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RESEARCH ADVANCE

ARCHAEOMAGNETIC STUDY OF THE EDIFICIO DE LAS COLUMNAS COMPLEX, EL TAJIN, MESOAMERICA

Estudio arqueomagnético del complejo del Edificio de las Columnas, El Tajín, Mesoamérica

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ABSTRACT. *We report the initial results of an archaeomagnetic study on ceramic samples from the Edificio de las Columnas architectonic complex, located in the northern sector of El Tajin, an archaeological site. Measurements of magnetic properties include low-field susceptibility, direction and intensity of natural remanent magnetization, magnetic hysteresis, temperature-dependent susceptibility, isothermal remanent magnetization (IRM) acquisition curves and back-field demagnetization of saturation IRM. We studied the vectorial composition and stability of remanent magnetization using alternating field and thermal demagnetization. Magnetic carriers are fine-grained titanomagnetites and magnetite with pseudo-single domain states. Characteristic magnetizations are determined from the high-temperature unblocking spectra. Determinants of paleointensity, which meet quality criteria, have high and low values. Possible explanations include alterations during thermal treatments and secondary overprints. The influence of alterations and the multivectorial magnetizations of overlapping spectra require detailed analysis to estimate the paleointensities.*

KEYWORDS: *Archaeomagnetism, magnetic properties, Mesoamerica, Edificio de las Columnas, Tajin Chico, El Tajin.*

RESUMEN. *Reportamos resultados del estudio arqueomagnético en muestras de cerámicas en el complejo arquitectónico del Edificio de las Columnas, localizado en el sector norte de El Tajín. Las mediciones de propiedades*

Figure 1. Partial view of excavation in Building 40, Edificio de las Columnas architectonic complex, El Tajin.

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magnéticas incluyen susceptibilidad magnética, dirección e intensidad de la magnetización remanente natural, histéresis, variación de la susceptibilidad con temperatura, curvas de adquisición de magnetización isotermal y desmagnetización por campos directos de la magnetización isotermal de saturación. La composición vectorial y estabilidad de la magnetización remanente se investigaron por desmagnetización por campos magnéticos alternos y por temperatura. Las magnetizaciones muestran dos componentes que residen en titanomagnetitas y magnetita, con traslape en los espectros de temperaturas de bloqueo. Las determinaciones de paleointensidad, que cumplen con los criterios de calidad, presentan valores altos y bajos. Posibles factores involucrados son alteraciones durante los tratamientos térmicos y la presencia de magnetizaciones secundarias. La influencia de alteraciones y de magnetizaciones multivectoriales que residen en arreglos con espectros que traslapan requiere de análisis detallados para la estimación de paleointensidades.

PALABRAS CLAVE: *arqueomagnetismo, propiedades magnéticas, Mesoamérica, Edificio de las Columnas, Tajín Chico, El Tajín.*

INTRODUCTION

The archaeological site El Tajin flourished in the northeastern sector of Mesoamerica from about ~200 to 900–1250 AD. The site has attracted considerable interest, with several studies undertaken over the years since the eighteenth century, particularly in the past decades (Pascual-Soto 1990, 2006; Piña-Chan and Castillo-Peña 1999). El Tajin is distinguished by its architecture and location, with the use of terraces and impressive building complexes. Here we present initial results of an archaeomagnetic study of the Edificio de las Columnas (Palace of Columns) in El Tajin Chico. The architectonic complex was built on a terraced platform at the northern zone of the archaeological site. It underwent several constructive phases, which were completed in the 10th century. The building is characterized by a central patio and the remains of several columns with representations of scenes and persons, including one representing the Ruler 13 Rabbit.

Archaeomagnetic studies have been successfully used for characterization and provenance studies and for dating and correlation of archaeological remains. The success of archaeomagnetism depends on the wide range of magnetic properties spanning several orders of magnitude and on remanent magnetization records of the direction and intensity of the Earth's magnetic field. Recent developments on the directional and intensity reference curves and fitting/correlation methods have been reported. These are coupled with newly developed laboratory techniques, which improve the resolution and precision of archaeomagnetic dating (e.g. Pavón-Carrasco *et al.* 2014; Terán-Guerrero *et al.* 2016).

