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Geofísica Internacional, vol. 38, núm. 2, april-june, 1999, pp. 83-94
Universidad Nacional Autónoma de México
Distrito Federal, México

Geofísica Internacional (1999), Vol. 38, Num. 2, pp. 83-94

Preliminary results of a rock-magnetic study of obsidians from central Mexico

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Received: May 19, 1998; accepted: October 26, 1998.

RESUMEN

El análisis de parámetros de propiedades magnéticas (susceptibilidad de campo bajo, magnetización remanente natural (NRM), magnetización remanente isotermal (IRM) y coercitividad) medidos en muestras de 18 depósitos de obsidiana de la faja volcánica trans-mexicana permite la caracterización de estos depósitos. Los resultados preliminares indican que las obsidianas presentan diferencias en el contenido relativo de los óxidos de hierro y titanio y en su tamaño de grano, lo que resulta en un amplio rango de variación en las correspondientes propiedades magnéticas. En particular, se observa variación de hasta cinco órdenes de magnitud en la susceptibilidad y las intensidades de NRM e IRM. Las obsidianas provenientes de 13 diferentes depósitos muestran rangos para la susceptibilidad de 40 a 1500 10^{-6} SI, para la intensidad de NRM de 40 a 7130 mA/m y para la intensidad de IRM de 1370 a 23900 mA/m. Las obsidianas provenientes de 5 depósitos presentan en contraste valores más bajos, con susceptibilidades entre 10 y 20 10^{-6} SI, intensidades de NRM entre 0.1 y 26 mA/m e intensidades de IRM entre 4 y 500 mA/m. Gráficas logarítmicas para diferentes combinaciones de los parámetros magnéticos permiten una caracterización de las obsidianas. Sin embargo debe enfatizarse que se requieren estudios adicionales para refinar los resultados y permitir la distinción de depósitos individuales entre los dos grupos mayores observados con bajas y altas propiedades magnéticas.

PALABRAS CLAVE: Obsidiana, magnetismo de rocas, estudios de proveniencia, faja volcánica, centro de México.

ABSTRACT

Rock-magnetic parameters of obsidian samples from 18 localities of the Trans-Mexican volcanic belt indicate significant differences in relative contents of iron-titanium oxides and grain sizes of up to five orders of magnitude, particularly in low-field magnetic susceptibility, NRM intensity and IRM intensity. Obsidians from 13 deposits show susceptibility values between 40 and 1500 10^{-6} SI units, NRM intensities between 40 and 7130 mA/m, and IRM intensities between 1370 and 23900 mA/m. Samples from five localities show lower values, with susceptibilities between 10 and 20 10^{-6} SI, NRM intensities between 0.1 and 26 mA/m, and IRM intensities between 4 and 500 mA/m. Log-log plots of combinations of these magnetic parameters allow characterization of obsidians from different volcanic sources. However, further studies are required to permit a distinction of given deposits within the two major groups.

KEY WORDS: Obsidian, rock-magnetism, provenance studies, Trans-Mexican volcanic belt, central Mexico.

INTRODUCTION

Numerous studies have addressed the problem of identifying the geological sources of obsidian, dating, techniques for mining and working the obsidian, and cultural exchange relationships in Mesoamerica (e.g., Spence, 1967; Meighan *et al*., 1968; Cobean *et al*., 1971; Hammond, 1972; Stross *et al*., 1978, 1983; Pastrana, 1986; Gaxiola and Clark, 1989). The petrological and chemical properties of obsidians from several localities in central Mexico and from archaeological sites were discussed by Ordóñez (1892), Ericson and Kimerlein (1977), Darras (1987), Mosheim and Althaus (1988), Dahl *et al*. (1990), Joron *et al*. (1990) and Darling (1993). Special attention has been paid to studies of trace elements using a variety of techniques such as x-ray fluorescence, neutron activation analysis and optical spectroscopy. These chemical methods have been also successfully used elsewhere (e.g., Gordus *et al*., 1968; Hallam and Warren, 1976; Schakley, 1988). Studies of rock-magnetic properties offer advantages comparable to modern chemical techniques, including rapidity, non-destructive analyses and low costs (Tarling, 1983). Rock-magnetic studies have been successfully used in the study of archaeological obsidians (e.g., McDougall *et al*., 1983; Schmidbauer *et al*., 1986), but these methods have not been used in Middle America. A major limitation is the lack of information on the rock-magnetic properties of obsidians from geological sources. The purpose of this short note is to summarize the initial results of a long-term project directed to investigate the magnetic properties of obsidians and their potential application to archaeological problems. We find that obsidians from several localities have been used in pre-Hispanic times across the Trans-Mexican volcanic belt (TMVB) (Figure 1). Rock-magnetic properties vary over a broad range.

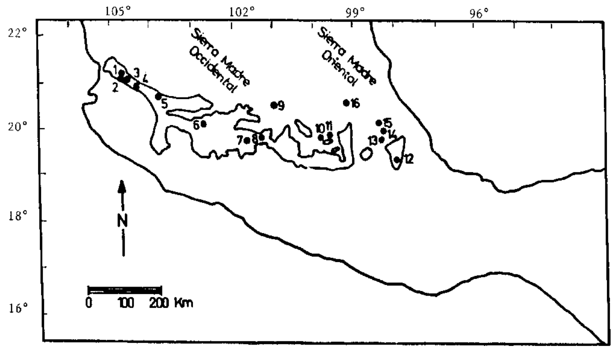

Fig. 1. Schematic map of the volcanic arc of central Mexico, the Trans-Mexican volcanic belt (TMVB) showing the location of the obsidian deposits studied (adapted from Mosheim and Althaus, 1988).

GEOLOGIC SETTING AND SAMPLES

The TMVB is formed by several tall andesitic stratovolcanoes, medium-sized shield volcanoes, thousands of cinder cones, tuff rings and maars, and silicic centers of Pliocene and Quaternary age (Mooser, 1972; Urrutia-Fucugauchi and Del Castillo, 1977). Archaeological studies in Mesoamerica have focused on lithic materials to investigate exchange relationships, degree of technological development and dating. Obsidian was widely used since the early civilizations. The Olmec civilization flourished from about 1150 to 400 B.C. in the humid and hot lowlands of the Gulf of Mexico coast, relatively far from volcanic terrains and obsidian outcrops. The occurrences of obsidian artifacts at Olmec sites are evidence of exploration and mining activities and/or exchange relationships (e.g., Cobean *et al*., 1971). The Olmecs made extensive use of volcanic materials; perhaps the most impressive examples are the colossal heads of basaltic lava. Quarrying and transport of the large rocks for these heads and for other major sculptures provide evidence of the technological development of the Olmecs and their knowledge and use of their environment. Obsidian was also widely used in later civilizations, and was traded in a complex network throughout Mexico and Central America.

