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1B Reef response to sea-level and environmental changes

Paleomagnetism and rock magnetism of IODP 325 Hole M0058A

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Abstract. We have studied the rock magnetic and paleomagnetic properties of a 41 meter-long core (Hole M0058A) recovering fine calcareous sediments located seaward of Noggin Reef, off Queensland, Australia. We have deployed 1-cc samples at every 10 cm down-core and subsampled the core by means of U-channels in order to obtain a continuous record. We have also conducted magnetic granulometry analyses and Curie point determinations. The thermomagnetic analyses indicate the presence of Ti- poor magnetite with Curie points from 560^{o} to 563^{o}C. Hysteresis loop experiments were carried out and the results show Mrs/Ms and Bcr/Bc ratios corresponding to Single Domain to Multi Domain (SD-MD) as well as Super Paramagnetic (SP) to Single Domain (SD, i.e. SP-PSD) ranges.

Key words: Paleomagnetism, Rock magnetism, Coral, Great Barrier Reef, Australia.

Introduction

At the end of the Expedition 325, “Great Barrier Reef Environmental Changes” (GBREC), of the Integrated Ocean Drilling Program, a core 40 m long collected fine sediments from seaward of Noggin Reef, Queensland, Australia. Initial uranium-thorium and radiocarbon measurements give relative ages of ~10 to ~30 ka. The main aim of the expedition was an investigation of the magnitude and nature of sea-level changes in relation to the Last Glacial Maximum. Paleoenvironmental analyses will study the sea-level changes in relation to the glacial-interglacial phases.

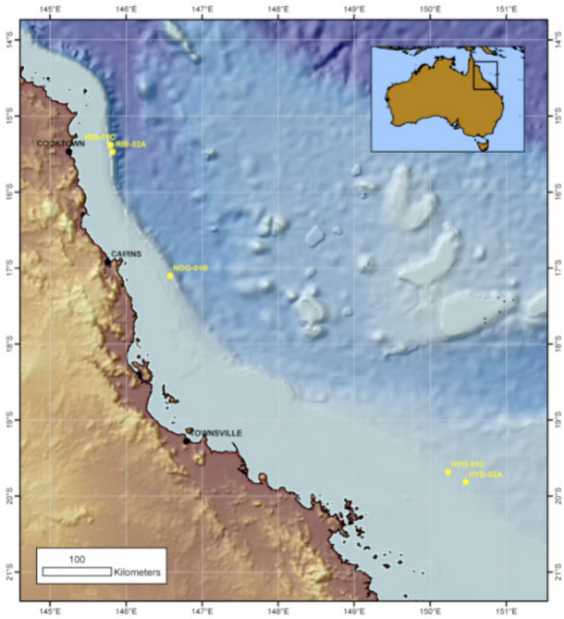
Paleomagnetism and rock magnetic properties of sediments and sedimentary rocks provide information about the environmental processes and conditions of when the sediments had deposited in addition to diagenetic history and settings.

Here, we present the paleomagnetic and rock magnetic study of a calcareous sequence of approximately 41 meters of sediments recovered during IODP Expedition 325 in order to further understand the correlation between the recorded excursions with respect to the radiometric dates obtained so far and the general stratigraphy of the site in question (i.e. M0058a).

Sampling Site IODP 325 (M0058A)

Hole 325-M0058A (58A, 146^{o} 35.357’ E and 17^{o} 5.8356’S) is the deepest hole at 172 m in terms of current water depth, drilled during IODP 325 Expedition in spring 2010 along a seven-drill-site transect SE of Cairns offshore of the Great Barrier Reef (Figure 1). The 41.4 m-long sedimentary sequence recovered in Hole 58A is mainly composed of three unconsolidated green mud sections intercalated with two distinct sandy intervals. In the muddy parts of the core, planktonic foraminifera are very common in three levels characterized by highest reflectance values (or the lightest colors) combined with the lowest magnetic susceptibility values (Figure 2). The upper sand/grainstone section, at least 2 m thick, consists of fine to medium sand with large rock fragments, as big as cobble-sized, of well cemented grainstone and visible fragments of mollusks, bryozoa, coralline algae, echinoids, ‘Larger’ benthic foraminifera, and serpulids. The lower sand section is about 7 m thick and characterized by fine to medium sand. The observed lithologic cyclic pattern in Hole 58A is clearly illustrated in the color reflectance and the magnetic susceptibility record data (Figure 2) *Harper et al., (2010)*.

The cyclic variations observed up the sedimentary section in Hole 58A are interpreted to represent deepening (fining) upward sequences, corresponding to the last two and one half glacial-interglacial cycles from Marine Isotope Stage MIS-7 to MIS-1. During glacial intervals, as Last Glacial Maximum and during MIS-6, a live coralgal reef had to be established in close vicinity of Hole 58A where the water depth was approximately 40 m at that time and was shedding coarse neritic material towards the site of Hole 58A.