As part of the archaeological projects in El Tajin (Pascual-Soto 2013), paleointensity studies using the double-heating Thellier method are being carried out on samples from the Edificio de las Columnas building complex. The Thellier experiments give high-quality analytical data, but with distinct high 52.6 μT and low 37.2 μT paleointensities. This study on the magnetic properties and vectorial nature of the remanent magnetization record grew from the need to evaluate the contrasting results. We focus on magnetic properties and the paleodirectional record of the archaeomagnetic samples.

SAMPLES AND METHODS

Description of the archaeological excavation projects in El Tajin is given in Pascual-Soto (1990, 2006, 2013). The Edificio de las Columnas consists of four platforms built on a larger platform. The inner patio of the complex has stairs with sculptures and mural paintings. The ceramic samples were collected from the K3/2012 excavation unit at the II-III layer-contact in Building 40 (substructure 2) of the Edificio de las Columnas complex (Fig. 1).

The low-field magnetic susceptibility was measured with the Bartington susceptibility MS2 system equipped with the MS2E sensor. Additional measurements were made with the MS2B dual-frequency sensor. The intensity and direction of the natural remanent magnetization (NRM) were measured with the RS-6 spinner magnetometer. Samples are unoriented and NRM directions are plotted in sample coordinates. The vectorial composition was analyzed using alternating field (AF) and thermal demagnetization. AF demagnetization was carried out up to maximum fields of 100 mT in a Molspin demagnetizer. Thermal demagnetization was carried out in 10–12 steps up to maximum temperatures of 600 °C in a Schonstedt thermal demagnetizer. Directions are analyzed using Zijderveld vector plots and end-point analysis. The variation of magnetic susceptibility with temperature was deter-

