hueda-Tanabe *et al.*, 2004 PRJr
	TLATELOLCO	Cui 13 Tlecuil Etapa II	19.45	260.9	b	4	100	339.6	24.6	4.8	69.4	155.4	AD. 1396–1417	st	AD. 1391–1401	Guerrero, 2003 uPRJr
		Cui 4a9 Tlecuil Etapa IVB	19.45	260.9	b	4	100	352.2	48	6.2	78.1	252.9	AD. 1469–1481	st	AD. 1468–1474	Guerrero, 2003 uPRJr
	CHAPUL-TEPEC	Cha 1a22 kiln	19.37	260.7	b	11/22	100	353.4	32.8	10.4	83.6	158.2	AD. 350–550	st	AD. 512–634	López-Delgado *et al.* ,2011 PRJr
	COYOA-CÁN	CHQ1y2 floor	!9.35	260.8	b	7/7	100	10.5	30	9.85	79.5	7.2	AD. 600–900	st	AD. 599–681	Soler-Arechalde *et al.* , 2013a uPRJr
	TEMPLO MAYOR	TM2601 Cuauhxicalco	19.44	260.9	ub	4/8	100	2	60.2	8.6	68.3	265	AD. 1440–1469	st	AD. 1459–1496	Soler-Arechalde *et al.* , 2012
		TM2604 4[th] Floor	19.44	260.9	ub	7/8	100	354.3	42.7	9.6	82.5	217.2	AD. 1469–1481	st	AD. 1462–1474	Soler-Arechalde *et al* ., 2012
		TM2605 E wall	19.44	260.9	ub	6/8	100	0.5	25.6	9.15	84	76.2	AD. 1440–1469	st	AD. 1444–1464	Soler-Arechalde *et al.* , 2012
		TM2606 Arriate	19.44	260.9	ub	7/8	100	4.5	46.1	12.5	81	287.3	AD. 1440–1469	st	AD. 1461–1473	Soler-Arechalde *et al.* , 2012
		TMOQ	19.44	260.9	b	7/8	100	0.6	36.8	7.4	88.8	288.6	AD. 1440–1469	st	AD. 1461–1473	Soler-Arechalde *et al* ., 2013b
JALISCO	TEUCHITLÁN, GUACHIMONTONES	Gu1 y 2 St3 La Joyita B	20.68	256.13	ub	9/16	100	347.7	29.9	3.4	79	31	300 BC.– AD. 200	st	117–112 BC.	López-Delgado *et al.* , 2017 PRJr
		Gu3 Stove La Joyita A	20.68	256.13	b	4/10	100	354.9	46.5	8.13	83.1	40	2250+/-50 BP	rc	248–77 BC.	López-Delgado *et al.* , 2017 PRJr
		Gu4 Floor St8 Circle 2	20.68	256.13	b	4/4	100	358.7	36.6	3.85	74.8	109.6	300 BC.–AD. 200	st	113–100 BC.	López-Delgado *et al.* , 2017 PRJr
		Gu5 2nd wall St7 Circle 1	20.68	256.13	ub	7/7	100	8	24.3	8.2	58.9	203.1	AD. 700–900	st	AD. 683–771	López-Delgado *et al* ., 2017 PRJr
		Gu6 3rd Wall St7 Circle 1	20.68	256.13	ub	7/7	100	4.2	28.3	8.8	84.4	162.6	AD. 700–900	st	AD. 682–758	López-Delgado *et al.* , 2017 PRJr
		Gu7 1st Wall St7 Circle 1	20.68	256.13	ub	3/7	100	351.6	15.4	7.3	75.4	310.8	AD. 700–900	st	AD. 751–820	López-Delgado *et al.* , 2017 PRJr
		Gu8 PLatform2 Circle 1	20.68	256.13	ub	5/5	100	329.2	55.8	5.17	75.1	306.6	1870+/-40	rc	AD. 116–175	López-Delgado *et al.* , 2017 PRJr
		Gu9 PLatform A Circle 7	20.68	256.13	ub	12/48	100	354	36.4	5.39	82.9	27.6	300 BC.–AD. 200	st	100 BC.– AD. 224	López-Delgado *et al.* , 2017 PRJr
		Gu10 y 16 Intern Central tamped Circle B	20.68	256.13	ub	6/11	100	13.5	47.4	10.8	82.4	207.8	AD. 400–700	st	AD. 556–625	López-Delgado *et al.* , 2017 PRJr
		Gu11 Central Oven NW Ball Game	20.68	256.13	b	8/27	100	13.2	48.7	8.73	83.2	138	AD. 400–700	st	AD. 427–523	López-Delgado *et al.* , 2017 PRJr
		Gu13y14 Big oven	20.68	256.13	b	6/11	100	353.7	43.8	4.36	83.1	40	AD. 400–700	st	AD. 556–625	López-Delgado *et al* ., 2017 PRJr
		Gu15 Big oven	20.68	256.13	b	9/9	100	353.7	32	4.4	74.8	109.6	AD. 400–700	st	AD. 530–575	López-Delgado *et al* ., 2017 PRJr
MEXICO	TEOTIHUACAN	317 Teopancazco	19.7	261.2	b	9/9	NRM	7	50	3	79.4	296.9	AD. 425–600	st	AD. 360–455	Wolfman, 1990b PRJr
		540 Viking Group	19.7	261.2	b	8/8	NRM	3.9	40.2	3.3	85.2	309.1	AD. 425–725	st	AD. 455–510 AD. 270–350	Wolfman, 1990b PRJr
		786 Viking Group	19.7	261.2	b	8/8	NRM	2.1	41.1	3.1	85.7	287.4	AD. 425–725	st	AD. 450–520 AD. 260–340	Wolfman, 1990b PRJr
		564 Palace 3 Rm.7 s564	19.7	261.2	b	8/8	NRM	2.4	42.7	3	84.5	284.1	AD. 425–725	st	AD. 435–495 AD. 250–345	Wolfman, 1990b PRJr
		TE170 Ciudadela, Conjunto 1D	19.7	261.2	b	8/8	5	2.4	40.8	1.6	85.7	291.9	AD. 425–475	st	AD. 465–505 AD. 285–330	Wolfman, 1990b PRJr
		TE171 Ciudadela, Conjunto 1D	19.7	261.2	b	8/8	5	3	39.1	0.6	86.3	309.3	AD. 425–475	st	AD. 475–495 AD. 295–325	Wolfman, 1990b PRJr

Table 1. Magnetic parameters of each sample *(continued).*

STATE	Site	Sample	Site lat N	Site long W	b/ub	n/N	Demag	Dec	Inc	a_{95}	PLat	PLon	Estimated Date	Radiocarbon date(rc) Stylistic datw (st)	Archeomagnetic date	Reference
MEXICO	TEOTIHUACAN	TE172 Ciudadela, Conjunto 1D	19.7	261.2	b	8/8	10	1	40	1	86.8	277.9	AD. 425–475	st	AD. 480–510 AD. 285–310	Wolfman, 1990b PRJr
		TE173 Unidad 11 Cuadro 85	19.7	261.2	b	8/8	15	2.2	40.6	0.9	85.9	291.5	AD. 425–475	st	AD. 465–495 AD. 290–315	Wolfman, 1990b PRJr
		TE176 Unidad Punto 36	19.7	261.2	b	6/6	NRM	5.4	43.3	3.6	82.5	302	AD. 425–475	st	AD. 410–480 AD. 300–375	Wolfman, 1990b PRJr
		TE1 Ciudadela	19.7	261.2	b	10/10	100	3.8	38.7	5.75	85.9	319.5	AD. 515–635	st	AD. 553–606	Hueda-Tanabe and Soler-Arechalde 2001 uPRJr
		TE4 West Square Complex	19.7	261.2	b	6/6	100	6	38.6	8.26	84	329.9	AD. 515–635	st	AD. 551–607	Hueda-Tanabe and Soler-Arechalde 2001 uPRJr
		Tp2 Teopancazco S1R206P13 N458E91	19.7	261.2	b	1/1	100	351.7	34	10	82.1	165	AD. 310–390	rc	AD. 325–424	Hueda-Tanabe *et al.* , 2004 PRJr
		Tp3 Teopancazco S1R14 N435E87	19.7	261.2	b	20/20	100	4	36.7	3.51	85.7	321.3	AD. 515–635	rc	AD. 491–629	Hueda-Tanabe *et al.* , 2004 PRJr
		Tp8 Teopancazco S1R53 F1 N464 E107	19.7	261.2	b	4/5	100	356.8	36.9	2.17	86.9	188.8	AD. 1375–1415	st	AD. 1414–1423	Hueda-Tanabe *et al.* , 2004 PRJr
		Xal1,2,3,4 Xalla S4R1 F1	19.7	261.2	b	4/4 31spc	100	352.4	40..5	9.8	85.5	324	AD. 415–460	st	AD. 550–575	Soler-Arechalde *et al* ., 2006 PRJR Rodríguez-Ceja, 2003
		X1,2,3,4,5 Xalla S1 F1	19.7	261.2	ub	4/4 12spc	100	356.8	38.5	3.57	86.4	205.3	AD. 415–460	st	AD. 525–575	Soler-Arechalde *et al* ., 2006 PRJr Rodríguez-Ceja, 2003
		X6, 7 Xalla Red walls	19.7	261.2	ub	3/3	100	351.4	42.7	8.11	74.3	185.9	AD. 240–350	st	AD. 545–605	Soler-Arechalde *et al* ., 2006 PRJr Rodríguez-Ceja, 2003
		Tp73 Teopancazco R408FP6	19.7	261.2	ub	3/3	100	3	39	15	69.7	267.8	AD. 1–200	st	AD. 150–210	Beramendi-Orozco *et al* ., 2009 and 2012 PRJr Hernández-Ávila, 2010
		Tp38,39,40, 41 Teopancazco R262FP3	19.7	261.2	b	4/4	75	332	68	9.52	51.7	232.7	AD. 200–270	rc	AD. 306–346	Beramendi-Orozco *et al* ., 2009 and 2012 PRJr Hernández-Ávila, 2010
		TP78 Teopancazco R181B-261 P4	19.7	261.2	ub	7/11	100	355.3	37	6.4	85.5	184.4	AD. 240–350	rc	AD. 335–385	Beramendi-Orozco *et al* ., 2009 and 2012 PRJr Hernández-Ávila, 2010
		Tp30-31 Teopancazco R181B-261 P4	19.7	261.2	b	4/4	100	4.2	39.4	9.32	85.3	316.3	AD. 240–350	rc	AD. 407–433	Beramendi-Orozco *et al* ., 2009 and 2012 PRJr Romero-Hernández, 2008
		Tp32-34 Teopancazco R181B-261 P4	19.7	261.2	ub	3/3	100	4.3	44.3	14.8	82.5	292.4	AD. 240–350	rc	AD. 407–433	Beramendi-Orozco *et al* ., 2009 and 2012 PRJr Romero-Hernández, 2008
		TP75 Teopancazco R162CP2	19.7	261.2	b	3/4	80	335.2	30.2	3.1	66.2	166.8	AD. 240–350	rc	AD. 300–340	Beramendi-Orozco *et al* ., 2009 and 2012 PRJr Romero-Hernández, 2008
		TP84 Teopancazco R213AP2	19.7	261.2	ub	14/14	100	358.3	34.3	8.64	88.2	143.8	AD. 240–350	rc	AD. 340–380	Beramendi-Orozco *et al* ., 2009 and 2012 PRJr Hernández-Ávila,2010
		TP77 Teopancazco R213AP2	19.7	261.2	ub	6/9	100	359.5	37.5	4.76	88.6	241.6	AD. 460–545	rc	AD. 405–445	Beramendi-Orozco *et al* ., 2009 and 2012 PRJr Romero-Hernández, 2008
		CQE1 Ciudadela Quetzalcoatl Pyramid	19.7	261.2	b	9/10	100	359	37.6	3.9	88.3	226.8	AD. 325– 415	st	AD. 344–352	Terán-Guerrero, 2016 PRJr Terán-Guerrero, 2013
		CQE2 Ciudadela Quetzalcoatl Pyramid	19.7	261.2	b	10/10	100	2.9	38.4	2.6	86.7	315.4	AD. 415–460	st	AD. 412–477	Terán-Guerrero, 2016 PRJr Terán-Guerrero, 2013
		CQE3 Ciudadela Quetzalcoatl Pyramid	19.7	261.2	ub	15/18	100	348.5	40.2	1.7	78.8	189.9	AD. 325– 415	st	AD. 327–345	Terán-Guerrero, 2016 PRJr Terán-Guerrero, 2013

