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Rock-magnetic properties of the Cretaceous/Tertiary Micara Formation in the Guantánamo area, eastern Cuba

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RESUMEN

Se presentan los resultados iniciales del estudio de propiedades magnéticas de la sección sedimentaria Calabazas, de 35 m de espesor de la Formación Micara, expuesta en el occidente de Cuba. Estudios anteriores de la Formación Micara interpretaron la ocurrencia del límite Cretácico/Terciario (K/T) dentro de la secuencia sedimentaria, con base en evidencia del análisis de los foraminíferos planctónicos y correlaciones laterales entre afloramientos. El límite K/T en las secciones carbonatadas en Gubbio, Italia y Caravaca, España se caracteriza por una anomalía magnética asociada a un enriquecimiento de óxidos de hierro (magnetita), en adición a la anomalía de iridio. El estudio de propiedades magnéticas en la sección Calabazas permite la documentación de tres horizontes caracterizados por incrementos en la abundancia de minerales magnéticos localizados a los 4, 12 y 20 m sobre la base de la secuencia. El horizonte de 4 m se caracteriza por valores de susceptibilidad magnética de cerca de 90 x 10^{-5} SI, mientras que el resto de la sección tiene valores del orden de 20 x 10^{-5} SI. Las intensidades de NRM e IRM son de cerca de 7 mA/m y 7 A/m. El horizonte de 12 m se caracteriza por intensidades de NRM e IRM de 14 mA/m y 22 A/m, respectivamente, mientras que el horizonte de 20 m presenta valores del orden de 16 mA/m y 3 A/m, respectivamente. La anomalía magnética a los 4 m corresponde a la concentración mayor de minerales magnéticos, indicada por los valores altos de susceptibilidad magnética y posiblemente está relacionada a magnetitas de grano fino con comportamiento de dominio pseudo-sencillo. Esta anomalía magnética sin embargo presenta un rango estratigráfico amplio en comparación con otras secciones K/T, lo que sugiere otras interpretaciones en términos de cambios en la abundancia y tipo de minerales magnéticos. La interpretación preferida es en términos de fluctuaciones en el contenido relativo de minerales producto de los procesos de erosión y que la sección corresponde al Paleoceno y no incluye al límite K/T dentro del intervalo estudiado.

PALABRAS CLAVE: Propiedades magnéticas, Formación Micara, Cretácico, Paleoceno, Cuba.

ABSTRACT

Initial results of a rock-magnetic study of the 35 m thick Calabazas sedimentary section of the Micara Formation, eastern Cuba are reported. Previous studies have interpreted the Cretaceous/Tertiary (K/T) boundary within the Micara Formation, based mainly on analyses of planktonic foraminifera assemblages and lateral correlations. The K/T boundary in sedimentary sections in Gubbio, Italy and Caravaca, Spain is characterized, in addition to the iridium anomaly, by a rock-magnetic anomaly that is related to enrichment of iron oxide minerals (magnetite). Study of rock-magnetic properties in the Calabazas section identifies three horizons characterized by increased abundance of magnetic minerals, which are located at about 4, 12 and 20 m above the base of the outcrop, respectively. The 4 m horizon is characterized by magnetic susceptibility values of about 90 x 10^{-5} SI, whereas in the rest of the section values are around 20 x 10^{-5} SI. The corresponding NRM and IRM intensities are about 7 mA/m and 7 A/m, respectively. The 12 m horizon is marked by 22 A/m IRM intensity and 14 mA/m NRM intensity. The 20 m horizon is marked by 16 mA/m NRM intensity and 3 A/m IRM intensity. The magnetic anomaly at 4 m corresponds to the highest concentration of magnetic minerals, likely iron-rich fine-grained magnetites with pseudo-single domain behavior. However, this magnetic anomaly in the Calabazas section displays a wider stratigraphic range than in other K/T boundary sections. The characteristics of the wide magnetic anomaly suggest an alternative interpretation in terms of sedimentary input of magnetic material not related to the hot early impact ejecta. The Calabazas section lies in the Paleocene, and the magnetic peaks observed in the sediments result from fluctuations in the relative contents of magnetic minerals.

KEY WORDS: Rock-magnetic properties, Micara Formation, Cretaceous, Paleocene, Cuba.