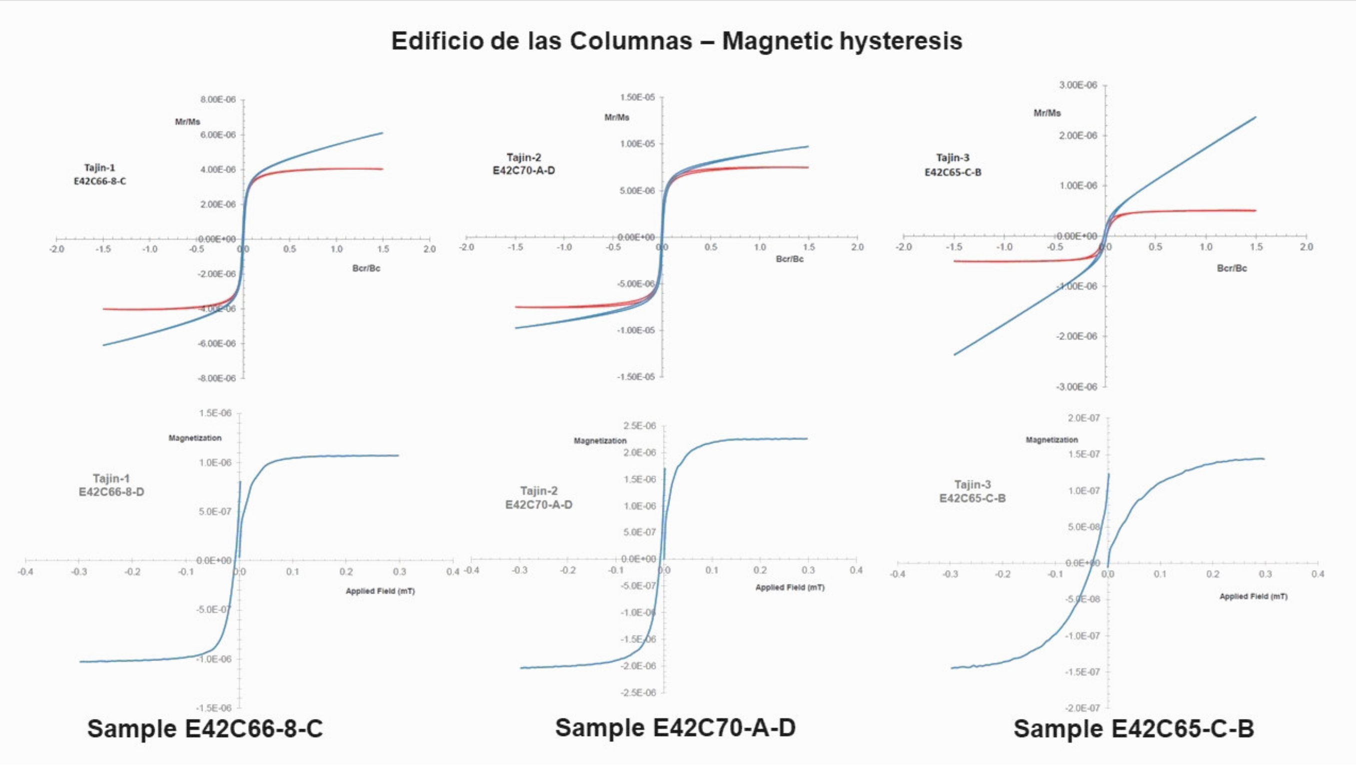

Figure 2. Magnetic hysteresis data, with hysteresis loops shown before (blue) and after (red) the slope correction. The relative contributions of paramagnetic minerals can be estimated from the slope of the hysteresis loops before correction (blue curve). The acquisition curves of isothermal remanent magnetization (IRM) and the back-field demagnetization of saturation IRM are included in the bottom diagrams.

mined using the Bartington high-temperature unit. Susceptibility-temperature curves were measured continuously from room temperature up to 600 °C or 700 °C during heating and cooling. The magnetic hysteresis loops and the isothermal remanent magnetization (IRM) acquisition curves and back-field demagnetization of saturation IRM were determined with the MicroMag system in fields up to 1.5 tesla. Domain states are investigated using the magnetization (Mr/Ms) versus coercivity (Bcr/Bc) ratio plots (Day *et al.* 1977; Dunlop 2002).

MAGNETIC PROPERTIES

The low-field magnetic susceptibility ranges from 20 up to 1430 10^{-4} SI. The NRM intensity varies from 2.2 A/m to 2-4 mA/m. High Koenisberger Q ratios indicate dominance of remanent magnetizations with respect to induced magnetizations.

The hysteresis loops show variable contents of paramagnetic minerals, as indicated on the varying slopes in the loops (Fig. 2). The hysteresis loops show saturation in low fields, suggesting fine grained titanomagnetites. Samples plot in the pseudo-single domain field in the Day magnetization vs. coercivity ratios plot. The Mr/Ms and Bcr/Bc ratios after paramagnetic correction vary from ~0.15 to ~0.23 and from ~1.23 to ~2.14, respectively. Remanent Mr intensities range from ~70 to ~1450 nA/m^2 and Bcr coercivities range from ~6 to ~14 mT. In the magnetization vs. coercivity ratio plot, samples fall in the pseudo-single domain field (Fig. 3a). Magnetization and coercivity ratios are plotted for measurements taken before and after the thermal treatment for the paleointensity determinations.

Changes of magnetic susceptibility as a function of temperature indicate a Curie temperature of ~545 °C, with distributed spectra above 300 °C (Fig. 3b). The susceptibility-temperature curves for the samples show varying magnetic susceptibilities, with most samples showing weak susceptibilities. The Curie temperature and distributed spectra indicate poor-titanium titanomagnetites and magnetite.

