Journal of Archaeological Science: Reports 21 (2018) 504–511

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Archaeomagnetic evidence of pre-Hispanic origin of Mezcal

Avto Goguitchaichvili[a,*], Miguel Cervantes Solano[c], Jesús Carlos Lazcano Arce[b], Mari Carmen Serra Puche[b], Juan Morales[a], Ana María Soler[a], Jaime Urrutia-Fucugauchi[a]

[a] Servicio Arqueomagnético Nacional, IGF-IGUM, UNAM, Campus Morelia, Universidad Nacional Autónoma de México, Mexico
[b] IIA-UNAM, Instituto de Investigaciones Antropológicas, Universidad Nacional Autónoma de México, Ciudad Universitaria, Mexico
[c] Arqueomagnético Nacional, ENES Campus Morelia, UNAM, Universidad Nacional Autónoma de México, Mexico

A R T I C L E I N F O

Keywords:
Mesoamerica
Archaeomagnetism
Pottery
Kilns
Magnetic properties
Mezcal

A B S T R A C T

For centuries, and until a few years ago, it was considered that the distillation process had been brought to the new world by the Spaniards, who in turn learned it from the Arabs. For this reason, it was believed that the only alcoholic beverage of the Mesoamerican societies was *pulque* - a ferment of maguey. However, recent archaeological investigations revealed that the alcohol distillation was known in Mesoamerica long before the arrival of Europeans, for at least 25 centuries. The direct evidence comes from the ceremonial and administrative center of Xochitécatl-Cacaxtla (state of Tlaxcala) with several ovens where cooked maguey remains were discovered. The corresponding archaeological context was radiometrically dated from 600 to 400 BCE. Here, we report a detailed archaeomagnetic study on burned archaeological artifacts found in these cooking ovens. 35 specimens belonging to two pottery fragments, one burned rock and two burned soil samples were pre-selected for archaeointensity experiments. Pottery samples exhibited essentially reversible behavior during thermomagnetic experiments pointing to Ti-poor titanomagnetite (almost magnetite phase) as main magnetic carrier while two ferromagnetic phase seems to co-exist in burned soils. In contrast, burned rock samples exhibited some instabilities during the heating at high temperatures and indirect evidence of the presence of antiferromagnetic hematite grains. In total, 29 specimens allowed the estimation of absolute geomagnetic intensity recorded during the last use of the furnace. Archaeomagnetic dating yielded two possible time intervals between 878 to 693 BCE and 557 to 487 BCE. These new data reinforce the initial hypothesis and corroborate the temporality of these pre-Hispanic kilns.

1. Introduction

The pre-Hispanic evidence of distilled beverages still remains highly controversial in Mesoamerica. A fermented drinks from the agave plant known as *pulque* (agave wine) was systematically consumed in central and northern Mesoamerica before European conquest. Tequila, however, was first produced in the 16th century in the town of Tequila (State of Jalisco, Western Mexico). The distillation procedure of Tequila involves only the blue agave (*tequiliana weber*), while any type of agave may be used to produce Mezcal. Thus, Tequila is a type of Mezcal. It is produced in almost everywhere in Mexico, being Oaxaca State the major Mezcal producer.

The origin of mezcal is a matter of debate and it is still unclear whether distilled drinks were produced in Mexico before the Spaniards arrival (Zizumbo-Villarreal et al., 2009). The idea about the pre-Hispanic origin became popular (Serra Puche, 1994, 1997a, 1997b; Serra Puche and Lazcano, 1997, 1998a, 1998b; Serra Puche and Palavicini, 1996; Serra Puche et al., 2000) since middle 90th. Serra Puche et al. (2000) and Serra Puche and Lazcano (2002a, 2002b), based on the study of pre-Hispanic conical kilns, argued that around 400 BCE the inhabitants of Xochitecatl-Cacaxtla (state of Tlaxcala) already knew the process of fermentation and distillation of Mezcal as a ritual drink. On the other hand, Colunga et al. (2013) found some vessels that may have been used to distill beverages between 1500 through 1000 BCE in the state of Colima (western Mexico). The great importance of agave as food since approximately 8000 BCE was first underlined by Flannery (1986) and Smith (1986) while other authors like Benz (2002), Benz et al. (2006), Schöndube, 2000, Zizumbo-Villarreal et al., 2009 documented its use as fiber and fermented beverage since the Late Formative period in western Mesoamerica (Colima and Jalisco states mainly). In this context, Kelly (1974, 1980) studied Capacha (Colima State) gourd and trifid vessels belonging to the Early Formative period (approx. 1500 through 1000 BCE) that could be used to produce distilled beverages.

