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Magnetic features of marine black turtle natal beaches and implications for nest selection

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Resumen

Las playas de Colola y Maruata en la costa de Michoacán en el sur de México constituyen dos de los sitios principales de anidación de la tortuga marina negra *Chelonia agassizi*. Los hábitos migratorios de las tortugas marinas, su capacidad de navegación en mar abierto y su habilidad para retornar a sus lugares de nacimiento han sido investigados con base en su capacidad para utilizar claves magnéticas para orientar su navegación a larga distancia. Las tortugas marinas quizás también utilicen claves magnéticas para refinar su posición geográfica una vez ubicadas en sus áreas y playas natales. En esta nota, presentamos resultados sobre las características de las propiedades magnéticas de las arenas de las playas natales. Los datos de histéresis magnética permiten caracterizar los ambientes magnéticos de las playas natales y no natales. Pensamos que estos resultados tienen implicaciones en el proceso de identificación y selección de sitios de anidación.

Palabras clave: Tortuga marina negra, magnetismo de rocas, arenas de playa, playas de Colola y Maruata, sur de México.

Abstract

The beaches of Colola and Maruata, Michoacán, southern México are nesting places of the marine black turtle, *Chelonia agassizi*. Marine turtles use magnetic cues to orient their long distance navigation, and might also use magnetic such to refine their geographical position within their natal area. We present results on the characterization of nesting beaches in terms of magnetic properties. Hysteresis parameters may allow distinguishing nesting from non-nesting beaches. The results may have implications for the selection and identification of nesting sites by marine black turtles, in the context of magnetic orientation mechanisms.

Key words: Marine black turtles, rock magnetism, beach sands, Colola and Maruata beaches, southern Mexico.

Introduction

The migratory behavior of marine turtles and their ability to navigate across vast distances along the open ocean have long been studied. Marine turtles show remarkable accuracy for navigating between distant feeding sites and their natal areas (e.g., Koch *et al*., 1969; Lohmann *et al*., 1999; Lohmann and Lohmann, 1996; Avens and Lohmann, 2003). The nature and sources of long-range orientation cues used by sea turtles for long distance navigation, positional accuracy and homing have been a matter of intense research for the last several years. Navigational cues are derived from the earth´s magnetic field parameters. Once in the natal rockeries and within the beaches' local settings, turtles also need to identify their natal beach and to pin point the best nesting site. Very little is known on the informational elements that guide such behaviors (Carr, 1967, Kamel and Morosovsky, 2004, 2005 and 2006), but local magnetism might be a source of useful information (reviewed in Freake *et al*., 2006). In this note, we present some initial results on the magnetic characterization of Colola and Maruata beach sands and implications for nesting site selection. Colola and Maruata beaches are among the main nesting sites of the black sea turtle *Chelonia agassizi* (Alvarado and Figueroa, 1989, Alvarado and Delgado, 2001).

Colola and Maruata Beaches

These protected beaches extend for some 12.4 km on the Pacific coast of Michoacan, Mexico. Maruata beach is located at 18° 16’ N, 103° 20’ W. It is an arcuate beach some 40 m wide and 2.3 km long within a small bay enclosed by tall intrusive rocks that includes Cerro Centinela. Colola beach is at 18° 18’ N and 103° 26’ W (Fig. 1). It is an elongated open beach some 150 m wide and 4.8 km long. Morphological studies of Pacific ocean coast have been reported by Ramírez-Herrera and Urrutia-Fucugauchi (1999). Samples from nesting and non nesting areas were collected at eleven sites along Colola and at nine sites along Maruata. Some samples were also collected from La Ticla and Llorona non - nesting beaches, which are located farther northwest. Several samples were collected at each site, and they were further divided into representative fractions for the analyses.

