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Inside...

IRM gets new shielded room and u-channel magnetometer

Julie Bowles
IRM

The IRM is pleased to announce the recent installation of a new 2G Enterprises pass-through u-channel magnetometer system (Fig. 1). The system enables the measurement of intact u-channel cores for the first time at the IRM, and we are excited about the ability of serving a new group of users.

The magnetometer was installed in our new shielded room, completed in March by Gary Scott and his team from Lodestar Magnetics. The shielded room consists of two layers of transformer steel and attenuates the background magnetic field by ~250 times to a few hundred nano-Tesla. The room now houses both the old and new 2G magnetometers, our DTech alternating field (AF) demagnetizer, ASC paleointensity furnace, and (as needed) our ancient but still reliable Schonstedt spinner magnetometer. The shielded room is already a hotspot of activity, and with two magnetometers now online we expect the room to be buzzing with the joyful noise of data acquisition (Fig. 2)!

The new magnetometer, with a 4.2 cm bore, accommodates a standard u-channel core section. It is designed with a track system for automated sample handling and continuous measurement of cores or multiple discrete samples. The dynamic range of the instrument is considerably greater than that of our old magnetometer with RF SQUIDS, which remains in heavy use. This will allow for the measurement of weakly magnetic samples and for the more rapid processing of strongly magnetic samples, which previously had to be measured on the spinner magnetometer. The absolute sensitivity of the instrument is limited by SQUID noise, which is ~2×10^{-12} Am^2 (1 standard deviation) at high frequencies. This is roughly 50 times more sensitive than the old magnetometer (Fig. 3).

Figure 1. The new magnetometer. Visible from right to left are a portion of the sample handling track, the degausser/ARM unit, and the measurement region with pulse-tube cryo-cooler.

Figure 2. IRM graduate students Ioan Lascu and Jessica Till try out the new instrument.

An in-line degausser can AF demagnetize samples along all three axes and has a longitudinal ARM coil. The planned addition of a transverse ARM coil and sample rotation system will enable the automated measurement of ARM anisotropy on discrete samples. A pulse magnetizing coil, while not in-line, will additionally allow users to apply a uniform isothermal remanence to an entire u-channel core.

The system will be available to both Visiting Fellows and informal visitors, and a separate application process will be instituted for those who wish to visit primarily to use the magnetometer. Until formal applications are available, please feel free to contact us by phone or e-mail to inform us of your interest in visiting as a u-channel user.

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Visiting Fellows' Reports

Magnetic properties of the Dawros peridotite Cr-spinel seams, Western Ireland

Brian O'Driscoll[1] & Michael S. Petronis[2]

[1] Keele University, Staffordshire, UK, b.o'driscoll@esci.keele.ac.uk
[2] New Mexico Highlands University, Las Vegas, NM, mspetro@nmhu.edu

Serpentinisation is the most extreme example of reduction during metamorphism with the fluids evolving from serpentinites reaching a pH > 10[1]. Magnetite formation during serpentinisation is driven by extraction of Si from the $Fe_3Si_2O_5(OH)_4$ component of serpentine and is responsible for the reducing conditions[2]. The Dawros peridotite in western Ireland constitutes the westernmost portion of the ~470 Ma Dawros-Currywongaun-Doughruagh Complex and principally comprises a folded sequence of massive orthopyroxenites, harzburgites, and layered lherzolites[3]. In many places throughout the intrusion, olivine and orthopyroxene are completely altered to serpentine with the spaces between Cr-spinel crystals filled predominantly by serpentine. Reflected light petrography reveals the presence of a high-reflectivity, fine-grained phase in addition to the Cr-spinel (Fig. 1). To evaluate the high-reflectivity phase, complete hysteresis loops were measured on rock chips up to maximum field of 1.5 Tesla (T) using the MicroMag™ VSM and temperature dependent susceptibility measurements were carried out in a stepwise heating/cooling fashion from 25°C to 700°C in an Argon atmosphere using the AGICO KLY3 susceptibility meter with a CS-3 furnace attachment. Representative samples show evidence of two Curie points (T_c), ~400ºC and ~580ºC, which are defined by an intervening magnetization plateau; all samples are irreversible on the cooling curve (Fig. 2).