INTRODUCTION

Interest in studying sedimentary sections that span the Cretaceous/Tertiary (K/T) boundary has increased following the discovery of the iridium anomaly in the Gubbio section, Italy and its interpretation in terms of a large bolide impact by Alvarez and co-workers (1980). The geochemical anomaly marked by anomalous enrichment of siderophile elements was rapidly documented at several other K/T sections, demonstrating its global nature (Ganapathy, 1980; Smit and Hertogen, 1980; Kyte *et al*., 1980). The impact hypothesis was further supported by discoveries of abundant spheroidal debris (Smit and Klaver, 1981; Montanari *et al*., 1983), shocked quartz (Bohor *et al*., 1984), Ir enrichment in continental K/T sections (Orth *et al*., 1981) and several other lines of evidence of a large bolide impact event. In the last section of their paper, Alvarez *et al*. (1980) discussed questions related to the impact site, nature of the crater, etc, and the potential difficulties in eventually documenting this part of the impact hypothesis. Nevertheless, numerous studies in the succeding decade investigated several craters worldwide and identified potential K/T candidates. Eventually, identification of high-energy sedimentary deposits in Texas (Bourgeois *et al*., 1988) and Caribbean Sea (Hildebrand and Boynton, 1990; Alvarez *et al*., 1992) focused interest in the Gulf of Mexico-Caribbean region, that culminated with the re-discovery of the Chicxulub crater in the northwestern Yucatan peninsula as a prime candidate for the K/T impact site (Hildebrand *et al*., 1991; Pope *et al*., 1991; Sharpton *et al*., 1992). The crater was initially documented by geophysical surveys and deep exploratory drilling by the Mexican Oil Company Pemex (Penfield and Camargo, 1981); although alternative interpretations in terms of an igneous feature and a late Maastrichtian age were also considered (e.g., López Ramos, 1983). Subsequent research that included Ar-Ar dating, paleomagnetism, geochemistry, petrography, etc has supported the impact interpretation and a K/T age (e.g., Hildebrand *et al*., 1991; Sharpton *et al*., 1992).

Detailed studies on the K/T boundary sections in the region have questioned some of the major conclusions regarding the age, depositional environment and biotic effects associated with the Chicxulub large impact event (e.g., Officer *et al*., 1992). For instance, Iturralde-Vinent (1992) and Jehanno *et al*. (1992) examined K/T sections in central Cuba and in Beloc, Haiti, respectively and concluded that there is no link between the deposits and a large impact event in the Caribbean area. G. Keller, W. Stinnesbeck and colleagues have reported their studies concerning several K/T sections in Mexico and Guatemala and concluded that there is no evidence supporting a major sudden environmental catastrophe associated with the Chicxulub impact event (e.g., Keller *et al*., 1993, 1994; Stinnesbeck *et al*., 1993).

As part of a long-term project to study the K/T boundary events, we have examined several K/T boundary sections in the Gulf of Mexico and the Caribbean. In this paper we report our initial findings on the Calabazas sedimentary section of the Micara Formation of eastern Cuba.

GEOLOGIC SETTING AND SAMPLING

K/T boundary sections in Cuba have been relatively less studied than other sections in the region (with some notable exceptions, e.g., Iturralde-Vinent, 1992). Fernández *et al*. (1991) have summarized the information concerning the Cretaceous and Paleocene sequences exposed in eastern Cuba (Figure 1), particularly in the Sagua de Tanamo basin and the southern flank of the Nipe-San Cristobal range. The Cretaceous and Paleocene sedimentary sequences have been grouped into the La Picota, Micara, Gran Tierra and Sabaneta Formations.