Table 1. Magnetic parameters of each sample *(continued).*

STATE	Site	Sample	Site lat N	Site long W	b/ub	n/N	Demag	Dec	Inc	a_{95}	PLat	PLon	Estimated Date	Radiocarbon date(rc) Stylistic datw (st)	Archeomagnetic date	Reference
MEXICO	TEOTIHUACAN	CEE2 Ciudadela Conjunto E	19.7	261.2	b	9/9	100	1	38.3	2.8	87.9	287.9	AD. 415–460 AD. 550–600	st	AD. 412–427 AD. 520– 528	Terán-Guerrero, 2016 PRJr Terán-Guerrero, 2013
MEXICO	TECAMAC	HT2A Tlecuil Front I-A SII E1 SqJ2	19.6	260.9	b	3/4	100	322.5	41.9	4.9	55	185.3	AD. 1500–1600	st	AD. 1474–1487	Saavedra-Cortés,2010 uPRJr
MORELOS	XOCHICALCO	XO40-52 Acropolis S8 R6	18.83	260.6	ub	6/13	100	302	10	5.6	81.4	47.5	AD. 652–675	st	AD. 676–738	Soler-Arechalde and Caballero-Miranda, 2008a uPRJr
MORELOS	XOCHICALCO	XO60-61 Acropolis S5 south E2 wall	18.83	260.6	ub	16/16	100	1.2	28.7	5.4	85.5	66.8	AD. 652–675	st	AD. 677–752	Soler-Arechalde *et al.*, 2008b uPRJr
MORELOS	XOCHICALCO	XO30-32 S2 Sector G	18.83	260.6	ub	13/15	100	351	14	3.3	78.2	85.5	AD. 664–723	st	AD. 716–768	Soler-Arechalde and Caballero-Miranda, 2008a uPRJr
MORELOS	XOCHICALCO	XO7-8 West Altar Observatory floor	18.83	260.6	b	10/10	100	341	20	9.16	69.8	148.4	AD. 980–1025	st	AD. 967–1031	Hueda-Tanabe and Soler-Arechalde, 2001 uPRJr
MORELOS	XOCHICALCO	XO11 Acropolis wall	18.83	260.6	ub	8/8	100	352	31	13.43	82.1	156.4	AD. 980–1025	st	AD. 1017– 1115	Hueda-Tanabe and Soler-Arechalde, 2001 uPRJr
OAXACA	BRAWBEHL	408 Feat 69-27	16.9	263.7	b	8/6	NRM	357.3	36	2.9	86	224.2	250 BC.–AD. 200	st	AD. 60–120	Wolfman, 1990b PRJr
OAXACA	LAMBITYECO	318 Feat 68-24	16.9	263.7	b	8/7	NRM	1	15.2	1.2	80.8	77.5	AD. 700–800	st	AD. 700–730	Wolfman, 1990b PRJr
OAXACA	LAMBITYECO	319 Feat 69-2 Md. 190	16.9	263.7	b	8/7	NRM	348.9	27.7	2.9	79.1	163.8	AD. 900–1200	st	AD. 1049–1090 CA 1200?	Wolfman, 1990b PRJr
OAXACA	LAMBITYECO	321 Md 190	16.9	263.7	b	8/7	NRM	348.3	29.8	2.7	78.7	170.7	AD. 900–1200	st	AD. 1055–1100 CA 1200?	Wolfman, 1990b PRJr
OAXACA	LAMBITYECO	407 Md 190 Zone B	16.9	263.7	b	8/8	NRM	348	32.6	3.4	78.5	179.6	AD. 900–1200	st	AD. 1070–1155 CA 1200?	Wolfman, 1990b PRJr
OAXACA	MONTE ALBÁN	541 Md. 88 Baked area No.11	17	263.3	b	14/16	NRM	354.6	30.4	2.6	84.8	166.7	AD. 400–700	st	AD. 565–600	Wolfman, 1990b PRJr
OAXACA	MONTE ALBÁN	744 Cerro Atzomba, Patio E	17	263.3	b	8/8	NRM	354.9	34.2	3	84.8	193.9	AD. 400–700	st	AD. 510–575	Wolfman, 1990b PRJr
OAXACA	TIERRAS LARGAS	527 Area A Feat. 11	17.1	263.2	b	8/8	NRM	355.4	16.3	2.1	79.7	109.4	AD. 700–1200	st	AD. 645– 680 AD. 895– 940	Wolfman, 1990b PRJr
OAXACA	TIERRAS LARGAS	529 Feat. 2 Hearth 1	17.1	263.2	b	8/8	NRM	354.8	16.9	1.9	80.2	114.9	AD. 700–1200	st	AD. 635–670 AD. 900–945	Wolfman, 1990b PRJr
OAXACA	TOMALTEPEC	749 Feat.3	17	263.3	b	8/8	NRM	0.2	39.2	2.5	84.8	265.8	250 BC.–AD. 200	st	AD. 245–305	Wolfman, 1990b PRJr
OAXACA	TOMALTEPEC	754 Floor A5	17	263.3	b	6/8	NRM	359.4	35.1	1.7	87.6	250.5	250 BC.–AD. 200	st	AD. 55–85	Wolfman, 1990b PRJr
PUEBLA	CERRO ZAPOTECAS	596 Md.2 Excav.A, Lev.6	19	261.7	b	8/8	NRM	0.7	30.4	1.9	87.3	66.9	AD. 500–900	st	AD. 785–820	Wolfman, 1990b PRJr
PUEBLA	MANZANILLO	783 N milpa, Sec.2	19	261.8	b	7/8	NRM	359.8	38.5	2.6	87.3	258.6	AD. 350–500	st	AD. 470–530 AD. 245–315	Wolfman, 1990b PRJr
PUEBLA	MANZANILLO	784 Sq. 55AA	19	261.8	b	8/8	NRM	2.8	39	0.8	86	302.5	AD. 350–500	st	AD. 475–495 AD. 295–325	Wolfman, 1990b PRJr
QUINTANA ROO	DZIBANCHÉ	DZ1 S 2	18.6	271.2	ub	4/8	100	313.3	38.5	13.3	46.2	193.5	AD. 540–650	st	AD. 274–316	Straulino-Mainou *et al.*, 2016 PRJr
QUINTANA ROO	DZIBANCHÉ	DZ3 East. Building Small Acropolis	18.6	271.2	ub	5/10	100	359.4	55.6	15.4	72.5	269.6	AD. 550–600	st	AD. 422–521	Straulino-Mainou *et al.*, 2016 PRJr
QUINTANA ROO	DZIBANCHÉ	DZ4 North Building Small Acropolis	18.6	271.2	ub	6/10	100	49.5	65	9.4	40.8	314.5	AD. 550–600	st	AD. 463–508	Straulino-Mainou *et al.*, 2016 PRJr
TLAXCALA	XALASCO	XA4 Floor early Xolalpan	19.41	262.2	ub	6/6	100	358.8	32	8.2	87.6	111.3	AD. 325–415	st	AD. 330–393 AD. 399–410	Terán-Guerrero, 2016 Terán-Guerrero, 2013 PRJr
TLAXCALA	XALASCO	XA7 Floor early Xolalpan	19.41	262.2	b	8/8	100	341.3	28.5	9.6	71.7	161.8	AD. 540–720	st	AD. 540–589 AD. 651–720	Terán-Guerrero, 2016 Terán-Guerrero, 2013 PRJr
VERACRUZ	LA JOYA	Lj26A-29B East Platform Pre Classic Oven wall	19.1	263.8	b	7/8	100	12.5	25	6.8	76.6	18.3	BC. 400–170	rc	BC. 400–170	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
VERACRUZ	LA JOYA	Lj30A-33B East Platform Pre Classic Oven floor	19.1	263.8	b	9/9	100	4.7	29	8.3	84.3	31.7	BC. 400–170	rc	BC. 400–170	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
VERACRUZ	LA JOYA	LJ11 Pyramid Pre Classic Oven wall	19.1	263.8	b	5/5	100	348.8	17.9	7.6	75.3	132.9	BC. 350–300	rc	BC. 350–300	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
VERACRUZ	LA JOYA	LJ12A-15B North Platform St II floor	19.1	263.8	ub	5/6	100	352.2	46	5.9	79	224.5	AD. 230–410	rc	AD. 420–440	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr

Table 1. Magnetic parameters of each sample *(continued).*

STATE	Site	Sample	Site lat N	Site long W	b/ub	n/N	Demag	Dec	Inc	a_{95}	PLat	PLon	Estimated Date	Radiocarbon date(rc) Stylistic datw (st)	Archeomagnetic date	Reference
VERACRUZ	LA JOYA	LJ16A-19A North Platform St II floor	19.1	263.8	b	3/4	100	349.8	38	7.5	80.2	188.9	AD. 230–410	rc	AD. 337– 360 AD. 406–430	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
		LJ20A-25G North Platform St I & II floor	19.1	263.8	b	13/13	100	323.9	56.6	8.4	53.7	211.4	AD. 230–410	rc	AD. 304–325	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
		JO50 North Platform St I & II floor	19.1	263.8	b	16/16	100	352.1	37	2.9	82.4	187.2	AD. 230–410	rc	AD. 409–427	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
		JO37 East Platfotm St IIIA Floor 1	19.1	263.8	b	1/1	100	359.9	39.9	7.1	86.4	262.4	AD. 380–580	rc	AD. 423–432	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
		JO38 East Platform St IIIA Fl. 2	19.1	263.8	b	1/1	100	348.4	23.1	5.7	76.8	143.4	AD. 380– 580	rc	AD. 365–420	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
		JO39 East Platform St IIIA Floor 3	19.1	263.8	b	2/2	100	342.8	32	5.3	73.6	170.6	AD. 380– 580	rc	AD. 327–371	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
		JO40 East Platform St IIIA inf floor	19.1	263.8	b	10/12	100	353.7	38.2	3.3	83.6	197.1	AD. 400–570	rc	AD. 412–429	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
		JO41 East Platform St IIIA inf floor	19.1	263.8	b	8/8	100	347.7	36	4.9	78.4	180.3	AD. 400–570	rc	AD. 408–425	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
		JO42 East Platform St IIIA inf floor	19.1	263.8	b	3/3	100	349.1	28.3	6.4	78.8	154.5	AD. 400–570	rc	AD. 340–422	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
		JO43 East Platform St IIIA inf floor	19.1	263.8	b	6/6	100	348.4	34.4	6.9	79	174.8	AD. 400–570	rc	AD. 402– 424	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
		JO44 East Platform St IIIA inf floor	19.1	263.8	b	6/8	100	352.6	29.4	6	82.2	149.7	AD. 400–570	rc	AD. 353–423	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
		JO45 East Platform St IIIA inf floor	19.1	263.8	ub	11/12	100	355.9	42.2	7.1	83.5	229	AD. 400–570	rc	AD. 415–435	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr
		Jo01-Jo22 East Platform St V-VI Floor	19.1	263.8	ub	22/22	100	356.7	39.1	3.1	85.7	219	AD. 400–570	rc	AD. 700–1000	Aguilar-Parra and Morales-Sánchez, 2011 uPRJr