Rock Magnetic Properties

Samples for measuring magnetic susceptibility and the intensity of remanent magnetization (NRM) were placed in acrylic 12cc cubes. Smaller sample fractions of less than few micrograms were also used to carry out experiments aimed at determining magnetic hysteresis and the acquisition/saturation of isothermal remnant magnetization (IRM) through magnetization/demagnetization experiments. Low field magnetic susceptibility was measured with the Bartington MS-2 system equipped with the dual frequency sensor. Measurements were taken at low and high frequencies to determine the frequency dependence of susceptibility, which was estimated in terms of the frequency dependence factor (fd). Susceptibility data is reported in terms of mass susceptibility. The NRM intensity was measured with the JR-5 spinner magnetometer (calculated after four-orthogonal measurements). Results are summarized in Table 1. The susceptibility and NRM intensity were higher in Maruata sites than in Colola sites. An interesting feature is the wide range of variations in the magnetic parameters, which likely reflects spatial distribution and transport processes in the beaches. The spatial variability is reflected in both NRM intensities and magnetic susceptibility suggesting that magnetic minerals occur in different concentrations and grain sizes. Magnetic susceptibility depends on magnetic mineral concentration and mineral type (particularly iron oxides). For comparison, we included initial data from La Ticla and Llorona beaches. These two beaches were selected for the study because they represent non-natal beaches (Fuentes-Farias, 2008). Both La Ticla and La Llorona showed similar values of the magnetic parameters even

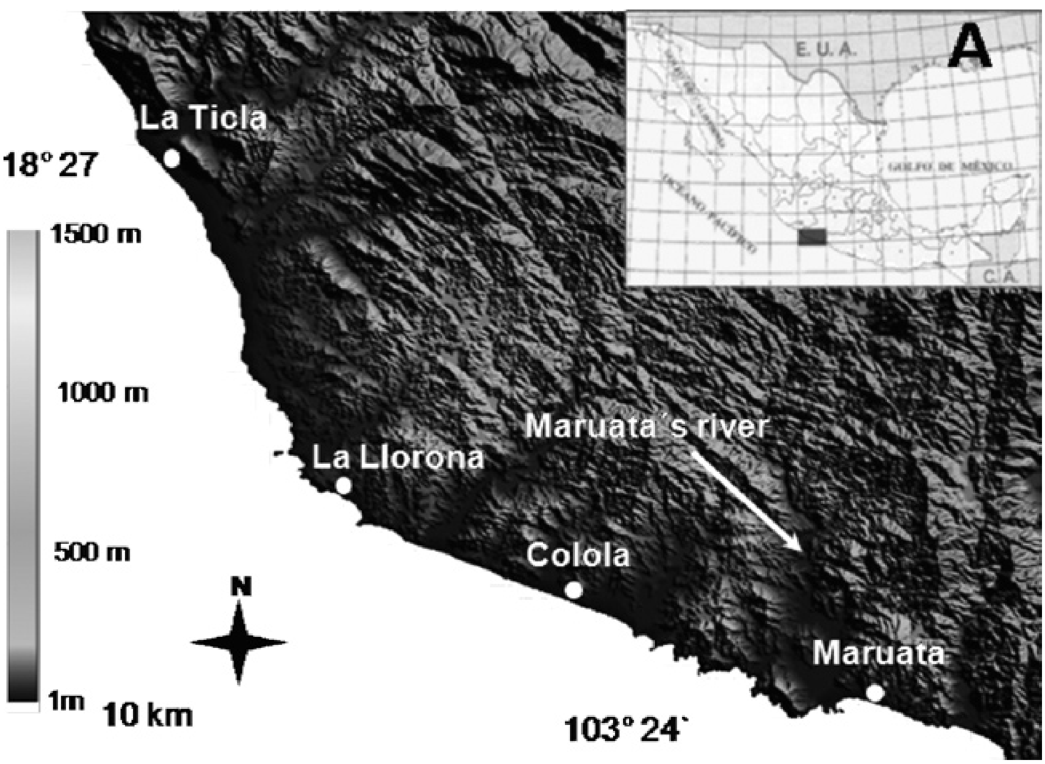

Fig. 1. Digital model of the terrain of the southwest coast of Michoacan, Mexico. The location of studied beaches La Ticla, La Llorona, Colola and Maruata is shown. The map of the Mexican Republic in the upper right corner (A) illustrates location of the quadrant from where the digital model was generated.

though they are geographically distant one from the other. Finally, in Table 2, we separated the data of natal beaches into two groups, namely, nesting and non-nesting sites. In Maruata, the non-nesting sites tended to present higher values of magnetic susceptibility and NRM intensity. The opposite was true for Colola.

