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RESEARCH ADVANCE

COERCIVITY AND VECTOR MAGNETIZATION ANALYSIS OF OBSIDIAN SAMPLES FROM THE TRANS-MEXICAN VOLCANIC BELT

Coercitividad y análisis de magnetización vectorial de muestras de obsidianas de la faja volcánica transmexicana

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Figure 1. Schematic map of obsidian outcrop localities in the eastern, central and western sectors of the Trans-Mexican volcanic belt. Basemap: courtesy of NASA, JPL, Landsat Thematic Mapper.

ABSTRACT*. This note presents initial results of a paleomagnetic study of obsidian from twenty localities in the eastern, central and western sectors of the Trans-Mexican volcanic belt in central Mexico. We focus on the coercivity and vector composition of the remanent magnetization, which are critical for paleodirectional and paleointensity studies. Alternating field demagnetization shows that obsidians carry single and two-component magnetizations residing in low- and high-coercivity magnetic minerals, with discrete and overlapping coercivity spectra. Magnetic minerals are likely iron-titanium oxides with fine-grain sizes characterized by pseudo-single domain states.*

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KEYWORDS: *Mesoamerica, Obsidians, Magnetic properties, Paleomagnetic record.*

RESUMEN. *Se presentan los resultados preliminares del estudio de obsidianas de veinte localidades en los sectores este, central y oeste de la faja volcánica transmexicana. Los análisis se concentran en la coercitividad y la composición vectorial de la magnetización remanente, que son propiedades claves para evaluar los registros de direcciones e intensidades. La desmagnetización por campos alternos revela la presencia de magnetizaciones de una y dos componentes, que residen en minerales con baja y alta coercitividad con espectros que traslapan y discretos. Los minerales magnéticos son óxidos de hierro-titanio con grano fino y estados de dominio seudosencillo.*

PALABRAS CLAVE: *Mesoamérica, obsidianas, propiedades magnéticas, registro paleomagnético.*

INTRODUCTION

Archaeological research relies on different chemical, mineralogical and physical techniques, which are then incorporated into archaeological analyses. Archaeomagnetic studies provide information useful for dating and correlation, sourcing, site characterization and manufacturing techniques. Magnetic minerals can acquire a remanent magnetization under a range of conditions, including heating and cooling of volcanic rocks, ceramics and kilns, which record the direction and magnitude of the ambient magnetic field.

Lithic materials have been characterized using a wide range of analytical techniques over the past years. Magnetic properties show wide ranges over several orders of magnitude and have been successfully used for sourcing and characterization of obsidians (e.g. McDougall *et al.* 1983; Urrutia-Fucugauchi 1999; Vazquez *et al.* 2001; Frahm *et al.* 2013, 2014). Studies show that magnetic methods support the characterization of volcanic glasses in cases where they display similar macroscopic features, textures and chemical composition (Frahm *et al.* 2014).

Rapid cooling results in aphanitic textures with small grain sizes. Fine grained single domain and pseudo-single domain iron-titanium oxide particles are the most stable remanence carriers and are reliable recorders of the ambient magnetic field. Obsidians are potentially ideal recorders for paleodirectional and paleointensity studies (Ferk *et al.* 2011). Recent developments in the reference secular variation curves, curve matching and statistical analyses and use of full-vector data are improving the resolution and precision of archaeomagnetic dating (e.g. Pavon-Carrasco *et al.* 2014; Urrutia-Fucugauchi *et al.* 2016). Incorporation of new materials like lime plasters, copper slags, mural paintings and obsidians opens new possibilities.

In this note we present results from an ongoing rock magnetic and paleomagnetic study of archaeological and geological obsidians from central Mexico (Fig. 1). Our study focuses on the magnetic properties and vectorial composition of the remanent magnetization, which are critical for assessing the paleodirectional and paleointensity records.