Thermal demagnetization documents multi-vectorial magnetizations, with secondary components and a high-temperature component interpreted as the characteristic remanence (Fig. 4). The magnetization components reside in fine-grained iron-titanium oxide

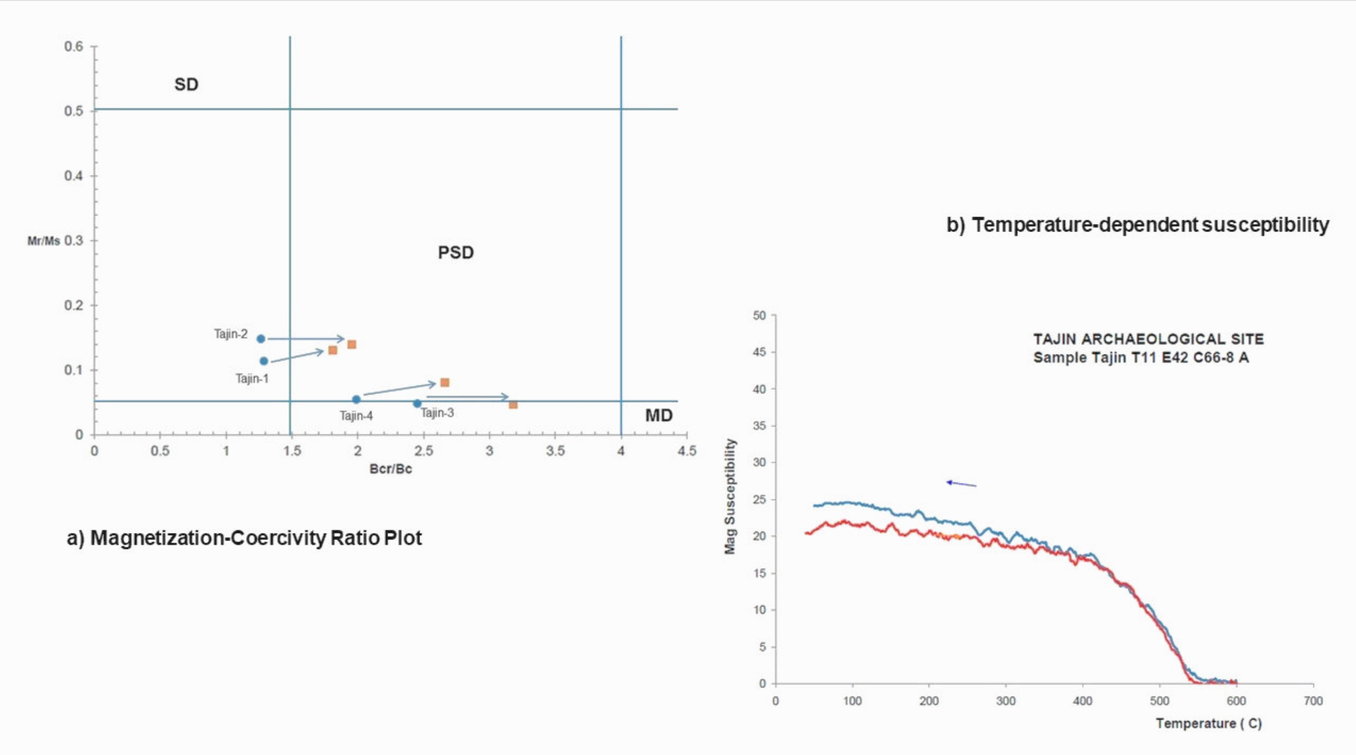

Figure 3. (a) Day diagram of domain states, with magnetization Mr/Ms ratios plotted as a function of coercivity Bcr/Bc ratios. Domain fields correspond to: SD, single domain, PSD, pseudo-single domain and MD, multidomain. Samples fall in the pseudo-single domain field. Hysteresis ratios are plotted for samples before and after the thermal treatment for the paleointensity determination double-heating cycles. (b) Variation of magnetic susceptibility as a function of temperature (red curve is the heating cycle and blue curve is the cooling cycle).

minerals with overlapping unblocking temperature ranges. The characteristic component is defined by linear fits going through the vector plot origin, with the unblocking spectra distributed towards high temperatures.