In pre-Hispanic times, obsidian was mined from different localities scattered across the TMVB. Several of these localities have been identified and studied in previous investigations (e.g., Spence and Parsons, 1967; Rul, 1972; García-Bárcena, 1975; Stocker and Cobean, 1984; Stocker, 1989; Pastrana, 1986). Twenty-two obsidian samples from 18 different localities distributed across the TMVB (Figure 1), previously studied by Mosheim and Althaus (1988), have been investigated in this study (see Table 1 of their paper for major oxide and trace element data). The obsidian localities may be grouped into three large regions:

(1) Western Mexico: Mesa de las Salvias, Nayarit (locality 1; also referred to as Ixtlan del Río), Magdalena, Jalisco (locality 2; also known as Etzatlan), Teuchitlan, Jalisco (locality 3), Tequila, Jalisco (locality 4), Sierra de la Primavera (locality 5), and Jocotepec, Chapala, Jalisco (locality 18). A locality to the west in Zináparo, Michoacán (locality 6; Figure 1) has also been studied.

(2) Central Mexico: San José El Rincón, Michoacán (locality 7; also referred to as Zinapécuaro), Ucareo, Michoacán (locality 8), San Miguel El Colorado, Querétaro (locality 9), Cerro de las Navajas, Hidalgo (locality 10; also referred to as Pachuca), Atempan, Puebla (locality 17) and Buenavista, Mexico (locality 11; also referred to as Barranca de los Estetes or Otumba in the Teotihuacan Valley).

(3) Eastern Mexico: Jacal, Veracruz (locality 12; also referred to as Pico de Orizaba), Guadalupe Victoria (locality 13; also referred to as Pico de Orizaba), Altotonga (locality 14), Zaragoza (locality 15) and Zacualtipan (locality 16).

RESULTS

Volcanic rocks and glasses usually contain a low weight percentage of iron; part of it as iron-titanium oxide minerals. Some solid-solution members of the iron-titanium oxide minerals are ferrimagnetic at room temperature and are capable of stable remanent magnetization (e.g., Tarling, 1983; Urrutia-Fucugauchi *et al*., 1984; Schmidbauer *et al*., 1986). The iron-rich titanomagnetites dominate the magnetic properties of volcanic glass. The rapid cooling process of volcanic glass results in small grain sizes with characteristic single-domain and pseudo-single domain behaviors. In this study of magnetic properties of obsidian, we have used the following magnetic parameters: low-field susceptibility, NRM intensity, IRM intensity, and coercivity.

Low-field magnetic susceptibility was measured with a susceptibility bridge connected to the Molspin system. The intensity and direction of natural remanent magnetization (NRM) was measured with a spinner Molspin magnetometer. The NRM direction was referred to an arbitrary reference, in order to quantify the vectorial composition of the remanence. Further investigation of the magnetic coercivity spectra and the nature of magnetic remanence carriers were accomplished by inducing a laboratory remanence by application of direct magnetic fields. Samples were given an isothermal remanent magnetization (IRM) in steps by applying magnetic fields up to fields of 500-700 mT with a pulse magnetizer. The saturation magnetization or maximum IRM was then demagnetized by applying alternating magnetic fields (AF) up to 100 mT. AF demagnetization was carried out in

Table 1

Magnetic properties of obsidians from central Mexico

No.	Locality	Symbol	Sus	NRM	IRM	Hs	MDF
14	Altotonga, Veracruz	AL1	136.0	360.4	13519.6	>500	61
14	Altotonga, Veracruz	AL2	63.7	135.4	6495.8	400	
17	Atempan, Puebla	AT1	42.5	38.9	3287.5	450	61
17	Atempan, Puebla	AT2	40.2	42.1	3565.2	400	58
11	Buenavista, Mexico	BV1	127.8	158.2	10301.3	>400	57
11	Buenavista, Mexico	BV2	137.5	75.3	7586.7	500	52
10	Cerro de las Navajas Hidalgo	CN	11.3	0.09	3.8	300	15
9	El Colorado, Querétaro	EC	15.3	0.72	24.4	450	44
13	Guadalupe Victoria Puebla	GV	325.8	2139.0	15623	250	10
12	Jacal, Pico Orizaba Veracruz	JC	221.3	101.6	6679.3	250	18
18	Jocotepec, Jalisco	JO	16.2	19.9	718.7	>700	>100
5	La Primavera, Jalisco	LP	18.0	26.4	495.2	>300	112
1	Mesa de las Salvias, Jalisco	MS	247.5	1657.4	23884.7	500	64
7	San José El Rincón, Michoacán	JR	121.5	226.7	13578.9	500	60
3	Teuchitlán, Nayarit	TH	11.9	2.7	136.2	500	76
4	Tequila, Jalisco	TQ	259.5	581.6	8554.5	800	13
2	Tequila Magdalena Jalisco	TM	104.7	117.9	5812.2	600	100
8	Ucareo, Michoacán	UC	115.7	45.1	6135.8	>400	80
16	Zacualtipan, Hidalgo	ZH	133.1	7133.1	15386	>500	67
6	Zináparo, Michoacán	ZI1	814.7	112.7	1370.0	500	31
6	Zináparo, Michoacán	ZI2	1449.8	87.3	1936.6	>500	34
15	Zaragoza, Puebla	ZZ	66.7	86.9	3367.1	>500	11

Summary of rock-magnetic properties for central Mexico obsidians. Note: Sus, magnetic susceptility in 10^{-6} SI units; NRM, intensity of natural remanent magnetization in milliampere/meter (mA/m); IRM, intensity of isothermal remanent magnetization in mA/m; Hs, coercivity in milliTesla (mT); and MDF, AF median destructive field in mT.

steps by using a Schonstedt AF demagnetizer equipped with a reverse tumbling mechanism.