SAMPLES AND METHODS

We analyzed thirty-eight obsidian samples from twenty sites in central Mexico, representing different geological settings and ages in the Trans-Mexican Volcanic Belt (TMVB). Samples, selected from the laboratory collection (Urrutia-Fucugauchi 1999), originate from the following regions: eastern sector (Jacal, Pico de Orizaba, Altotonga, Veracruz, Guadalupe Victoria, Puebla, Zaragoza, Puebla and Atempa, Puebla), central sector (San Jose El Rincon, Zinapecuaro, Ucareo, Zinaparo, Los Azufres, Michoacan, Zacualtipan, Hidalgo, Cerro de las Navajas, Hidalgo and Buena Vista, Mexico) and western sector (Jocotepec Chapala, Jalisco, Volcan Colima 4 km and 8 km Magdalena, Tequila, Jalisco, Mesa de las Salvias, Jalisco, Primavera, Jalisco and Teuchitlan, Nayarit).

The samples display different macroscopic properties, ranging from the green obsidians from the Cerro de las Navajas, Hidalgo to the gray (Zaragoza, Puebla), dark gray (Zinaparo, Michoacan), dark brown (Altotonga, Veracruz) and black (Zacualtipan, Hidalgo) of other sites. They appear macroscopically fresh, although further analyses are underway to identify alterations. Major and trace element chemistry of obsidian has been investigated in different studies, which have focused on similarities and differences for characterization and sourcing (Jimenes-Reyes *et al.* 2001).

In this study, we used the alternating field (AF) demagnetization technique. AF demagnetization involved 10–12 steps up to maximum fields of 100 mT in a Molspin AF tumbling demagnetizer. The intensity and direction of the natural remanent magnetization (NRM) were measured with a spinner magnetometer.

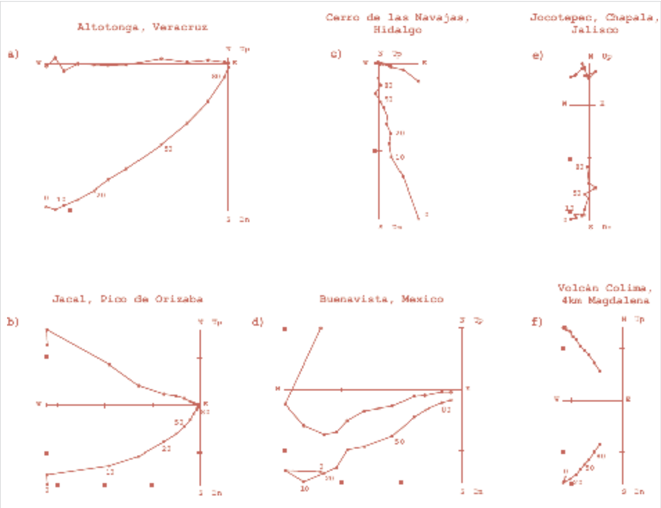

Figure 2. Alternating field demagnetization of natural remanent magnetization plotted in Zijderveld vector diagrams. Symbols: circles indicate horizontal plane and crosses indicate vertical plane. Numbers indicate some of the applied fields in mT.

Samples were unoriented and NRM directions were plotted in sample coordinates. Directions were analyzed using Zijderveld vector plots and great-circle and end-point analysis. NRM intensities were displayed in normalized intensity diagrams. The Median Destructive Field (MDF), an applied field that results in a reduction of 50% of the initial NRM intensity, was used as a rough estimate of the coercivity. MDF is biased in the case of low coercivity overprints, which here resulted in a sharp initial decay of remanent intensity. Other estimates of coercivity were provided by the percentage intensity remaining after 100 mT demagnetization step or the applied field required to reduce the intensity to 10% of the initial NRM intensity.

