



## MAGNETIC MINERALOGY OF OCEANIC ANOXIC EVENT (OEA1) AND CRETACEOUS OCEANIC RED BEDS FROM POGGIO LE GUAINE DRILL CORE, CENTRAL ITALY

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### ABSTRACT

The Aptian is characterized by important global climatic events (marked in the sediments by Oceanic Anoxic Events, OAEs, and Cretaceous Oceanic Red Beds, CORBs) that affect the input of terrigenous minerals and the local redox environment in the deep sea. The resulting magnetic mineralogy is thus controlled by these two factors and can be used as a proxy for the environmental changes throughout this period. We studied magnetic mineralogy variations on upper Barremian to lower Aptian pelagic sediments of Maiolica and Marne a Fucoidi formations at the Poggio le Guaine Core Drill Core, sampled in central Italy. Magnetic susceptibility, isothermal remanence magnetization acquisition curves, thermomagnetic curves, hysteresis curves and first order remanence curves (FORC) diagrams were measured in samples of different lithologies (black shales, gray olive marlstone, and reddish marlstone). Our data shows variations at the onset of the OAEs and CORBs at the lower Aptian, when an increase in concentration parameters precedes two of the major anoxic events, the Selli and Noir levels.

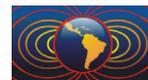
**Keywords:** Magnetic Mineralogy, Ocean Anoxic Events, Cretaceous Oceanic Red Beds, Paleoenvironment.

### Introduction

The Aptian period (126.3-112.0 Ma, Ogg, 2012) is characterized by important variations on the Earth's envelopes, from the core to the hydrosphere and the atmosphere (Skelton *et al.*, 2003; Föllmi, Gainon, 2008; Biggin *et al.*, 2012; Föllmi, 2012). One of the most important events is the Cretaceous Normal Superchron (or C34), when the geomagnetic field did not experience reversals for approximately 35 Ma. The Aptian is also interesting for the extensive changes in the ocean-climate system (Skelton *et al.*, 2003). For example, several Oceanic Anoxic Events (OAE1a to OAE1d) (Schlanger, Jenkyns, 1976; Arthur *et al.*, 1990) and Oceanic Red Beds (ORB) (Wang *et al.*, 2009) take place in this period pointing to episodic changes in redox conditions at the ocean bottom, and rapid biotic turnovers (Leckie *et al.*, 2002).

An accurate determination of the magnetic mineralogy in the weakly magnetic carbonate rocks is crucial to determine their magnetic carriers in paleomagnetic studies. But in addition to that, the type and relative amount of magnetic minerals can also provide information about the formation, transport, deposition, and post-depositional alteration of the rocks and its magnetic minerals (*e.g.* Liu *et al.*, 2012).

Here, we will present a preliminary study of the magnetic mineralogy of rocks from the Poggio le Guaine Drill Core (PLG Core), central Italy. A detailed study of magnetic mineralogy is important as a complementary dataset to provide a high-resolution age model and a high-resolution relative magnetic paleointensity

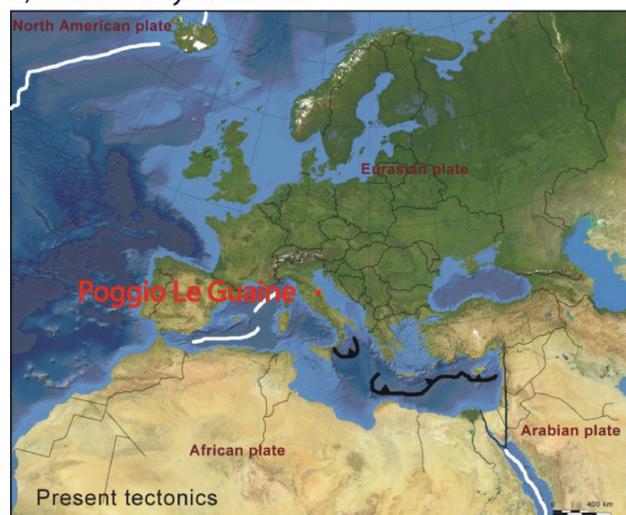


reference curve for the Aptian interval. Here, the magnetic mineralogy will be used to provide information about changes in paleoredox conditions at OAE and ORB paleoclimatic events.