The measurements were carried out in the paleomagnetic laboratories of Oklahoma, Pittsburgh and California. In Oklahoma the samples were measured in a Princeton Applied Research (PAR) spinner magnetometer. In Pittsburgh, most of the samples were measured in a Superconducting Technology (SCT) cryogenic magnetometer, and some in a PAR spinner magnetometer. A SCT cryogenic magnetometer and a Schoendsted spinner magnetometer (SSM—1A) were used in almost all cases.

Most directions of the Natural Remanent Magnetization (NRM) showed good clustering with α_{95} less than 4° and their temporalities consistent with other chronological contexts. Alternative-field demagnetization was done in Oklahoma and Pittsburg laboratories using over 10 samples, only 4 of Teotihuacan. With the 35 data samples from of Mexico in addition to the 29 samples from Guatemala, El Salvador and Honduras, Wolfman constructed the first secular variation curve for Mesoamerica. All the samples were dated by architectural style, ceramics or stratigraphy, which potentially decreases the accuracy of the curve.

2.1. SITES PREVIOUSLY SAMPLED BY WOLFMAN

CHIAPAS STATE

Chachi y Panteón (16.4°N, 267.3°W). Site located at Maya lowlands of Chiapas, in the Central Depression occupied by Mixe-Zoque groups since 125 BC. to AD. 1000. Two samples were taken, 569 of earlier occupations and 570 of the latest.

HIDALGO STATE

Huapalcalco (20.1°N, 261.6°W). A site with its major development during the Epiclassic (AD. 700–900) due to the obsidian exploitation under Teotihuacan influence is considered as the precedent of Tula. Two samples were taken here from this period: samples 539 and 563.

Tula (20°N, 260.7°W). The capital city of the Toltecs, a Mesoamerican civilization that was developed between AD. 850 until AD. 1150. Wolfman sampled between 1969 and 1972, accepting that the chronology of the site ended around AD. 1000. New evidences and radiocarbon data allowed to expanding the chronology, related to samples 415, 440, 611, 613, 612 and 785, initially rejected by Wolfman. Samples accepted by Wolfman were 488 and 598.

OAXACA STATE

Brawbehl (16.9°N, 263.7°W). This is the first settlement of Tlacolula Center, Valley of Oaxaca. A sample stratigraphically related to the time span 250 BC. to AD. 200 was taken, its number is 408.

Lambityeco (16.9°N,263.7°W). Site located in the Valley of Tlacolula and belonging to the Central valleys of Oaxaca. The age of this site seems to be contemporary with Monte Alban specialized in salt production. Its greatest splendor was during the Postclassic (AD. 800–1200), coinciding with the decline of Monte Alban. Four samples were obtained from Epiclassic to Postclassic: 318, 319, 321 and 407.

Monte Alban (17.0°N, 263.3°W). Zapotec site that dominated the central valleys of Oaxaca during the Classic (AD. 400–800). Two samples of this period were taken: 541 and 744.

Tierras Largas (17.1°N, 263.2°W). Formative-period site located in the Etla Valley of Oaxaca with the evidence of occupation until the Postclassic. Two samples of Postclassic (AD. 700–1200) were sampled: 527 and 529.

Tomaltepec (17.0°N, 263.3°W). Formative site of the central valleys of Oaxaca (200 BC.–AD. 250). Two samples were collected from this period: 749 and 754.

PUEBLA STATE

Cerro Zapotecas (19.0°N, 261.7°W). Epiclassic site (AD. 650–900) located west of Cholula, that grew with the latter's decay. Sample: 596.

Manzanillo (19.0°N, 261.8°W). Located to the SW of Cholula, its remains correspond to a Classic site (AD. 350–500). Sample: 784.

STATE OF MEXICO

Teotihuacan (19.7°N, 261.2°W). This is one of the largest centers of Mesoamerica, it has an area of

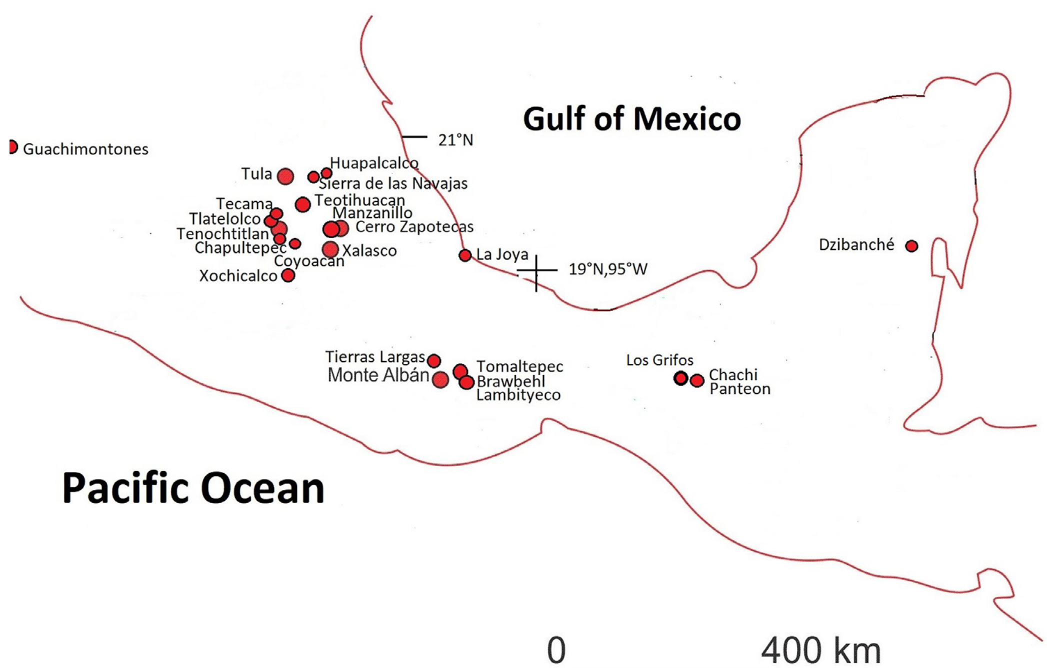

Figure 1 Location of the archaeological sites in Mexico sampled for archaeomagnetic research.

20 km², large pyramids, ceremonial, administrative and residential areas where more than 100000 people lived. The population was multiethnic and five principal stages of occupation have been determined since AD. 1 to 650. The city was divided into the ceremonial area, and several neighborhoods as Teopancazco and Xalla among others. The ceremonial area and Teopancazco were sampled in 2000. During different excavation campaigns such as 2001, 2003 and 2005 more samples of these areas were taken. Samples of Wolfman are 317, 540, 786, 564, TE170, TE171, TE172, TE173, TE176.

2.2. SAMPLED SITES SINCE 1999 OR REVISITED

CHIAPAS STATE

Los Grifos (16.8°N, 265.6°W). This is a rocky shelter with occupation from the Formative to the Postclassic. Two samples of the Postclassic yielded good results. Three samples from the Formative also showed good records but due to their temporality (8800 years BP) they were not reported in this work. Samples: LG01 and LG02.

HIDALGO STATE

Tula (20.0°N, 260.7°W). Revisited. New explorations and radiocarbon data suggest its chronology reaches at least until AD. 1200. 23 new samples from burned and unburned stuccos were taken in the area during 2010, only 5 with good results, 2 of them unburned with α_{95} less than 15. The low success rate of these samples might be caused by the low content of magnetic minerals, due to the abundance of limestones or because of the intense weathering, as a result of the industrial pollution, given that even samples with clear evidence of high temperatures do not record the magnetization. The samples with good results come from the 2010 excavation: TU06, TU17, TU22, TU23.

Sierra de las Navajas (20.8°N,261.4°W). One of the principal sites that provided obsidian to Teotihuacan since Tlamimilolpa era. It is located 50 km NW of Teotihuacan, in Hidalgo State and its remains are evidence that it was a large center to exploitation, work and distribution of obsidian. Ceramics of Tlamimilolpa, Xolalpan and Metepec (AD. 200–600) were recollected. Four oriented fragments belonging to burned soils were sampled in 2006. Samples: SNE1 and SNE2.

JALISCO STATE

Guachimontones (20.68°N, 256.13°W). Guachimontones of Teuchitlán is an archaeological site housed in a lake basin within the valleys of the Tequila volcano, West of Mexico. The site is characterized by circular structures of monumental size surrounded by platforms that were built with masonry, a mixture of rocks and fine clays. Two exhaustive sampling of detailed stratigraphic sequences were done in 2005 and 2009. Sixteen samples from the Pre-classic to the Epiclassic (300 BC.–AD. 900) were taken showing good agreement with the stratigraphy, ceramics and radiocarbon dates. Samples: Gu1y2*, Gu3, Gu4, Gu5, Gu6, Gu7, Gu8, Gu9, Gu10y16*, Gu11, Gu13y14* and Gu15 (*two samples but processed together).

MEXICO CITY

Templo Mayor of Tenochtitlan (19.44°N, 260.9°W). Tenochtitlan is the city founded by the Mexicas in 1325, its different stages of evolution were marked by its different governors or tlatoanis. The site was sampled in 2000, but only one sample gave a good result. In 2012 a new excavation produced four samples with better results of two different stages. Samples: etapa III, TM2601, TM2604, TM2605 and TM2606.

Tlatelolco (19.45°N, 260.9°W). City located Northwest of the Templo Mayor of Tenochtitlán. This place was built in the year of 1337 by a group of Mexicas that left Tenochtitlán, and its constructive evolution is also marked by its governors. Two samples of burnt stucco are reported: Cui13 and Cui 4a9.