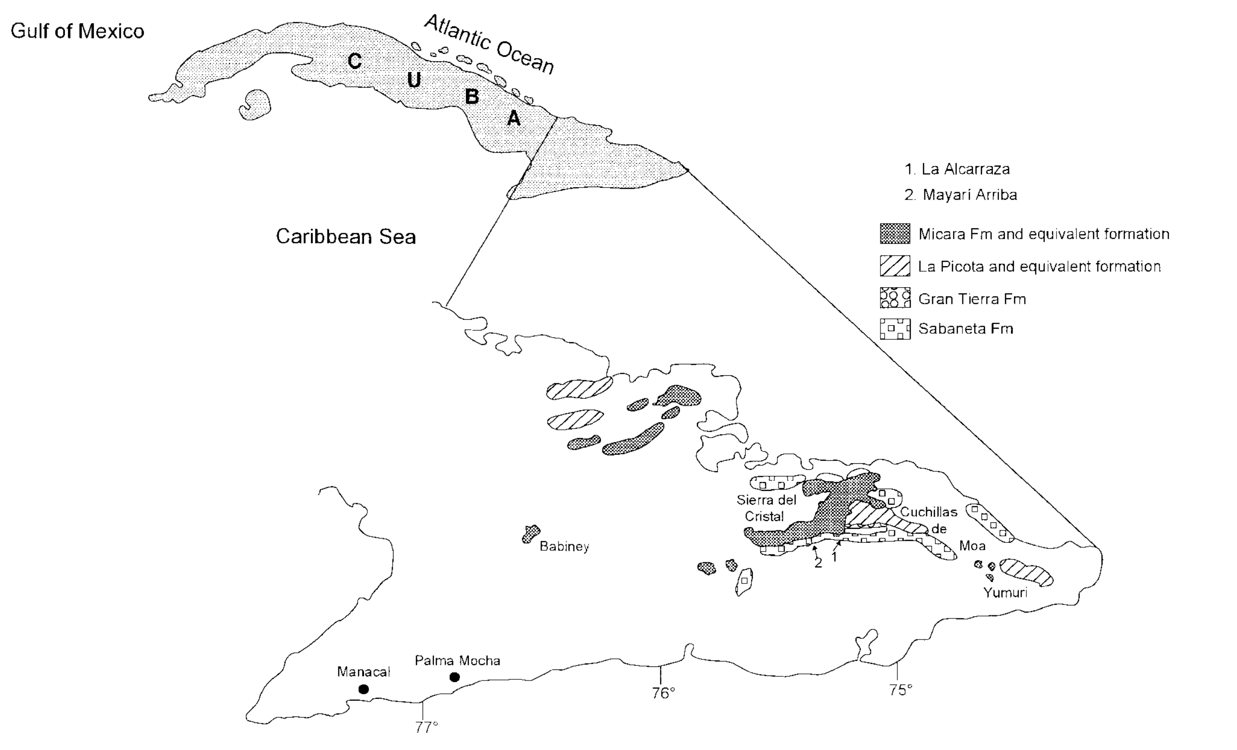

Fig. 1. Schematic map of Cuba showing the Oriente Province, eastern Cuba and approximate extension of Late Cretaceous and early Teriary units (Micara formation, La Picota Formation, Gran Tierra Formation and Sabaneta Formation). Location of the study area of La Alcarraza and Mayari Arriba is marked with numbers 1 and 2. Figure taken from Fernández *et al.* (1991).

The Micara Formation was defined by Iturralde-Vinent (1976), who described it as a thick succession of limolites, sandstones and conglomerates. The clasts in the conglomerates are mainly derived from volcanic and volcano-sedimentary rocks of the Santo Domingo Formation, and from gabbros, diorites, limestones and serpentinites. The Micara Formation is overlain by the Gran Tierra Formation. Close to the contact, the Micara Formation shows a higher content of clay and carbonate, with thick biocalcarenite and biocalcirudite beds, which suggests a gradational transition to the Gran Tierra sequence (Fernández *et al*., 1991). The planktonic foraminifera assemblage is characteristic of the upper Maastrichtian, including the *Racemiguembelina fructicosa* biozone. This biozone also contains *Guembelitria cretacea, Globotruncana havanensis, G. petaloidea, Rosita contusa, Globotruncanita conica, Pseudotextularia varians, Globotruncana* spp., *Rugoglobigerina* sp., *Heterohelicidadae* and *Archaeoglobigerina* sp. (Fernández *et al*., 1991). In the locality of Calabazas of Sagua de Tanamo, the Micara Formation is formed by thick beds of sandstones and conglomerates, with volcanic and limestone clasts. In the Naranjo Agrio and Calabazas locality, Fernández *et al*. (1991) report a section formed by a rythmic turbiditic sequence with Danian microfossil assemblage formed by *Globorotalia compresa, G. elongata, G. pseudobulloides, Globorotalia* cf. and *G. Imitata*.

The Tierra Grande Formation has been described by Iturralde-Vinent (1976) as formed by a flysch-like sequence of basal volcanic conglomerates with calcareous cement, fine-grained sandstones, limolites, biocalcarenites and marls. The formation is exposed in La Alcarraza, Mayari Arriba and the east-northeast of Sagua de Tanamo basin. In La Alcarraza locality, the section is formed by a basal angular volcanic conglomerate and towards the top by a sequence of limestones and marls. The biocalcarenites are formed by clasts of reef limestone with corals, algae and miliolids that display a typical rhythmicity of turbiditic origin. Intraformational breccias are observed in the northern sector of Mayari Arriba. Fernández *et al*. (1991) related the Gran Tierra formation to two distinct sources for the turbiditic deposits, derived from reefs and from the volcanic and serpentinitic terrains. The fossils include foraminifera *Globorotalia imitata, G. pseudobulloids* and *G. trinidadensis*, and ostracoda *Hermanites* sp., *Bairdia* and *Xestoleberis* sp., which are indicative of an early Paleocene age.

A total of 62 samples were collected from a section of the Micara Formation in the Calabazas locality, within the Guantánamo area of eastern Cuba (Figure 2). The section, named the Calabazas section, is about 35 m thick (Figure 3) and is characterized by an alternancy of about 24 thick calcareous sandstone beds, spaced about every 1 to 3 m. Samples were collected in standard non-magnetic plastic cubes of about 12 cc.