Magnetic susceptibility was measured in low-fields with the Bartington MS2 meter equipped with the laboratory dual-frequency sensor at low and high frequencies. Further analyses of the coercivity and magnetization involved measuring the magnetic hysteresis, acquisition of isothermal remanent magnetization (IRM) and back-field demagnetization of saturation IRM using the Micromag instrument. Domain states were analyzed using the magnetization (Mr/Ms) versus coercivity (Bcr/Bc) ratio plot (Day *et al.* 1977; Dunlop 2002).

MAGNETIC PROPERTIES

AF demagnetization results show mostly single-component magnetizations with low-coercivity secondary overlaps as well as two-component magnetizations with discrete or overlapping coercivity spectra. Examples of vector plots and normalized magnetization intensity diagrams for sites in eastern, central and western TMVB

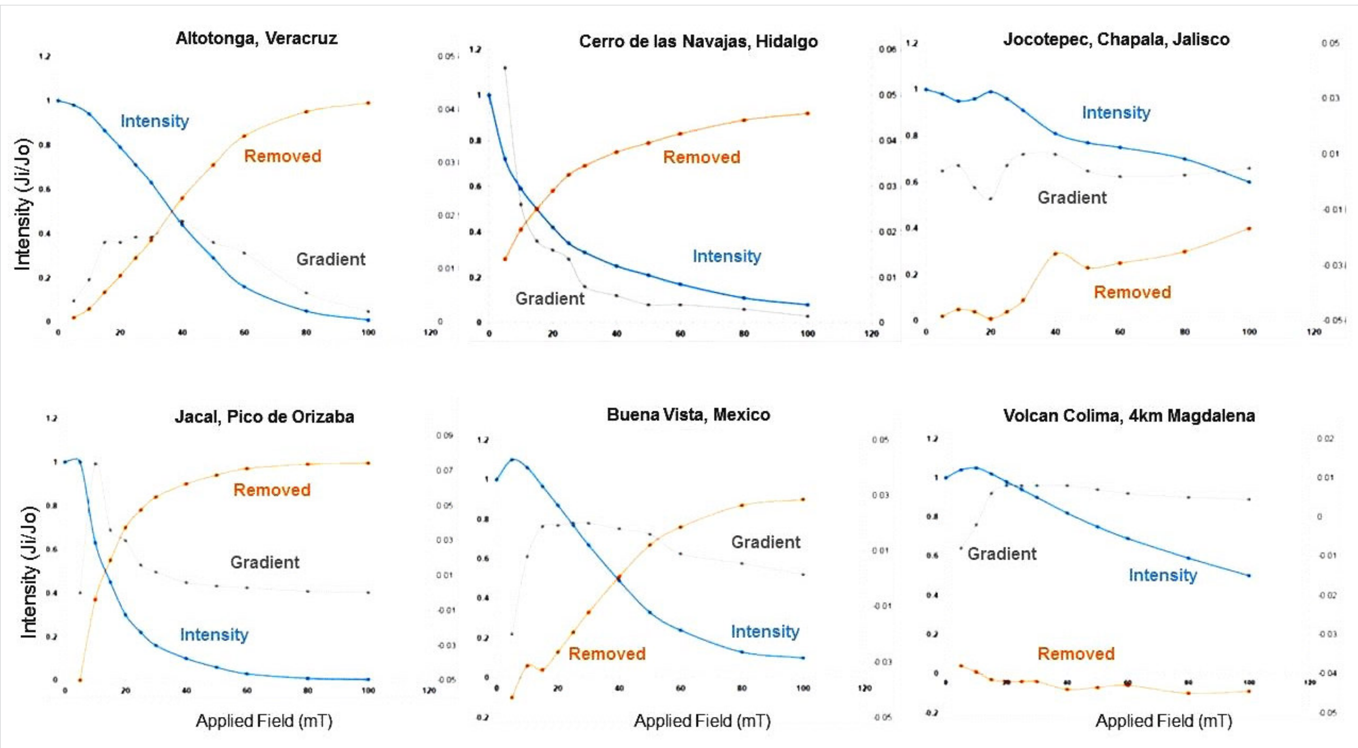

Figure 3. Normalized intensity diagrams for alternating field demagnetization. Curves indicate the intensity remaining after given applied field step, intensity removed and gradient of remaining intensity curve.

