Geochemistry Geophysics Geosystems G3
AN ELECTRONIC JOURNAL OF THE EARTH SCIENCES
Published by AGU and the Geochemical Society

Technical Brief
Volume 4, Number 6
14 June 2003
1050, doi:10.1029/2002GC000454
ISSN: 1525-2027

U channel track for susceptibility measurements

Ray G. Thomas
Department of Geological Sciences, 241 Williamson Hall, P.O. Box 112120, University of Florida, Gainesville, Florida, 32611, USA (rgthomas@geology.ufl.edu)

Yohan Guyodo
Institute for Rock Magnetism, Department of Geology and Geophysics, 108 Pillsbury Hall, Minneapolis, Minnesota, 55455, USA (guyodo@umn.edu)

James E. T. Channell
Department of Geological Sciences, 241 Williamson Hall, P.O. Box 112120, University of Florida, Gainesville, Florida, 32611, USA (jetc@nersp.nerdc.ufl.edu)

[1] A lightweight, transportable, and inexpensive magnetic susceptibility track for u channel samples is described. The track utilizes a Sapphire Instruments 3.3 cm square coil having a response function of shape similar to that of the 2G-Enterprises u channel magnetometer, and a half-peak width of 3 cm. The instrument has been calibrated using a u channel standard made of manganese dioxide. The software incorporates automated track control and measurement drift correction. Susceptibility measurements on this system compare favorably with the 45 mm circular Bartington loop used for u channel samples at the Laboratoire des Sciences du Climat et de l'Environnement (Gif-sur-Yvette, France) and with data from the whole core susceptibility track aboard the Ocean Drilling Program research vessel *JOIDES Resolution.*

Components: 2687 words, 4 figures.

Keywords: Paleomagnetism; rock magnetism; U channels; magnetic susceptibility.

Index Terms: 1594 Geomagnetism and Paleomagnetism: Instruments and techniques; 1540 Geomagnetism and Paleomagnetism: Rock and mineral magnetism.

Received 17 October 2002; **Revised** 19 February 2003; **Accepted** 19 March 2003; **Published** 14 June 2003.

Thomas, R. G., Y. Guyodo, and J. E. T. Channell, U channel track for susceptibility measurements, *Geochem. Geophys. Geosyst.*, *4*(6), 1050, doi:10.1029/2002GC000454, 2003.

1. Introduction

[2] Low-field magnetic susceptibility provides a rapid and non-destructive means of sediment core correlation, and is routinely measured on the majority of oceanographic research vessels. Aboard the *JOIDES Resolution*, susceptibility data from the measurement system track (MST) are very often the basis for hole-to-hole correlation and composite depth construction. Down-core susceptibility variations in marine sediment cores are usually controlled by fluctuations in the concentration of ferrimagnetic magnetic minerals such as magnetite or maghemite. The concentration of these minerals may be controlled by a myriad of different factors such as carbonate content (surface water productivity), strength of bottom currents and/or episodes of ice rafted debris (IRD).

[3] The 2G-Enterprises pass-through magnetometer aboard Ocean Drilling Program (ODP)

JOIDES Resolution is designed to measure 6.6 cm inner diameter whole-cores or half-cores, and the pick-up coils have response functions with half-peak widths in the order of ten centimeters. The need to measure magnetic remanence at greater resolution has led to the development of pass-through magnetometers designed for u channel samples. These samples have a 1.8 × 1.9 cm interior cross section and are up to 1.5 m in length [*Tauxe et al.*, 1983]. U channels are collected from the pristine center of core sections either aboard ship or post-cruise, and avoid complications from disturbances or sediment mixing on the side of the core liner. Furthermore, the small cross section of u channel samples, relative to the whole core, and the reduced width of the magnetometer response function in magnetometers designed for u channels [*Weeks et al.*, 1993], leads to improved resolution of remanence measurements. The parallel need for susceptibility data from u channel samples has led us to design an inexpensive track for u channel samples. The width at half-maximum of the response function of the susceptibility coil (3 cm) is comparable with the values for the response functions of the 2G-Enterprises model 760R u channel magnetometer at the University of Florida.

2. Description of the Susceptibility Measurement Track

[4] The measuring system is made up of three main components: a Sapphire Instruments SI2B magnetic susceptibility meter, a sample transport track, and an IBM personal computer (PC). The SI2B susceptibility meter utilizes a 1 cm-long square pick-up coil with a cross section of 5 × 5 cm. The coil is thermally insulated with polystyrene foam, making the inside dimensions 3.3 × 3.3 cm. A Faraday shield surrounds the coil inside and outside. This custom-built high sensitivity coil operates at a frequency of about 19075 Hz.