DISCUSSION

El Tajin is characterized by its architectural development, with the building complexes and sculptures (Pascual-Soto 1990, 2006; Piña-Chan and Castillo-Peña 1999). The Morgadal Grande project investigates urban development and construction stages, with studies on the Edificio de las Columnas architectonic complex focusing on the late constructive phases. The archaeomagnetic study is intended to provide further constraints on the chronology, using the paleointensity method, which on burned clays generally provide reliable chronologies. In the Tajin study, despite the high-quality analytical results, high 52.6 μT and low 37.2 μT values were obtained. The differences do not permit us to constrain the chronology from correlation to the reference curve (Korte *et al.* 2009; Pavón-Carrasco *et al.* 2014). Accurate paleointensity determinations depend on a number of factors, including the stability and vectorial composition of the remanent magnetization. Evaluation of the analytical results prompted this study, aimed to characterize the rock magnetic properties and the nature of the paleodirectional record.

Thermal demagnetization shows two component magnetizations, with overlapping unblocking temperature spectra. Characteristic components are isolated in the high-temperature range, above 450 °C (Fig. 4). The unblocking temperature spectra are distributed, indicating a range in iron-titanium composition. The variation of magnetic susceptibility with temperature shows a Curie temperature around 545-550 °C, indicating poor-Ti titanomagnetites with no other major phases (Fig. 3b). The temperature-dependent susceptibility curves up to 600 °C indicate generation of small amounts of magnetite upon heating and cooling. Temperature treatment required for the paleointensity determination, with the double-heating Thellier method, results in chemical alteration, with formation of magnetite. The domain states as inferred from the magnetization vs. coercivity ratio plot fall in the pseudo-single