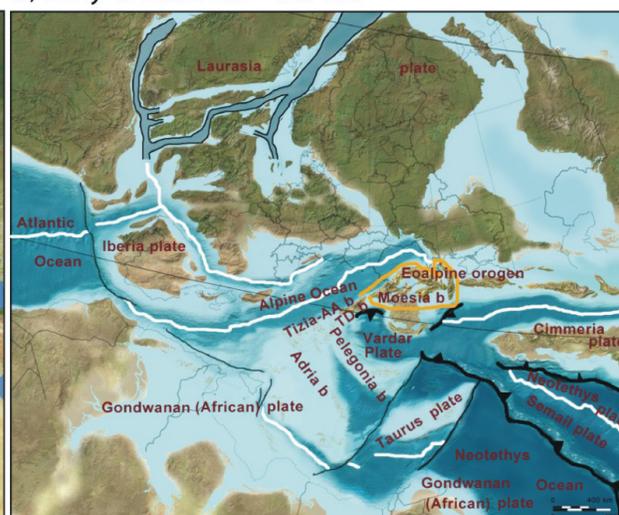
### Geological setting, materials and methods

The Poggio le Guaine core (lat. 43° 32' 42.72" N; long. 12° 32' 40.92" E) was drilled at Monte Nerone, to the west of the town of Cagliari. The Marne a Fucoidi Formation from the adjacent Poggio le Guaine outcrop was well studied for biostratigraphy, ciclostratigraphy, and magnetostratigraphy by Fiet *et al.* (2001), Satolli *et al.* (2008), Coccioni *et al.* (2012), and references therein. The carbonates in that location were deposited well above the calcite compensation depth (CCD) at middle to lower bathyal depths (1000-1500 m) and at ~20° N paleolatitude over the southern margin of the western Tethys Ocean (fig. 1).

a) Present Day Tectonics



b) Early Cretaceous - 125 Ma



**Figure 1.** (a) Present day location of the Poggio le Guaine drill site in the Umbria-Marche Basin (northern Apennines, central Italy). (b) Early Cretaceous (125 Ma) paleoreconstruction showing the Tethyan Ocean (<http://www.epgeosystems.com/eurotectonic.html>).

For the magnetic susceptibility analysis we collected samples along the core with a sampling spacing average of approximately 3 cm. We measured the magnetic susceptibility of 391 cubic samples collected between depths of 80.0 and 94.0 meters. IRM acquisition and thermomagnetic curves were performed for four representative cubic samples along the studied sections. Furthermore, hysteresis curves were performed for 16 powder samples. FORC diagrams for 2 samples were measured to identify the presence or absence of magnetic fossils.

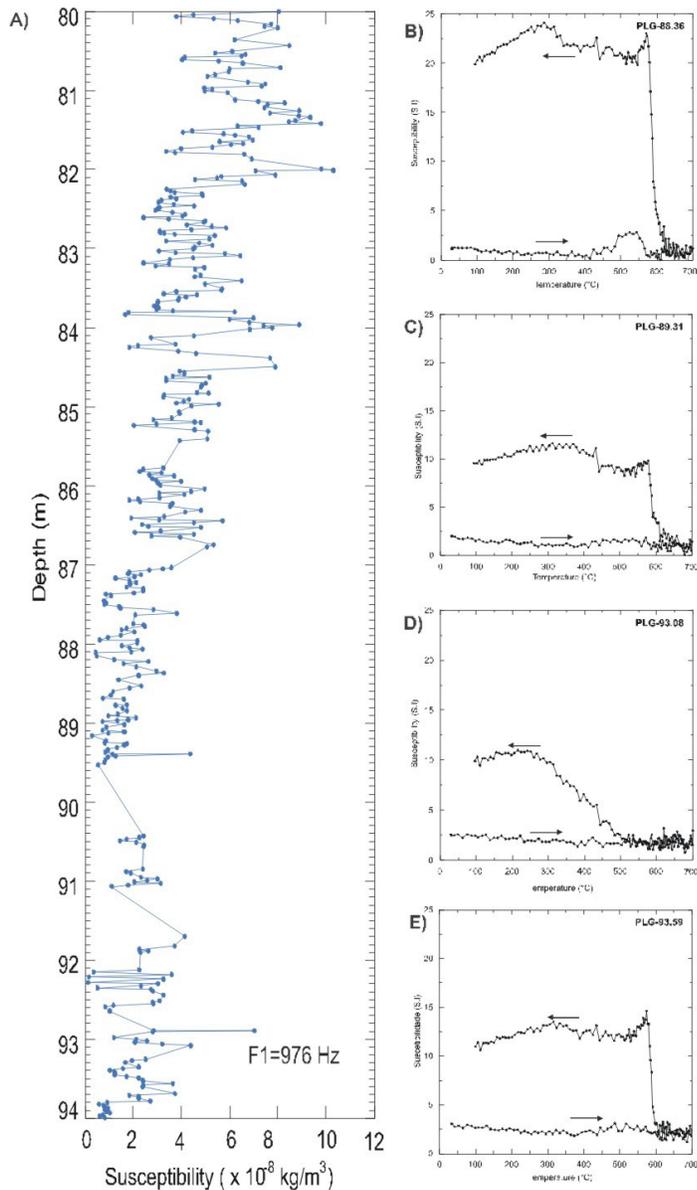
All magnetic measurements were performed at the Paleomagnetic Laboratory of the IAG-USP. Magnetic susceptibility data were obtained using a Kappabridge MFK1-FA apparatus in a frequency of 976 Hz, with a field intensity of 200 A/m, with a sensitivity of  $2 \times 10^{-8}$  SI (Dearing *et al.*, 1996). Isothermal remanent magnetization acquisition curves were measured by applying incrementally increasing inducing fields from natural remanent magnetization (NRM) up to 1000 mT along 45 steps. The field steps were applied using a 2G-Enterprises pulse magnetizer and measured in a 2G-Enterprises SQUID magnetometer. The IRM curves were then modeled using the method of Gaussian Cumulative Curves of Kruiver *et al.* (2001). For each sample, we obtained the saturation isothermal remanent magnetization (SIRM), medium coercivity ( $B_{1/2}$ ), and dispersion index (DP) of Robertson, France (1994). In order to determine the Curie/Néel temperatures characteristic of each magnetic phase we performed thermomagnetic curves from room temperature up to 700°C with a Kappabridge KLY-4S (AGICO) coupled with a CS4 furnace.