The investigation conducted by Serra Puche and Lazcano (2016)

* Corresponding author.
E-mail address: avto@geofisica.unam.mx (A. Goguitchaichvili).

https://doi.org/10.1016/j.jasrep.2018.08.022
Received 28 March 2018; Received in revised form 20 July 2018; Accepted 12 August 2018
2352-409X/

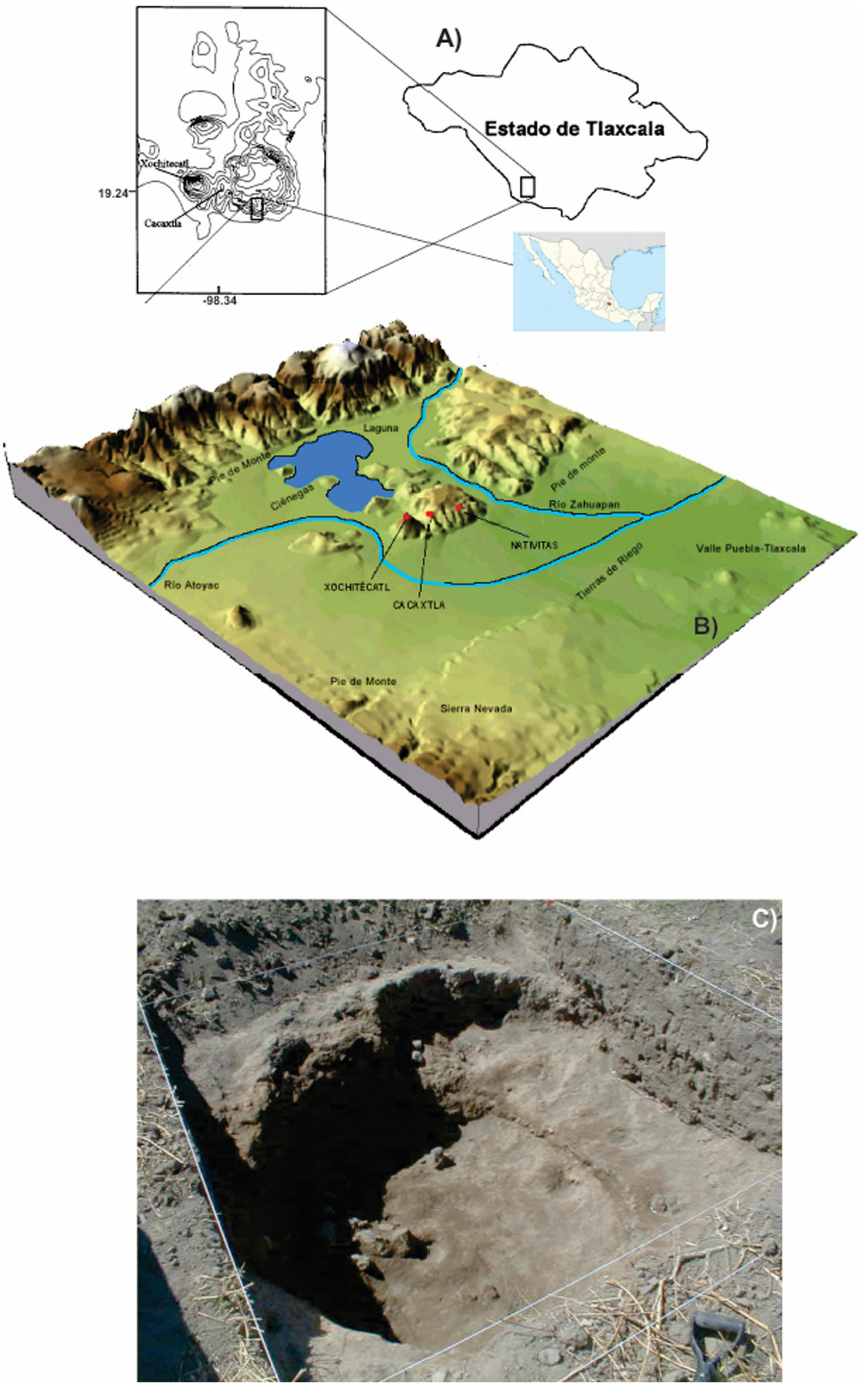

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Fig. 1. A) Location of studied site and B) Tlaxcala Valley digital elevation model indicating the Xochitecatl-Cacaxtla archaeological complex. C) Typical furnace found in Xochitécatl housing area presumably used for alcohol production.