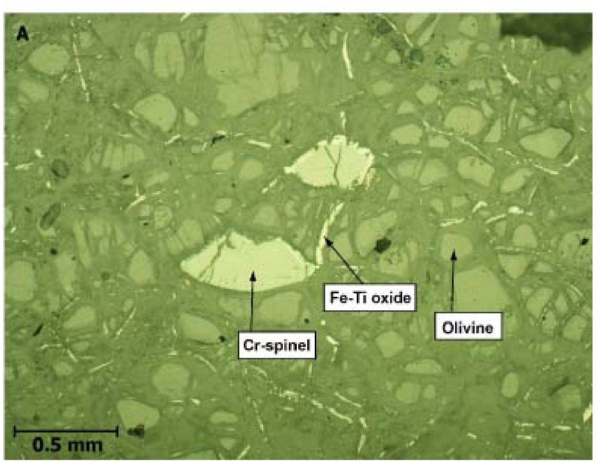

Figure 1: Reflected light photomicrograph of relict olivine grain surrounded by serpentine and an opaque mineral showing reticulate texture.

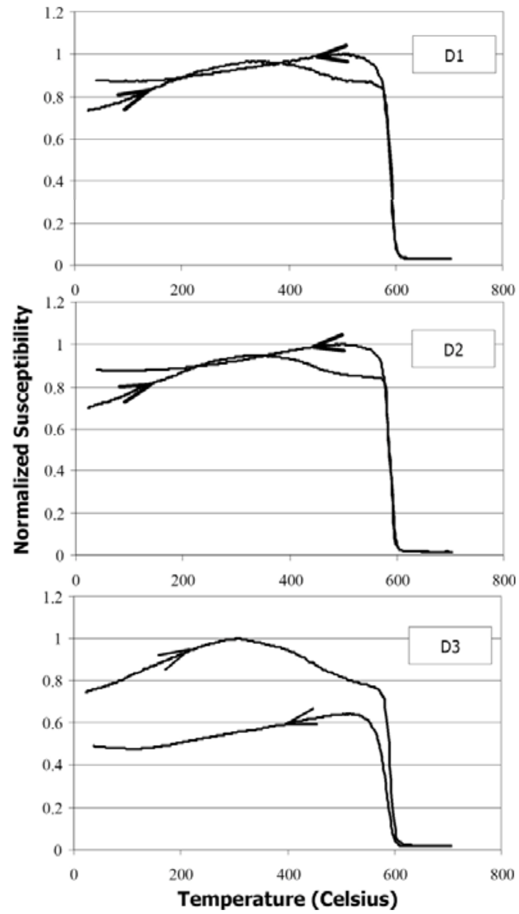

Figure 2: Representative temperature dependence of susceptibility diagrams.

Inferred Tc are between 572ºC to 582ºC using the inflection point method. The bulk susceptibility magnitudes are surprisingly low (3.0×10^{-5} SI), given that the high Tc are typical of a low-Ti magnetite phase[4,5,6,7]. Hysteresis loops yield steep acquisition and reach saturation by about 300 A/m. H_{cr}/H_c values range from 1.67 – 1.73 and Mr/Ms values is between 0.170 and 0.227. The H_{cr}/H_c ratios suggest the SD grain size[8] and the M_{rs}/M_s ratios are within the range predicted for the PSD grain size. Coerceive forces are between 8.2 mT to 12.5 mT. The values of M_{rs}/M_s and H_c fall on a hydrothermal trend defined by several authors[9]. Published Tc for Cr-spinel range from 25° ± 50° to 260°C[10,11], although this has been found to depend strongly on composition. The susceptibilities are very low (10^{-5} SI), though the T_c range is suggestive of the presence of low Ti titanomagnetite to pure magnetite phase. Hysteresis data yield low M_{rs}/M_s and H_{cr}/H_c ratios that fall inside the Day Plot fields for PSD behavior. The low M_{rs}/M_s and H_{cr}/H_c ratios might reflect low-temperature alteration of primary titanomagnetite formed during serpentization to titanomaghemite. Given the low susceptibility, high T_c, and hysteresis results, it is likely that minor amounts (i.e. < 0.1 weight %) of titanomaghemite are the principal magnetic phases distributed within the Cr-spinel seams[12]. The increase in susceptibility between 200°C to 450°C on the heating curve and its subsequent absence on cooling may reflect the inversion of titanomaghemite during heating to a phase assemblage that includes magnetite[13,14]. Incipient formation of small (PSD) grains in cracks in olivine crystals during serpentinisation is likely to be responsible for the observed magnetic characteristics (Fig. 1). We attribute the magnetic behavior to the presence of very small amounts of titanomaghemite, which is the secondary, low temperature alteration product of the titanomagnetite solid solution series[15]. The titanomaghemite likely grew at a late-stage only after significant hydration during serpentinisation process.