Examples of IRM acquisition curves are shown in Figures 2a (Zináparo), 3a (Jocotepec), 4a (Mesa de las Salvias), 5a (Tequila) and 6a (Jacal). The corresponding AF demagnetization curves for the maximum IRM are given in Figures 2b to 6b. A summary of the rock-magnetic results is shown in Table 1. The relationships can be simply displayed by using plots of parameter relationships such as intensities of remanent and saturation magnetizations as a function of low-field susceptibility (Figures 7 and 8). The relative relation between intensities of remanent magnetization (Mr) and saturation magnetization (Ms) is a function of the type of oxide, the concentration, the grain size and the domain state. The ratio Mr/Ms usually increases with decreasing grain size, thus defining the multi-domain (MD), pseudo-single domain (PSD) and single domain (SD) states.

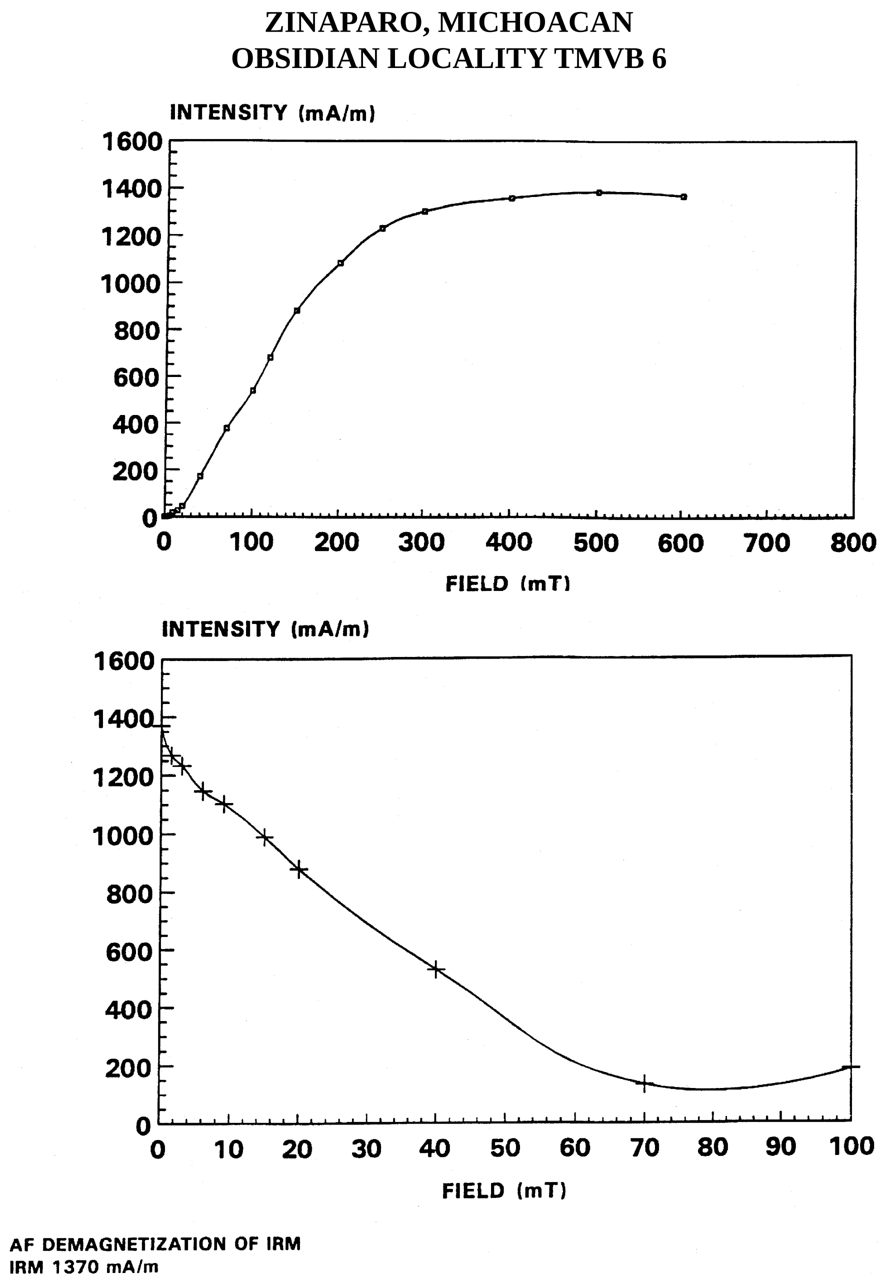

Fig. 2. Examples of (a) IRM acquisition curve and (b) AF demagnetization curve, for an obsidian sample from locality 6 in Zináparo, Michoacán (ZI). This sample is characterized by the highest magnetic susceptibility and the lowest IRM intensity observed in the obsidian suite examined in this study.