[5] The sample transport track was constructed from solid square bars of polyvinyl chloride (PVC). The sample guide has an overall length of 3.38 m and was constructed from U-shaped square channels (Figure 1). Samples are transported through the sensor coil on a sample carrier constructed from a 54 × 2.54 cm fiberglass tape (0.38 mm thickness). A high-torque 5-phase stepper motor and a driver (Oriental Motor UPK564AA) are used to rotate the drive sprocket. This motor was selected for its size and its low vibration. The shaft of the stepper motor is coupled to a 40 teeth No-Slip sprocket (PIC FMG6-40), which drives a molded polyurethane positive drive belt (Figure 1c). The drive belt has two stainless steel cores that provide for lowest stretch, and is connected to the sample carrier with a 1 mm in diameter high-modulus polyethylene cord. This cord was selected for its less than 4% ultimate elongation. The line is connected to the sample carrier with clips fashioned from titanium wire. Figure 1a illustrates the drive mechanism.

[6] A small microswitch, placed at the motor end of the track, is used to sense the home position of the sample carrier (Figure 1b). This insures that the sampling starts from the same position each time a sample is measured. An IBM PC equipped with an RS-232 serial port and a digital I/O board (Computer Boards CIO-D1024) control both track and sensor. The I/O board uses a single Intel 8255 programmable peripheral interface (PPI) digital integrated circuit interfaced to the PC bus. The A register of the PPI is configured as an output port for controlling the stepper motor driver electronics, and the B register is configured as an input port for sensing the state of the home switch.

[7] The track drive is controlled by a modified version of the GWBASIC software supplied with the SI2B susceptibility meter. The software controls sample transport, measurement, data storage, and data analysis and plotting. The measurement process begins with the software commanding the stepper motor to move the sample transport to the home position. The sample is then moved to a position 10 cm away from the susceptibility measuring coil where the first reference (in air) measurement is taken and stored. A second background measurement is taken after the u channel has been measured and the two background measurements are used to calculate a drift correction for the u channel data set. This drift is assumed to be linear and values of the drift are calculated for each data

