

U-CHANNEL MAGNETOMETRY

1. Overview

U-channels are continuous, single-box subsamples of sediment core sections. Their collection is intended for the analysis of magnetic properties of sediments, such as magnetic susceptibility, or natural and laboratory-imparted remanent magnetization (RM). Magnetic susceptibility can be measured at LacCore using two types of Multi-Sensor Core Loggers (see LacCore susceptibility procedure), while RM can be analyzed at University of Minnesota Institute for Rock Magnetism, which has recently acquired a 2G Enterprises Long-Core Magnetometer with remanence imparting and measuring capabilities (Figure 1).

The purpose of collecting RM information from sediment cores is two-fold. First, the natural RM (NRM) of a sedimentary sequence can provide information about the intensity and orientation of the Earth's magnetic field at the time of sediment deposition. Second, laboratory-imparted remanences such as anhysteretic RM (ARM) and isothermal RM (IRM) can be used to determine the concentration, grain size, and mineralogy of magnetic minerals in lake sediments, complementing magnetic susceptibility measurements in providing paleoenvironmental information about processes such as soil development, erosion, water column geochemistry, and diagenetic environment. (e.g., Snowball et al. 1999, 2002; Geiss et al. 2003, 2004; Egli 2004c; Ortega 2006)



Figure 1. U-channel magnetometer

2. U-channel Sample Preparation

U-channels are long plastic boxes that are used to sample the center of split cores for magnetic analysis. Subsampling is necessary because the magnetometer chamber cannot accommodate whole sections of core. Sampling in the center of a core section avoids the contaminated or deformed material near the outside of the core, giving the most representative sample of the sedimentary sequence. If NRM is of interest, the direction of magnetic north should be marked on all core sections at the time of sediment collection. When splitting the core sections it is preferable to do so either parallel or perpendicular to the marked north direction.

To sample, the uncapped U-channel container (cut to the length of the sediment) is inserted perpendicularly into the split core until it is full of sediment (Figure 2). The core ID and an arrow indicating “up” should be written on the U-channel box at this point. If NRM will be measured, core “north” should also be transferred on the sample box. Fishing line is run under the open side of the U-channel to free it from the sediment during the extraction of the U-channel box. For highly unconsolidated sediments, the core with the inserted sample box (and fishing line in place) is placed into a D-tube that has a slit the width of a U-channel box on the top flat side (Figure 3). The D-tube is turned upside down to allow the extraction of the sediment with the help of gravity. The sediment on either side of the U-channel box will remain in the split liner, held in place by the D-tube. The full U-channel box is cleaned of excess sediment, capped, sealed with polyethylene tape at both ends, wrapped in plastic film, and stored at 4 °C.



Figure 2. Inserting the U-channel box into a core can be challenging if the sediment is stiff.



Figure 3. D-tube modified for U-channel sampling of highly unconsolidated sediments.

The sample should be analyzed as soon as possible to avoid core shrinkage due to water loss, or magnetic mineral signal loss due to sediment oxidation. Before starting the analysis the sample should be brought to room temperature (e.g., stored overnight in the magnetometer room) to avoid instrument drift caused by temperature fluctuations.

U-channel sampling demands a large amount of sediment (2x2 cm for the length of the core), and where possible (i.e., when U-channels do not need to be saved in perpetuity) it is desirable to subsample the U-channel for other analyses after it has been studied for magnetic properties.

3. Remanent Magnetization Acquisition in Natural Sediments and Laboratory Specimens

Remanent magnetization is acquired either through natural processes, or as a result of exposure to laboratory-imparted magnetic fields. Once the RM is acquired, the magnetization is measured using extremely sensitive magnetometers, which should ideally operate in a zero magnetic field. The SI units are Am^2/kg for mass-normalized magnetization (used for discrete samples), and A/m for volume-normalized magnetization (used for discrete and continuous U-channel samples).

NRM is acquired at the time of sediment deposition, as sedimentary magnetic particles align with the Earth's magnetic field, which has strengths on the order of $30\text{-}60 \times 10^{-6}$ Tesla (T). This process occurs from the moment the particles start sinking through the water column until they become mechanically locked in the sedimentary matrix during sediment compaction. If NRM is of interest, it should be measured first, because this property is lost once the sample is exposed to laboratory magnetic fields.

ARM and IRM are two of the most commonly used laboratory-grown remanent magnetizations in environmental magnetism studies.