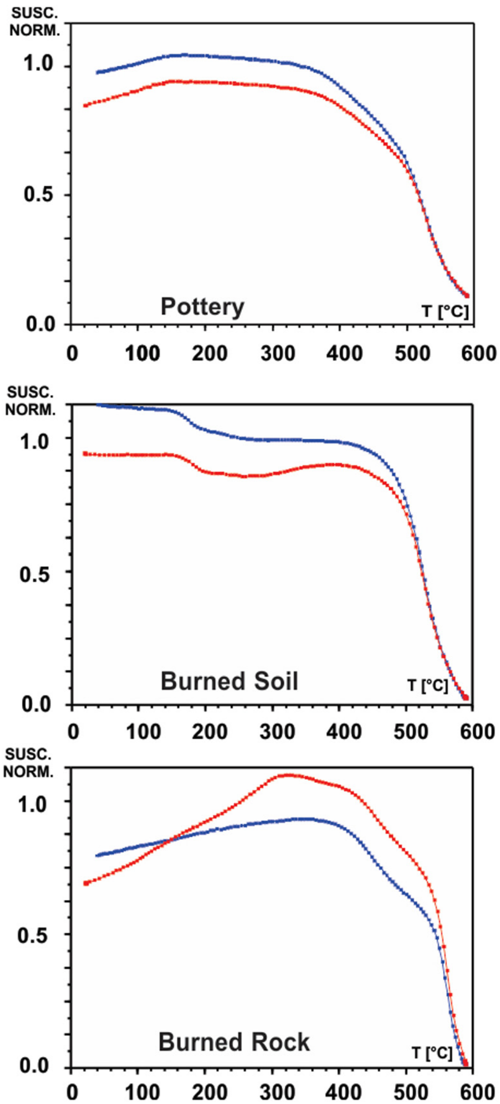


Fig. 2. Susceptibility vs. temperature curves for burned soil, rock and pottery representative samples.

was based on the production of mezcal from archaeological, ethno-historical and ethno-archaeological perspectives. Mezcal is obtained from the maguey through traditional work processes such as: the cooking of the pineapples (through the use of kilns dug in the ground in its most traditional form), crushing of cooked pineapple (with axes and clubs) and the fermentation, originally in wooden basin. Finally, the distillation process is achieved in primitive pots, currently copper and filtering dishes. The objective was to establish analogies which may potentially allow understanding the meaning of the cultural material documented in the housing units of the archaeological site of Xochitecatl-Cacaxtla. For this purpose, different studies were carried out in numerous communities in Mexico, southern United States and Guatemala in order to register the diversity of agaves and instruments used in the production of Mezcal to identify the degree of specialization and the current elements that allow to infer whether the archaeological evidence (furnaces, pots, etc.) found in the housing area of Xochitecatl-Cacaxtla has a relationship with elaboration of distilled beverages during the pre-Hispanic times (Serra Puche and Lazcano, 2016).

Present study is aimed to magnetically date pottery, burned soil and burned rock samples found in some maguey cooking ovens at Xochitécatl-Cacaxtla archaeological site. These baked artifacts contain small quantities of magnetic minerals that register the Earth's magnetic field at the time of their last firing and subsequent cooling. In ideal case, archaeomagnetic directions (declination and inclination) may greatly help to precise the absolute ages. However, in situ, consolidated materials were extremely hard to found and thus no oriented samples were obtained.

2. Archaeological context

The valley of Tlaxcala (Fig. 1) is delimited by mountainous formations, some of them of more than five thousand meters height, standing out the Popocatépetl, the Iztaccíhuatl, the Tláloc, the Telapón and the La Malinche volcanic events. Around the settlements of Xochitecatl-Cacaxtla, a large part of the population gathered, which had a continuous growth since the Middle Formative period (800–200 BCE). This is due to its privileged location in a high place and as a passage of exchange and trade routes. Xochitecatl archaeological complex is located in the valley of Tlaxcala, southwest of the state of the same name in the central part of Mexico. It is a ceremonial center located on top of an old volcanic cone that was built during the Formative period (800 BCE–100 CE). There is no radiometric age information available of the volcanic lavas and lava cones that outcrops within the settlement. In the vicinity of Xochitecatl, rises another important architectural complex of Cacaxtla dedicated to civic-administrative functions. Both areas, however, may be considered as a single archaeological site, a big city that covered a huge area of the surrounding valleys sharing the spatial and temporal elements (Serra Puche and Palavicini, 1996).