Chapultepec (19.37°N, 260.7°W). Hill located at West of Mexico City center. In 2004, remains of Teotihuacan-type habitation units were are located on the south slope of the hill. Ceramics of the Metepec and Coyotltatelco periods (AD. 550–900) were also found. Burned material of the surface of a kiln was sampled and identified like Cha1a22. Coyoacan (19.37°N, 260.7°W). Postclassic (AD. 600–900) vestiges of a residential unit very damaged due to the construction of a "tlatel", artificial fill to gain ground to the lake. Sample: CHQ1y2.

MORELOS STATE

Xochicalco (18.83°N, 260.6°W). The city of Xochicalco is a fortified settlement of Epiclassic (AD. 600–1100). It is one of the cities that emerged due to the fall of Teotihuacan. Its location over a 300 m hill allowed it to control the trade networks between Morelos, Oaxaca and Mexico Basin. The first sampling of the site was in 1999, and new excavations and sampling were done in 2004, 2006 and 2007. Samples: XO40-52, XO60-61, XO30-32, XO7-8 AND XO11.

STATE OF MEXICO

Teotihuacan. (19.7°N, 261.2°W). Revisited. Samples: Tp2, Tp3, Tp8, Xal1,2, 3, 4, X1, 2, 3, 4, 5, X6, 7, Tp73, Tp38, 39, 40, 41, Tp78, Tp30-31, Tp32-34, Tp75, Tp84, Tp77, CQE1, CQE2, CQE3, CEE2.

Tecama (19.6°N, 260.9°W). It was founded in AD. 1200 by the Mexicas during their pilgrimage to Tenochtitlan. Two occupation stages were sampled: Azteca III (AD. 1300–1500) and Azteca IV (AD. 1500–1600). Sample: HT2A.

QUINTANA ROO STATE

Dzibanché (18.6°N, 271.2°W). Maya site occupied since 300 BC. to AD. 1500. During the Classic (AD. 450–700) was governed by Kaan dynasty. The samples come from murals taken from the main group of buildings, where two constructions of Classic stages were identified. The principal component of the red pigment is hematite. It was the first sampling of murals for archaeomagnetic studies in the Maya area. The sampling was done in 2014. Samples: DZ1, DZ3 and DZ4.

TLAXCALA STATE

Xalasco (19.41°N, 262.2°W). Site occupied by teotihuacanos since AD. 100 to 700. Five unburned stucco samples were taken in 2008, two gave good results: XA4 and XA7.

VERACRUZ STATE

La Joya (19.1°N, 263.8°W). La Joya is the capital of a political entity of the so-called Central Veracruz culture descendant of the Olmecs; a major site built of stamped earth, dating from 400 BC. to AD. 1000. The samples come from oven walls, burned floors and only two from unburned floors of two periods of excavation: 2005 and 2009. Samples: Lj26A-29B, Lj30A-33B, LJ11, LJ12A-15B, LJ16A-19A, LJ20A-25G, JO50, JO37, JO38, JO39, JO40, JO41, JO42, JO43, JO44, JO45 and Jo01-Jo22.

3. Methods

3.1. SAMPLING

The locations of the 40 new structures that are reported in this paper are shown in Figure 1 (geographic coordinates are shown in Table 1). Most of the structures are stuccos exposed to fire, oven or hearths (44 samples). Between 8 and 12 specimens were collected employing a wooden cylinder and oriented with a Brunton compass. In some cases, unburned stucco was also sampled because it was proved that they have a magnetic sedimentary fabric whose magnetic signal was enhanced due to the volcanic scoria and cinder that was added to the mortars (Hueda-Tanabe *et al.*, 2004).

3.2. MAGNETIC MEASUREMENTS

The NRM direction and intensity were measured with an AGICO JR6 magnetometer. Alternate Fields (AF) stepwise demagnetization was carried out over 8 to 12 steps until 100 mT in a Molspin demagnetizer to determine the main remanence components and stability of magnetization.

3.3. ROCK MAGNETIC PROPERTIES

Hysteresis measurements and Isothermal Remanent Magnetization (IRM) cycles were performed using an AGFM Micromag magnetometer

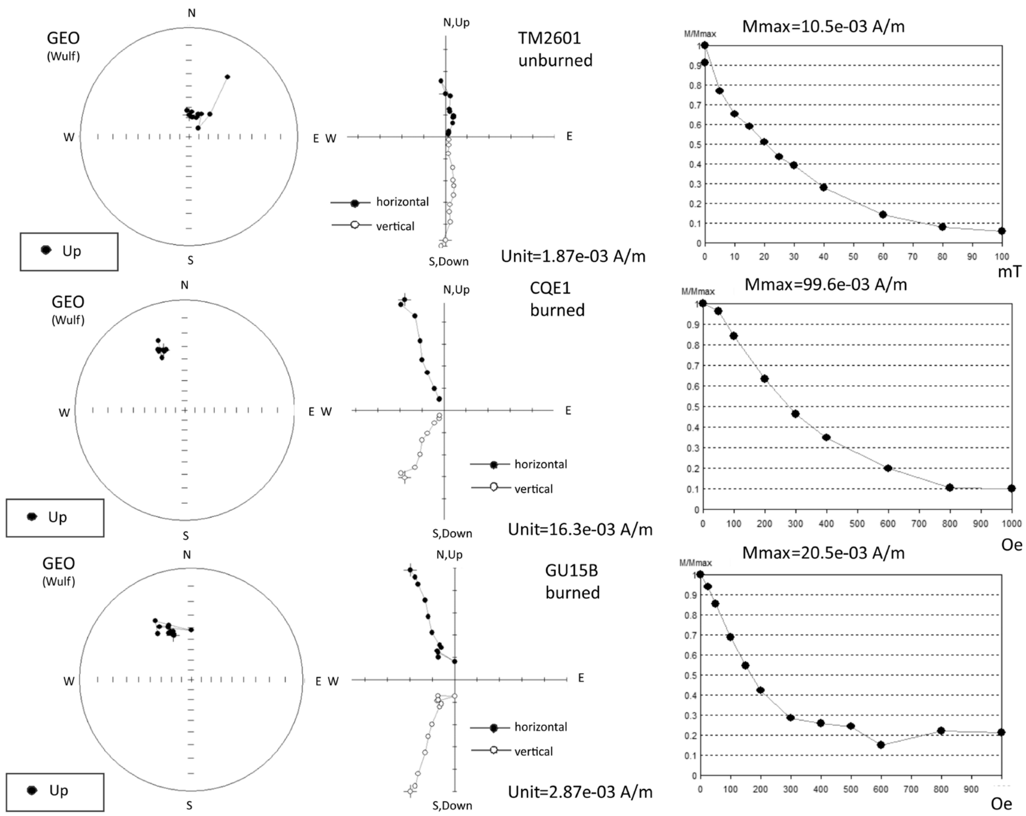

Figure 2 **Stereonet, Vectorial Diagram and Demagnetization spectra of representative samples of unburned (TM2601) and burned (CQE1 and Gu15b) stuccos.**

(Princeton Measurements Corp.) with maximum applied field of 1.2 T. Hysteresis parameters after paramagnetic correction were obtained: saturation magnetization (Ms), saturation remanence (Mrs) and coercitive force (Hc). IRM acquisition was measured for determination of coercitivity of remanence (Hcr). Anisotropy of Magnetic susceptibility (AMS) was measured in an AGICO´s Kappa bridge KlY2. This study was carried out to determine the magnetic fabric for unburned stuccos. In many sites of Mexico, cinder and volcanic scoria was added to the mortars and the anisotropy could reveal the preferred orientations when the stucco dries. We expected a sedimentary fabric, with the minor axes clustered and perpendicular to the plane of deposit. This fabric will allow inferring if the magnetization of unburned stuccos is of a sedimentary origin and if the measured direction is of a primary character.

4. Results

Many of the new data reported now are included in Bachelor and Master theses of students from Physics, Archaeology and Earth Sciences areas since 2003, whose paleomagnetic experiments and measurements were performed in the Paleomagnetic Laboratories of the Geophysics Institute of the National University of Mexico (CDMX and Morelia). Other data were reported in unpu blished Reports requested by and delivered to the excavation projects headed by the INAH. These reports allow access to data from which there are no digital versions.

In many cases, specimens have a linear and univectorial component of magnetization and the characteristic remanent magnetization (ChRM) may be easily determined as may be observed in examples shown on Figure 2 for well heated and unburnt structures. Principal component analysis was used to get the primary magnetization direction of each sample. Fisher statistics was applied to obtain the mean direction of the samples (Fisher, 1953).

The resulting data are listed in Table 1 and some stereonet examples are shown in Figure 3. We only consider acceptable the samples with α_{95} less than 10 and until 15 in the case of the unburned stu ccos. Nine samples of this type are included in the present catalog belonging to some well identified archaeological contexts and with archaeomagne tic dates that correspond with the chronology of strata.

Some hysteresis and IRM cycles that exemplify the behavior of many of the samples are reported in Figure 4. The behavior observed corresponds to poor Ti titanomagnetites. Pseudosingle domains are preponderant in the modified Day diagram (Day *et al.*, 1977) by Dunlop (2002) (Figure 5).

Temperature-dependent magnetic susceptibility experiments carried out in a Bartington MS2 furnace indicate low-Titanium Titanomagnetites as the principal magnetic carrier. Hematites sometimes co-exist but their contribution in remanent magnetization appears to be minor.

Some examples of the AMS of unburnt and burned stuccos could be observed in the Figure