Table 1

Remanent intensity and susceptibility values of sand samples obtained from Colola, Maruata, La Llorona and La Ticla.

Beach	Susceptibility (Mass Susceptibility)		Intensity (A/m x 10^{-6})
	HF	LF	
Maruata n=9	166.8+164.1	183.7+182.6	68.3+83.1
Colola n=11	9.2+7.2	9.4+7.3	3.3+2.4
Llorona n=3	19.8+2.3	18.6+2.8	4.2+0.9
La Ticla n=3	17.6+1.92	17.03+1.9	12.1+10.6

HF, obtained under high frequency magnetic fields
LF, obtained under low frequency magnetic fields

The magnetic hysteresis loops, isothermal remnant magnetization (IRM) acquisition curves and backfield demagnetization of saturation IRM were measured with the MicroMag system. Hysteresis loops and IRM curves were measured following increments of the magnetic field for up to 1.5 teslas. Examples of magnetic hysteresis loops and IRM acquisition and saturation IRM demagnetization curves for samples of Colola and Maruata beaches are shown in Figs. 2 and 3, respectively. Analyses of the magnetic hysteresis data was performed based upon hysteresis parameter ratios and domain states by using the plot of magnetization ratios (Mr/Ms), as a function of coercivity ratios (Hcr/Hc). The plot was used to separate domain fields for single (SD), pseudo-single (PSD) and multiple (MD) domains (Day *et al*., 1977; Dunlop, 2002). Results for samples from the four beaches are summarized in Fig. 4 in the Day diagrams. Most samples showed particles within the PSD and MD fields (Fig. 4). Hysteresis parameter ratios show distinct trends for La Ticla and La Llorona. These beaches were characterized by scattered ratio values of PSD particles with contributions from very fine grained to superparamagnetic (SPM) ones, particularly for La Llorona. Samples from La Llorona also contained material with MD states that were not present in La Ticla. In contrast, the hysteresis parameter ratios in Maruata and Colola were characterized by two linear trends in the PSD and MD fields, indicating variable contributions from SD and MD particles with varying grain sizes and domain states. Colola had a trend to display greater particle size. Ocurrence of very fine grained particles with superparamagnetic behaviour may enhance magnetic viscosity (Urrutia-Fucugauchi, 1981, Thompson and Oldfield, 1986). Additional analyses are needed to confirm and quantify the relative contributions.

The initial magnetic hysteresis data pointed to different trends among the beaches, indicating different assemblages of magnetic minerals (types and grain sizes). For Colola and Maruata, there were marked differences in the domain state (grain size). Colola showed apparent differences along the beach between nesting and non-nesting areas. Interestingly, such differences correlated with the distribution and the number of nests in the western, central and eastern sectors of the beach (Fuentes-Farias, 2008); black turtle nest preferentially in the western (around 800 m long) and central (around 350 m long) sectors of Colola (Alvarado and Figueroa, 1989). Then, to further characterize potential differences, additional samples were collected from nesting and non nesting sites. In Fig. 5, data for nesting and non nesting sites in Colola beach are plotted. The results show a trend across the PSD and MD state fields. The trend can be interpreted in terms of grain size variation, with domain states from SD to MD. Sand samples from non nesting areas fall into the PSD and MD fields, indicating larger grain sizes as compared with sand samples from nesting sites (Fig. 5).

Table 2

Magnetic parameters of the sand of nesting and non-nesting sites along Colola and Maruata beaches, Coast of Michoacan.

