CHEMICAL VS. DETRITAL REMANANCE MAGNETIZATION IN REDBEDS. AN EXAMPLE FROM THE ZICAPA FORMATION, SOUTHERN MEXICO.

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ABSTRACT

We show new data regarding the rock magnetic signature of chemical vs. depositional remanence of the Zicapa Formation, a continental to transitional marine sedimentary sequence from southern Mexico. Thermal demagnetization shows a multivectorial behavior with a north-directed low unblocking-temperature component (<200° C) interpreted as a viscous remanent magnetization residing mainly in detrital magnetite. A north-northwest intermediate unblocking-temperature component (250-500° C) is interpreted as an early acquired CRM residing in pigmentary haematite. A high-temperature component with unblocking temperatures >600° C is interpreted as a DRM residing in specular haematite. Often two polarities are recorded at the same stratigraphic level. Petrographic and rock magnetic experiments confirm the mixture of magnetic phases with contrasting grain size and/or coercivities. Detrital magnetite particles show low coercivities ($H_{1/2}$ = 5-10 mT). Hematite in modeled IRM acquisition curves is recognized by a wide coercivity range $H_{1/2}$ from 200 to 800 mT in response to systematic grain-size variations. Possible detrital goethite grains are found in few samples with a small contribution and coercivities up to 1.5 T. We consider that despite the presence of large grains of hematite in the detrital fraction, the main contribution to the bulk magnetization is given by the small fraction (pigmentary haematite). Elongation/Inclination analysis suggests that both components, DRM and early CRM, require applying an f-factor of about 0.4. In intervals that contain polarity transitions an early acquisition of chemical magnetization on pigmentary haematite was determined to be locked-in in a maximum of about 0.2 to 1 Ma.

Keywords: Redbeds, hematite, paleomagnetism, coercivity, México.

INTRODUCTION

The Zicapa Formation overlies Middle Jurassic quartz-rich siliciclastic strata of the Tecocoyunca Group, which together with volcanogenic sediments and basement rocks, are the primary source of its detritus. The Zicapa Formation has been divided into five members (Sierra-Rojas, Molina, 2014), but sampling concentrated in the middle Ajuatetla Member (Fig. 1). In this work, we sampled 19 sites from a sequence of coarse to very fine lithic sandstones tinted purple to reddish brown by pigmentary haematite. Details on the age of the Zicapa Formation and depositional environment can be obtained in Sierra-Rojas and Molina-Garza (2014).

All magnetic measurements were made at the palaeomagnetic laboratory of the Centro de Geociencias, UNAM, at the Juriquilla campus. Rock magnetic experiments were used to characterize magnetic carriers. Hysteresis parameters, isothermal remnant magnetization, and backfield curves of saturation of IRM were determined with a Princeton Measurements Corp. MicroMag 2900 vibrating sample magnetometer. Thermomagnetic curves were obtained in a custom-made Curie balance using about 3.5 gr of pulverized sandstones in a DC field of 0.4 T in air, with heating-cooling rates of 30-40 °C/min. The petrography of samples was studied in thin sections with a petrographic microscope of polarized light (Olimpus Bx-51), and textures of magnetic oxides were studied with a scanning electron microscope (SEM).