Many human settlements existed across the Puebla-Tlaxcala Valley region during the Early Preclassic (1500–900 BCE) period. Many of these places, first conceived as villages, consolidated during the Middle and Late Preclassic (900 BCE–200 CE) becoming soon the sites of control and regional supremacy with its apogee at the Epiclassic (650–950 CE). The city of Xochitecatl-Cacaxtla, a pre-Hispanic settlement (Fig. 1), was planned and built around 800 BCE. It is located 117 km from the Mexico City at an average altitude of 2200 m. Near the ceremonial center, Serra Puche and Lazcano (1998a, 1998b) found housing units, which allowed them to imagine a wider panorama of this pre-Hispanic city and discover that its inhabitants were dedicated to various trades, such as stone polishers and potters among some others. An important finding was the discovery a series of ovens (Fig. 1) similar to those currently used to burn the maguey heart. At the external part of the houses, a hole of two meters in diameter by three of depth was made, and it was filled with volcanic rocks, soils and pottery fragments in order to keep the heat inside the oven. When doing the chemical analyzes of the runoff, experts from Institute of Chemistry of the UNAM (National University of Mexico) detected an organic material identified as burnt maguey pieces. The ages obtained with ^{14}C systematics of the residues of maguey in ovens found in the ceremonial and administrative center of Xochitécatl-Cacaxtla, in Tlaxcala, correspond to the first period of occupation of the city, from 600 to 400 BCE.

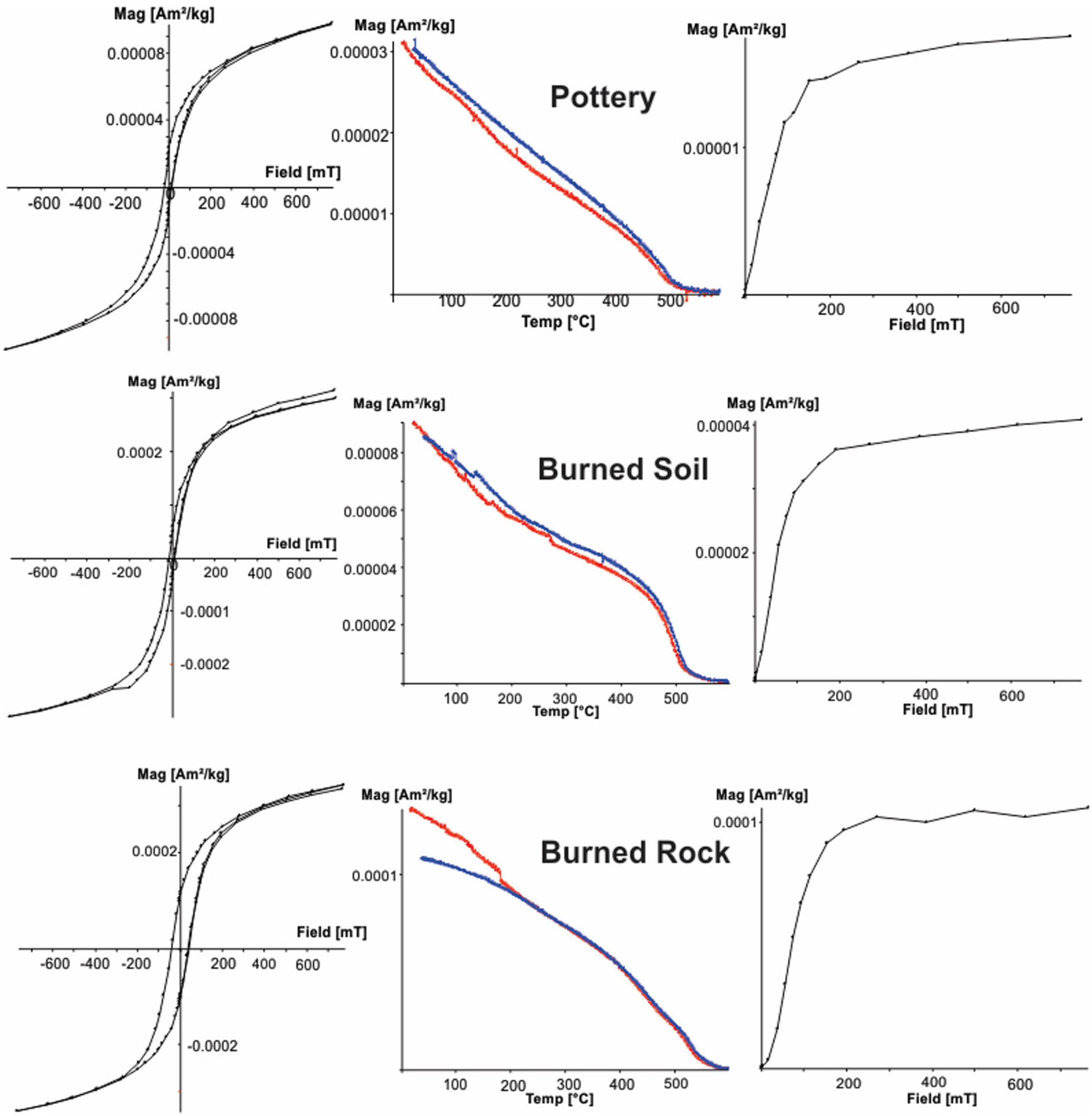


Fig. 3. A summary of rock-magnetic experiments for the representative samples: Saturation magnetization vs. temperature curves, the red curve represents the heating curve and the blue to the cooling curve. Hysteresis experiments and associated isothermal remanence acquisition curves obtained with a Variable Field Translation Balance. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Laboratory procedures