The low values of color reflectance and the high values of the magnetic susceptibility data (Figure 2) can be explained by input of siliciclastics during intervals of sea level lowstands when the Queensland continental shelf was mostly exposed. Once the deglaciations (MIS-2 to 1, and MIS-6 to 5) were initiated, the coralgal reefs had to migrate westward and upward to keep up with the 120 m sea level rise (*Harper et al., 2010*). The site was subsampled by means of U-Channels and also 1-cc mini-cubes deployed at every 10 centimeter intervals to study both their magnetic properties and the entire magnetostratigraphy of the carbonaceous sediments.

Rock Magnetic Experiments

a) Magnetic susceptibility

It is well known that all materials become magnetic when placed within an inducing magnetic field and magnetic susceptibility (MS) is an indicator of the strength of this magnetism within a sample. In the MS measurement, essentially all mineral grains are "susceptible" to becoming magnetized in the presence of a magnetic field. In the very weak and low inducing magnetic fields that we use, the MS is largely a function of the concentration and composition (mineralogy and grain morphology) of the "magnetizable" material in a sample. MS has the advantage of being quickly and easily measured on small samples using commercially available devices such as balanced coil induction systems (susceptibility bridges) that can be adapted for use in the field. In addition, MS is free of many of the problems associated with polarity (reversal) magnetostratigraphy. For example, it is possible to measure the MS for small, unoriented, irregular lithic fragments and highly friable material.

Low-field magnetic and mass-specific susceptibility (χ) was measured on mini-cores using a KLY 2 (AGICO) Kappabridge 119 with an operating frequency of 920 Hz, with a magnetic induction of 0.4 mT (noise level of 2 x10-10 m3/kg-1). The instrument used for the experiment is in the paleomagnetics laboratory of the Bremen IODP Repository. The low-field bulk magnetic susceptibility values have been iteratively checked with a Multisensor Core Logger data and with reflectance experiments in order to study the relation with continuous proxies (e.g. density, volume-specific magnetic susceptibility and resistivity) and color of the sediments. Samples were obtained as 2.5 cm (1-inch) mini-cores drilled perpendicular to the split face of the rock cores. Samples were spaced at irregular intervals in the rubble material sections, with the object of collecting at least one sample per every section. Samples were collected at a spacing interval of ~1 meter in relation to the availability of the material. For sections that comprised continuous material, we collected discrete mini-cores with a spacing interval of 10 cm. Low-field magnetic susceptibility data were recorded as corrected mass specific units (x 10–6 m3/kg). The accuracy of the Kappabridge was checked using a calibration standard with a bulk susceptibility of 1153 x 10–06 SI. This calibration piece was centered in the Kappabridge at 1 calibration run per 6 core sections. Oriented paleomagnetic samples were recovered when possible from all core intervals where up- down orientation was preserved. Unfortunately, some intervals were composed of rubble coral materials. Thus, the azimuthal orientation of each individual core section was random, and shorter intervals within each core section were obviously rotated relative to each other. As a result, any potential paleomagnetic analysis will be limited to inclination and relative paleointensity determinations. As stated above, magnetic susceptibility is an indicator of the strength of the transient magnetism within a sample in the presence of a magnetic field (*Nagata, 1961*).

The magnetic susceptibility is a function of the concentration and composition of the "magnetizable" material in a sample. The study of susceptibility when compared to rock magnetic analyses provides quantitative and qualitative information about the paramagnetic and ferromagnetic materials present in the sediments.

Therefore, the presence of cyclic trends in the magnetic susceptibility record in marine environments can be related to fluxes of detrital sediments as results of climate changes and consecutively driven from Milankovitch cyclicity (*deMenocal et al., 1991; Weedon et al., 1999; Ellwood et al., 2000, 2007*). This can be related to periodical enhanced erosion and may be due either to detrital or eolian components, or both. These materials are brought into the marine environment and mobilized throughout the oceans thanks to sea currents, (*Sachs and Ellwood, 1988; Ellwood et al., 2006*).