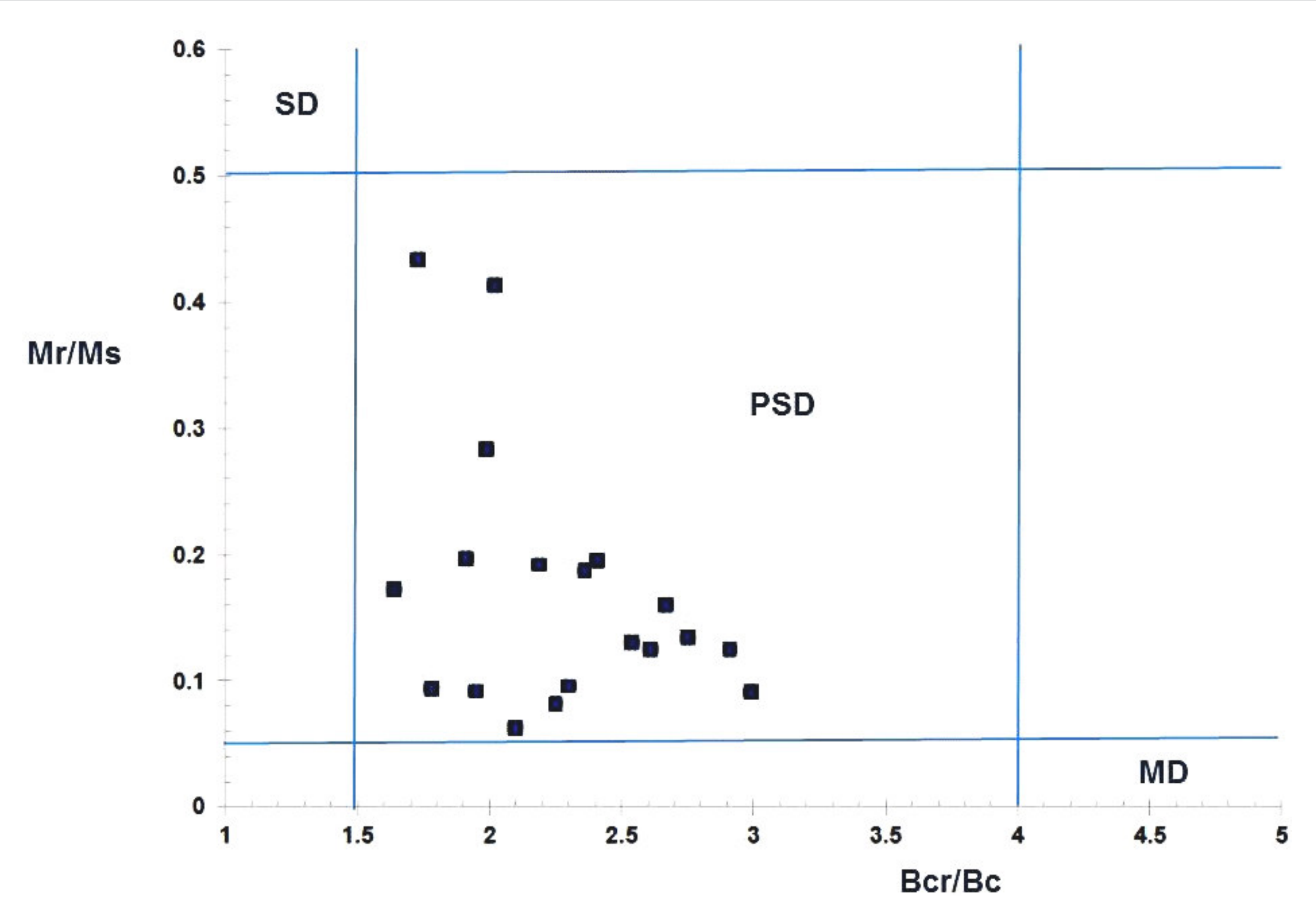

Figure 4 Magnetic hysteresis data plotted in the Mr/Ms versus Bcr/Bc ratios Day diagram with the domain state fields: SD (single domain), PSD (pseudo-single domain) and MD (multidomain).