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Rock magnetic study of Arctic deep-sea sediments

Chuang Xuan and James E.T. Channell

University of Florida
xuan2005@ufl.edu

Paleomagnetic records from Brunhes-aged high latitude deep-sea sediments from the Arctic and Norwegian-Greenland Sea often show apparent excursions (e.g., Løvlie et al., 1986; Nowaczyk and Antonow, 1997; O'Regan et al., 2008) of the geomagnetic field with durations far exceed those determined elsewhere. Variations in sedimentation rates may have 'amplified' these excursional records (Worm, 1997) although it is also possible that negative inclinations are associated with a secondary magnetization process associated with sediment diagenesis. To solve the puzzle, it is important to determine which magnetic minerals are carrying magnetic remanence in these high latitude sediments, and to determine their origin.

U-channel samples have been collected from cores (6JPC, 8JPC, and 10JPC) recovered by the Healy-Oden Trans-Arctic Expedition 2005 (HOTRAX) to the Mendeleev Ridge. The natural remanent magnetization (NRM) of each u-channel was measured at 1 cm intervals before demagnetization and after alternating field (AF) demagnetization at 14 steps in the 10-100 mT peak field range. For the uppermost few meters, NRM of these cores yields a down-core inclination pattern of well-defined positive and negative intervals, however, component inclinations are generally much lower than the expected inclinations for a geocentric axial dipole field at these sites (~84°). Knowledge of the sedimentation history on the Mendeleev Ridge based on amino acid racemization, radiocarbon ages and sparse biostratigraphic data implies that sedimentation rates in this region are in the few-cm/kyr range (Polyak et al., 2004; Kaufman et al., 2008), constraining the uppermost ~10 m of the cores to the Brunhes Chronozone.

Thermal demagnetization of three-axis isothermal remanences acquired in DC fields of 1.2 T, 0.5 T, and 0.1 T imposed along three orthogonal axes of the sample (method of Lowrie 1990), applied to samples from both typical positive and negative NRM inclination intervals, indicate that the samples are dominated by soft (<0.1 T) and medium (0.1-0.5 T) coercivity magnetic components. Samples from negative NRM inclination intervals have a higher proportion of the medium coercivity magnetic component. An abrupt drop in intensity of the medium coercivity fraction below 300°C indicates the presence of an iron sulfide such as greigite or pyrrhotite. The occurrence of magnetite was indicated by the abrupt drop in intensity of both the soft and medium coercivity fraction at ~580°C.

At IRM, we conducted high and low temperature experiments (Fig. 1) for samples collected from both typical positive and negative NRM inclination intervals of the uppermost few meters of the cores using the furnace-equipped vibrating sample magnetometer (VSM) and magnetic properties measurement systems (MPMS), respectively. All samples were freeze-dried prior to travel to IRM.

Hysteresis loops were measured at different temperatures (every 25°C from room temperature up to 700°C), in helium atmosphere, on a VSM. The results show abrupt drops in saturation magnetization (Fig. 1a) below 300°C and below 580°C for samples from both typical positive and negative NRM inclination intervals, consistent with the initial three-axis isothermal remanences thermal demagnetization experiments, indicating the presence of greigite/pyrrhotite and magnetite. The magnetic moment, in a 0.5 T field and a helium atmosphere, was also measured during thermal cycling for samples from typical negative NRM inclination intervals (Fig. 1b). The reduction in magnetic moment on cooling from 300°C (Fig. 1b) may be associated with formation of (paramagnetic) pyrite during initial thermal alteration of greigite, and the increase in magnetic moment on cooling from temperatures above 400°C can be associated with transformation to magnetite (Dekkers et al., 2000).

Room temperature saturation isothermal remanences (RT-SIRM) were monitored using an MPMS on cooling to 20 K and warming to room temperature (Fig. 1c). In addition, field cooled (FC) and zero-field cooled (ZFC) low-temperature SIRMs on warming from 20 K to room temperature (Fig. 1d) show the Verwey transition at ~120 K for samples from both typical positive and negative NRM inclination intervals. The lack of a low temperature transition at ~33 K (Fig. 1c and d), characteristic of pyrrhotite (Rochette et al., 1990), tends to rule out pyrrhotite as the dominant iron sulfide. The larger difference between the FC and ZFC curves for typical negative inclination interval samples, than for typical positive inclination interval sample (e.g. Fig. 1d), around the Verwey transition is quite repeatable for all three cores and may provide evidence that there is a lower proportion of magnetite (higher proportion of greigite) in samples from negative inclination intervals.