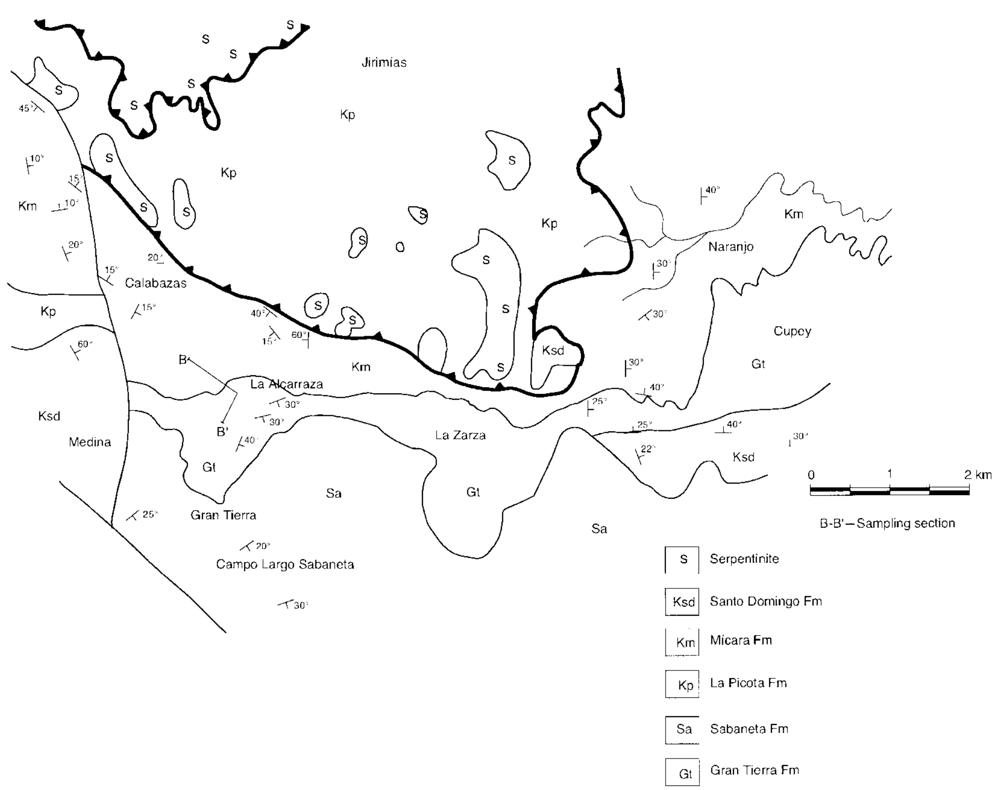

Fig. 2. Schematic map of the Mayari Arriba-La Alcarraza area in the Oriente Province, Cuba and location of study section in the Calabazas area. Figure taken from the study by Fernández *et al*. (1991).

Fig. 3. Partial view of the Calabazas section in eastern Cuba.

ROCK-MAGNETIC STUDY

The low-field magnetic susceptibility was measured with the MS2 Bartington susceptibilitymeter at low (Hz) and high (kHz) frequencies. The intensity of natural remanent magnetization (NRM) was measured with the Molspin fluxgate spinner magnetometer. The magnetic coercitivity was investigated by imparting the samples a laboratory remanence with the application of high magnetic fields at various steps with a pulse magnetizer. The resulting isothermal remanent magnetization (IRM) was measured in the Molspin magnetometer after application of each magnetic field step, until saturation was reached. Further investigation of the coercivity spectra and magnetic mineralogy was achieved by measuring the hysteresis loops in micro-samples with a MicroMag instrument.

The low- and high-frequency magnetic susceptibility is plotted as a function of stratigraphic position in Figure 4 a and b, respectively. The values are lower than 40 x 10^{-5} SI, except for the horizon between 3 and 5 m in which these values are higher. Maximum values are about 90 x 10^{-5} SI, and occur at about 4 m. In the rest of the section the susceptibility fluctuates between 5 x 10^{-5} SI and 38 x 10^{-5} SI, around about 20 x 10^{-5} SI. The pattern resembles the fluctuations typically documented in sedimentary sections that indicate variation in the amount of magnetic minerals being deposited. The NRM intensity plotted as a function of stratigraphic position shows three peaks at about 4 m, 12 m and 20 m (Figure 5a). The highest values of about 17 mA/m and 14 mA/m occur at 20 m and 12 m, respectively. The intensity at 4 m is about 7 mA/m. In the rest of the section, intensities fluctuate around 1 mA/m, with several minor maxima up to 3 mA/m. The saturation IRM intensity shows maximum values of up to 22 A/m at 12 m and about 7 A/m at 4 m. For comparison of the coercivity spectra of the samples, the intensities after the 100 mT and after saturation were plotted as a function of stratigraphic position (Figure 5 b and c). The IRM intensity after application of a 100 mT field display a similar pattern, with maxima of about 9 and 4 A/m at 12 and 4 m, respectively. The corresponding ratios indicate that the partial IRM for samples at 4 m are higher than those at 12 m. This is consistent with the results of the individual IRM acquisition curves.