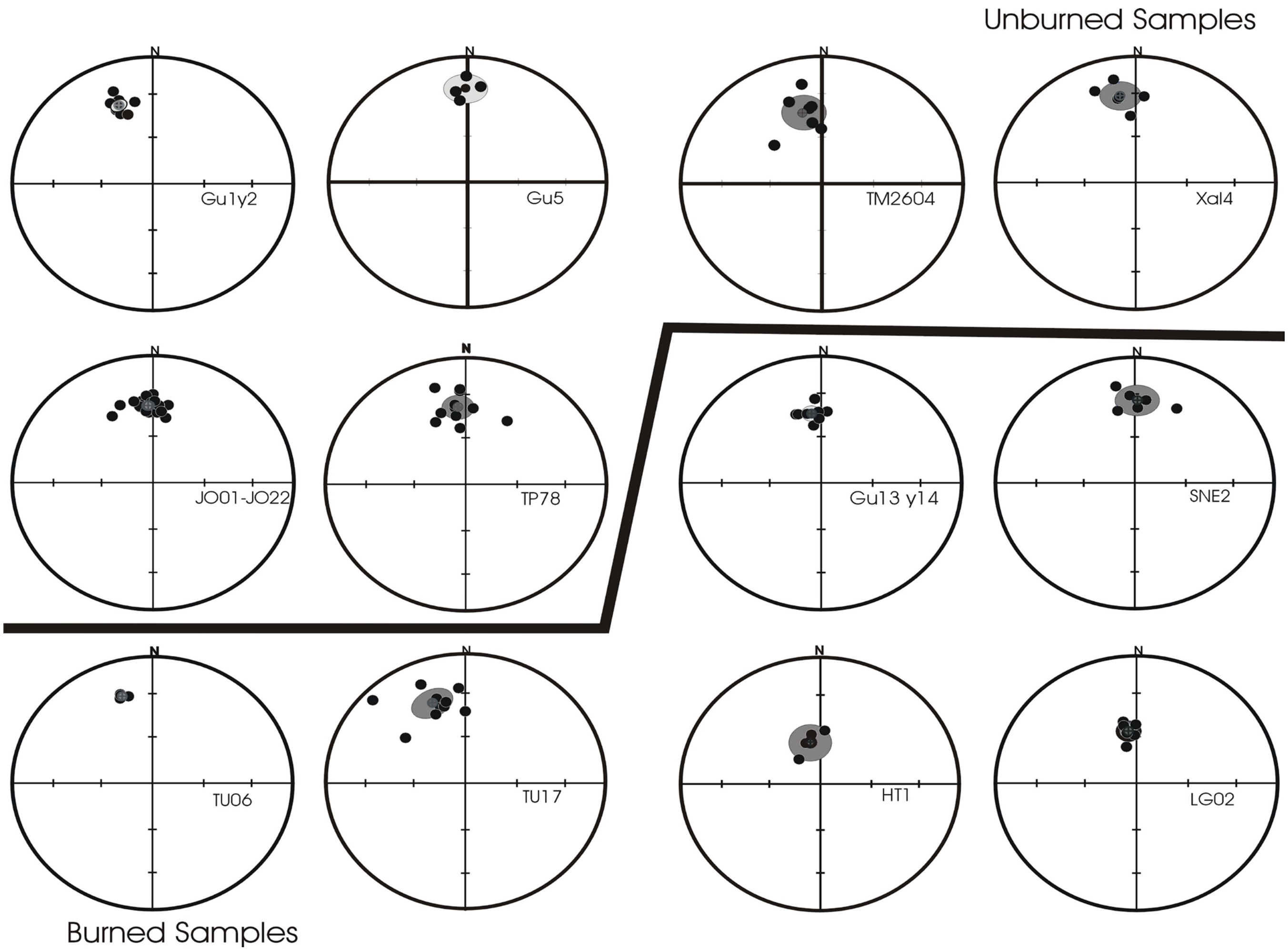

Figure 3 Stereonet of Mean characteristic magnetization of the unburned samples: Gu1y2, Gu5, TM2604, Xal4, JO01-22, TP78 and of burned samples: Gu13y14, SNE2, TU6, TU17, HT1, LG02.

6. All of the magnetic fabrics are of sedimentary type supporting the hypothesis that the unburned stuccos can record the direction of the geomagne tic field at the time of deposition. Burned samples: CQE1, Tp30 to Tp59 of Teotihuacan and Tu05, 06y7 of Tula. Unburned samples: Tu23 of Tula, Gu10 of Teuchitlán and Jo45 of La Joya.

The archaeomagnetic dates of Wolfman (1990b) were obtained from the curve that he constructed following the distribution of the VGPs and their chronological order based on stratigraphic consi deration, ceramics and architecture style. Wolfman proposed two curves: one from AD. 1 to 300 and the other from AD. 300 to 1200.

The curves have a gap between AD. 100 to 300 and between AD. 915 to 1060, because there is a lack of data for these periods. The dating was performed by the intersection of the curve with the direction considering its error (α_{95}).

The secular variation curve from 50 BC. to AD. 1600 obtained in the year 2000 for the archaeomagnetic dating, included the Wolfman data

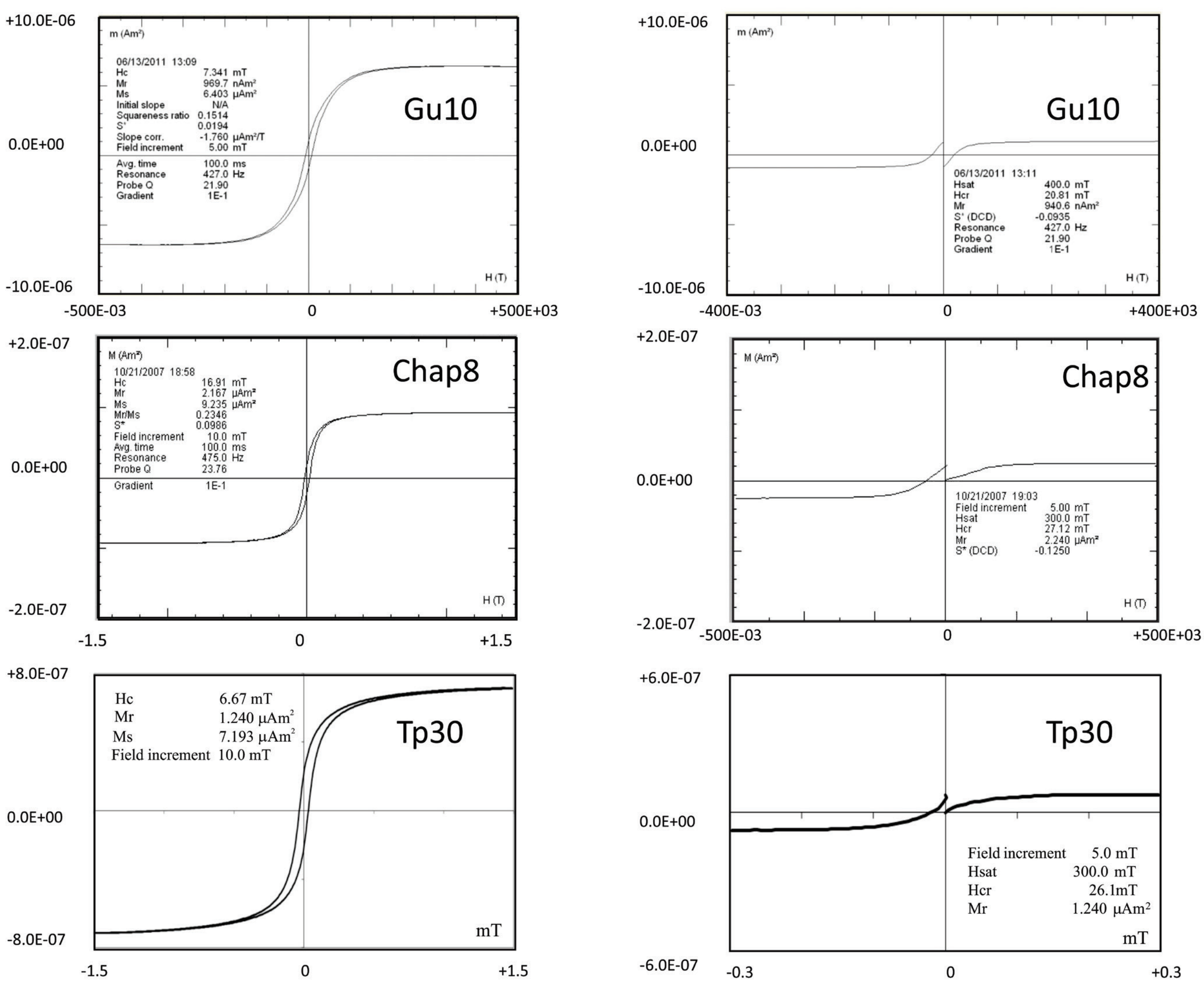

Figure 4 Hysteresis and IRM cycles of the samples Gu10, TU04, Tp30..

(1990b) from Mexico, Salvador and Guatemala, as well as the lava flow of Xitle volcano (100 BC.– AD. 60) data of Urrutia-Fucugauchi (1996) and the stalagmite data DAS2 (AD. 750–1975) of Latham and co-workers (1986). We employed the crossing point technique (Le Goff *et al.*,2002; Noel and Batt,1990) to get the intersections with the curve and achieve the dating. To better constrain the dates, stratigraphic restrictions were considered. The whole dataset was reduced to Teotihuacan (19.7°N, 261.2°E) because the greatest number of samples comes from this emblematic site.

In 2010 with the publication of the software Rendate (Lanos, 2008) a new curve was modeled with cubic splines and the previous directions were processed obtaining better age restrictions. Figure 7 shows the secular variation curves obtained. Most of the new excavation projects have been taking samples for radiocarbon dating improving the local chronologies (Beramendi *et al.*, 2009) providing new data to complete and expand the secular variation curve of central and south Mexico.

Table 1 compiles all the information concerning the location of samples, and their features: burned or unburned (b/ub), number of specimen employed to calculate the statistical means n, the total number of the specimens in the sample N. The Demag column indicates NRM if the samples were not demagnetized or, the maximum peak demagnetizing field in mT. Dec, Inc and α_{95} are the parameters of the mean direction of the sample resulted from the Fisher statistic; plat and

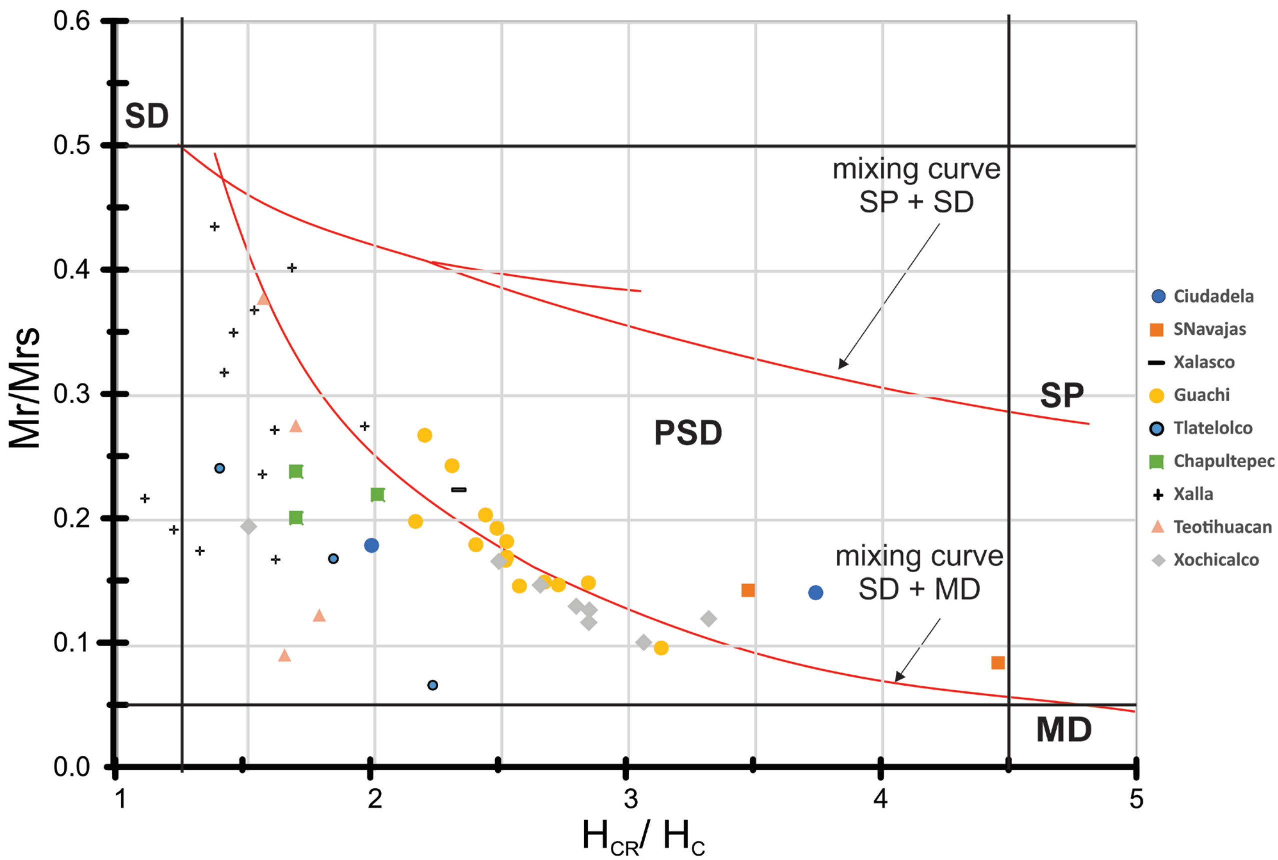

Figure 5 Day diagram of representative samples of Teotihuacan: Ciudadela and Xalla, Sierra de las Navajas, Xalasco, Guachimontones, Tlatelolco, Chapultepec and Xochicalco.

plong are the paleolatitude and paleolongitude of Virtual Geomagnetic Poles (VGP). Estimated date is the date of the sample assigned by ceramic style, stratigraphy (st) or radiocarbon date (rc) related. Archaeomagnetic date is the date obtained by Rendate software. A key to identify the data Published in Referee Journals (PRJr) or the data of thesis and internals reports (uPRr unPublished in Referee Journals). As can be observed the mean α_{95} of unburned samples is 8.5 and usually grea ter than 4°. For unburned samples we accept α_{95} values less than 15° because of the type magnetization and potential inclination error. In all cases of unburned stuccos, the magnetic fabric has been measured confirming the sedimentary fabric (Figure 6).