These results indicate that magnetite and greigite are present in the samples, and that greigite is more prevalent in samples that show the anomalous magnetization directions. As thermal demagnetization of NRM (data not shown) indicates that the negative NRM inclinations in these Brunhes-aged sediments are carried by greigite, the negative NRM inclinations are possibly caused by magnetic interactions (partial self-reversed chemical remanent magnetization) between a secondary authigenic greigite and a primary magnetite rather than any special behavior of the geomagnetic field at these high latitudes. Current work involves building on data collected at IRM, thermomagnetic measurements, and scanning electron microscope (SEM) analyses designed to more fully understand remanence acquisition in these sediments.

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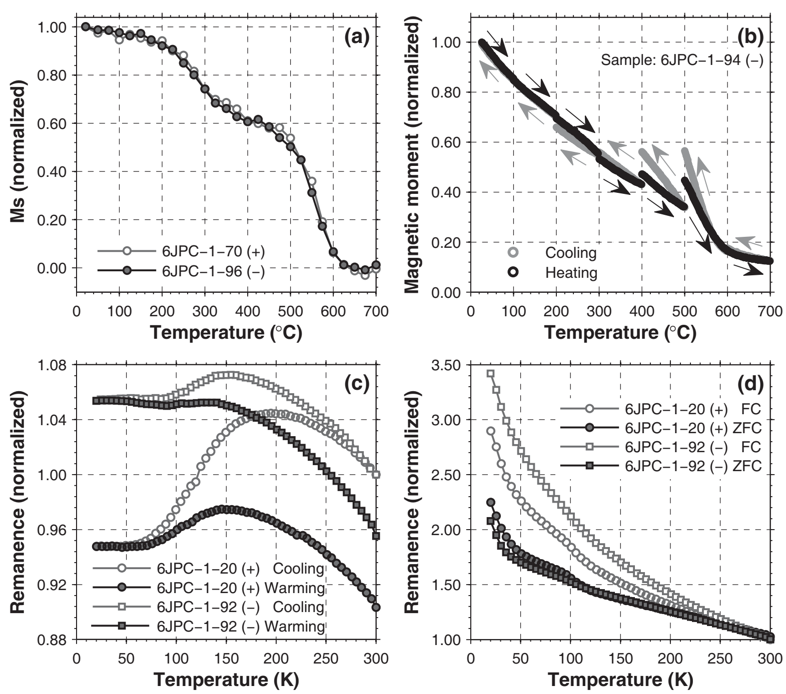

Figure 1: High and low temperature magnetic measurements for typical samples from positive (indicated by '+' after sample name) and negative (indicated by '-' after sample name) inclination intervals. (a) Saturation magnetization (Ms) from hysteresis loops measured at increasing temperatures (at 25°C steps in a helium atmosphere) using VSM. Values have been normalized to the room temperature measurement. (b) Magnetic moment in a 0.5 T applied field measured during thermal cycling where black and gray circles denote heating and cooling, respectively. The sample was heated in 100°C increments during measurement at ~1°C steps, then cooled by 100°C during measurement, then heated through 100°C without measurement to the onset temperature of the next thermal cycle. Values have been normalized to the room temperature measurement before heating. (c) RTSIRM demagnetization curves measured on cooling and warming using MPMS. Measurements have been normalized to the room temperature measurement of the sample on cooling. (d) FC (2.5 T) and ZFC low-temperature SIRM measured on warming. Measurements have been normalized to the FC measurement of the sample at room temperature.

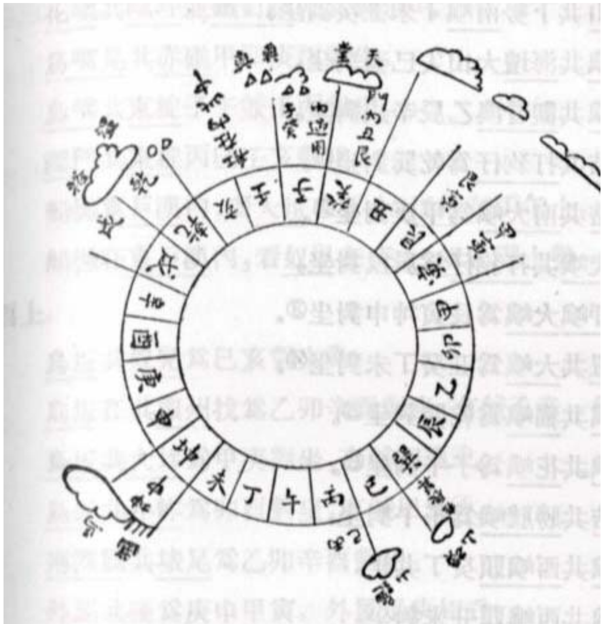

Diagram of a Ming Dynasty (1368 - 1644) mariner's compass.