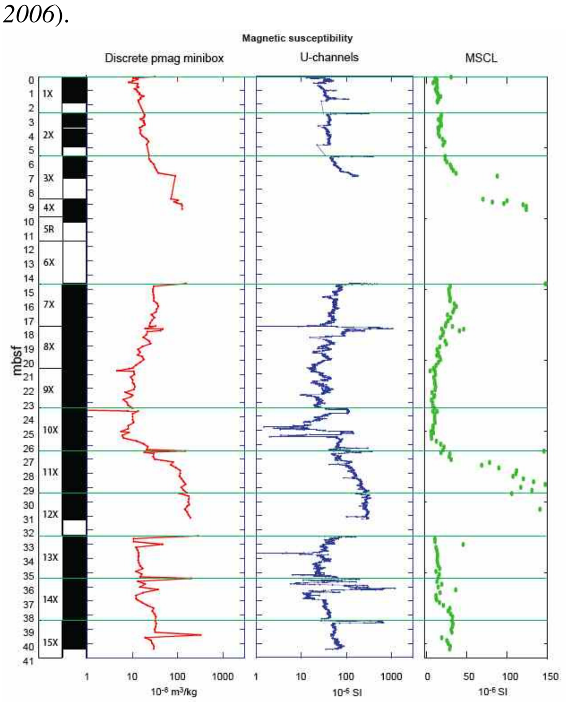


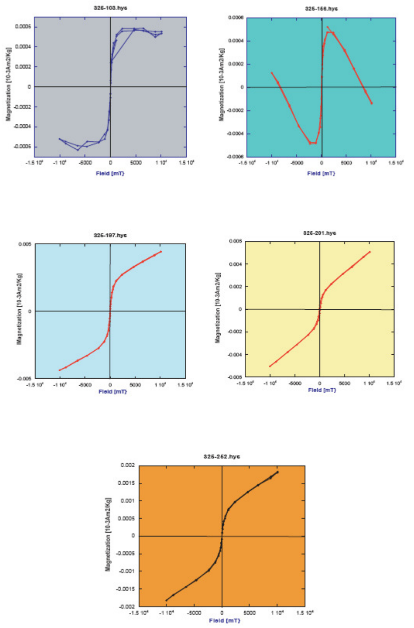
Figure 2. Shows the composite figure of the magnetic susceptibility experiments conducted on the soft sediments of site M0058-A, depicting the correlation amongst the three different experiments such as discrete samples, U-Channels and in-situ well logging. The results indicate a very good correlation of the main susceptibility features such as the positive magnetic susceptibilities occur throughout the entire core ranging from 4.50 up to 277.78 x 10-8 m3/kg having an arithmetic mean value of 38.24 x 10-8 m3/kg.

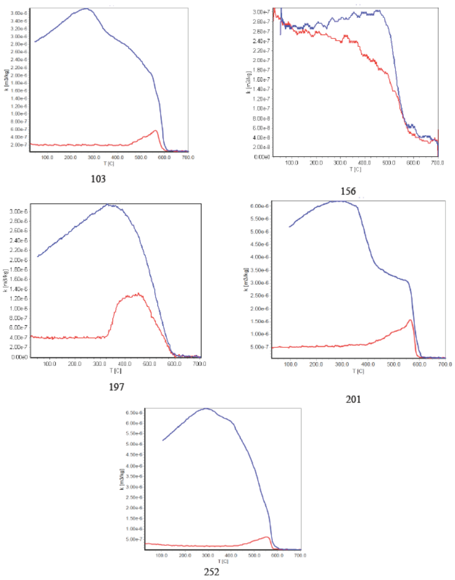
The diagram shows two zones of high susceptibility with respect to the rest of the base values. The first zone is located between 8.63 down to 14.80 mbsf and the second one is located from about 27.00 down to 32.60 mbsf with a maximum value of 277.78 x 10-8 m3/kg as mentioned above. These positive susceptibilities indicate the presence of ferromagnetic minerals repeated on the U-Channel and MSCL records.