5. The PSV curve for Central Mexico

The early proposed curve has been improved by including only data supported by dates obtained by other alternative methods, in our case only radiocarbon data are available. The stalagmite data

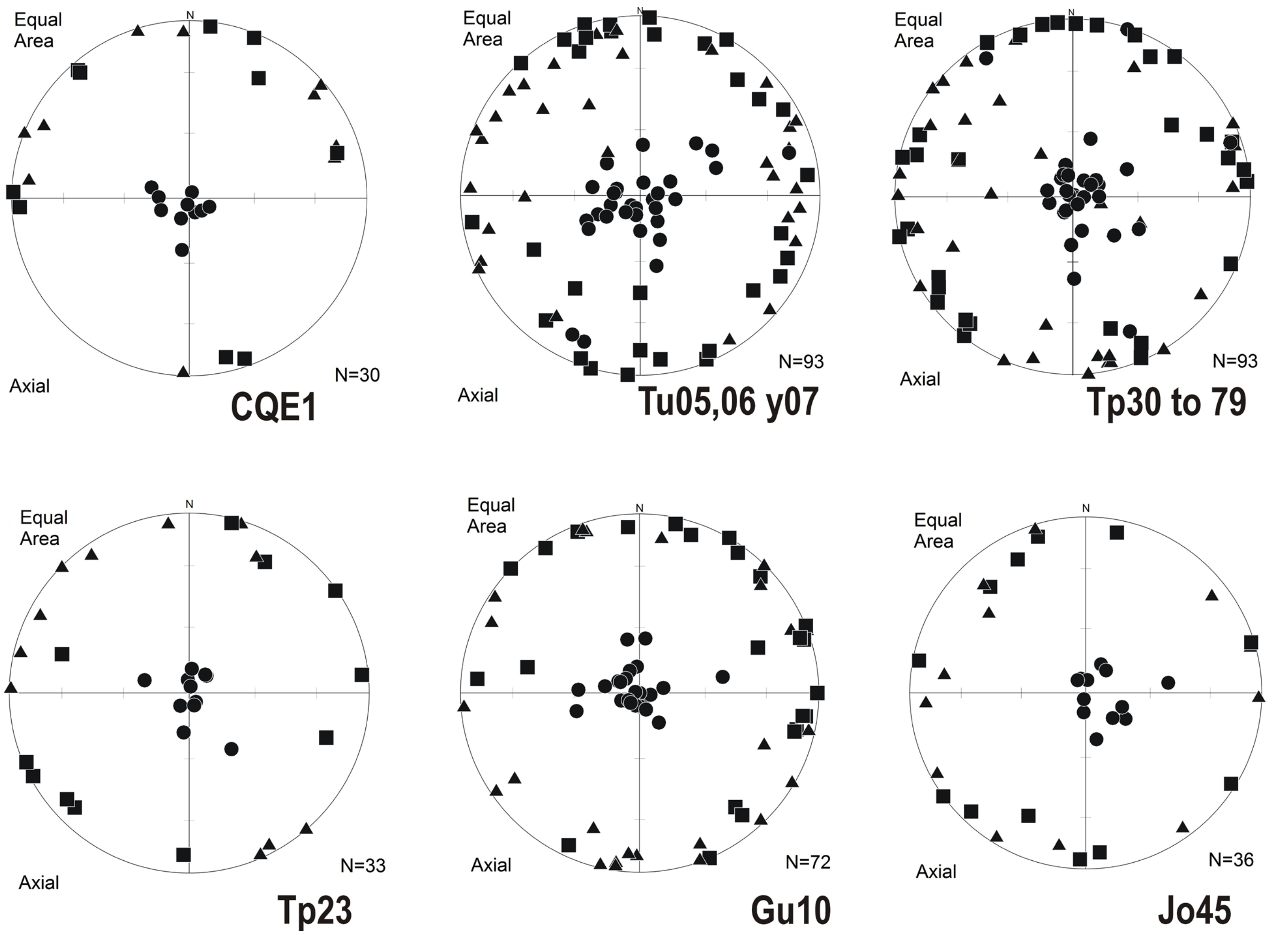

Figure 6 Magnetic Anisotropy Susceptibility of the burned samples: CQE1 of Teotihuacan TU05,06 & 7 of Tula, TP30 to TP59 of Teotihuacan and Gu10 of Teuchitlan. Anisotropy of Magnetic susceptibility of unburned samples: TU23 of Tula and JO45 of La Joya. (circles – minimum - k3, square - intermediated- k2, triangle -maximum – k1).

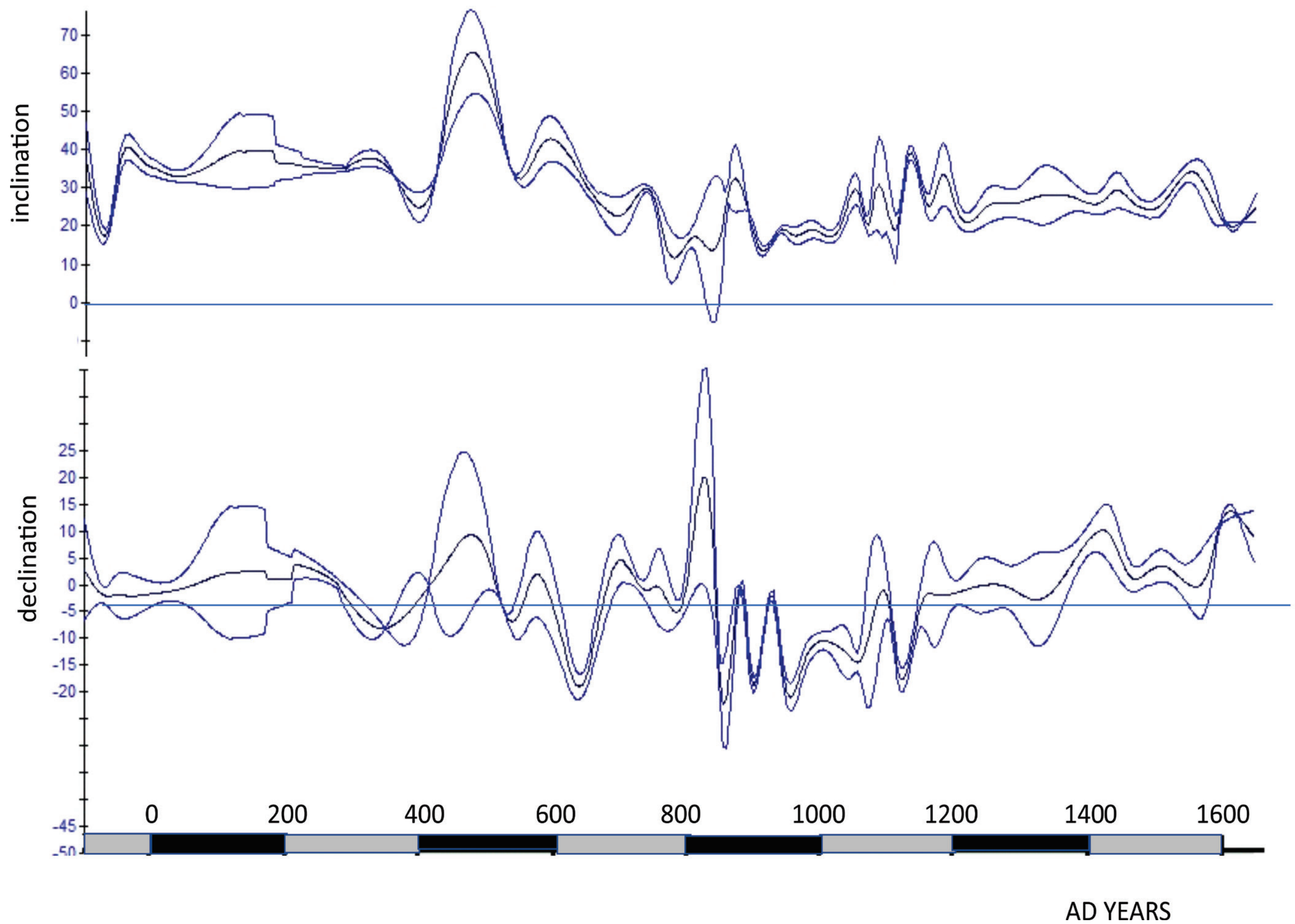

Figure 7 **Previous Secular variation curve reduced to Teotihuacan (19.7N,261.2E) with their errors ΔI and ΔD. The curve includes geological and archaeomagnetic data.**

(Latham *et al.*, 1986) have been removed due to controversy in their records. The data of the Xitle (Urrutia-Fucugauchi ,1996) was also removed to include only archaeomagnetic samples.

The new curve presented includes the archaeomagnetic data of Wolfman (1990b) and those of the researches carried out in the Laboratory of Paleomagnetism of the UNAM (located in CDMX) and of Morelia Laboratory, the current National Archaeomagnetic Service since 1999, all of them compiled in Table 1.

Fisher's statistic mean-directions and VGP poles were obtained every 50 years with a mobile window of 100 years. Table 2 shows the results and Figure 8 shows them in an equal area projection. It is important to point out that more data is still needed in the Preclassic time-span (500 BC.–AD. 200), and for the Postclassic especially after AD. 1100.