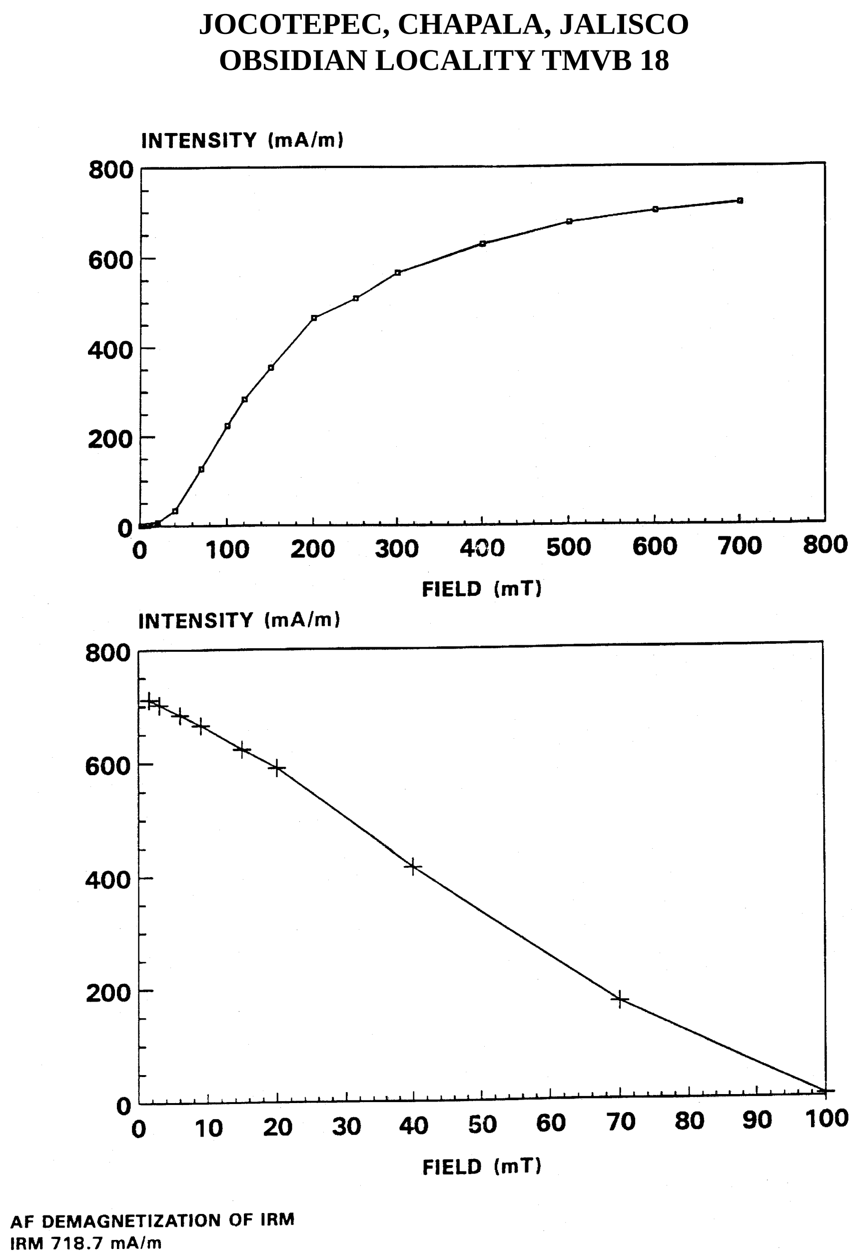

Fig. 3. Examples of (a) IRM acquisition curve and (b) AF demagnetization curve, for an obsidian sample from locality 18 in Jocotepec, Jalisco (JC). This sample forms part of the group characterized by weak magnetic properties (low values of magnetic susceptibility, NRM intensity and IRM intensity).

DISCUSSION

Magnetic properties of volcanic rocks depend on composition, amount, grain size and shape, oxidation state and distribution of the iron-titanium oxide minerals (Tarling, 1983). The titanomagnetites and magnetites usually represent a few percent of the minerals in a volcanic rock or a glass. In the obsidians, the crystalline phases in the glassy groundmass present small grain sizes associated with the rapid cooling process. Magnetic properties of these ferrimagnetic minerals may permit identification of given silica-rich magmas subject to cooling conditions and subsequent alteration histories (McDougall *et al*., 1983; Urrutia Fucugauchi *et al*., 1984; Schmidbauer *et al*., 1986). In the obsidian samples examined, the low-field susceptibility, intensity of remanent magnetization and saturation magnetization vary over several orders of magnitude (Table 1). Remanent magnetization intensity may be modified by the presence of sec-