Rock-magnetic analysis was carried out in order to reveal the magnetic carriers and estimate their thermal stability. These experiments consisted of the continuous record of susceptibility vs. temperature curves (Fig. 2) using an AGICO MFK1B susceptibility bridge equipped with furnace, saturation magnetization versus temperature, hysteresis cycles (Fig. 3) and associated isothermal remanent magnetization acquisition (IRM) experiments performed using a Variable Field Translation Balance (VFTB). IRM acquisition curves were recorded in a maximum applied field of 0.85 T. Hysteresis parameters were determined after paramagnetic and diamagnetic corrections. RockMag Analyser 1.0 software was used for the data analysis (Leonhardt, 2006). Continuous thermomagnetic curves were obtained by heating samples in air up to 600 °C and cooling them down to room temperature. The heating and cooling rate was set to 10 °C/min thorough whole cycle. Remanent magnetization was measured using a JR6 spinner magnetometer while an ASC TD48 dual chamber thermal demagnetizer served

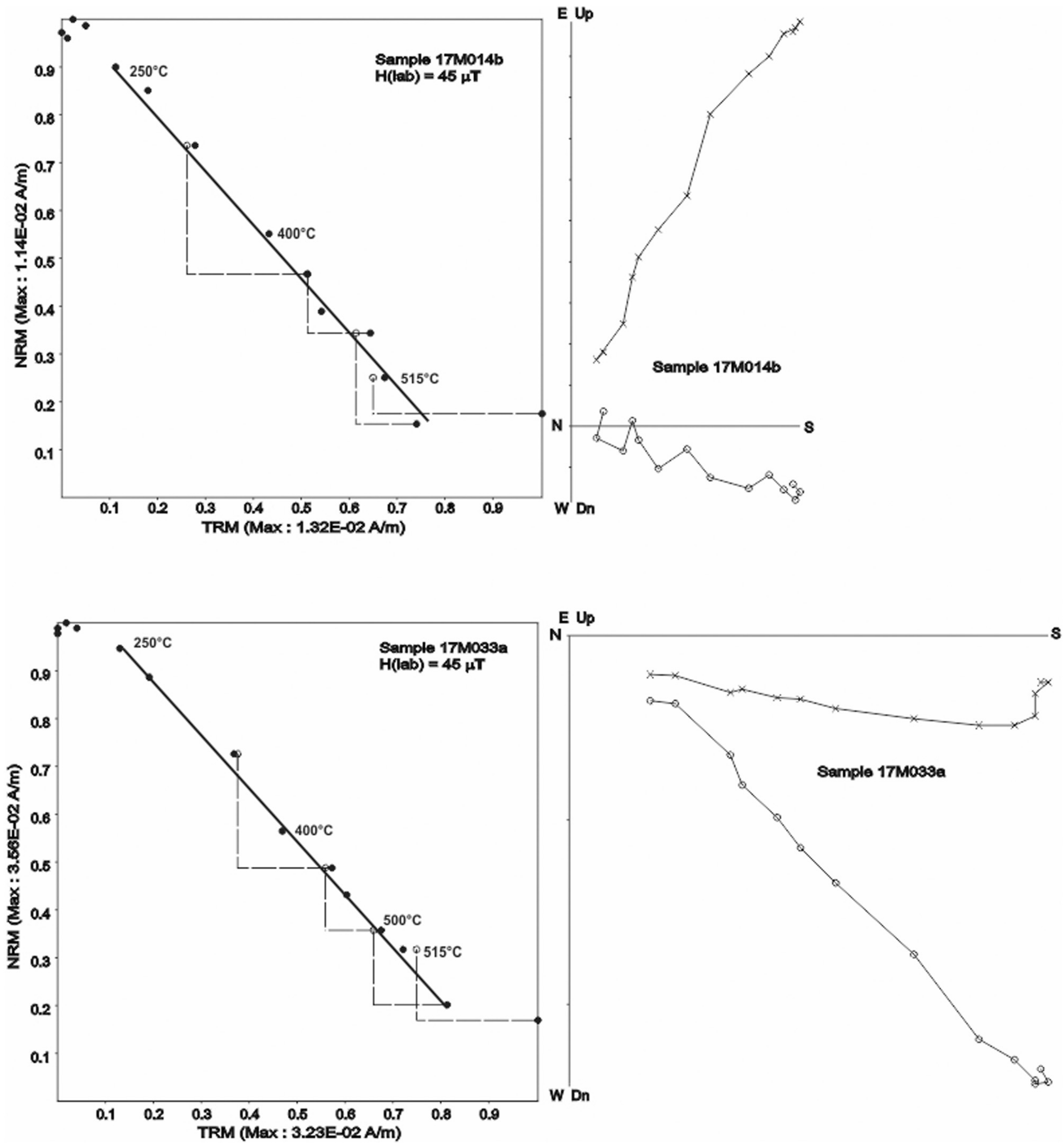


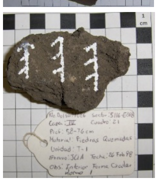
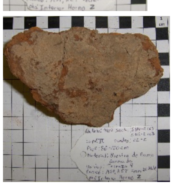
Fig. 4. Representative Natural Remanent Magnetization (NRM)–Thermomagnetic Remanent Magnetization (TRM) plots (so-called Arai-Nagata plots) and associated orthogonal vector demagnetization diagrams for the representative samples.

to demagnetize and remagnetize samples during absolute intensity experiments using Coe et al. (1978) modification of Thellier and Thellier (1959) method. The laboratory controlled field was set to 45 μT, with a 0.3 μT or less precision. Twelve temperature steps were distributed throughout the whole experiment and the control heatings (so-called pTRM checks) were performed four times (Fig. 4). All pottery, rock and soil fragments were divided into seven fragments and oriented in salt pellets with six different positions in order to reduce the magnetic anisotropy effects (Morales et al., 2001). Cooling rate experiments were performed following a modified procedure from that described by Chauvin et al. (2000). The duration of slow cooling was between 7 h and 15 min and 7 h and 35 min.