Beach	Susceptibility (Mass Susceptibility units)				Intensity (A/m x 10^{-6})	
	Nesting		Non/nesting		Nesting	Non/nesting
	HF	LF	HF	LF		
Maruata n=6	65+37	66+38	109+112	116+118	10+6	17+24
Colola n=6	20+11	21+ 11	6+1	6+1	5.6+0.2	1.2+0.6

HF, obtained under high frequency magnetic fields
LF, obtained under low frequency magnetic fields

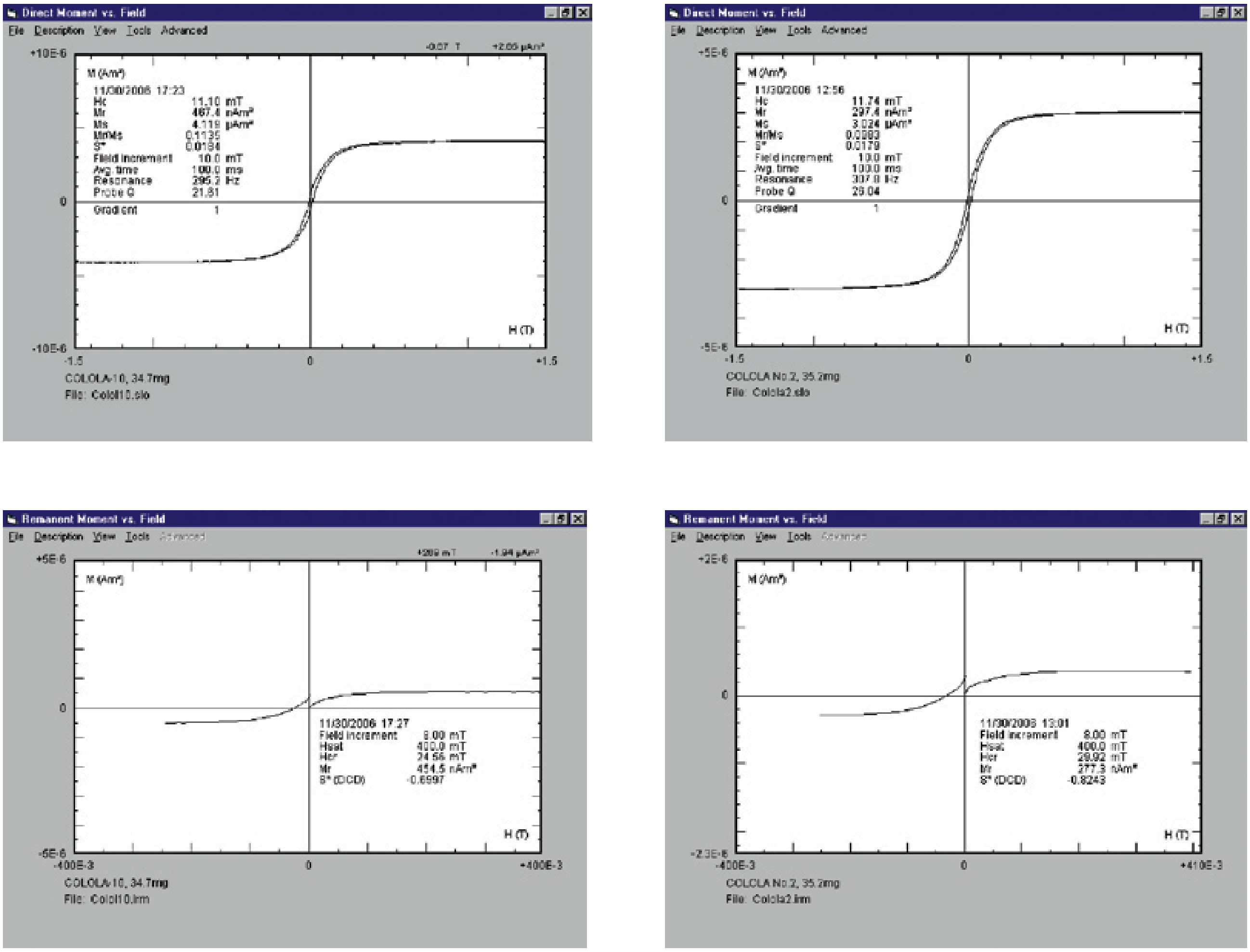

Fig. 2. Examples of magnetic hysteresis loops (upper diagrams) and IRM acquisition and saturation IRM demagnetization (lower diagrams) for sand beach samples from Colola beach.