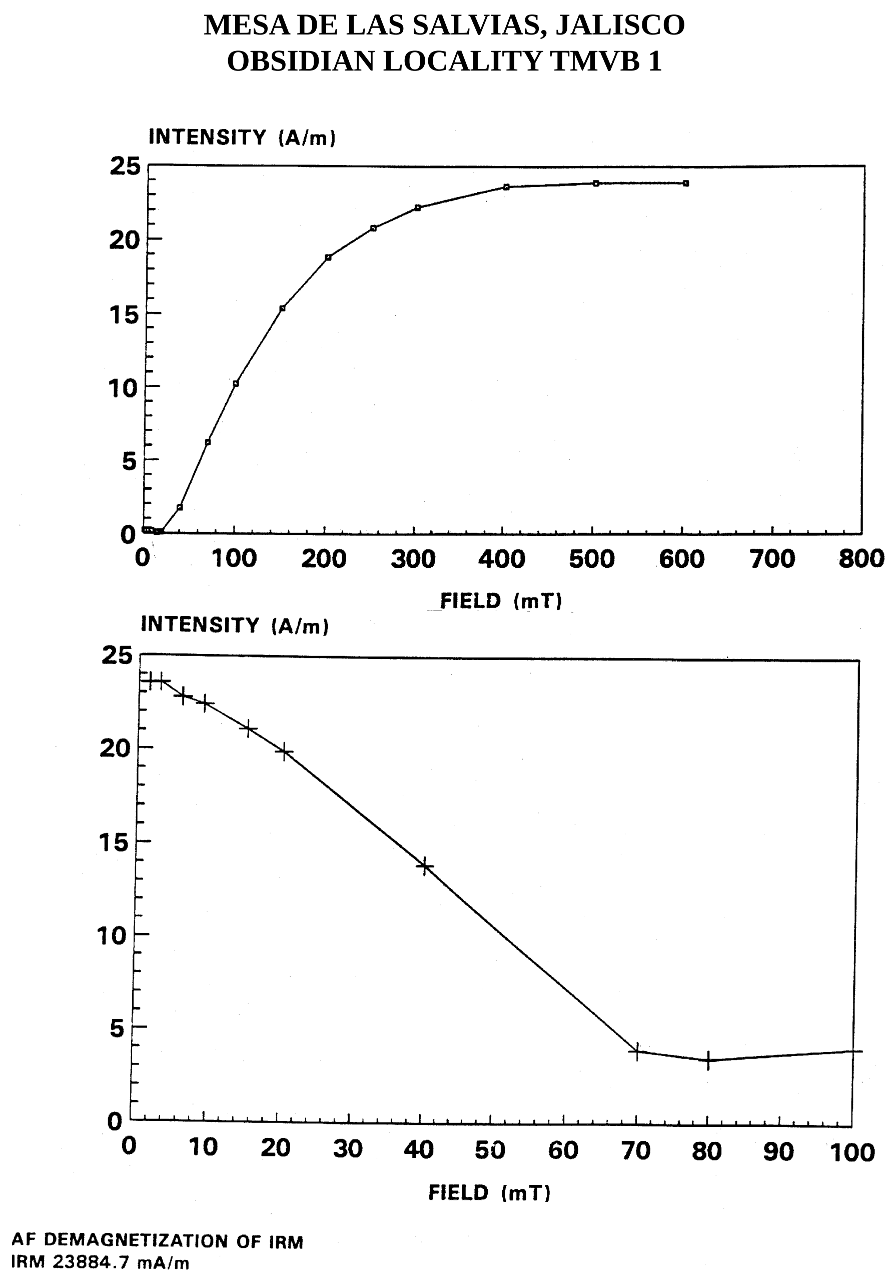

Fig. 4. Examples of (a) IRM acquisition curve and (b) AF demagnetization curve, for an obsidian sample from locality 1 in Mesa de las Salvias, Jalisco (MS). This sample is characterized by the highest IRM value observed in the obsidian suite examined.

ondary magnetization components. In contrast, isothermal remanent intensity is not affected by secondary components. In the samples examined, however, there is a good overall correlation between these parameters, and examination of the AF demagnetization plots does not indicate the occurrence of secondary remanence components. The relatively large differences in the magnetic parameters of obsidians, particularly in the IRM-magnetic susceptibility plot (Figure 8), permit to distinguish different obsidian deposits.

The obsidians examined from various areas of the TMVB are characterized by low-field susceptibility values between 40 and 1500 10^{-6} SI. The corresponding intensities of NRM and IRM vary between 40 and 2140 mA/m and between 1370 and 1560 mA/m, respectively (Figures 7 and 8). In general, there is a tendency for higher intensities to be associated with high susceptibility. The range of variation is sufficiently wide to allow discrimination of individual obsidians. Obsidians from other five localities (i.e., Cerro de

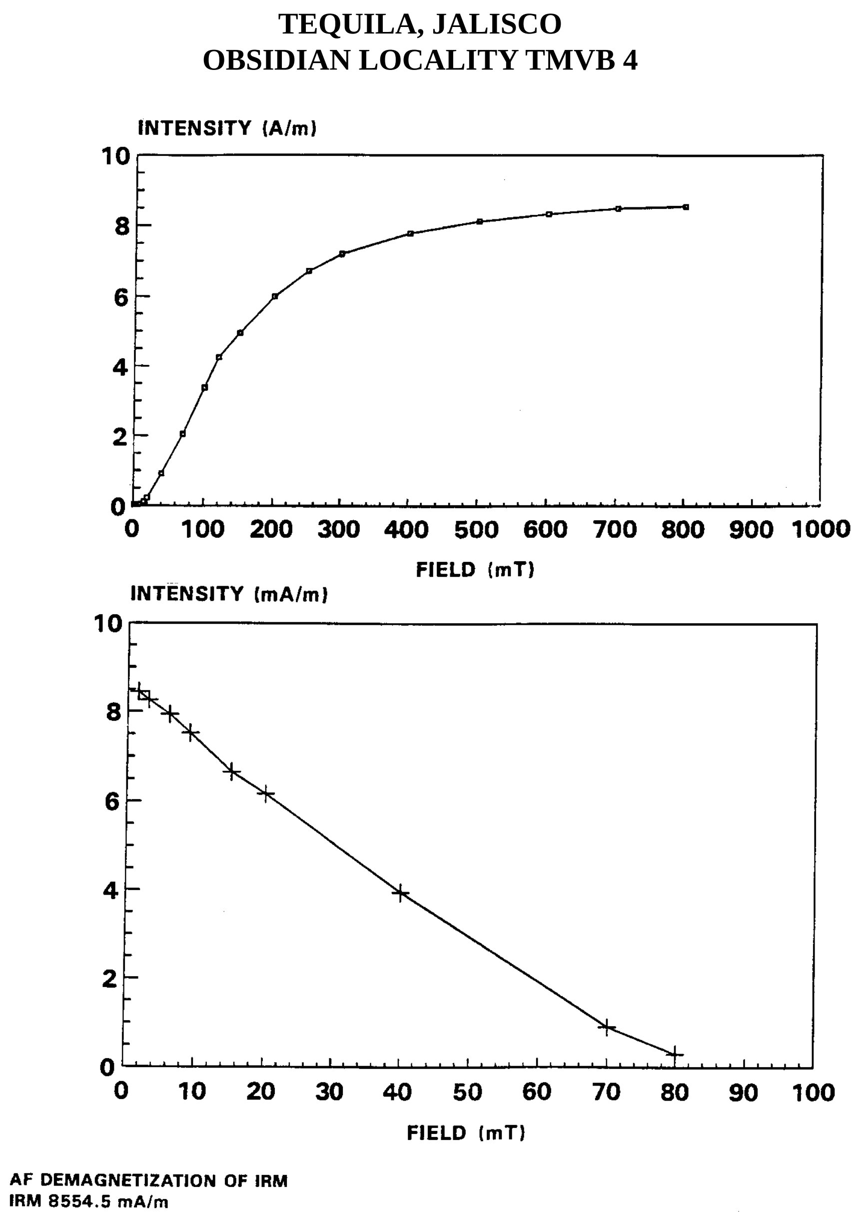

Fig. 5. Examples of (a) IRM acquisition curve and (b) AF demagnetization curve, for an obsidian sample from the locality 4 of Tequila, Jalisco (TQ). This sample forms part of the group of obsidians characterized by relatively high values of magnetic susceptibility, NRM intensity and IRM intensity. It presents higher values than samples from the nearby localities of Magdalena and Teuchitlan, also associated with pyroclastic flows from Tequila volcano.

las Navajas, Hidalgo, Tequila, Jalisco, El Colorado, Querétaro, Jocotepec Jalisco and La Primavera, Jalisco) show lower values that extend the range of variation up to five orders of magnitude. The low-field susceptibility varies between 10 and 20 10^{-6} SI. The NRM and IRM intensities vary between 0.1 and 26 mA/m and between 4 and 500 mA/m, respectively (Figures 7 and 8). These five obsidian localities do not seem to display any simple geographic pattern. Thus the deposits of Magdalena, Teuchitlan and Tequila show different properties yet originate from a single volcanic source in Tequila volcano. The source regions are shown in Figure 1.