4. Main results and concluding remarks

Rock magnetic experiments were carried out on pottery, burned

Table 1
Results of Thelleir archaeointensity experiments, T_{min}–T_{max}: the temperature interval of absolute intensity determination; N: the number of heating steps used; B_{corr}: archaeointensity value corrected for cooling rate effect, *f*, the fraction of NRM used for intensity determination; *g*: the gap factor; *q*: the quality factor as defined by Coe et al. (1978).

Fragment	Specimen	Lab code	N	T_{min}–T_{max}	B_{corr}	σB	*f*	*g*	*q*
	1a	17M001	6	350–515	38.1	3.4	0.45	0.77	3.7
	2b	17M002	6	350–515	37.9	3.2	0.38	0.78	3.5
	3a	17M003	5	350–500	38.2	1.9	0.36	0.80	4.5
	4a	17M004	7	300–515	41.2	3.1	0.43	0.79	3.7
	5b	17M005	6	350–515	40.9	2.1	0.32	0.76	4.2
	6c	17M006	6	300–500	41.2	2.3	0.36	0.78	5.8
	7b	17M007	6	350–515	44.7	2.6	0.38	0.79	4.6
	8a	17M008	8	250–540	47.6	3.1	0.63	0.78	7.3
	9b	17M009	8	250–540	42.1	2.6	0.71	0.82	9.5
	10b	17M010	8	250–540	43.4	2.3	0.69	0.81	7.8
	11b	17M011	8	250–540	43.5	2.5	0.72	0.80	7.3
	12b	17M012	9	250–560	40.2	1.8	0.76	0.83	11.8
	13a	17M013	8	250–540	41.2	1.6	0.72	0.81	8.6
	14b	17M014	8	250–540	42.5	1.8	0.73	0.84	15.7
	15b	17M015							
	16b	17M016							
	17b	17M017							
	18a	17M018							
	19b	17M019							
	20c	17M020	6	350–515	39.2	3.2	0.35	0.84	5.8
	21b	17M021							
	22b	17M022	8	300–540	43.7	1.8	0.66	0.83	20.5
	23b	17M023	8	300–540	44.7	1.6	0.69	0.79	14.5
	24a	17M024	8	300–540	44.8	1.6	0.80	0.85	31.7
	25b	17M025	7	350–540	44.5	1.7	0.78	0.86	16.9
	26b	17M026	8	300–540	45.6	2.1	0.61	0.84	22.5
	27b	17M027	8	300–540	39.2	1.9	0.59	0.81	11.2
	28b	17M028	8	300–540	42.6	1.5	0.65	0.88	19.7
	29c	17M029	10	250–570	43.7	2.1	0.81	0.84	14.9
	30b	17M030	9	300–570	46.2	2.3	0.84	0.83	16.5
	31b	17M031	10	250–570	42.6	2.4	0.82	0.86	16.3
	32c	17M032	10	250–570	45.3	1.8	0.81	0.88	18.5
	33a	17M033	9	250–540	41.7	2.1	0.82	0.85	15.9
	34a	17M034	10	250–570	40.8	1.6	0.79	0.82	14.6
	35b	17M035	10	300–570	41.3	2.0	0.80	0.87	28.3