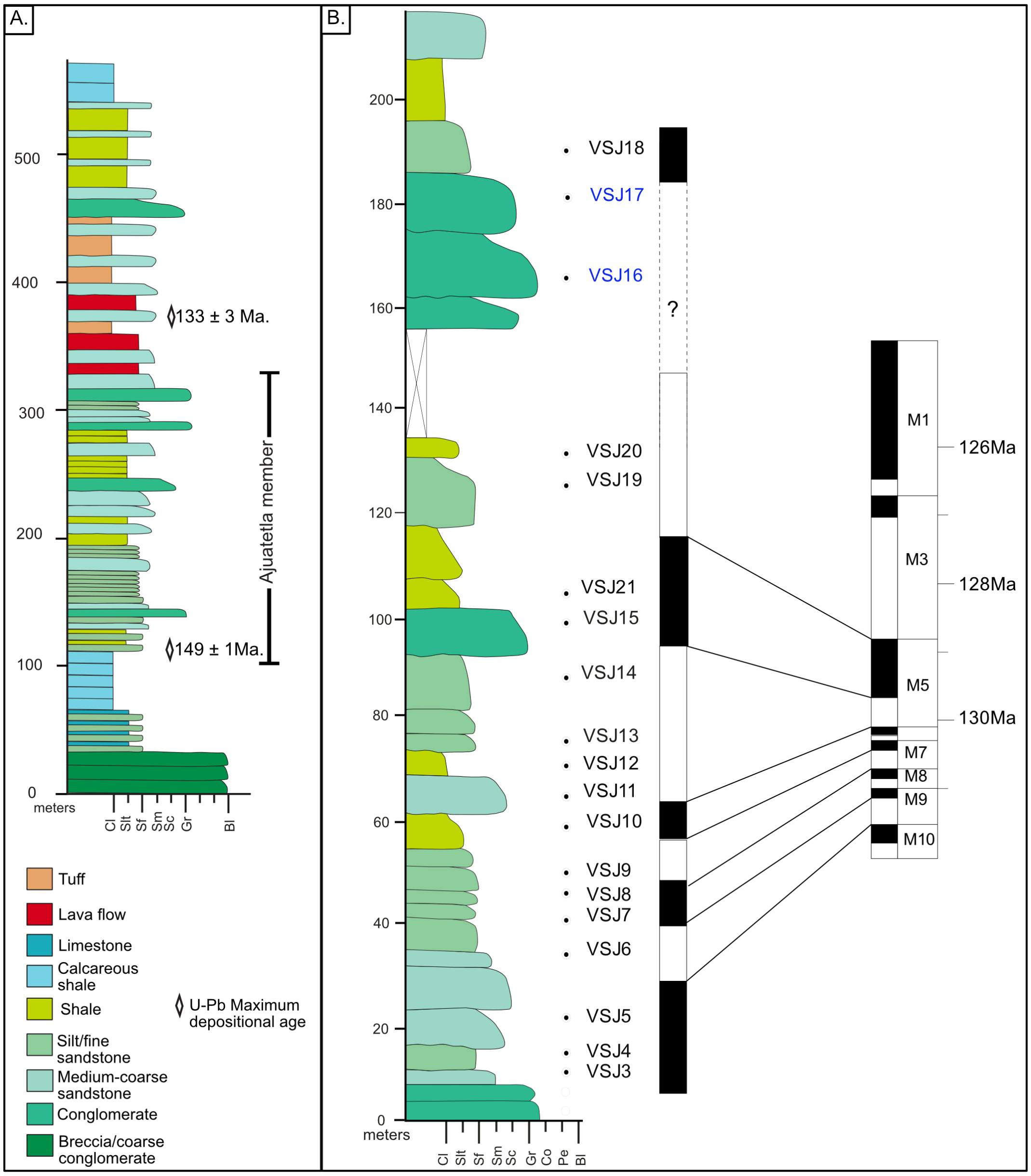

Figure 1. A. Generalized column of Zicapa Formation. B. Stratigraphic section and magnetostratigraphy of the Ajuatetla Member, Zicapa Formation (base 17.77457, -99.0813 top 17.76489, -99.08405). The location of the sampling sites is shown in each stratigraphic level. The black bars represent normal polarity intervals and the white bars reverse polarity intervals. The magnetic polarity zonation is correlated with the Geomagnetic scale for the Early Cretaceous (Ogg, 2012).