Other technique widely used in rock magnetic studies is the magnetic hysteresis loops. The hysteresis parameters, saturation remanence ( $M_r$ ), saturation magnetization ( $M_s$ ), coercive force ( $H_c$ ), and coercivity



remanence (Hcr), and the Mr/Ms and Hcr/Hc ratios are useful in discriminating domain state and magnetic grain size (Day *et al.*, 1977; Dunlop, 2002). However, the interpretation of Day plots with these hysteresis parameters can be ambiguous in terms of grain size distributions for mixtures of SP and SD, or SD and MD grains (Roberts *et al.*, 2000). Thereby, FORC diagrams are an important tool to identify the presence or absence of magnetotactic interactions and contributions of SP, SD, PSD and MD grains to the magnetization of the sample (Pike *et al.*, 1999; Roberts *et al.*, 2000; Egli, 2010). Hysteresis curves were performed with a VSM and FORC measurements were performed with a AGM apparatus, both manufactured by Princeton Inc. Since PLG samples are magnetically very weak, FORC diagrams were drawn only after stacking of ten runs (corresponding to 24 hours of measurement time per sample). The diagrams were calculated using a smoothing factor (SF) of five with the software of Egli *et al.* (2010).

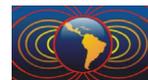
## Results and Analysis



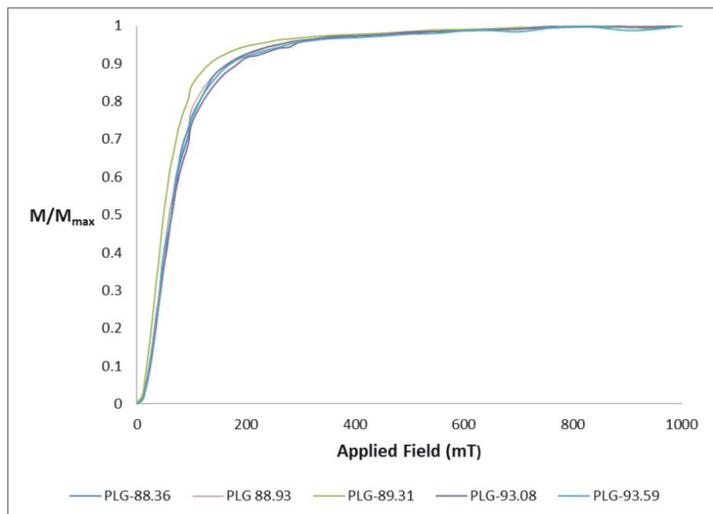
**Figure 2.** Magnetic susceptibility variations (measurement frequency of 976 Hz), and four thermomagnetic curves along on the core (right panel) showing a step at  $\sim 580^\circ \text{C}$  typical of magnetite.