rock and soil samples found within ovens where maguey was cooked. They exhibited different magnetic mineralogy and thermal behavior. Thermomagnetic curves obtained from ceramic samples (Fig. 2) yielded reasonably reversible behavior between heating and cooling cycle pointing to almost magnetite or Ti-poor titanomagnetite as main magnetic carrier. Burned soil revealed two magnetic phases, first one with Curie temperature between 190 and 210 °C while second one corresponds to almost pure magnetite. These curves display a reasonably reversible behavior and both phases are found in heating and cooling cycles. In contrast, burned rock samples showed marked irreversibility and thermal instability. Magnetite seems to co-exist together with Ti-poor titanomagnetite or even titanomaghemite. Saturation magnetization vs. temperature curves (Fig. 3) basically confirms the magnetic mineralogy revealed by k-T experiments. In any case, susceptibility curves are more sensitive to thermal evolution of natural samples (Goguitchaichvili et al., 2001). Main outcome from hysteresis and associated isothermal remanent magnetization experiments is the fact that the IRM curves are not completely saturated at 0.85 T which may attest that some antiferromagnetic phase most probably hematite is also present. Its contribution however in remanence seems to be minor. In contrast, burned rock samples (Fig. 3) reached the saturation at about 250 mT.

35 specimens belonging to two pottery fragments, one burned rock and two burned soil samples (Table 1) were pre-selected for archaeointensity experiments (Fig. 4). The following acceptance criteria were applied to the individual archaeointensity determinations: a) There is no evidence of deviation of natural remanence end points towards the laboratory field directions (transversal). b) There is no apparent concave-up behavior on Arai-Nagata plots. c) The control heatings also known as pTRM checks are positive (within 10% at high temperatures and within 15% at temperatures less than 300 °C). d). The quality factor *q* generally about five or higher. e). A remanence fraction *f* more than one third of initial remanence determined on at least 5 aligned points. We exceptionally accepted quality factors less than 5 in cases when the individual archaeointensity values are close to the fragment mean archaeointensity. The best technical quality determinations comes from burned soil samples while rock samples yielded only one determination out of 7 analyzed samples. Pottery samples yielded generally less technical quality determinations but their mean values are indistinguishable with the soil fragment mean archaeointensities considering their uncertainties (Table 1). In total, 29 specimens allowed the estimation of absolute geomagnetic intensity recorded during the last use of the furnace.