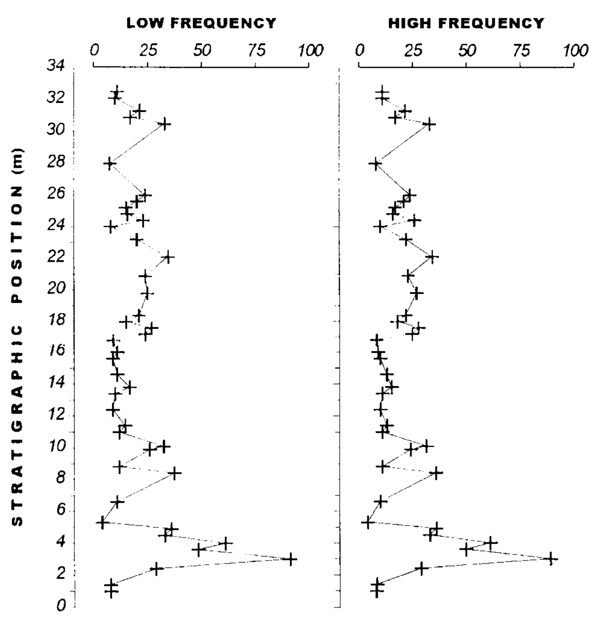

Fig. 4. (a) Low-field magnetic susceptibility at low frequencies plotted as a function of relative stratigraphic position through the sequence. (b)Low-field magnetic susceptibility at high frequencies plotted as a function of relative stratigraphic position through the sequence.

Examples of hysteresis loops obtained with the MicroMag are illustrated in Figure 6. The field is given in Teslas (T) and the magnetization in nano-Ampere-meter (nAm). The loops have been corrected for the paramagnetic contribution, and the corresponding slope correction in uAm/T is listed in the summary table in the graphs. A plot (Figure 7) of the ratios of remanent magnetization (Mr) to saturation magnetization (Ms) as a function of the coercivity ratio (remanent coercivity/saturation coercivity, Hr/Hc) indicates that the magnetic carriers lie in the range of pseudo-single domain behavior (Day *et al*., 1977). The mineral assemblage is relatively homogenous, independent of stratigraphic position within the section (Figure 7).

DISCUSSION

Smit and Kyte (1984) examined the K/T boundary sections of Furlo and Petriccio in the Umbria province of Italy and showed that they were characterized by siderophile-rich magnetic spheroids. The spheroids contain small crystals of magnetite (in the range 1 to 50 µm). These magnetites display skeletal and well-developed dendrites that indicate rapid crystallization from a high-temperature liquid rich in Fe, Ni, Mg and Al. The magnetic spheroids present high abundances of Ir, as well as of Pd, Os, Pt and Au, which supports a close relation to the K/T impact (Montanari *et al*., 1983; Smit and Kyte, 1984). Urrutia-Fucugauchi (1992) examined the rock-magnetic properties of the K/T boundary section in Gubbio, Italy and reported the presence of a sharp magnetic anomaly in the K/T boundary clay, associated with the siderophile-rich spheroids. Coercivity analysis showed that the anomaly is due to low-coercivity minerals of the titanomagnetite series, likely fine-grained magnetite with single- or pseudo-single domain behavior. Worm and Banerjee (1987) reported the occurrence of a magnetic anomaly characterized by high magnetic susceptibility values in the Petriccio section, Italy and marine sediment DSDP sections. Subsequent studies have documented the occurrence of a sharp magnetic anomaly at other K/T sections in Europe such as the classic Gubbio section, Italy (Urrutia-Fucugauchi, 1992), the Caravaca section, southern Spain (Urrutia-Fucugauchi and Osete, 1993) and