Magnetic susceptibility ( $\chi$ ) variations for the 14-m-thick interval studied here are shown in Figure 2. Below 87 m,  $\chi$  values were dominantly low, with most values below  $4 \times 10^{-8} \text{ m}^3/\text{kg}$ . In the upper part of the section an increasing trend in  $\chi$  is observed. This variation correlates well with changes in lithology. These changes in lithology and  $\chi$  could be associated with a greater detrital influx into this section at that time. This upper part of the section with higher susceptibility values corresponds to one of the ORBs, which is composed mainly by red and olive green carbonate (with more intense magnetization, and therefore higher susceptibility), and gray to dark gray carbonate, with variations in clay content and frequent intercalations of black shale. During the Selli event (89.24 at 91.19 meters) and the Noir event (88.00 at 88.20 meters) (Erba *et al.*, 2010; Föllmi and Gainon, 2008) magnetic susceptibility is very low due to the low concentration of magnetic materials at these organic-rich levels.

The  $\chi$ -T curves of representative samples (88.36, 89.31, and 93.59 m) reveal irreversible behavior. During heating, susceptibility is almost constant and increases abruptly during cooling at  $580^\circ \text{C}$ , at the Curie point of magnetite. The same behavior is not observed in sample 93.08 m (fig. 2), where again the



curve is irreversible, but with a much lower Curie temperature, which can be associated with magnetite with substitution (Al, Ti), or defects in the crystalline lattice (e.g., Dunlop, Özdemir, 1997).

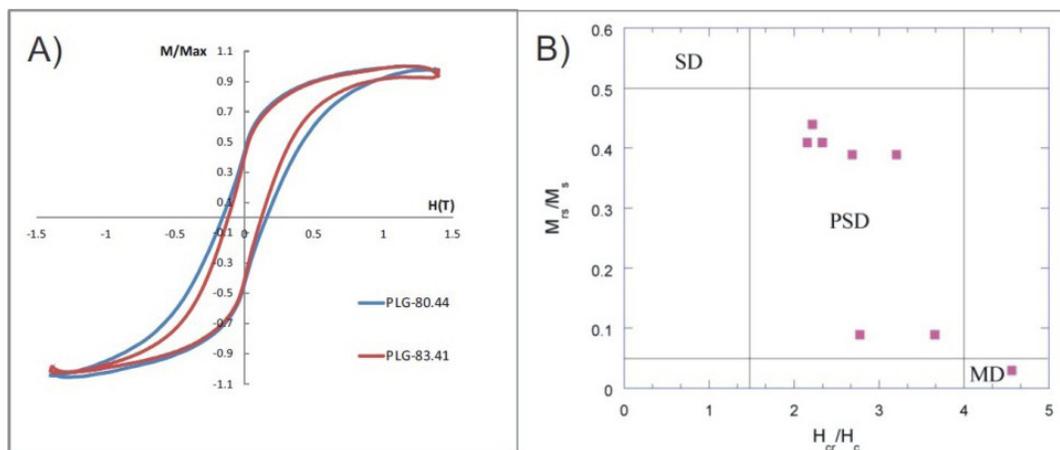


**Figure 3.** IRM acquisition curves ( $M/M_{max}$  versus Applied Field) for five representative samples. These curves indicate only one magnetic carrier characterized by low saturating fields.

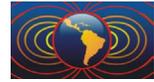
IRM acquisition curves for the same four samples used for obtaining the thermomagnetic curves exhibit similar behavior (fig. 3). Saturating fields below 300 mT indicate a predominance of low-coercivity magnetic minerals (e.g., magnetite). Using the method of Robertson and France (1994) we obtained values for IRMs,  $B_{1/2}$  and DP. The parameters for each curve are shown in Table 1. The curves are adjusted by a maximum of two components. The first component represents the low-coercivity magnetic phase, ranging between 91 and 97% of the constituent magnetic mineralogy of the samples (Table 1). The second component consists of a minor, high-coercivity magnetic phase present in some samples (Table 1).

**Table 1.** Table contribution analysis of coercivity minerals removed from the cumulative Gaussian curves method (see Kruiver *et al.* 2001).