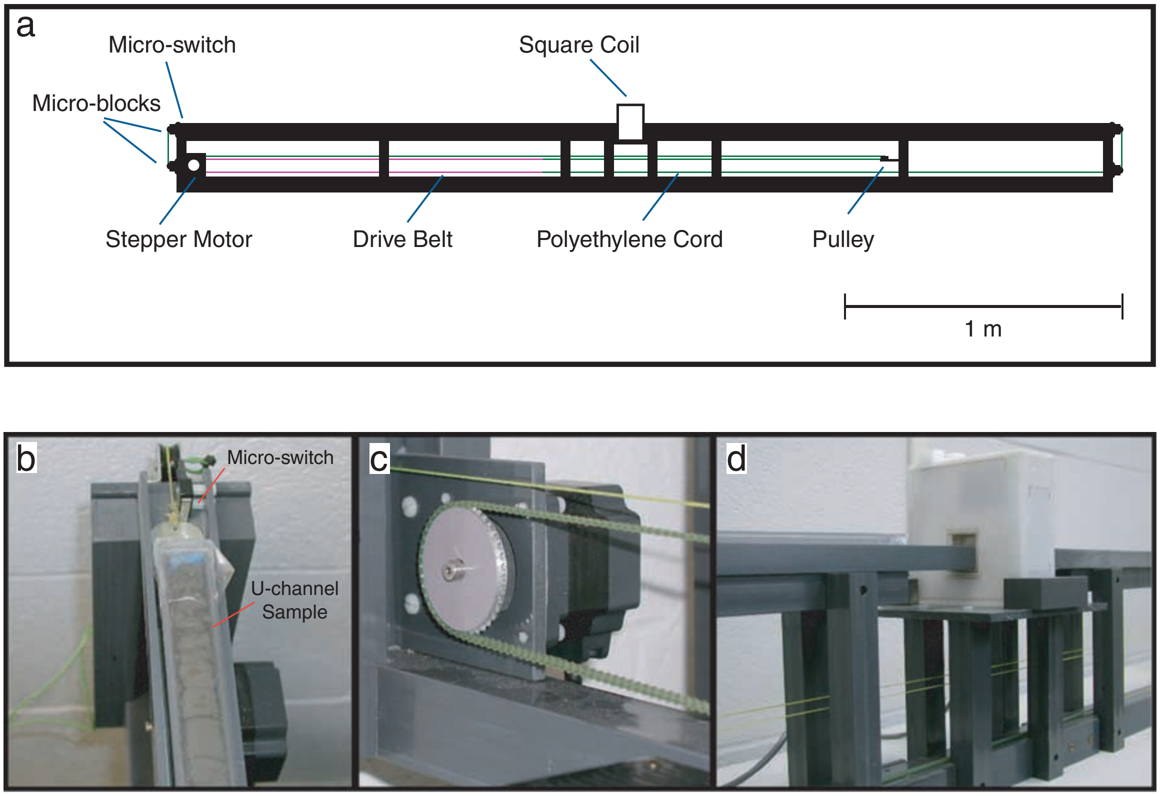

Figure 1. (a) Side view of the sample track and square-coil sensor of the u channel susceptibility system. (b) Photograph of the left-end of the track (top view), picturing the microswitch and a u channel sample. (c) Photograph of the stepper-motor, sprocket, and drive belt. (d) Photograph of the square-coil sensor.

point by linear interpolation over the time between the two background measurements.

3. Response Function of the Susceptibility Coil

[8] The response function of the susceptibility coil has been mapped using a two dimensional target made of magnetic recording media having a surface area corresponding to the interior cross section of a standard u channel (1.8 $\times$ 1.9 cm). Measurements were made as this target was moved along the axis (Z axis) of the track at 2 mm steps. Figure 2 shows the response of the coil, as a function of the distance from the center of the coil, superimposed on the X and Z axes response functions of the 2G-Enterprises u channel magnetometer used for magnetic remanence measurements [*Guyodo et al.*, 2002]. For the susceptibility coil, the width of the half-maximum of the response function is about

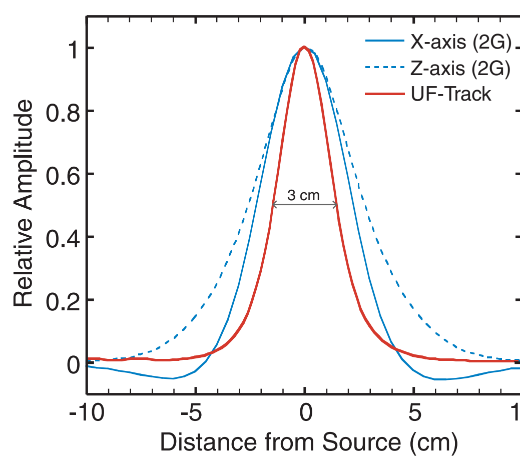

Figure 2. Response function of the Sapphire Instruments square coil used in conjunction with the u channel susceptibility measurement track (red line). The width at half-height of the response function is represented by a double arrow. Response functions of the X and Z axes of the 2G-Enterprises model 760R u channel magnetometer have been added for comparison (blue lines). Data have been normalized to their peak value.

3 cm, slightly less than those associated with the three axes of the 2G-Enterprises u channel magnetometer (Figure 2).

[9] Determination of the volume susceptibility requires that the effective sample volume be calculated by integration of the response function (area under the curve). As the response function was determined using a 2-D (X-Y oriented) target, the normalized response function represents a measure along the Z axis of the portion of a u channel actually detected by the coil. The effective volume detected by the coil is thus obtained by integrating the normalized response function (over the entire length of the response function) and multiplying it by the target cross section (3.42 cm^2). The effective volume was determined to be 11.65 cm^3.

4. Calibration

[10] The magnetic susceptibility is determined through measurement of the coil inductance. Considering a perfect coil, the relative magnetic permeability (κ_m) of a sample completely filling the coil is given by the ratio of the coil inductance in the presence of the sample (L_s) to the coil inductance without the sample (L_a). Under these conditions, the magnetic susceptibility of the sample is

$$\kappa = \mu_0(\kappa_m - 1),$$

where μ_0 is the magnetic permeability of vacuum ($\mu_0 = 4\pi \times 10^{-7}$ H/m). Replacing κ_m by its expression as a function of the coil inductance, the expression becomes