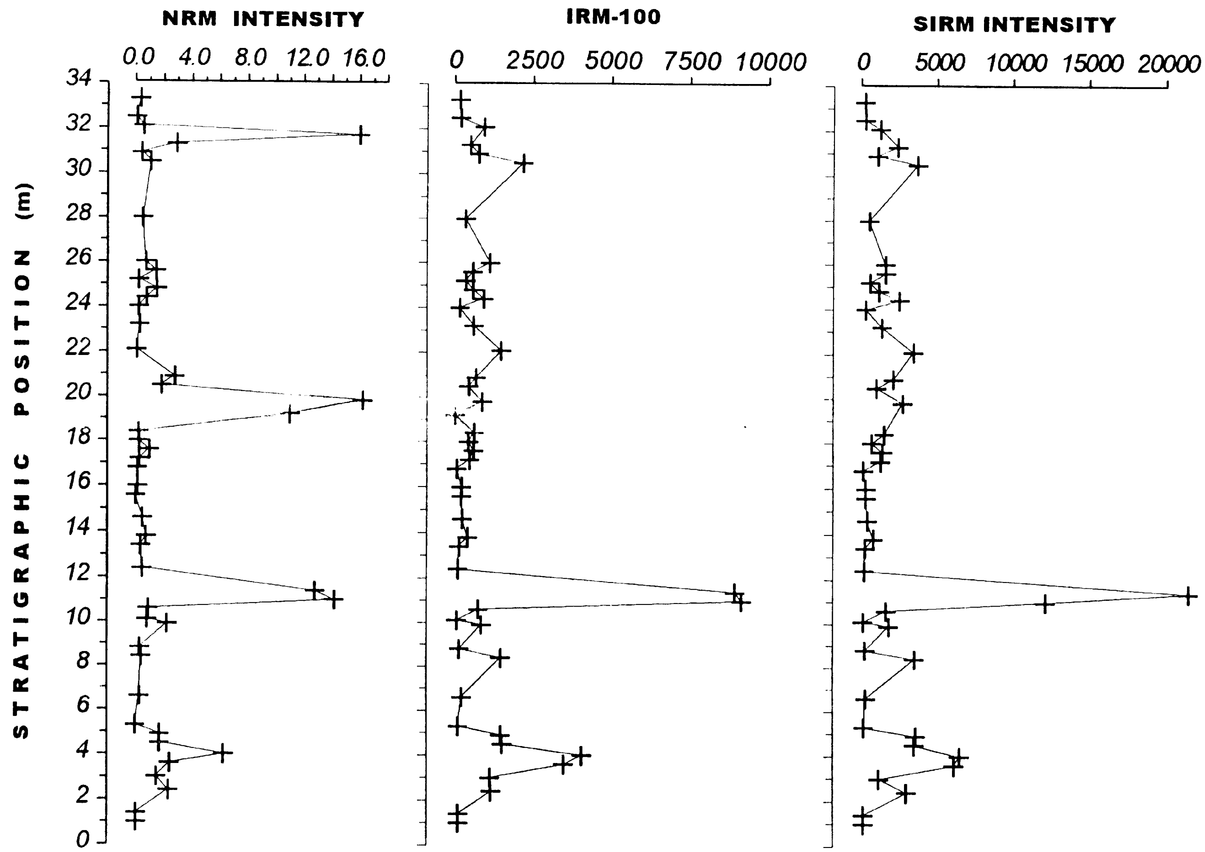

Fig. 5. (a) Natural remanent magnetization (NRM) intensity plotted as a function of relative stratigraphic position through the sequence. (b) Partial isothermal remanent magnetization (IRM) intensity measured after application of a 100 mT field plotted as a function of stratigraphic position. (c) Saturation isothermal remanent magnetization (IRM) intensity plotted as a function of stratigraphic position.

in the Guayal and Bochil sections, southern Mexico (Urrutia-Fucugauchi *et al*., 1995).

In the Calabazas section, there is a magnetic susceptibility peak at around 4 m (Figure 4). This maximum of 90 x 10^{-5} SI is about 4.5 times the average values in the rest of the section. The corresponding NRM and IRM intensities are 7 mA/m and 7 A/m, respectively, which are higher than the average values through the section (Figure 5). NRM intensities are around 1 mA/m and IRM intensities are around 1 A/m. In the NRM intensity record (Figure 5a), there are two larger peaks at 12 and 20 m, with values up to 14 and 17 mA/m. The 12 m anomaly shows an IRM value of about 22 A/m that is much larger than the value at the 4 m level (Figure 5c). The IRM to NRM and partial IRM to saturation IRM ratios and analysis of the IRM acquisition curves indicate that the magnetic minerals correspond to low coercivity titanomagnetite minerals. The hysteresis curves indicate the presence of fine-grained magnetites with pseudo-single domain behavior (Figures 6 and 7). The magnetic susceptibility peak at 4 m is similar in magnitude to that documented for the K/T boundary in other sections. Using either the susceptibility or the saturation IRM intensity as proxy measures of the relative concentrations of magnetic minerals, it seems that the enhancement is lower than that in the Gubbio and Caravaca sections, but of similar magnitude than that recorded in the Guayal and Bochil sections. For instance, the magnetic susceptibility anomaly of the sections in southern Mexico are about 3 to 4 times the section background (Urrutia-Fucugauchi *et al*., 1995). The magnetic anomaly at 4 m may thus correspond to the K/T boundary anomaly and the bulk of the Calabazas section to the Paleocene, with the lower 4 m of Maastrichtian rocks.

However, attempts to isolate magnetic spheroids in the samples corresponding to the anomaly horizons of 4 m, 12 m and 20 m were unsuccessful. Magnetic minerals may not reside in siderophile spheroids but in detrital or autigenic minerals in the sediments (e.g., enhancement related to increased erosion periods). This interpretation is supported by the pattern of fluctuations in the various magnetic parameters. The magnetic susceptibility values show a pattern of maxima and minima through the section, in addition to the maximum at 4 m, which are characteristic of sedimentary patterns related to variation in input of magnetic minerals into the basin. Although the peak at 4 m is similar in magni-