Current Articles

A list of current research articles dealing with various topics in the physics and chemistry of magnetism is a regular feature of the IRM Quarterly. Articles published in familiar geology and geophysics journals are included; special emphasis is given to current articles from physics, chemistry, and materials-science journals. Most abstracts are taken from INSPEC (© Institution of Electrical Engineers), Geophysical Abstracts in Press (© American Geophysical Union), and The Earth and Planetary Express (© Elsevier Science Publishers, B.V.), after which they are subjected to Procrustean culling for this newsletter. An extensive reference list of articles (primarily about rock magnetism, the physics and chemistry of magnetism, and some paleomagnetism) is continually updated at the IRM. This list, with more than 10,000 references, is available free of charge. Your contributions both to the list and to the Abstracts section of the IRM Quarterly are always welcome.

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Shen Kuo
b. 1031, Qiantang (modern-day Hangzhou, Zhejiang province), China
d. 1095, Ching-k'ou (modern-day Zhenjiang, Jiangsu province), China

A skilled administrator and diplomat, Shen held many government positions during the Northern Song Dynasty. A true polymath, he was skilled in fields as diverse as mathematics, astronomy, meteorology, geology, zoology, botany, pharmacology, archaeology, cartography, engineering, poetry and music. Later in life, he compiled results from many of his studies in the encyclopedic *Dream Pool Essays*. This work contains the first extant account of a suspended magnetic needle compass. Shen understood the concept of magnetic poles, describing magnetized needles that sometimes point north and other times south. He was also the first to document the notion of true north as distinct from magnetic north; he noted that magnetic needles are always displaced somewhat from true north, a valuable concept in advancing navigation. Shen was intrigued at finding fossil shells in mountains far from any ocean, a discovery that led him to reason that land can be reshaped, uplifted, and eroded over long periods of time. After discovering a fossil bamboo in northern China where none currently grows, he was one of the first to understand that climate changes and shifts geographically over time.

Model of a Han Dynasty (206 BCE - 220 CE) south-pointing ladle used for geomancy rather than navigation.

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New Magnetometer, continued from pg. 1

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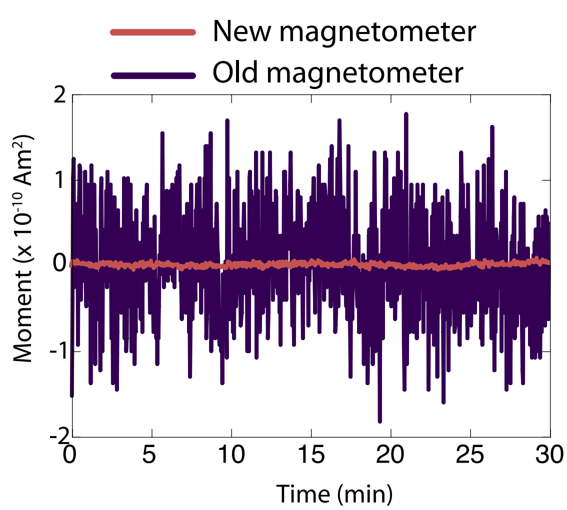

Figure 3. Background noise measured on the Y-axis SQUID on both the old and new magnetometers. The new instrument provides an approximately 50-fold increase in sensitivity.

University of Minnesota
291 Shepherd Laboratories
100 Union Street S. E.
Minneapolis, MN 55455-0128
phone: (612) 624-5274
fax: (612) 625-7502
e-mail: irm@umn.edu
www.irm.umn.edu

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Julie Bowles
Institute for Rock Magnetism
University of Minnesota
291 Shepherd Laboratories
100 Union Street S. E.
Minneapolis, MN 55455-0128
phone: (612) 624-5274
fax: (612) 625-7502
e-mail: jbowles@umn.edu
www.irm.umn.edu

UNIVERSITY OF MINNESOTA