1. Results

1.1 Paleomagnetism

AF demagnetization showed almost no change in the NRM, leading to conclude that most of the magnetization resides in phases of high coercitivity such as haematite. In contrast, thermal demagnetization allowed to isolate two to three unblocking-temperature components (Fig. 2). A low temperature component (LTC) removed after 200° C, an intermediate temperature component (ITC) removed between 250° C and 550° C, and a high temperature component (HTC) removed after 600° C. The ITC and HTC are northwest to west-northwest directed with moderate positive inclination, or its antipodal. The ITC is commonly of normal

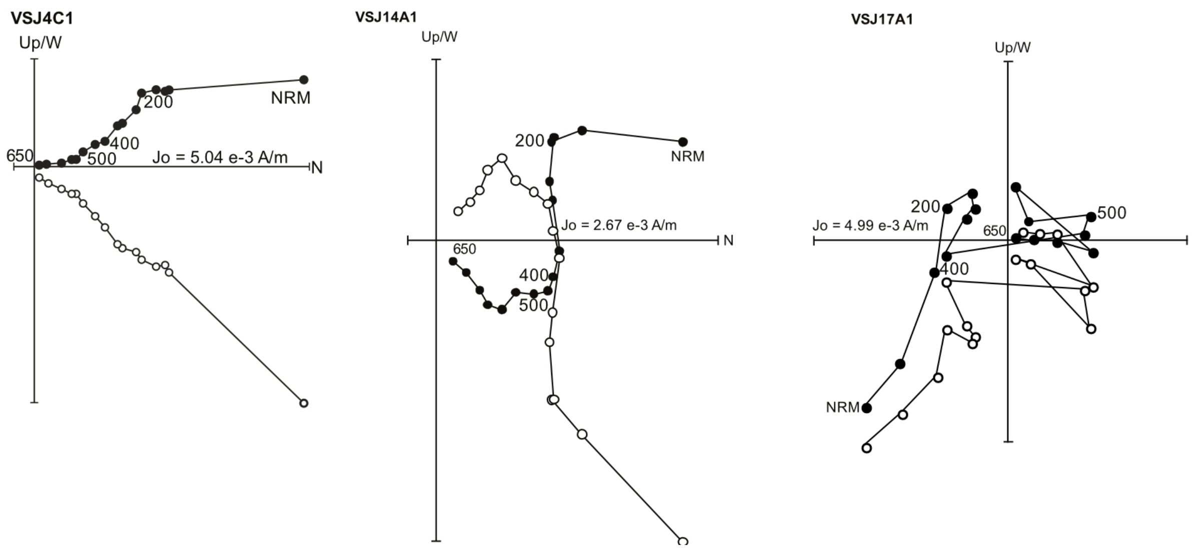

Figure 2. Representative examples of orthogonal demagnetization diagrams of samples of the Zicapa Formation.

polarity when the high component is of reverse polarity, but mixed polarities are observed within a single site for the ITC.

Some sites show a complex record when analyzed in stratigraphic context. If adjacent sites are of opposite polarity, the intermediate polarity magnetization more often does not correspond to that of the direction of the high temperature component of the overlying site.

Overall means were calculated using Fisher's statistics inverting reverse polarity magnetizations. The tilt corrected means of the ITC and HTC components, which are statistically indistinguishable, show anomalously shallow inclination and declination scatter of sample directions, which suggests a possible effect of sedimentary inclination shallowing. We performed an Elongation-Inclination (E/I) correction in both ITC and HTC (Tauxe and Kent, 2004). For the ITC the E/I analysis determined a crossing-point model for the data, predicting inclination of I = 28°, which represents the inclination *vs* elongation pair more consistent with the geomagnetic model. For the HTC the result is similar with a flattening factor of f = 0.4 and an inclination I = 34.6°. The overall means of the ITC and HTC sample directions after correcting for inclination shallowing with a f-factor of 0.4 are D = 282.0, I = 28.2°, and D = 272.5, I = 36.5°, respectively.

1.2 Rock magnetism

The hypothesis of varying contributions to the remanence from fine-grained authigenic and coarser detrital haematite was evaluated after the results in AF demagnetization and the observation of components that reside in intermediate (250-500º C) and high unblocking temperature ranges (600-650º C).

Detrital grains and cement with cross-cutting relations are shown in the SEM backscattered images and in the reflected light images of the sandstones. Detrital magnetic grains are often martite with trellis texture, laterite grains, and hematite grains with rutile inclusions. Hematite cement is also observed in pore spaces with euhedral habits.