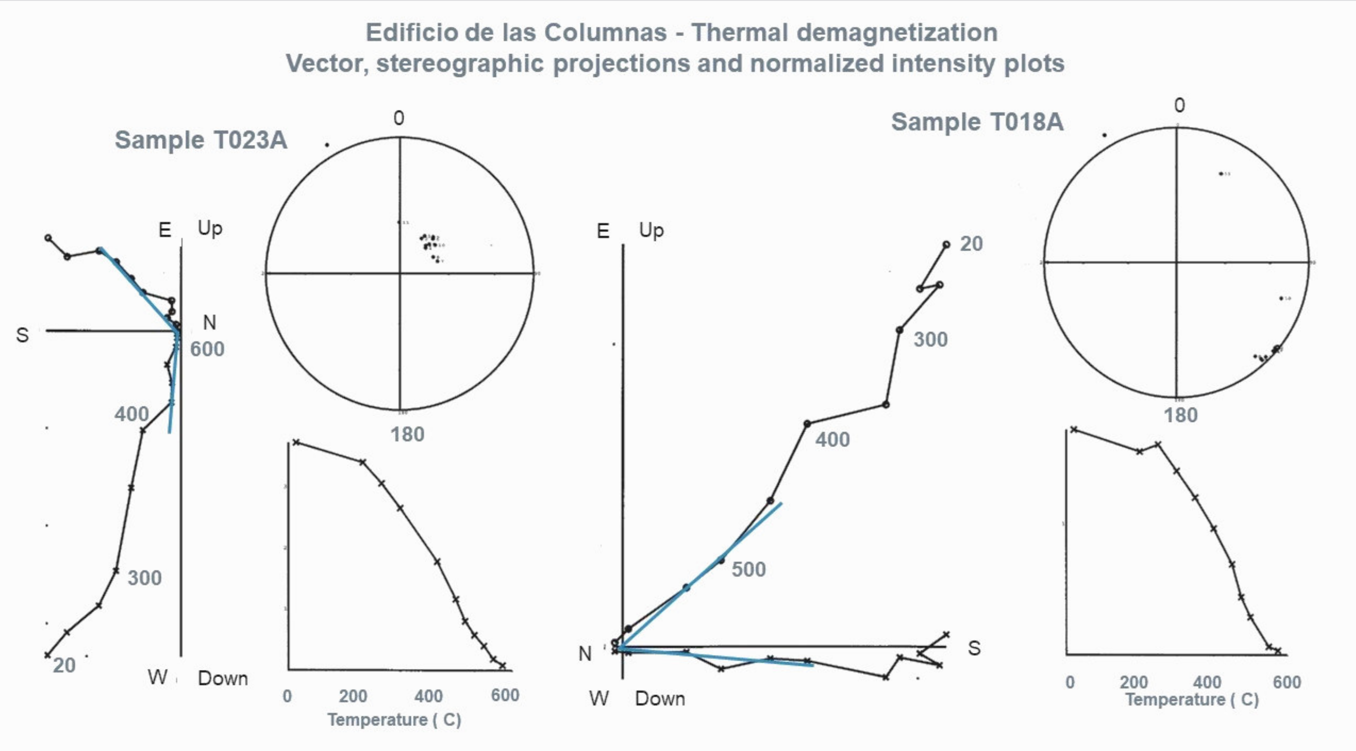

Figure 4. Thermal demagnetization of ceramic samples. The changes in direction and intensity of the remaining magnetization are plotted in stereographic projections, Zijderveld vector plots and normalized intensity diagrams. The characteristic magnetization, estimated by least-square fitting of demagnetization data points going through the plot origin is indicated in the diagrams.

domain field, with low magnetization ratios (Fig. 3a). After heating to 600 °C, the coercivity ratios increase, with little change in the magnetization ratios. The changes are associated with increase in the remanent coercivity and influence of multidomain particles. Magnetic hysteresis and temperature-dependent susceptibility indicate samples had not been stabilized during previous heating/cooling cycles. The magnetic hysteresis loops indicate variable contents of paramagnetic minerals (indicated by the differences in the loops before and after paramagnetic slope corrections). Saturation is reached at low coercivities, compatible with fine-grained titanomagnetites (Fig. 2). Samples with high paramagnetic mineral contents show saturation at higher coercivity values.

Archaeomagnetism has been successfully applied to provenance and characterization, and for dating and correlation of Mesoamerican archaeological remains (e.g. Urrutia Fucugauchi *et al.* 2016; Terán-Guerrero *et al.* 2016). Archaeomagnetic sourcing and dating depend on the wide range of magnetic properties and on the accuracy of remanent magnetization records (Kostadinova-Avramova and Kovacheva 2013; Schnepp *et al.* 2016). Analysis of Tajin ceramic samples highlight the difficulties in interpretation.

The construction phases for the Edificio de las Columnas expanded the building over time, to conform to plans of Tajin Rulers and/or to adapt the construction according to astronomical orientations. The Tajin Chico presents a distinct orientation that contrasts with the other constructions constrained by topographic relief. The complex has an orientation of ~105° 25', associated with the beginning of the Mesoamerican year (Flores-Gutiérrez 2013). The expansion of El Tajin took place between 850 to 1250 AD, with the construction stages of Edificio de las Columnas in the interval between 850 to 950 AD. For the first and second millennia, reference curves are less well constrained, which limit accurate correlations. Improved paleointensity determinations from Tajin samples are required to constrain the chronology.

CONCLUSIONS

Archaeomagnetic studies have been undertaken on the Edificio de las Columnas complex, one of the most emblematic in El Tajin archaeological site. The complex was built on several stages on a large terraced platform overlooking the site. Demagnetization results indicate that ceramics preserve characteristic remanent magnetizations, residing in fine-grained titanomagnetites. Secondary overprints show overlapping unblocking temperature spectra. Alterations during thermal treatment and the two-component nature of remanent magnetization may explain the range in archaeointensity values obtained. Magnetic susceptibility, NRM and IRM intensities and micromagnetic hysteresis data show varying contents of paramagnetic minerals and fine-grained poor-Ti titanomagnetites with pseudo-single domain states. These results highlight the importance of detailed rock magnetic measurements for sample selection and interpretation of paleointensity data. Further analyses on a wider sample collection are needed to expand the paleomagnetic characterization and constrain the chronology of the building complex.

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