In Figure 9 we can observe the comparison results amongst the available curves for the SW of USA. The employed data are from papers of Eighmy *et al.*, (1990), Lengyel and Eighmy (2002) and Sternberg and McGuire (1990). The data comes from the states of Colorado, Arizona, New Mexico, Arkansas, Missouri, Louisiana and Tennessee. Lengyel and Eighmy (2002) focused on a proposal to solve the problem of damping by the use of the moving window and to the small number of samples in certain periods. Some large differences are observed between AD. 600 to 650 and AD. 925 to 1100 which can be tentatively attributed

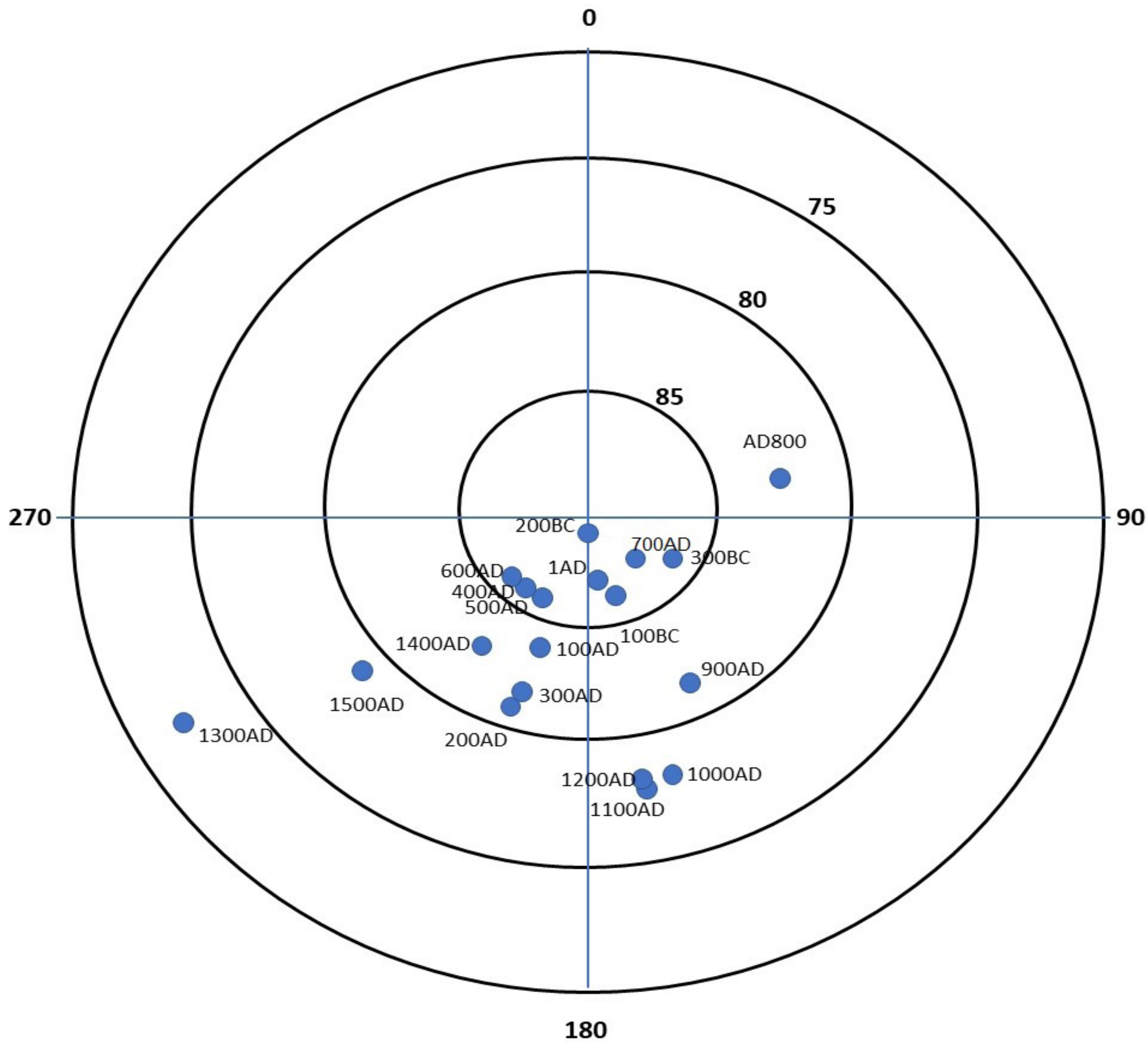

Figure 8 Stereonet of Virtual Geomagnetic Poles for Central and South of Mexico for 300 BC to AD 1500 every 100 years.

Table 2. Mean Fisher magnetic direction of geomagnetic field for Mexico every 50 years, obtained with a moving window of 100 years. Plat: North latitude of VGP, Plong: East longitude of VGP.

DATE	DEC	INC	a95	R	K	PLAT	PLONG
350 BC.	0	30.2	16.3	3.908	32.65	86.5	81.2
300 BC.	357.2	31	8.4	6.887	52.94	86	123.4
250 BC.	359	35.5	5.8	8.899	79.35	89.1	167.4
200 BC.	359	35.5	5.8	8.899	79.35	89.1	167.4
150 BC.	359	33.2	5.7	8.901	81.18	88.2	112.3
100 BC.	356.1	34.7	5.8	6.945	109.8	86.3	162.6
50 BC.	356.1	34.7	5.8	6.945	109.8	86.3	162.6
AD. 1	356.9	35.3	5.2	7.939	114.3	87.1	167.7
AD. 50	354.4	39.1	7.5	7.874	55.38	84.2	196.9
AD. 100	354.4	39.1	7.5	7.874	55.38	84.2	196.9
AD. 150	354.4	39.1	7.5	7.874	55.38	84.2	196.9
AD. 200	351.7	41.1	5.4	19.5	38.11	81.4	199.3
AD. 250	348.4	43.4	7.7	12.6	30.14	77.9	201
AD. 300	352.3	40.5	5.9	16.57	37.16	82.1	198.1
AD. 350	353.8	38.6	4	20.68	63.22	83.8	191.8
AD. 400	356.6	39.4	2.4	40.55	88.48	85.9	211.4
AD. 450	356.6	39.1	2.3	42.52	87.57	86	209
AD. 500	357.1	38.6	2.6	40.46	73.46	86.6	208.9
AD. 550	357.1	39	2.7	40.41	67.64	86.4	212.5
AD. 600	357.1	39	3.1	35.41	59.59	86.4	212.5
AD. 650	356.1	37.1	5.9	24.04	24.94	86.2	187.3
AD. 700	357.5	33.2	5.6	25.05	26.32	87.2	137.8
AD. 750	359.9	30.7	4.6	19.62	50.43	86.8	82.9
AD. 800	0.1	23.3	4.4	10.91	110.4	82.5	80.5
AD. 850	0.1	23.6	4.8	9.911	101	82.6	80.4
AD. 900	351.7	30.9	4.3	27.35	41.54	81.6	151.5
AD. 950	349	31.9	4.4	22.54	47.48	79.3	160
AD. 1000	347.9	32.6	4.6	20.59	48.6	78.4	163.4
AD. 1050	347.5	33.4	4.6	19.63	51.33	78.1	166.3
AD. 1100	347.6	34.1	4.9	17.66	50.14	78.2	168.4
AD. 1150	347.6	34.1	4.9	17.66	50.14	78.2	168.4
AD. 1200	347.6	34.1	4.9	17.66	50.14	78.2	168.4
AD. 1250	352	55.5	5	5.95	109.57	72.2	239.6
AD. 1300	352	55.5	5	5.95	109.57	72.2	239.6
AD. 1350	351.1	43.2	19	3.877	24.36	80.1	206.4
AD. 1400	354.4	42.3	9.5	8.735	30.13	83	214.8
AD. 1450	354.2	43	7.6	10.73	36.97	82.5	216.9
AD. 1500	353.9	48.1	8.4	9.733	33.68	79.1	231.9

more to the lack of reliable data in the SW of USA than to the local non-dipole field, but great differences can be observed between AD. 1200 to 1325 where the lack of data is in Mexico. It is evident that more high-quality data supported by radiometric ages are strongly needed to improve the reference curves of Mesoamerica and SW of USA. Special effort should be place on put to the time intervals of 500 BC. to AD. 200 and AD. 1200 to 1325, which represent the major lack of reliable archaeomagnetic results in Mexico.

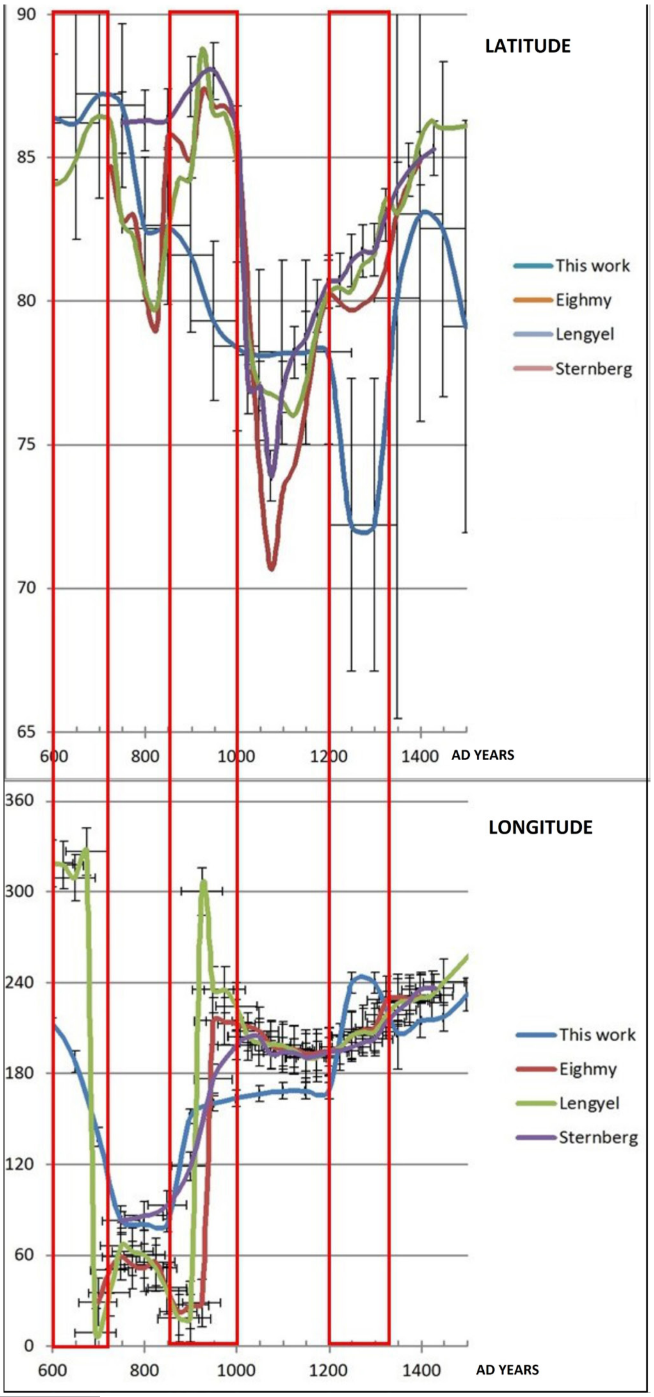

Figure 9 Polar Secular variation curves of center and south of Mexico and SW of USA from AD 600 to AD 1500.