b) Curie point determinations and Magnetic Granulometry

In addition to the magnetic susceptibility experiments we have conducted Curie point determinations as well magnetic grain sizes experiments. We have analyzed the field-dependent and temperature-dependent magnetic behavior of five discrete samples (~200 mg) from the working half sampled from the top down to the end of the core at five different stratigraphic levels as follows: 103, 156, 197, 201 and 252 cm from the top of the core. All analyses were conducted at the SOEST-HIGP Paleomagnetics and Petrofabrics Laboratory of the University of Hawaii at Manoa. The field dependent measurements included determination of the low-field susceptibility versus temperature and hysteresis loops carried out at room temperature. Temperature dependent measurements involved determination of the Curie temperature. Hysteresis loops allow determination of the magnetic grain size that provides insight into the intrinsic magnetic characteristics of the carbonaceous sediments in question and their possible subsequent alteration processes. This, together with the determination of the Curie temperature, which constrains the magnetic mineralogy, alteration, and possible oxidation processes of the soft sediments under study. Magnetic hysteresis measurements were performed on five small amounts of sediment (~200 mg) using a Petersen variable field translation balance (VFTB) capable of generating fields of up to 1.2T located at the SOEST HIGP Paleomagnetics and Petrofabrics Laboratory of the University of Hawaii at Manoa. For the VFTB measurements sediment samples of up to 200 mg were used, in a maximum field of 1 Tesla. The hysteresis curve and the backfield demagnetization of SIRM were determined. The VFTB has a measurement range of 10-8–10-2 Am2. Saturation remanent magnetization (Mr), saturation magnetization (Ms), and coercive force (Hc) were calculated after removing the paramagnetic contribution. Figure 3 shows the results of the hysteresis loops. Magnetic grain sizes can also be indicative of the behavior of the samples upon demagnetization and thus the stability of magnetization. Saturation remanent magnetization (Mr), saturation magnetization (Ms), and coercive force (Hc) were calculated after removal of the paramagnetic contribution. The coercivity of remanence (Hcr) suggests that the NRM is carried by low coercivity grains. The ratios of the hysteresis parameters show that most grain sizes are scattered within the multi-domain (MD) range. The samples studied from top to bottom of the core such as specimens 103 (Mrs/Ms=0.10156 and Hcr/Hc=10.5289) fall along the superparamagnetic (SP)-single domain (SD) mixing curve (10nm). Specimen 156 (Mrs/Ms=0.04072 and

Hcr/Hc=8.2128) fall close to SD-multidomain (MD) mixing curves. Specimen 197 (Mrs/Ms= 0.09399 and





Hcr/Hc=9.2848) falls in between the SP-SD mixing curves and the SD-MD mixing curves. Specimen 201 (Mrs/Ms=0.21567 and Hcr/Hc=2.6767) falls on the SD-MD mixing curves and specimen 252 (Mrs/Ms=0.00446 and Hcr/Hc=5.9271) falling along the SD-MD mixing theoretical curves of *Dunlop* (2002) which all suggests that the magnetic carriers contain superparamagnetic (SP), SD and MD Ti-poor magnetites , see hysteresis curves shown in Figure 3.

After measurement of the hysteresis loops and the back-field demagnetization curve of the SIRM, we carried out low-temperature versus susceptibility analyses (k–T) that were conducted on the same five samples per stratigraphic level in order to determine the magnetic carrier of the NRM. These Curie point determinations were carried out on small amounts of powder and analyzed in an air atmosphere. Heating and cooling rates were close to 20 °C/min, with a maximum temperature of 700 °C using a KLY2-CS3 apparatus (*Hrouda 1994; Hrouda et al., 1977*). These experiments identified basically one distinct group (see Figure 4), with the five specimens showing an irreversible complex k–T behavior. All the experiments showed a progressive increase in susceptibility up to <560 °C showing a Hopkinson peak. The heating curves indicate the presence of low-titanium to almost pure magnetite showing Curie point temperatures ranging between 560°C to 575°C. The vast majority showed irreversible cooling curves indicative of the creation of oxidized magnetite during the cooling process.

Discussion

The rock magnetic parameters measured along the studied IODP Expedition 325 core site M0058A demonstrate that the reef carbonate sequence contains a fairly concentrated ferromagnetic fraction. This fraction is primarily composed of titanium-poor magnetite showing a wide distribution range of superparamagnetic values, produced by the alteration and erosion of a wide range of rocks from continental Eastern Australia.

The Ti-poor magnetite is the main magnetic carrier of the carbonate sequence in agreement with the green mud sections intercalated with two distinct sandy intervals as well as the upper sand/grainstone section, at least 2 m thick, which consists of fine-to-medium sand with large rock fragments, some as cobble-sized, of well-cemented grainstone, and a section of about 7 m thick characterized by fine to medium sand. It seems likely that the remanence was acquired through detrital and post-detrital processes, although diagenetic and/or biogenic crystal growth cannot be ruled out. In fact, it has been reported that for the paleomagnetic analyses of sediment samples from ODP Leg 133, Site 820, located ~10 Km from the outer edge of the Great Barrier Reef that was undertaken to investigate the mineral magnetic response to environmental (and sea-level) changes, the authors of the research found preliminary evidence of the presence of biogenic magnetite that may play a significant role in the magnetization of these sediments (*Barton, et al., 1993a and b*). Chains of SD-sized crystals of pure magnetite are characteristic of biogenically produced (bacterial) magnetite (*Blakemore and Frankel, 1981*) which are being found increasingly in marine environments as the search for them proceeds (e.g., *Yamazaki et al., 1991*). Some caution is needed when interpreting these results, because: (1) clustering into chains might be produced during the magnetic extraction process, (2) the sizes of the magnetic grains can be influenced by dissolution, and (3) dissolution will favor the formation of isometric particles that will resemble biogenic magnetite crystals (*Maher et al., 1999*).

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