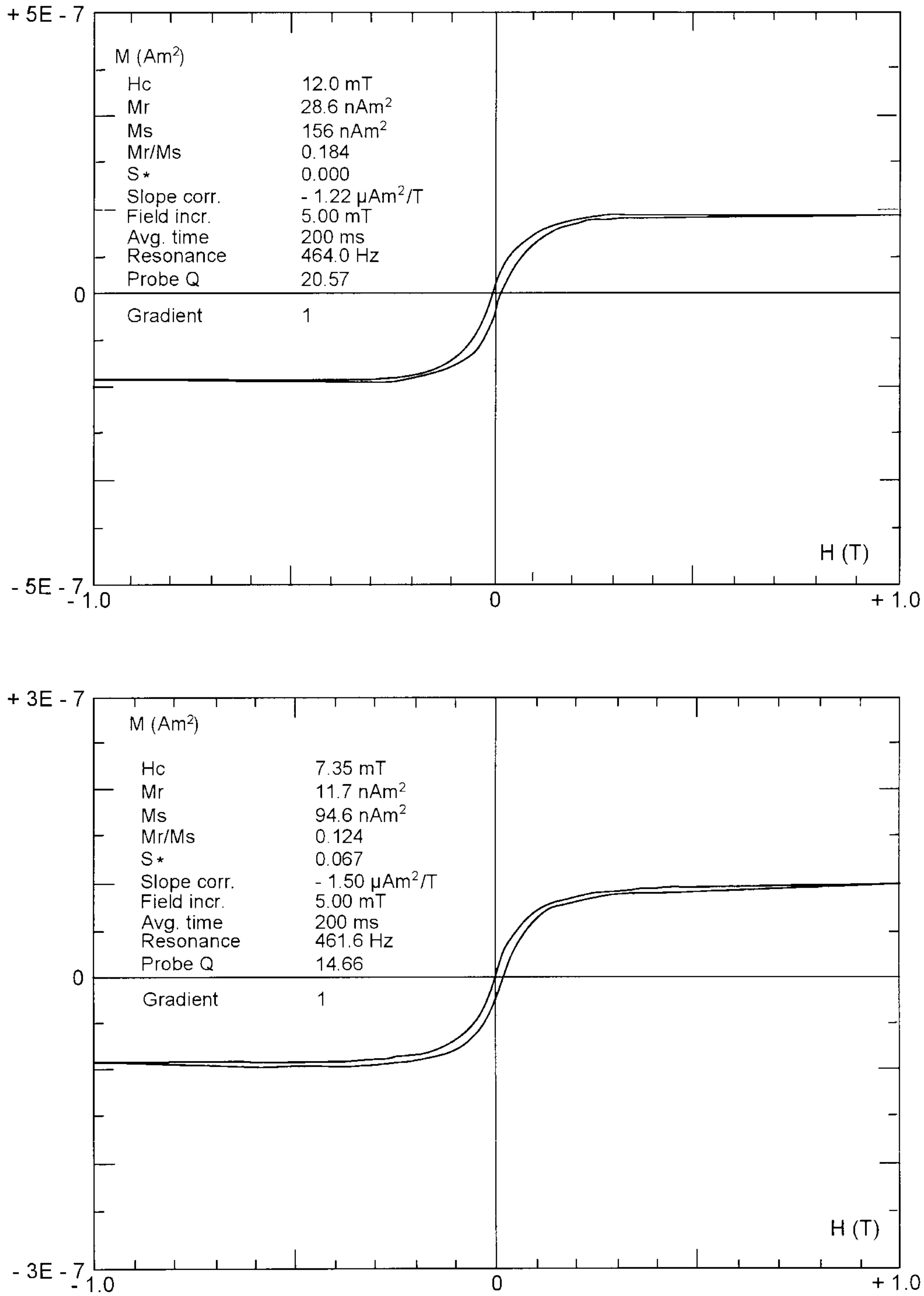

Fig. 6. Examples of magnetic hysteresis curves for samples of the Calabazas section. The corresponding hysteresis parameters are included in the tables: Hc, coercivity, Mr, remanent magnetization, and Ms, saturation magnetization. The slope correction refers to the contribution of paramagnetic minerals. The units of magnetization are in Ampere –square meter and the units of applied magnetic field are in Teslas. Measure ments are carried out in a MicroMag instrument with magnetic field increments of 5 mT.

tude to that observed in other K/T sections, the peak is considerably wider. In the Calabazas section the peak is about 2 m wide, which may be related to the sedimentary environment. Deposition of deep-sea carbonate sediments involves relatively little terrigenous input, unlike complex conditions prevailing in siliciclastic flysh sequences, with lithological changes and contrasting sediment sources. The magnetic anomalies in the Gubbio and Caravaca carbonate sections are characterized by sharp narrow peaks, indicating that the magnetic spherules lie within a small range in the boundary unit in contrast to the relatively wide Ir anomaly peaks. The apparent absence of siderophile-rich spheroids and the wide