Discussion and conclusions

Literature often comments on the ability of marine turtles to return to their natal beaches and nesting sites in a non-random, predictable fashion (Camhi, 1993 cited by Wood and Bjorndal, 2000; Nordmoe *et al.*, 2004; Weishampel *et al.*, 2006; Xavier *et al.*, 2006). Authors have attributed such a fidelity to sand humidity, pH, temperature, grain size, presence of organic matter and beach slope (Stancyk and Ross, 1978, Mortimer; 1990; Flores, 1992; Wood and Bjorndal, 2000; Kamel and Mrosovsky, 2004, 2005, 2006; Weishampel *et al.*, 2006). Magnetic characteristics of beach sands may also play a role. We measured low field susceptibility, remnant magnetization, NRM intensity, hysteresis parameters and IRM acquisition and saturation IRM demagnetization in sand samples of nesting and non-nesting sites along Colola and Maruata beaches. Overall, magnetic hysteresis data showed distinct trends among the beaches, indicating different assemblages of magnetic minerals among natal and non-nesting beaches. The distribution of domain states in Colola and Maruata was similar. La Llorona and La Ticla differed between them and from the nesting beaches.

Hysteresis parameter ratios for nesting and non nesting sites in Colola beach trend across the PSD and MD state fields, which can be interpreted in terms of grain size variation, with domain states from SD to MD. Sand samples from non-nesting areas fell preferentially into the PSD and MD fields, indicating larger grain sizes as compared with sand samples from nesting sites (Fig. 5). At Colola, values of magnetic susceptibility and NRM intensity are low but nesting areas show slightly higher values than in the non-nesting areas. At Maruata, where