Thermomagnetic curves show either a single magnetic phase with a Curie/Neel temperature of about 650º C, a dominant magnetic phase with a Curie temperature of about 580º C, or inflections that suggest similar contributions to the magnetization form these two phases (Fig. 3). In the heating cycle, the inflection at ~580° C confirms the presence of magnetite in some samples. All the samples are characterized by a change

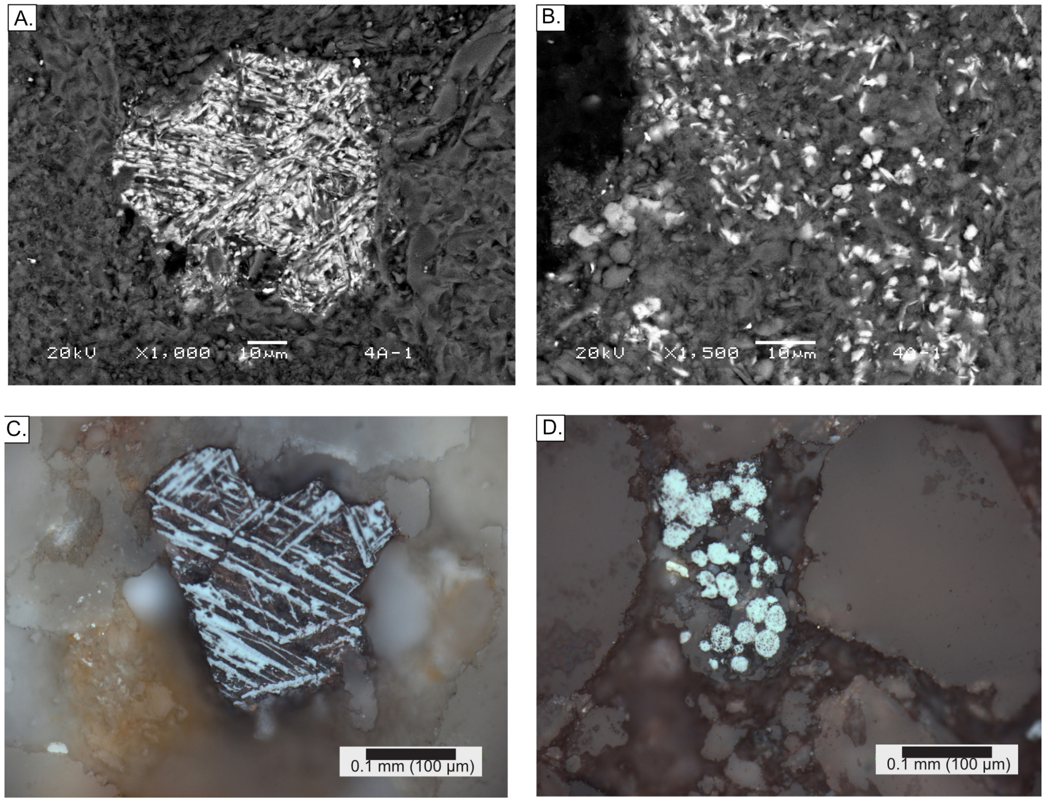

Figure 3. Results from thermomagnetic curves, and hysteresis loops for some of the samples.

in slope around 670° C associated with the Neel/Curie temperature of haematite (both pigmentary and detrital).

Hysteresis loops are almost all constricted in the middle section and widen in the lower and upper sections, which has been defined as a "wasp-waisted" hysteresis loop (Roberts *et al*., 1995; Tauxe, 1996). Wasp-waisted hysteresis loops, show coercive force ranging from 0.105 to 0.319 T, and ratios of remanent saturation *vs* saturation magnetization (M_{rs}/M_s) with values up to 0.53. A single sample, VSJ17, exhibits a low bulk coercive force, H_c (0.013 T), a remanent coercive force, H_{cr} (0.0039 T), and is near saturation at inductions of about 1T, suggesting that magnetite is present. The "goose-neck" hysteresis loops show the highest H_c value (0.3 T). Almost all samples are far from saturation even at inductions of 2T, show high M_{rs}/M_s values between 0.27 to 0.58 and H_{cr}/H_c ratios of about 1.5 to 3.5 which are consistent with SD haematite behavior (Özdemir and Dunlop, 2014).