The most interesting feature of this study is the fact that different

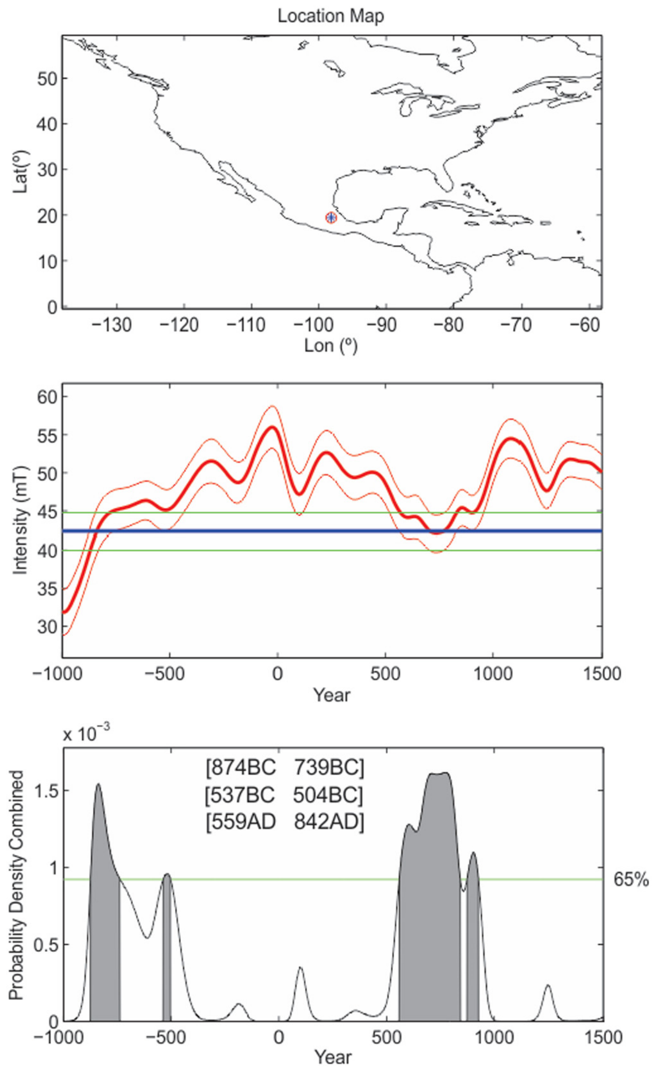


Fig. 5. Archaeomagnetic dating of pottery samples using a MATLAB tool provided by Pavón-Carrasco et al. (2011, 2014) considering the time interval between 1000 BCE and 1500 CE.

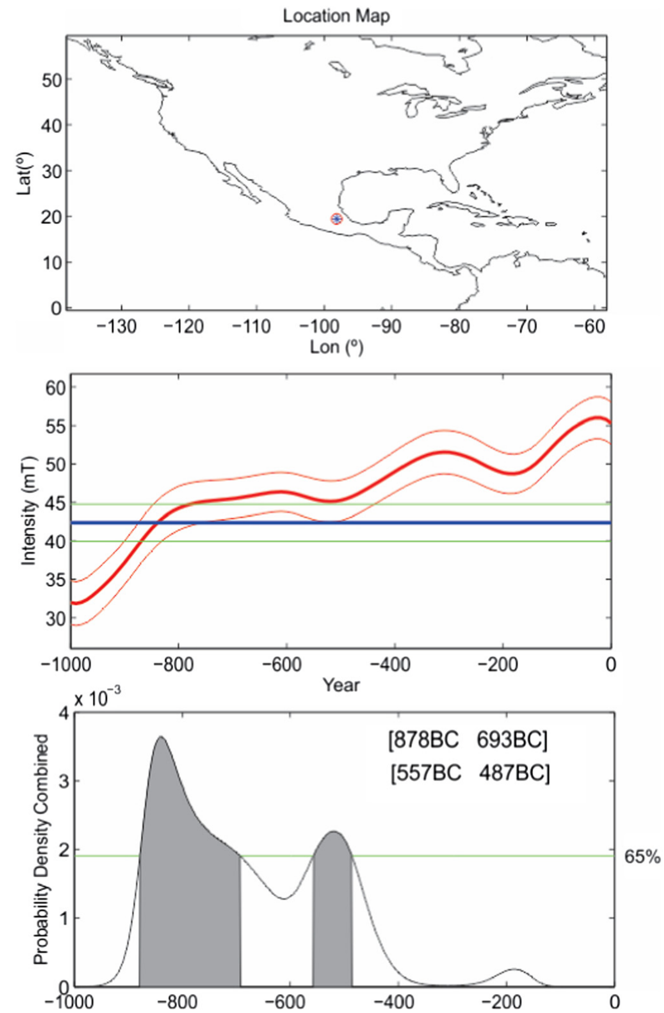


Fig. 6. Archaeomagnetic dating of pottery samples using a MATLAB tools provided by Pavón-Carrasco et al. (2011, 2014) considering the time interval between 1000 BCE and 0.

materials such as ceramics, burned soil and rock samples yielded statistically undistinguishable absolute intensity values which attest that they were cooled down almost same time and faithfully recorded the geomagnetic field strength at the time of the last use of the furnace. The archaeomagnetic dating using the last SHADIF14K model of Pavón-Carrasco et al. (2011, 2014) gives a time intervals between 874 BCE and 739 BCE (Fig. 5), 537 and 504 BCE and between 559 and 842 CE respectively. The last time interval, however, is less probable since all available radiometric dates and archaeological age consideration based on ceramic style points to pre-classic period. Thus we restricted the archaeomagnetic dating time interval obtaining two most probable ages: 878 to 693 BCE and 557–487 BCE (Fig. 6).

These new ages obtained directly from ovens correspond to the first occupation called as Zahuapan in the established chronological sequence. The main features of this stage are housing units where the ovens were found and are in good accordance with some few radiometric dates available. Therefore, these new datings, obtained directly from the ovens and vessels, give greater certainty to the temporality of the first occupation for at least 600 uninterrupted years. This period was characterized not only by mezcal distillation kilns but also by intense ceramic production (both ceremonial and utilitarian) and lithic workshops. These new absolute ages reinforce the initial hypothesis and corroborate the temporality of these pre-Hispanic kilns and thus firmly confirm the pre-Hispanic origin of Mezcal.

Acknowledgements

This work was supported by CONACYT project no. 252149. Critical reviews of two anonymous referees greatly improved the manuscript.

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