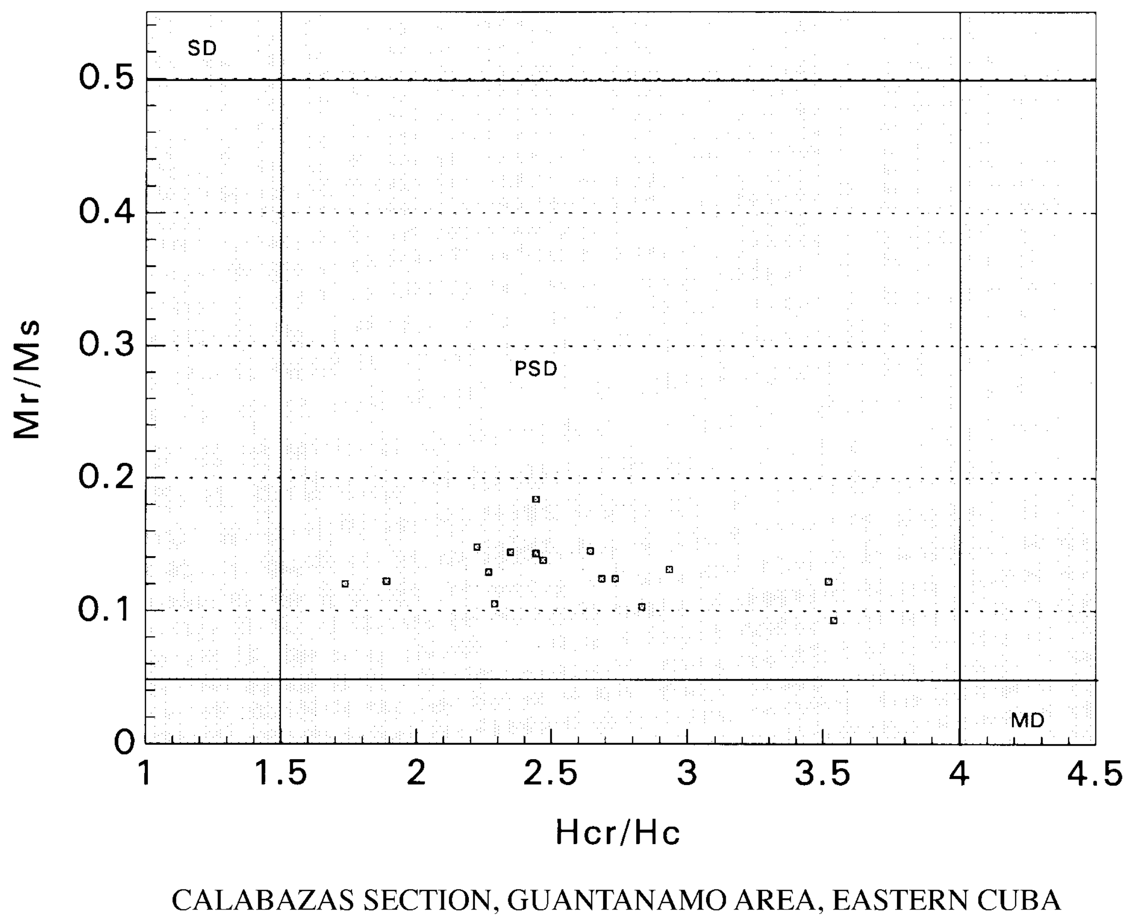

Fig. 7. Magnetic hysteresis diagram showing the ratios of remanent magnetic coercivity (Hcr) – magnetic coercivity (Hc) versus remanent magnetization (Mr) – saturation magnetization (Ms). The relation between the two ratios allows identification of the magnetic state: single domain (SD), pseudo-single domain (PSD) and multidomain (MD). Note that the hysteresis parameters for the Calabazas section plot in the PSD field, forming an elongated distribution with low Mr/Ms values and a wider distribution of Hcr/Hc values.

magnetic anomaly peak in the Calabazas section suggest that the enhancement in magnetic properties may be related to sedimentary effects and that the anomaly at 4 m does not correspond to the K/T boundary. The magnetic minerals present a relatively homogenous distribution within the pseudo-single domain field in the hysteresis plot of Mr/Ms versus Hcr/Hc (Figure 7). In this interpretation, the section lies in the Paleocene. The paleontological observations of the foraminiferal assemblage in the nearby Alcarraza section by W. Stinnesbeck (personal communication, 1998) are consistent with this interpretation. The Alcarraza section consists of a rythmic sequence of sandstones, siltstones, shales and a few conglomerates. The age is mid-Paleocene, with the upper limestones and marls in the Eocene (W. Stinnesbeck, personal communication, 1998). The position of the K/T boundary in the Calabazas section was defined by Fernández *et al*. (1991) based on lateral correlations referred to the Alcarraza section. Our results indicate the need for further study of the stratigraphic relationships.

CONCLUSIONS

The study of rock magnetic properties of sediments from the 35 m thick Calabazas section identifies three horizons at 4, 12 and 20 m (measured from the base of section) marked by increase in relative content of magnetic minerals. The 4 m horizon is characterized by magnetic susceptibility values of about 90 x 10^{-5} SI, whereas in the rest of the section values are around 20 x 10^{-5} SI. The NRM and IRM intensities are about 7 mA/m and 7 A/m, respectively. The 12 m horizon is characterized by 22 A/m IRM intensity and 14 mA/m NRM intensity. The 20 m horizon is characterized by 16 mA/m NRM intensity and 3 A/m IRM intensity. The magnetic peak at 4 m corresponds to the larger concentration of magnetic minerals (magnetite with pseudo-single domain behavior). The stratigraphic variation of magnetic properties and the characteristics of the anomaly peaks can be interpreted in terms of depositional conditions.

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