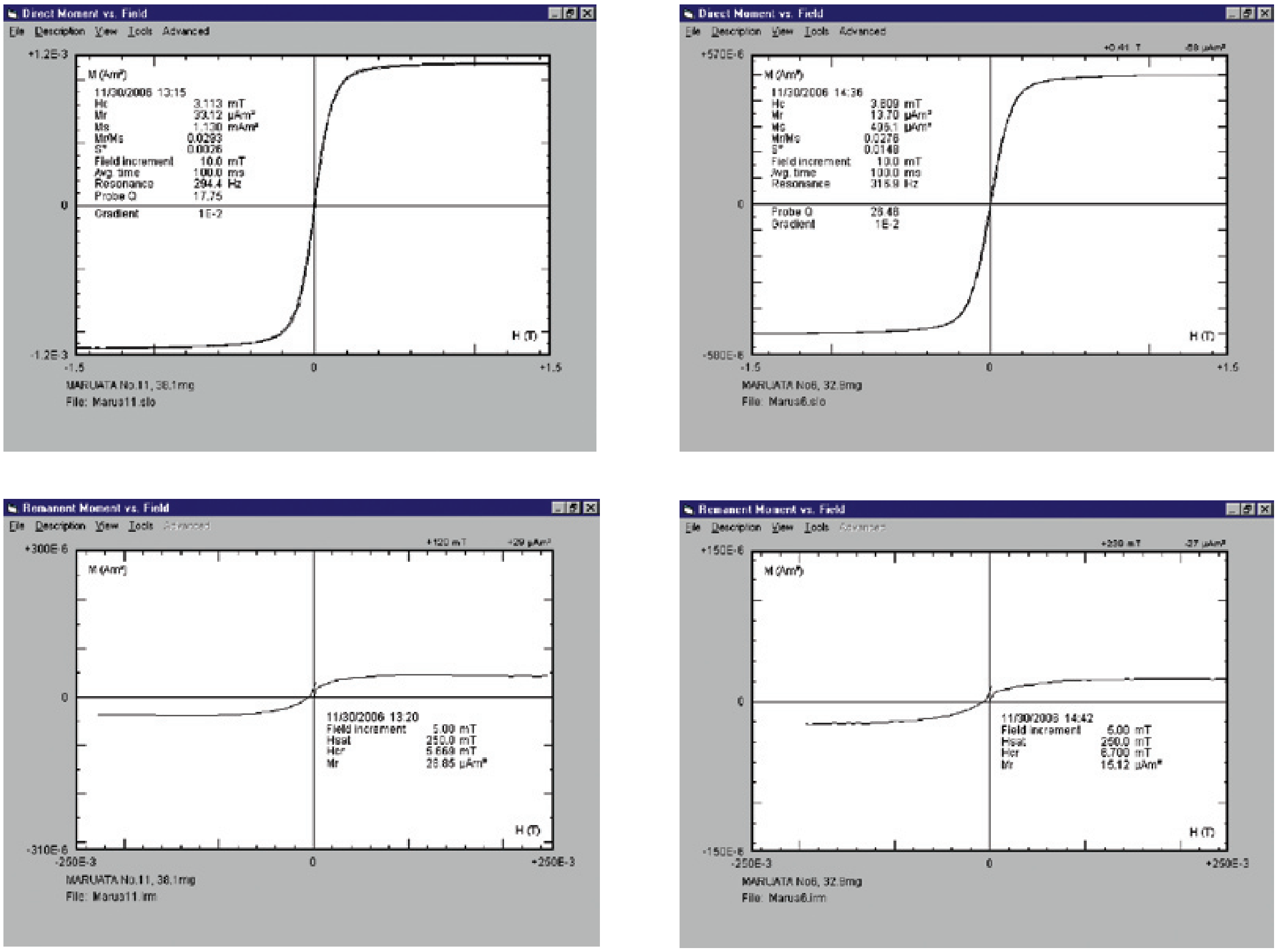

Fig. 3. Examples of magnetic hysteresis loops (upper diagrams) and IRM acquisition and saturation IRM demagnetization (lower diagrams) for sand beach samples from Maruata beach.

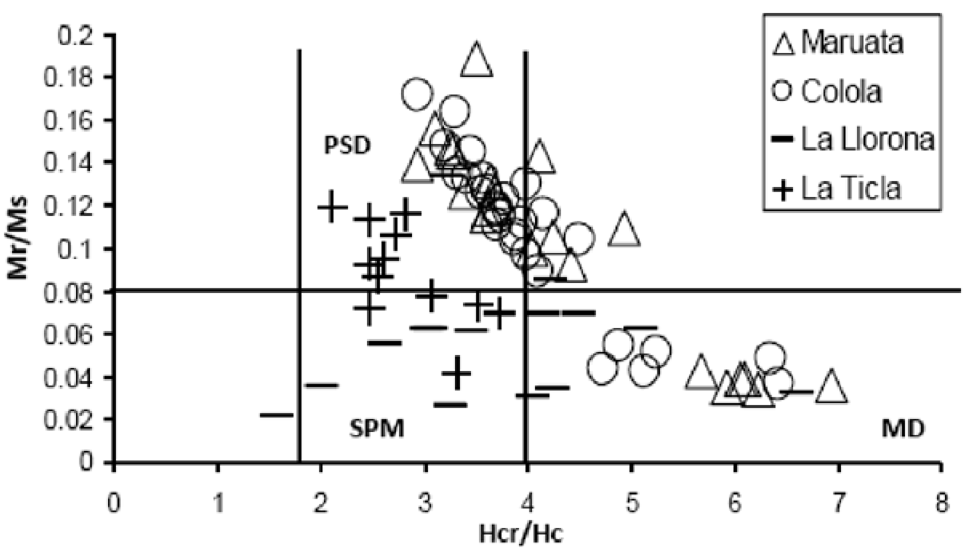

Fig. 4. Plot of magnetic hysteresis parameter ratios for beach sand samples from Colola and Maruata beaches. Data from Llorona and La Ticla beaches are also included for comparison. Domain state fields are given by PSD, pseudo-single domain, MD, multidomain and SPM, superparamagnetic. Observe the distinct distribution patterns among the ratios for the different beaches. See text for discussion.