We modeled the IRM acquisition curves (Kruiver *et al*., 2001) with more than one component (Fig. 4): a dominant mineral phase (~85 to 90% of the total IRM) with high coercivities ($H_{1/2}$ = ~500-800 mT), a very low coercivity phase (<10 mT) which contribute as much as 10% of total IRM, a very high coercivity phase (up to 1.5 T) in a few samples (<5% of the IRM), and finally, a moderately high coercivity component (40 to 70 mT) was required to fit most of the curves makes generally about 10% of the IRM.

The dominant component is characterized by $H_{1/2}$ between 400 and 600 mT likely representing magnetic particles that record the intermediate and the high unblocking temperature components of the NRM. The component with coercivities around 500 mT and ample peak in the GAP diagram, indicates ferromagnetic grains with wide coercivity range as a response to a distribution grain-size and/or composition (Abrajevitch *et al*., 2009). Also, the samples with this component are characterized by a dominant HTC. This magnetization is presumably carried by specular or detrital haematite with an IRM signal of high $H_{1/2}$, but not greater than about 500-550 mT. Few samples needed a very high coercivity component (1-1.5T) to fit the model, which can be attributed to detrital goethite in very small proportions, also observed in petrographic inspections from those same samples. The lowest representative component in the IRM curves has a $H_{1/2}$ between 5 and 10 mT, correlates with samples that carry a relatively large north-directed component, supporting the viscous origin of this NRM component. Usually the peak is wide, which can be interpreted as a wide distribution of MD particles of detrital origin (Abrajevitch *et al*., 2009).