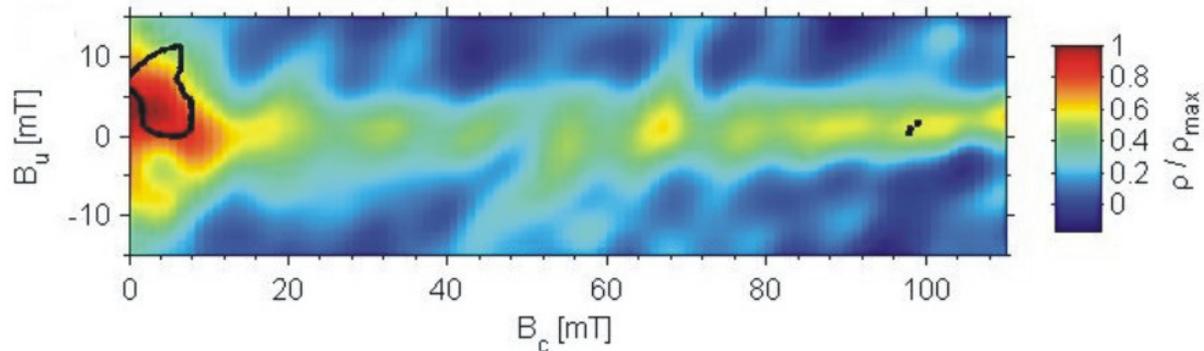
Sample ID	Depth (m)	Component	Contribution (%)	IRMs( $Am^2/kg$ )	$B_{1/2}(mT)$	DP
PLG-88.36	88.36	1	91	1.57E-05	57.5	0.3
		2	9	1.61E-06	398.1	0.29
PLG-88.93	88.93	1	97	8.90E-06	57.5	0.32
		2	3	2.90E-07	691.8	0.32
PLG-89.31	89.31	1	92	1.00E-05	50.1	0.33
		2	8	8.90E-07	1819.7	0.38
PLG-93.08	93.08	1	93	1.20E-05	60.3	0.30
		2	7	9.00E-07	302.0	0.31
PLG-93.59	93.59	1	95	1.10E-05	60.3	0.32
		2	5	5.50E-07	631.0	0.30



**Figure 4. A)** Hysteresis for two samples PLG-80.44 and PLG-83.41. **B)** Day's diagram indicating the predominance of PSD grains.



FORC distributions were determined for one representative sample (PLG-80.44) in the ORBs region (fig. 5). The other sample had a strong noise to signal ratio, and no coherent FORC distribution could be obtained notwithstanding the stacking of ten runs. FORC distribution (SF = 5) shows a vertical spreading at low-coercivity values between 0-20 mT, that indicates PSD and interacting SD particles (Roberts *et al.*, 2000). Moreover, we can also observe a small contribution of non-interacting SD particles due to a central ridge in the FORC distribution (Roberts *et al.*, 2000; Egli *et al.*, 2010).



**Figure 5.** FORC distribution (SF = 5) for the PLG-80.44 sample after stacking of 10 runs. The FORC distributions show a slight asymmetry in the y-axis suggesting magnetic interaction and a peak in FORC distribution at 5-10 mT indicating the dominance of a low-coercivity phase.

**Table 2.** Measured hysteresis for the samples from Poggio le Guaine Core Drill Core, central Italy.

Sample ID	Depth(m)	Mrs (Am <sup>2</sup> )	Ms (Am <sup>2</sup> )	Mrs/Ms	Hcr (mT)	Hc (mT)	Hcr/Hc
PLG-80.44	80,44	2,12E-08	4,84E-08	0,44	0,35	0,16	2,21
PLG-80.90	80,90	5,36E-08	1,37E-07	0,39	0,30	0,11	2,68
PLG-81.34	81,34	5,69E-08	1,40E-07	0,41	0,30	0,13	2,33
PLG-82.01	82,01	2,87E-08	7,31E-08	0,39	0,38	0,12	3,20
PLG-83.41	83,41	3,35E-08	8,11E-08	0,41	0,26	0,12	2,15
PLG-88.02	88,02	4,10E-10	1,34E-08	0,03	0,02	0,01	4,56
PLG-88.15	88,15	5,17E-10	5,53E-09	0,09	0,07	0,01	7,57
PLG-90.97	90,97	8,98E-10	1,04E-08	0,09	0,03	0,01	2,77
PLG-91.86	91,86	1,11E-09	1,24E-08	0,09	0,03	0,01	3,65

## Conclusions

In this paper we show a study of the magnetic mineralogy from the base of PLG core, Central Italy. From the base of the core until meter 87 we observe a predominance of magnetite as the main magnetic carrier of the sediments. Upward the meter 87 we have a mixture of low- and high-coercivity minerals indicated by hysteresis loops and FORC distribution.

## Acknowledgements

The authors thank Petrobras S.A. for the financial support and the authorization to disclose these results. We also thank Plinio Jaqueto and Daniele Brandt for all the help and patience.

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