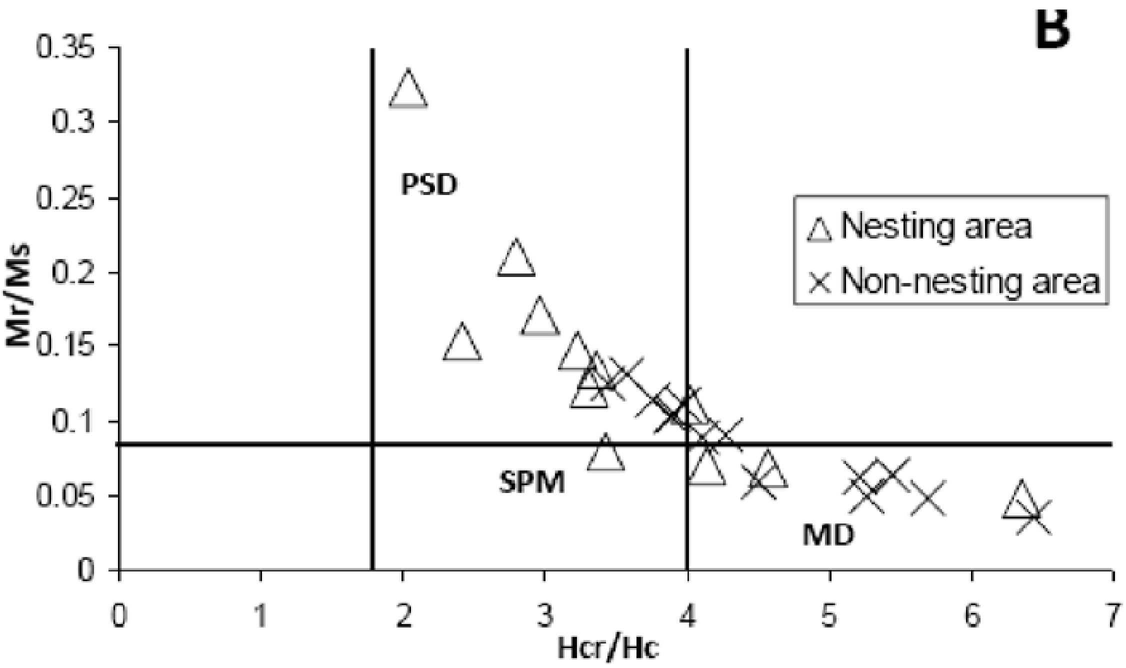

Fig. 5. Plot of magnetic hysteresis parameter ratios for samples from nesting and non nesting sites in Colola beach. Observe the trend defined by the data across the PSD and MD fields and the trend to MD values for non nesting sites. Compare with the diagram of Fig. 4 (please note change of vertical and horizontal scales).

magnetic susceptibility and NRM intensity are highest there was a mild trend for preferred nesting areas to have greater values in both parameters. At Colola beach, fine-grained magnetic particles are present, with SP and PSD domain states of sand grains in preferred nesting areas (Fig. 5). Non-preferred nesting areas have larger magnetic grain sizes, with MD domain states. Thus the magnetic moments of particles in the samples of preferred nesting areas tended to be more homogenous and suggested more stable magnetic microhabitats. The discrepancies observed between natal beaches might be explained by the fact that Maruata is subjected to higher levels of anthropogenic activity.

Our results may justify carrying out further studies aimed at evaluating the discrimination thresholds of the magnetic perception of black turtles to determine whether the sensitivity of the presumptive magnetoreceptor is sufficiently high to detect such small magnetic differences between the sand of nesting and non-nesting areas. This type of information is not available though the ability of sea turtles to perceive changes in the parameters of the earth's magnetic field is well documented. Future studies should also investigate the influence of the magnetic characteristics of the beach sand on the turtle's beach fidelity and nest site selection, as magnetite content may influence directly or indirectly grain size, color, temperature, humidity and compactness of the sand (U.S. Fish & Wildlife Service, 1999; Byrd, 2004).

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