sectors are shown in Figures 2 and 3, respectively. The obsidians from Jacal, Pico de Orizaba, Altotonga, Veracruz, Buena Vista, Mexico and Cerro de las Navajas, Hidalgo show magnetizations with low to intermediate coercivities. The obsidians from Jacal and Buena Vista are characterized by univectorial magnetizations with low-coercivity secondary components. Obsidians from Altotonga and Cerro de las Navajas show two-component magnetizations with partly overlapping coercivity spectra. Samples from Jocotepec, Chapala and Volcan Colima 4 km Magdalena show intermediate to high coercivities; though they are characterized by univectorial magnetizations with small secondary components. Obsidians from the Jocotepec and Volcan Colima localities show intermediate MDF fields around 40 mT and MDF fields above 100 mT.

Samples plot in the pseudo-single domain field in the Day plot (Fig. 4). The Mr/Ms and Bcr/Bc ratios vary from ~0.06 to ~0.4 and from ~1.64 to ~2.75, respectively. The low-field magnetic susceptibility ranges from diamagnetic up to 250 10^{-5} SI. Remanent Mr intensities range from ~0.3 to ~84 nA/m^2 and Hcr coercivities range from ~12 to ~80 mT.

DISCUSSION

Obsidians are ideal magnetic recorders due to their rapid cooling and the presence of fine-grained single domain iron-titanium oxide minerals in their glassy matrixes. Studies show that obsidians preserve accurate high-precision paleointensity records and that both cooling rate and anisotropy effects can be determined and corrected (Ferk *et al.* 2011). Alterations during hydration, devitrification and perlitization may affect the magnetic stability, gran size and domain states, resulting in overprinting of the paleomagnetic record.

The preliminary results presented here show a wide range of paleomagnetic behaviors, with presence of mostly single but also two-component magnetizations residing in low- and high-coercivity magnetic minerals (Figs. 2 and 3). Two-component magnetizations are characterized by discrete and overlapping coercivity spectra. For sites with two or three samples, internal variability was examined. In some locations, the coercivity and vectorial composition of magnetization showed internal variability, with single and two-component magnetizations residing in intermediate and high coercivity minerals. In samples from Jocotepec, Chapala, MDF fields varied from intermediate 40 mT fields up to high coercivities with more than 50% of initial remanence remaining after 100 mT demagnetization. At Jacal, Pico de Orizaba, samples show single and two-component magnetizations with overlapping coercivity spectra.

Constraining the magnetic carriers of obsidians has not been easy, and detailed micromagnetic and microstructural analyses are needed to characterize the fine-grained magnetic fractions as well as impurities and alterations. Zanella *et al.* (2012) used magnetic susceptibility, anhysteretic susceptibility and room and liquid-nitrogen temperature IRM to determine grain size variations, showing the usefulness of these techniques for obsidian sourcing.

Ferk *et al.* (2011) documented alterations resulting from heating in the paleointensity experiments; in their study, high paramagnetic mineral contents made difficult the characterization of magnetic carriers, which were likely fine-grained single domain minerals. Obsidians are clearly reliable materials for paleointensity studies, as shown by the high experimental quality data and tests with synthetic materials under laboratory conditions.