Results are now discussed separately for the three regions of the TMVB: western Mexico, central Mexico and eastern Mexico.

The obsidian deposits from Mesa de las Salvias, Nayarit (MS, locality 1) generally composed by small gray nodules, were quarried extensively in the region of Ixtlan del Río.

JACAL, PICO DE ORIZABA, VERACRUZ
OBSIDIAN LOCALITY TMVB 12

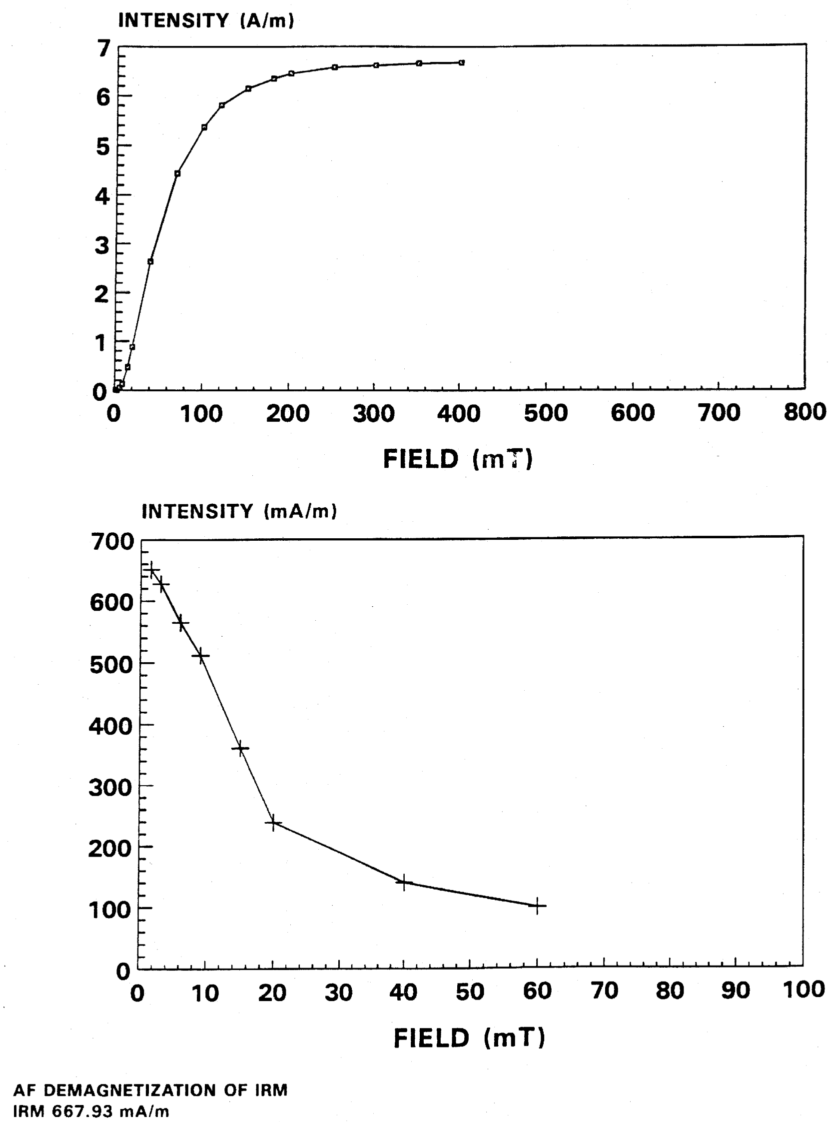

Fig. 6. Examples of (a) IRM acquisition curve and (b) AF demagnetization curve, for an obsidian sample from locality 12 in Jacal, Veracruz (JO). This sample forms part of the group characterized by relatively high values in magnetic properties. The locality is in flows from the Pico de Orizaba stratovolcano.

Trace element data show low contents of Yb (2 ppm), Ba (781 ppm), Zr (140 ppm) and Hf (4.5 ppm) (Ericson and Kimberlin, 1977). The magnetic susceptibility is high: 248 10^{-6} SI. The NRM and IRM intensities are among the highest values of the sample suite examined, with 1657 and 23885 mA/m, respectively (Figure 4). The obsidian deposits of Magdalena, Jalisco (TM, locality 2) are formed by clear green nodules in pyroclastic rhyolitic flows. Cobean *et al*. (1971) report contents of 195-230 ppm of Zr, 160-180 ppm of Rb, and 630-650 of Mn. Additional data are reported in Ericson and Kimberlin (1977), with high Ba (2330 ppm), Hf (19 ppm) and Yb (7 ppm). The magnetic susceptibility is 105 10^{-6} SI. The NRM and IRM intensities are 118 and 5812 mA/m, respectively. The obsidian from Teuchitlan, Jalisco (TH, locality 3) present similar trace element contents, with Zr between 265-460 ppm, Rb between 185-195 ppm and Mn around 480 ppm (Cobean *et al*., 1971). Ba, Yb and Hf also show similar values of 2282, 7, and 17 ppm, respectively (Ericson and Kimberlin, 1977). The magnetic susceptibility is low, being second to last in the suite examined, with 12

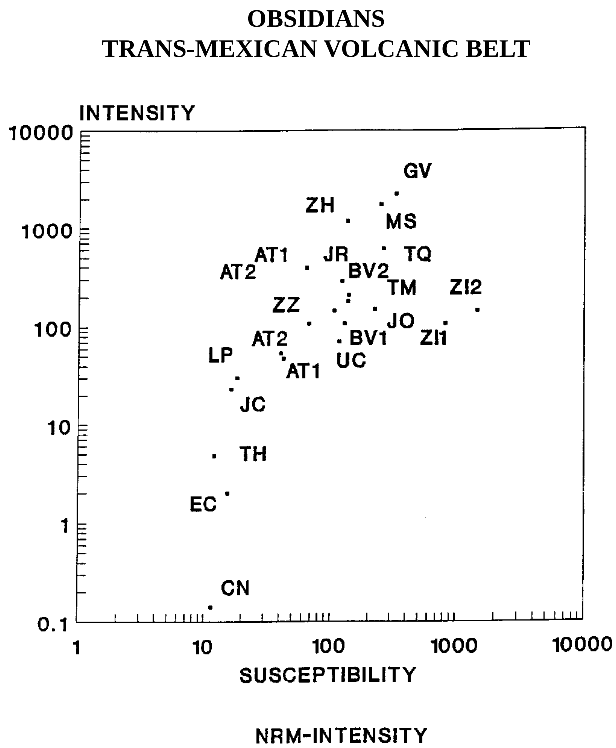

Fig. 7. Logarithmic plot of the intensity of natural remanent magnetization (NRM) as a function of the low-field susceptibility.