ARM is acquired through the combined effects of two superimposed magnetic fields: a small, constant direct current (DC) field, usually $50\text{-}100 \times 10^{-6}$ T, and a large, decreasing alternating frequency (AF) field (from peak values of 0.1-0.2 T to zero). The AF field alone would randomize the magnetization in the sample, essentially demagnetizing it. Through the biasing effect of the DC field a weak magnetization is induced in small grains with stable magnetic moments. ARM acquisition and subsequent measurement should be performed before doing experiments involving stronger direct magnetic fields (e.g., IRM acquisition).

IRM is acquired by exposing the sample for a short time (~ 0.1 s) to a large DC magnetic field, typically 0.1-1 T. As a result, all magnetic grains that are capable of carrying a RM will be magnetized in the direction of the applied DC field. Magnetic fields of 1 T and higher are usually strong enough to completely saturate most samples, meaning the magnetization will not increase with an increase of the applied field. In this case the remanence is called saturation IRM (SIRM).

4. Basic Interpretation of RM Types

NRM

The magnetization recorded naturally by sediments contains information about the intensity of the geomagnetic field at the time of particle lock-in, as well as its direction in space, defined by inclination (the angle made by local geomagnetic field lines with the horizontal), and declination (the angle between magnetic north and geographic north at the site of core collection). This allows researchers to investigate local variability in the geomagnetic field with time, and also permits dating of sediments for which other methods are not suitable (e.g., sediments older than radiocarbon limit, or those lacking datable material)

However, there are a few caveats of sediment-derived paleomagnetic records. Freshly deposited sediments are unconsolidated and water-rich, which allows magnetic mineral grains to rotate freely until these sediments are compacted by overlying, accumulating sediments. The time lag between sedimentation and consolidation is in most cases significant enough to introduce errors in pinpointing the actual time of magnetization acquisition. Compaction, slumping, turbidity currents, bioturbation, and dewatering can also bias the direction and intensity recorded by the magnetic mineral. If dissolution of primary magnetic minerals occurs during diagenesis, the initial paleomagnetic information will be erased, while magnetic mineral authigenesis can lead to these secondary minerals recording the ambient magnetic field vector at the time of their formation. Other problems associated with unconsolidated materials include sediment disturbance during collection, transport, and sampling in the laboratory.

ARM and IRM

Sediment magnetism has been successfully employed in environmental studies in part because of the usefulness of parameters like ARM and IRM, from which we can derive basic information about the magnetic particle concentration, grain size, and mineralogy.

ARM is generally indicative of the presence of fine-grained magnetic material, because of the nature of the ARM acquisition process, which affects almost exclusively particles in the single magnetic domain (SD) grain size range (e.g., 20-100 nm for magnetite). It should be noted however that ARM acquisition is extremely sensitive to magnetostatic interactions between magnetic grains, which means the acquisition process will be inefficient for particles close enough to generate interaction fields, thus behaving like larger, multi-domain (MD) particles. Therefore, the ARM should be used as proxy for the concentration of isolated fine-grained particles that do not interact with each other, and linear chains of particles, such as those produced by magnetotactic bacteria.

IRM acquisition affects all particle sizes that can hold a magnetic remanence, so it is often used as a proxy for total concentration of magnetic particles in sediments. However, the IRM acquisition efficiency varies greatly for different-sized magnetic grains. For example, magnetite SD particles (which can be thought of as tiny compass needles magnetized in one direction) are 10 to 50 times more efficient in acquiring an IRM than MD particles, in which the randomly oriented spin moments of individual domains in one grain tend to cancel each other out. In other words, it takes a volume 10 to 50 times larger of magnetite MD particles in order for the same IRM to be acquired. Therefore, it is recommended to use IRM as a magnetic concentration proxy only when the magnetic grain size is constant throughout the length of a core. In all other cases, magnetic susceptibility is a more suitable concentration proxy.

Environmental magnetism studies often employ RM interparametric ratios for a more complete sample characterization. A commonly-used parameter is the ARM ratio, obtained by normalizing a sample's ARM by its SIRM. It is generally viewed as a magnetic grain-size proxy, with larger values indicating finer granulometry. However, since ARM is sensitive to magnetostatic interactions between proximal particles, the ratio can be artificially lowered if

small particles occur in clumps, as is the case of collapsed bacterial magnetite chains, or clusters of SD pedogenic magnetite washed into the lake. Therefore, small-scale variations in the ARM ratio could point to interactions between particles rather than grain size changes, potentially offering information about the arrangement of particles in the sediment matrix (Egli 2006; Yamazaki 2008).