CONCLUSIONS

Mesoamerican cultures made use of a wide range of lithic materials and developed extensive networks for resources procurement and trade. Studies have documented the developments in extraction and manufacturing techniques and the extent of trade networks across far-away regions. Mesoamerica is characterized by active volcanism: in the volcanic provinces of the TMVB, the Chiapanecan arc and the Central American arc, volcanic products were readily available and were used in construction, in monuments, and for tools. Among these products, obsidian became an important material with diverse uses, and was highly valued in trade. Characterization and sourcing of obsidian are thus critical components of Mesoamerican archaeology (Cobean 2002).

Alternating field demagnetization on a suite of obsidian samples from twenty localities in central Mexico shows single- and two-component magnetizations residing in low- and high-coercivity magnetic minerals, characterized by discrete and overlapping coercivity spectra. Magnetic minerals are likely iron-titanium oxide minerals with fine-grain sizes and pseudo-single domain states. The paleomagnetic record of obsidians appears more complex that expected from the rapid cooling, aphanitic textures and relatively homogeneous iron-titanium oxide mineral assemblages.

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REFERENCES

Cobean, R.H. 2002. *A World of Obsidian: The Mining and Trade of Volcanic Glass in Ancient Mesoamerica.* Mexico: INAH and University of Pittsburgh Press.

Day, R., M. Fuller, V.A. Schmidt. 1977. Hysteresis properties of titanomagnetites: grain size and compositional dependence. *Physics of the Earth and Planetary Interiors* 13: 260–7.

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* 107/B3: EPM4-1-4-22.

Ferk, A., R. Leonhardt, K.U. Hess, D.B. Dingwell. 2011. Paleointensities on 8 ka obsidian from the Mayor Island, New Zealand. *Solid Earth* 2: 259–70.

Frahm, E., J.M. Feinberg. 2013. From flow to quarry: magnetic properties of obsidian and changing scales of archaeological sourcing. *Journal of Archaeological Science* 40: 3706–21.

Frahm, E., J.M. Feinberg, B. Schmidt-Magee, B. Gasparyan, B. Yerytsyan, S. Karapetian, K. Meliksetian, M. Muth, D.S. Adler. 2014. Sourcing of geochemically identical obsidian: multiscalar magnetic variations in the Gutansar volcanic complex and implications for Palaeolithic research in Armenia. *Journal of Archaeological Science* 47: 164–78.

Jimenez-Reyes, M., D. Tenorio, J.R. Esparza-Lopez, R.L. Cruz-Jimenez, C. Mandujano, S. Elizalde. 2001. Neutron activation analysis of obsidians from quarries of the central Quaternary Trans-Mexican volcanic belt. *Journal of Radioanalytical and Nuclear Chemistry* 250: 465–71.

McDougall, J.M., D.H. Tarling, S.E. Warren. 1983. The magnetic sourcing of obsidian samples from Mediterranean and Near Eastern Sources. *Journal of Archaeological Science* 10: 441–52.

Pavon-Carrasco, J., M. Osete, J.M. Torta, A. De Santis. 2014. A geomagnetic field model for the Holocene based on archaeomagnetic and lava flow data. *Earth and Planetary Science Letters* 388: 98–109.

Urrutia-Fucugauchi, J. 1999. Preliminary results of a rock-magnetic study of obsidians from central Mexico. *Geofísica Internacional* 38: 83–94.

Urrutia-Fucugauchi, J., A. Goguitchaichvili, L. Pérez-Cruz, J. Morales. 2016. Archaeomagnetic dating of the eruption of Xitle volcano, basin of Mexico: Implications for the Mesoamerican centers of Cuicuilco and Teotihuacan. *Arqueología Iberoamericana* 30: 23–29.

Vazquez, C.A., H.G. Nami, A.E. Rapalini. 2001. Magnetic sourcing of obsidians in southern South America: Some successes and doubts. *Journal of Archaeological Science* 28: 613–8.

Zanella, E., E. Ferrara, L. Bagnasco, A. Olla, R. Lanza, C. Beatrice. 2012. Magnetite grain-size analysis and sourcing of Mediterranean obsidians. *Journal of Archaeological Science* 39: 1493–8.