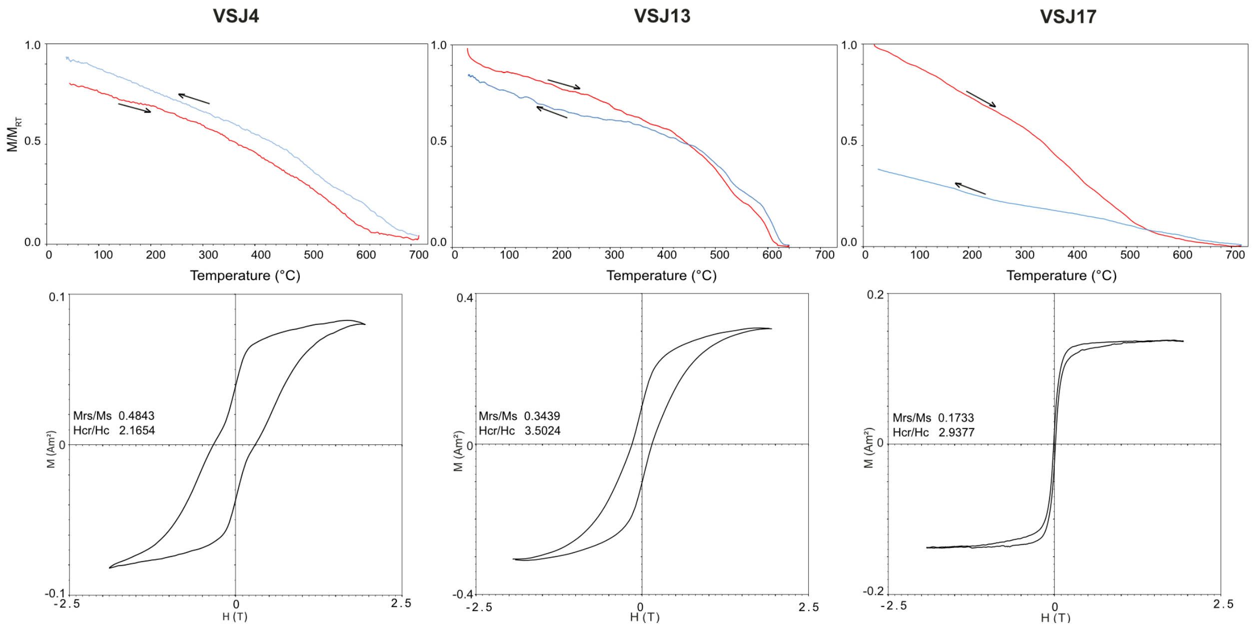

Figure 4. Representative samples of the IRM component analysis (Kruiver *et al*., 2001). From left to right the Isothermal remanent magnetization plot (IRM), the linear acquisition plot (LAP), and the gradient acquisition plot (GAP). IRM is in Am^2/kg, $\log_{10}$ ($H_{1/2}$) and DP are in $\log_{10}$ mT. Values of $H_{1/2}$ are displayed with the color code in the LAP. Identity of components in GAP after Abrajevitch *et al*. (2009) and reference therein.

2. Conclusions

Samples from the Zicapa Formation have a multivectorial NRM. A north directed magnetization of low unblocking temperature (<250º C) is carried by a magnetic phase with a Curie temperature near 580º C, and IRM curves suggest it has coercivities ~10 mT. It is interpreted as a viscous component, whose carrier is MD detrital magnetite. A intermediate temperature component with a distributed unblocking-temperatures between 300-500° C, and an additional component of high, discrete, laboratory unblocking-temperatures (600 to >650º C). A Curie-Neel temperature ~670° C, and relatively high coercivity (>~500-600 mT) indicate that the principal remanence carrier of the intermediate and high temperature components is haematite.

Modeled IRM acquisition curves, high resistance to AF demagnetization and >650º C maximum unblocking temperatures suggest that the dominant ferromagnetic phase, and the principal remanence carrier, is hematite. Laboratory unblocking temperatures and thermomagnetic curves suggest that the remanence resides primarily in the fine-grained haematite fraction. In most of the samples less than 20% of the remanence remains after heating to 600º C, with few exceptions.

The ITC is interpreted as a CRM obtained early after deposition and carried by authigenic haematite. The HTC is interpreted as a DRM, and its carriers where found in SEM as well as in petrographic inspection of thin sections, as laterite grains and specularite with high temperature textures (trellis texture).

References

Abrajevitch, A., Van der Voo, R. Rea, D.K., 2009. Variations in relative abundances of goethite and hematite in Bengal Fan sediments: Climatic vs. diagenetic signals. *Marine Geology 267*, 191-206.

Kruiver, P. P., Dekkers, M. J., Heslop, D., 2001. Quantification of magnetic coercivity components by the analysis of acquisition curves of isothermal remanent magnetisation. *Earth and Planetary Science Letters 189*, 269-276.

Ogg, J.G., 2012. Geomagnetic Polarity Time Scale, in *The Geologic Time Scale 2012*, (Gradstein, F. M., Ogg, J. G., Schmitz, M., Ogg, G, Eds), 85-113, Elsevier.

Özdemir, Ö., Dunlop, D. J., 2014. Hysteresis and coercivity of hematite. *Journal of Geophysical Research: Solid Earth 119*, 2582-2594.

Roberts, A. P., Cui, Y., Verosub, K. L., 1995. Wasp waisted hysteresis loops: Mineral magnetic characteristics and discrimination of components in mixed magnetic systems. *Journal of Geophysical Research: Solid Earth 100*, 17909-17924.

Sierra-Rojas, M. I., Molina-Garza, R. S., Lawton, T. F., 2016. The Lower Cretaceous Atzompa Formation in South-Central Mexico: Record of Evolution from Extensional Backarc Basin Margin to Carbonate Platform. *Journal of Sedimentary Research 86,* 712-733.

Tauxe, L., Kent, D. V., Opdyke, N. D.,1980. Magnetic components contributing to the NRM of Middle Siwalik red beds. *Earth and Planetary Science Letter, 47*, 279-284.

Tauxe, L., Kent, D. V., 2004. A simplified statistical model for the geomagnetic field and the detection of shallow bias in paleomagnetic inclinations: was the ancient magnetic field dipolar? In *Timescales of the Paleomagnetic field* 101-115.