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References

Aguilar-Parra, L.I., Morales-Sánchez, R., 2011, Estudio arqueomagnético: Una aplicación a la cronología de la arquitectura de tierra en el sitio "La Joya", Veracruz: Mexico, Escuela Nacional de Antropología e Historia, Bsc thesis of Archaeology, 195 p.

Beramendi-Orosco, L.E., González-Hernández, G., Soler-Arechalde, A.M., 2012, Cronología para Teopancazco: Integración de datos arqueomagnéticos a un modelo bayesiano de radiocarbono, *in* Manzanilla L R. (ed.), Una aportación a la cronología de Mesoamérica. Estudios Arqueométricos del centro de barrio de Teopancazco en Teotihuacan: Mexico, IIA-UNAM, 111–134.

Beramendi-Orosco, L.E., González-Hernández, G., Urrutia-Fucugauchi, J., Manzanilla, L. R., Soler-Arechalde, A.M., Goguitchaishvili A., Jarboe, N., 2009, High-resolution Chronology for the Mesoamerican Urban Center of Teotihuacan Derived from Bayesian Statistics of Radiocarbon and Archaeological Data: Quaternary Research, 71(2), 99–107.

Day, R., Fuller, M., Schmidt, V.A., 1977, Hysteresis properties of titanomagnetites: grain size and compositional dependence: Physics of the Earth and Planetary Interiors, 13, 260–267.

Dunlop, D.J., 2002, Theory and application of the Day plot (Mrs/Ms versus Hcr/Hc) 1. Theoretical curves and tests using titanomagnetite data: Journal of Geophysical Research. B: Solid Earth, 107(3), 5-1-5-15.

Eighmy, J.L., Hathaway, J.H, Kane, A.E, 1990, Archaeomagnetic Secular Variation in the American Southwest, AD. 700-900: Final Results from the Dolores Archaeological Program, *in* Eighmy J.L., Sternberg, R.S. (eds.), Archaeomagnetic dating: Tucson, The University of Arizona Press, 226–236.

Fisher, R.A., 1953, Dispersion on a sphere: Proceedings of the Royal Society of London, A217, 295–305.

Fregoso, D., 2010, Estudio Arqueomagnético del Abrigo Rocoso "Los Grifos", Chiapas. Sitio de Ocupación Temprana en América: Mexico, Universidad Nacional Autónoma de Mexico, Bsc Thesis of Physics, 124 p.

Gallet, Y., Genevey, A., Le Goff, M., 2002, Three millennia of directional variation of the Earth's magnetic field in western Europe as revealed by archeological artefacts: Physics of the Earth and Planetary Interiors, 131(1), 81–89.

Gómez-Paccard, M., Chauvin, A., Lanos, P., McIntosh, G., Osete, M. L., Catanzariti, G., Ruiz-Martínez, V. C., 2006, First archaeomagnetic secular variation curve for the Iberian Peninsula: Comparison with other data from western Europe and with global geomagnetic field model: Geochemistry, Geophysics and Geosystems, 7(12),1–20.

Guerrero, X., 2003, Análisis Arqueomagnético de Estucos del Valle de Mexico: Mexico, Universidad Nacional Autónoma de Mexico, Bsc Thesis of Physics, 40 p.

Hernández-Ávila, E. R., 2010, Control Cronométrico basado en arqueomagnetismo de Teopancazco, Estado de México: Mexico, Universidad Nacional Autónoma de Mexico, Bsc Thesis of Physics, 104 p.

Hueda-Tanabe, Y., Soler-Arechalde, A.M., 2001. Fechamiento arqueomagnético de los estucos en los sitios de Teopancazco, Teotihuacan y Templo Mayor, Tenochtitlán: Mexico, Informe presentado al Consejo de Arqueología del INAH en Agosto de 2001.

Hueda-Tanabe, Y., Soler-Arechalde, A.M., Urrutia-Fucugauchi, J., Barba, L., Manzanilla, L., Rebolledo, M., Gogitchaishvili, A., 2004. Archaeomagnetic studies in central Mexico –dating of Mesoamerican lime-plasters: Physics of Earth and Planetary Interiors, 147, 269–283.

Lanos, P., Dufresne, P., 2008. Bayesian Archaeomagnetic and Radiocarbon dating: the RenDate software, *in* Radiocarbon and Archaeology, 5th International Symposium. Zurich, Switzerland.

Latham, A.G., Schawrz, H.P., Ford, D.C. 1986. The paleomagnetism and U-Th dating of Mexican stalagmite. Earth and Planetary Science Letters, 79, 195–207.

LeGoff, M., Gallet, Y., Genevey, A., Warmé, N., 2002. On archeomagnetic secular variation curves and archeomagnetic secular variation curves and archaeomagnetic dating. Physics of Earth and Planetary Interiors, 134, 203–211. doi.org/10.1016/S0031-9201(02)00161-9

Lengyel, S.N., Eighmy, J.L., 2002, A Revision to the U.S. Southwest Archaeomagnetic Master Curve: Journal of Archaeological Science, 29, 1423–1433. doi:10.1006/jasc.2001.0807

López-Austin, A., López-Luján, L., 2014, Las Grandes Divisiones, *in* El pasado indígena: México, FCE, Colmex and FHA, 70–74.

López-Delgado, V., Soler-Arechalde, A.M., Esparza-López, J. R., Goguitchaichvili, A., Caballero-Miranda, C.I., Morales, J., 2017, Guachimontones de Teuchitlán: un estudio arqueomagnético para mejorar la cronología del Occidente de Mexico: Arqueologia Iberoamericana 33, 27–34

López-Delgado, V., Soler-Arechalde, A.M., Espinosa-Rodríguez, G., Goguitchaichvili, A., 2011, Rock-magnetic and archeomagnetic survey from some classical settlements at Chapultepec archeological site (western Mesoamerica): Studia Geophysica et Geodaetica, 55(2), 329–342

Martínez-Miranda, V., 2013, Tula el tiempo perdido- Fechamientos arqueomagnéticos: Mexico, Escuela Nacional de Antropologia e Historia: Bsc thesis in Archaeology,191 p.

Noel, M., Batt, C., 1990, A method for correcting geographically separated remanence directions for the purpose of archaeomagnetic dating: Geophysical Journal International, 102, 753–756.

Pavón-Carrasco, F.J., Rodríguez-González, J., Osete, M.L., Torta J.M., 2011, A Matlab tool for archaeomagnetic dating: Journal of Archaeological Science, 38(2), 408–419.

Rodríguez-Ceja, M., 2003, Análisis y Fechamiento arqueomagnético de estucos de Zonas habitacionales de Teotihuacan (Xalla) y Templo Mayor: Mexico, Universidad Nacional Autónoma de Mexico, Bsc Thesis of Physics, 65 p.

Romero-Hernández, E., 2008, Fechamientos Arqueomagnéticos de pisos con control estratigráfico de la excavación Teopancazco 2005, Teotihuacan: Universidad Nacional Autónoma de Mexico, Mexico, Bsc Thesis of Physics, 51 p.

Saavedra-Cortes, S. P., 2010, Estudio arqueomagnético en el área de Tecamac, Estado de México: Mexico, Universidad Nacional Autónoma de Mexico, Bsc Thesis of Physics, 85 p.

Sánchez-López, F., 2005, Nuevos fechamientos arqueomagnéticos de Xalla y Teopancazco, zonas habitacionales de Teotihuacan: Universidad Nacional Autónoma de Mexico, Mexico, Bsc Thesis of Physics, 80 p.

Schnepp, E., Lanos, P., 2005, Archaeomagnetic secular variation in Germany during the past 2500 years: Geophysical Journal International, 163(2), 479–490.

Sternberg, R.S., McGuire, R.H., 1990, Archaeomagnetic Secular Variation in American Southwest, A.D. 700-1450, in Eighmy J.L., Sternberg, R.S. (eds.), Archaeomagnetic dating: Tucson, The University of Arizona Press, 199–225.

Straulino-Mainou, L., Sedov, S., Soler-Arechalde, A.M., Pi-Puig, T., Villa, G., Balanzario-Granados, S., Doménech-Carbó, M.T., Osete-Cortina, L., Leonard, D., 2016, Maya Lime Mortars-Relationship between Archaeomagnetic Dating, Manufacturing Technique, and Architectural Function-The Dzibanché Case: Geosciences, 6(49), 1–27.

Soler-Arechalde, A.M., Barrera, A., Morales, R., 2012. Reporte de Datación arqueomagnética Templo Mayor, CDMX. Technical report delivered to Excavation Project Leader of INAH, 21p.

Soler-Arechalde, A.M., Barrera, A., 2013b. Reporte de Datación Arqueomagnética Ofrenda 161, Plaza Manuel Gamio, Templo Mayor, D.F.: Technical Report delivered to Excavation Project Leader of INAH, 9p.

Soler-Arechalde, A.M., Barrera, A., Martínez Longoria, A., 2013a, Reporte de Datación Arqueomagnética Templo de la Inmaculada Concepción, Coyoacán, DF: Technical report delivered to Excavation Project Leader of INAH, 14 p.

Soler-Arechalde, A.M., Caballero Miranda, C., 2008a, Reporte de Fechamiento Arqueomagnético. Xochicalco 2006: Technical report delivered to Excavation Project Leader of INAH, 6 p.

Soler-Arechalde, A.M., Orea, A., Caballero Miranda, C., 2008b, Reporte de Fechamiento

Arqueomagnético. Xochicalco 2007: Technical report delivered to Excavation Project Leader of INAH, 9 p.

Soler-Arechalde, A. M., Sánchez, F., Rodríguez, M., Caballero-Miranda, C., Goguitchaishvili, A., Urrutia-Fucugauchi, J., Manzanilla, L., Tarling, D. H., 2006, Archaeomagnetic investigation of oriented pre-Columbian lime-plasters from Teotihuacan, Mesoamerica: Earth, Planets and Space, 58(10), 1433–1439.

Terán-Guerrero, A.G., Soler Arechalde A.M., Gogichaishvili A., Caballero-Miranda, C., Morales, J., Urrutia-Fucugauchi, J., 2016, Dataciones arqueomagnéticas en la Ciudadela de Teotihuacán, Sierra de las Navajas y Xalasco: Arqueología Iberoamericana, 29, 15–20.

Terán-Guerrero, A. G., 2013, Estudios arqueomagnéticos en Ciudadela, Sierra de las Navajas y Xalasco, Cultura Teotihuacana: Mexico, Universidad Nacional Autónoma de Mexico, Master thesis in Earth Sciences,155 p.

Urrutia-Fucugauchi, J., 1996, Paleomagnetic Study of the Xitle-Pedregal de San Angel lava flow, southern basin of Mexico: Physics of the Earth and Planetary Interiors 97, 177–196.

Wolfman, D., 1990a, Archaeomagnetic Dating in Arkansas and the Border Areas of Adjacent States-II, *in* Eighmy J.L., Sternberg R.S. (eds.), Archaeomagnetic dating: Tucson, The University of Arizona Press, 237–260.

Wolfman, D., 1990b, Mesoamerican Chronology and Archaeomagnetic A.D. 1-1200, *in* Eighmy J.L., Sternberg R.S. (eds.), Archaeomagnetic dating: Tucson, The University of Arizona Press, 261–308.