Another common interparametric ratio is the so-called *S-ratio*, obtained by normalizing an IRM acquired in fields of 0.1-0.3 T by the sample's SIRM. The S-ratio is a measure of the degree of saturation the sample reaches in the smaller IRM field, and is indicative of magnetic mineralogy in samples containing more than one magnetic mineral type. If the S-ratio has a value close to unity, the magnetic assemblage is dominated by 'soft' magnetic minerals (e.g., magnetite, greigite), which reach saturation in fields of up to 0.3 T. S-ratio values that depart from unity indicate the presence of 'hard' magnetic minerals (e.g., hematite, goethite) that require saturating fields larger than 0.3 T. If the sample contains only one type of magnetic mineral, S-ratios can be used as magnetic grain size proxies, with higher values indicative of larger particles.

In some instances, bulk parameters are not sufficient for characterizing sample grain size or mineralogy. So-called spectral methods utilize entire magnetization curves (rather than singular value parameters) to "unmix" the magnetic signature of a sample containing several magnetic components. A technique involving stepwise demagnetization of a previously acquired IRM or ARM, using progressively increasing peak AF fields, generates a magnetization curve that contains detailed information about the nominal magnetic field values at which the magnetization decay has maximum values (Robertson and France 1994). These values can be linked to different origin magnetic components, such as biogenic, pedogenic, detrital, or fly ash from industrial pollution (Egli 2004a-c).

5. U-channel Magnetometer Operation for Continuous Measurements

The 2G magnetometer employed for measuring RM uses a superconducting quantum interference device (SQUID) that is very sensitive to extremely low concentrations of magnetic material (<0.1% by mass). For an explanation on how SQUIDS work see the short review available on the Institute for Rock Magnetism website at <http://www.irm.umn.edu/quarterly/irmq19-1.pdf>. The instrument at the Institute for Rock Magnetism is equipped with an online three-axis demagnetizer and ARM imparting device. An offline long-core pulse magnetizer allows the acquisition of IRM in fields up to 1 T. The magnetometer is akin to the magnetic susceptibility loop sensor at LacCore (see susceptibility procedure) in several aspects:

- a) the U-channel advances through a measuring chamber by means of an automated pull-through system;
- b) the magnetic signal is integrated over ~20 cm;
- c) background measurements can only be performed at the beginning and end of the measuring sequence;
- d) the magnetization is normalized by volume.

The resulting magnetization curves are thus smoothed records, so applying a deconvolution algorithm is necessary in order to obtain point-equivalent data. This is done by a program implemented in the Institute for Rock Magnetism sample data base. For details on the inversion method see paper by Jackson et al. (2010).

U-channel magnetometer users will receive training at Institute for Rock Magnetism according to the following operating procedure. (For discrete sample measurement procedure, as well as tuning of SQUID boxes, see IRM website: http://www.irm.umn.edu/manuals/2G_longcore_IRM_manual.pdf)

- 1) Open the program LongCore (icon should be on desktop) and go to **Utilities (A)**
 - a. Change User Directory
 - i. Select **“Set Data Paths and File Formats”**
 - ii. Navigate to main data path (c:/Long Core Data/Your Folder/)
 - iii. Navigate to backup data path (c:/Long Core Backup/Your Folder/)
 - iv. Do not change data file format.
- 2) Select **IRM database user name** to get sample info from database OR enter sample information in **Sample Data Table (B)**
 - a. Enter length of core (cm)
 - b. Depth (optional) is that of core in meters below lake floor (MBLF), or whatever coordinate system you desire, but assumes depth increases down-core.
 - c. Enter cross-sectional area of core (cm²)
 - d. For un-oriented cores, azimuth and dip are 0° and -90°.
- 3) Set up measurement sequence in **Measurement Queue Editor (C)**:
 - a. Select “Continuous” (near bottom of screen)
 - b. Select measurement interval (cm)
 - c. Select types of corrections desired (drift, tray)
 - d. Select length of leader and trailer (15 cm optimal for deconvolution)
- 4) Choose **Data file (D – Browse...)**. Either:
 - a. use sample name as file name; or
 - b. enter desired filename
- 5) **Measure tray (E)** – used for tray correction
 - a. clean first if desired –physically and/or AF
- 1) **Measure (F)**
 - a. Place U-channel box on tray.
 - b. Select sample name from list.
 - c. Go.

6. References

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