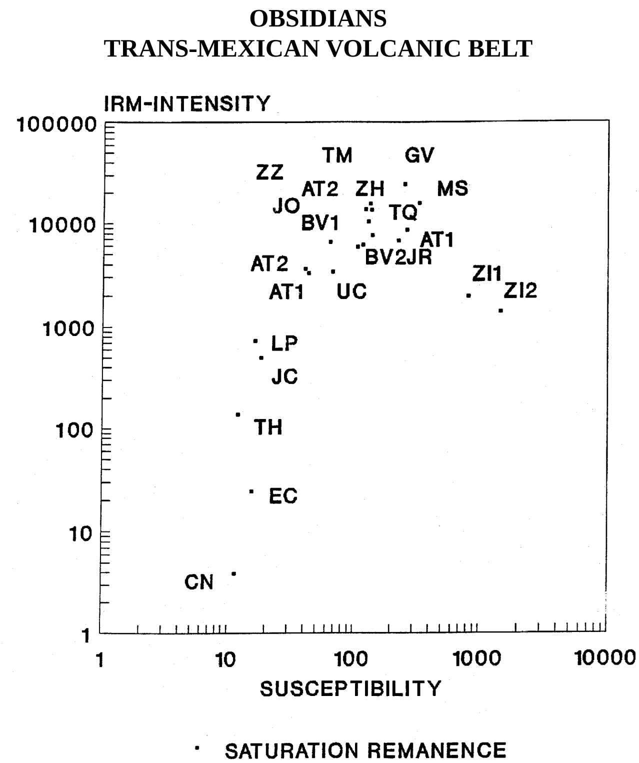

Fig. 8. Logarithmic plot of the intensity of isothermal remanent magnetization (IRM) as a function of low-field susceptibility.

10^{-6} SI. The NRM and IRM intensities are also low, with 3 and 136 mA/m, respectively. The deposit from Tequila, Jalisco (TQ, locality 4) is within a large flow with porphyritic gray obsidian. Zr contents are 200-225 ppm, Rb contents are 115-125 ppm, Sr contents are 55-60 ppm and Mn contents are 480 ppm (Cobean *et al.*, 1971). Ba, Yb and Hf are 1251, 3.8 and 10.5 ppm, respectively (Ericson and Kimberlin, 1977). The magnetic susceptibility is 260 10^{-6} SI. The NRM and IRM intensities are among the highest values observed, with 582 and 8555 mA/m, respectively (Figure 5). The obsidian deposits from Magdalena, Tequila and Teuchitlan display a large variation in magnetic properties, although they all belong to the rhyolitic flows of Tequila volcano. The variability in chemical composition of obsidians from Tequila volcano has been previously recognized (e.g., Stross *et al.*, 1976, 1983; Ericson and Kimberlin, 1977; Harris, 1986). Harris (1986) has documented several rhyolitic flows with varying compositions and ages that contain obsidian. The Teuchitlan and Magdalena deposits have been assigned to peralkaline flows emplaced at about 0.61-0.68 Ma. The Tequila deposit lies in a younger group of metaluminous rhyolitic flows emplaced at 0.55 to 0.3 Ma. The rock-magnetic analyses suggest that it is possible to distinguish obsidian samples from deposits of Teuchitlan, Magdalena and Tequila. La Primavera deposit (LP, locality 5) is within the pyroclastic deposits of the Sierra de la Primavera, a large silicic caldera complex located west of Guadalajara City. Ba, Sr, Rb, and Zr contents are <100, 46, 135, and 265 ppm (Mosheim and Althaus, 1988). The magnetic susceptibility, NRM intensity and IRM intensity are low, being about 18 10^{-6} SI, 26 mA/m and 495 mA/m, respectively. The deposit of Jocotepec, Jalisco (JC, locality 18) is exposed along the Jocotepec-Acatlan road in the Chapala Lake area. The magnetic susceptibility, NRM intensity, IRM intensity are low, with 16 10^{-6} SI, 20 mA/m and 719 mA/m, respectively (Figure 3). The deposit of Zináparo, Michoacan (ZI1 and ZI2, locality 6) is formed by large gray obsidian. The magnetic susceptibility, NRM intensity and IRM intensity are high, around 815-1450 10^{-6} SI, 87-113 mA/m and 1370-1937 mA/m, respectively (Figure 2). The site is located to the southwest of Penjamo, Guanajuato where another obsidian deposit has been studied (Cobean *et al.*, 1971). Zr, Rb, Ba, Yb, and Hf contents are 182, 131, 1086, 2.4 and 5.2 ppm, respectively (Ericson and Kimberlin, 1977). Mosheim and Althaus (1988) report similar data, except for lower Ba contents of 655 ppm. Data for the Penjamo deposit show larger contents of Zr (470-630 ppm), Rb (170-190 ppm) and Mn (510 ppm) (Cobean *et al.*, 1971).

The San José El Rincón, Michoacán (JR, locality 7) deposit of cloudy gray obsidian lies in an obsidian dome at the town of Zinapécuaro. The Zr, Rb and Mn contents are 90, 200-210 and 260 ppm (Cobean *et al*., 1971), and Ba, Yb and Hf contents are 932, 2.9 and 4.1 ppm (Ericson and Kimberlin, 1977). The magnetic susceptibility, NRM intensity and IRM intensity are 122 10^{-6} SI, 227 mA/m and 13579 mA/m, respectively. The magnetic susceptibility, NRM intensity and IRM intensity for the Ucareo deposit, Michoacan (UC, locality 8) are 116 10^{-6} SI, 45 mA/m and 6136 mA/m, respectively. The obsidian from Cerro de las Navajas, Hidalgo (CN, locality 10) presents a characteristic dark bottle-green color and high contents of Zr, up to 600 ppm (Cobean *et al*., 1971). The magnetic susceptibility, NRM intensity and IRM intensity are the lowest values observed in this study, with 11 10^{-6} SI, 0.09 mA/m and 4 mA/m, respectively. These obsidian mines north of Pachuca have been extensively studied (e.g., Spence and Parsons, 1967). The southern sector of the state of Hidalgo contains numerous obsidian localities. The magnetic susceptibility, NRM intensity and IRM intensity of the Atempan deposit (AT1 and AT2, locality 17) are 40-43 10^{-6} SI, 39-42 mA/m and 3288-3565 mA/m, respectively. Obsidian from the Querétaro area has been described for several localities, including Cadereyta de Montes, El Paraíso, San Martin, Bordo Blanco and San Miguel El Colorado (around locality 9; Figura 1). The magnetic properties show low values, comparable to the Cerro de las Navajas deposit, with magnetic susceptibility and NRM and IRM intensities of about 15 10^{-6} SI, 0.7 mA/m and 24 mA/m, respectively. Nearby localities include the obsidian from Buenavista, Mexico (BV1 and BV2, locality 11) also examined in this study. The corresponding magnetic susceptibility, NRM intensity and IRM intensity are about 128-138 10^{-6} SI, 75-158 mA/m and 7587-10301 mA/m, respectively. The Buenavista locality near Otumba contains extensive deposits of highly silicified gray obsidian. This obsidian has flaking properties suited for pressure flaking and prismatic blades, and was heavily exploited in central Mesoamerica since the Early Formative period. Cobean *et al*. (1971) describe El Paraíso obsidian as a fine black obsidian present in thin bands separated by layers of ash; whereas Ericson and Kimberlin (1977) refer to a clear green-gray obsidian. The samples from El Paraíso present low Zr contents of 85-130 ppm, and the samples from Cadereyta de Montes present high Zr of 580 ppm (Cobean *et al*., 1971). The samples from San Miguel El Colorado (EC, locality 9; Figure 1) analyzed in Mosheim and Althaus (1988) present higher Zr contents up to 1150 ppm and weak rock-magnetic susceptibility and remanence.

The obsidian from the Pico de Orizaba-Guadalupe Victoria area of Veracruz and Puebla (JO and GV, localities 12 and 13; Figure 1) is typically banded with irregular surface due to small inclusions, and rather low contents of zirconium, less than 50 ppm (Cobean *et al*., 1971). The magnetic susceptibility and NRM and IRM intensities of the Guadalupe Victoria deposit are 326 10^{-6} SI and 2139 mA/m and 15623 mA/m, respectively. The corresponding values for the Jacal deposit are lower than those of Guadalupe Victoria, being in a comparable range with 221 10^{-6} SI, 102 mA/m and 6679 mA/m, respectively (Figure 6). Even though it presents uneven textures and poor flaking quality, this brittle obsidian has been recognized as an important source in Mesoamerica during the Formative Period (Cobean *et al*., 1971). Samples come from the southeastern and northwestern flanks of the Pico de Orizaba volcano. The locality of Guadalupe Victoria (GV, locality 13) is an extensive stream laid deposit with weathered obsidian boulders. In contrast, obsidians from Altotonga and Zaragoza, Veracruz (AL1, AL2, and ZZ, localities 14 and 15; Figure 1) present smooth textures and good flaking quality. This obsidian is present as large nodules of dark translucent glass within ash flow tuffs. The magnetic susceptibility, NRM intensity and IRM intensity of the Altotonga deposit (AL1 and AL2, locality 14) are around 64-136 10^{-6} SI, 135-360 mA/m and 6496-13520 mA/m, respectively. The magnetic susceptibility, NRM intensity and IRM intensity for the Zaragoza deposit (ZZ, locality 15) are 67 10^{-6} SI, 87 mA/m and 3367 mA/m, respectively.

CONCLUSIONS

The magnetic susceptibility, NRM intensity and IRM intensity measured in obsidian samples from 18 different localities show a large range of variation by up to five orders of magnitude. Two groups in particular can be easily distinguished, with high and low magnetic properties (Figure 8). The obsidians from 13 deposits show magnetic susceptibility values between 40 and 1500 10^{-6} SI, NRM intensities between 40 and 7130 mA/m and IRM intensities between 1370 and 23900 mA/m (Table 1). The deposits with the lower and higher magnetic susceptibilities are Atempan, Puebla and Zináparo, Michoacán, respectively. The deposits with the lower and higher NRM intensities are Atempan, Puebla and Zacualtipan, respectively. The deposits with the lower and higher IRM intensities are Zináparo, Michoacán and Mesa de las Salvias, Nayarit, respectively. Obsidians from five deposits (i.e., Cerro de las Navajas, Hidalgo, Teuchitlan, Jalisco, El Colorado, Querétaro, Jocotepec, Jalisco, and La Primavera, Jalisco) are characterized by lower values, which extend the range of variation. Samples from these five weakly magnetic obsidian deposits show magnetic susceptibility varying between 10 and 20 10^{-6} SI, NRM intensities varying between 0.1 and 26 mA/m and IRM intensities varying between 4 and 500 mA/m (Table 1). Measurements of rock-magnetic parameters of magnetic susceptibility, NRM and IRM intensities, magnetic coercivity and domain state provide a simple method to characterize the obsidians from different sources. It should be emphasized that magnetic properties for some deposits overlap and that it is not possible to separate samples from given deposits. Further studies are required before the magnetic method can be used for sourcing and provenance studies; particularly, in order to refine the magnetic properties for the individual deposits within the two major groups. Detailed examination using additional magnetic hysteresis parameters and samples will follow from this preliminary study. Magnetic parameters alone may not be sufficient to characterize samples from different sources, particularly because of within-site variation, and additional physical and chemical properties (trace element data) are needed. Joint analysis of trace element data and magnetic parameters may provide the resolution for reliable sourcing of obsidian deposits.

ACKNOWLEDGMENTS

Dr. Eva Mosheim kindly provided the obsidian samples used in this study, as part of a collaboration project. Thanks are also due to Z. Jurado and A.M. Soler for collaboration with the laboratory studies and the project. Useful comments by two journal reviewers and the editor are acknowledged.

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