$$\kappa = \mu_0((L_s/L_a) - 1).$$

[11] In the experimental situation, however, the coil is not perfect, and sample volume and shape do not correspond to the inside dimensions of the coil. Therefore, this expression must be modified. Raw susceptibility measurements are divided by the effective volume and μ_0 is replaced by a coefficient μ determined after calibration of the coil using a standard sample of known magnetic susceptibility. Calibration of the susceptibility coil was performed using a 50-cm long u channel filled with a 99.6% pure manganese dioxide powder. The mass magnetic susceptibility of manganese dioxide is 3.29×10^{-7} m^3/kg (derived from *Lide et al.* [2002]), and the powder in the u channel had a density of 2.50 g/cm^3. This provided us with a standard characterized by a volume magnetic susceptibility of 8.23×10^{-4} (SI). This standard was first measured over its entire length using a default value for the calibration coefficient. The u channel average susceptibility was then compared to its expected value, and the calibration coefficient modified accordingly. Using this standard, we obtained a value for the calibration coefficient (μ) of 2.13×10^{-5} H/m. In practice, all measurements and initial calculations were carried out in cgs units, and data subsequently converted to SI units before storage in the output file. In cgs units (as entered in the program), $\mu_0 = 1$ (cgs, dimensionless) and the calibration coefficient is $\mu = 16.97$ (cgs).

5. Comparison With Other Data

[12] Many of the u channels measured at the University of Florida have been taken from sedimentary cores recovered by Ocean Drilling Program (ODP). Aboard the ODP research vessel *JOIDES Resolution*, magnetic susceptibilities for whole core sections (6.6 cm in diameter) are routinely determined on a measurement system track (MST). The shipboard MST utilizes an 88-mm diameter *Bartington Instruments* circular loop sensor. Different correction factors have been proposed to convert the raw values provided by the MST to SI units of volume susceptibility. For example, correction factors of 6.3, 6.6 and 6.8 $\times 10^{-6}$ have been used during ODP Legs 177, 172 and 178, respectively [*Shipboard Scientific Party*, 1998, 1999a, 1999b]. *Blum* [1997] proposed a correction factor of 7.7 or 8.0 $\times 10^{-6}$, based on comparison of shipboard MST data with discrete sample measurements. In Figure 3, ODP shipboard whole-core data are compared to that obtained with the University of Florida u channel susceptibility track, for a 10 m interval of ODP Site 984 [*Shipboard Scientific Party*, 1996a]. The difference between the averages values of the two data sets is only about 3% when a correction factor of 6.8 $\times 10^{-6}$ is used for the shipboard data, and about 10% when correction values of 6.3×10^{-6} and 7.7 $\times$

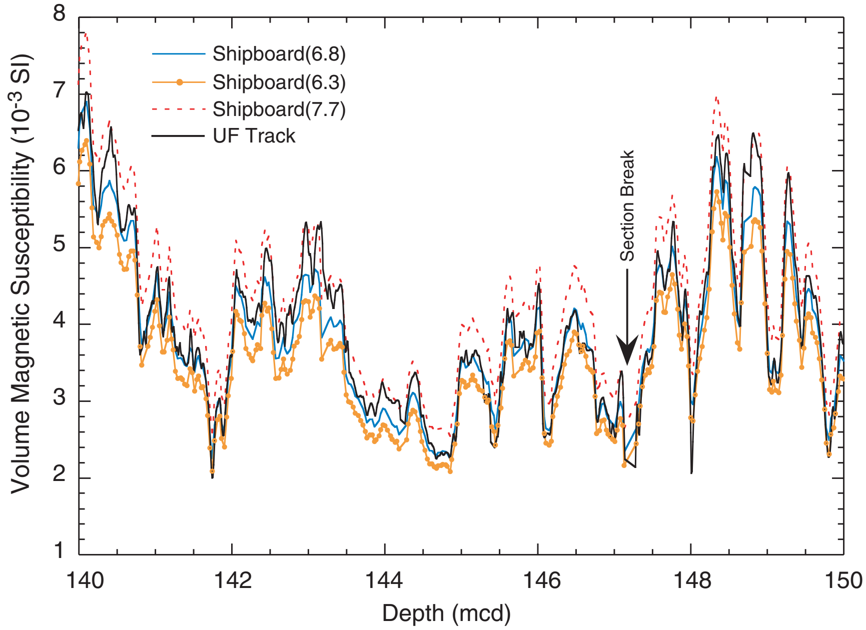

Figure 3. ODP Site 984: u channel susceptibility measurements from the University of Florida track compared with shipboard measurements, using three different correction factors (6.3, 6.8 and 7.7 × 10^{-6}) to convert raw shipboard measurement system track (MST) data to SI units of volume susceptibility. The intermediate correction factor (6.8 × 10^{-6}) provides the optimal fit to the u channel data. Depths are reported in meter composite depth (mcd).

10^{-6} are used (Figure 3). The correction faction of 6.8 × 10^{-6} is also close to a 7.0 × 10^{-6} factor obtained by calculating a linear regression between the raw shipboard data and the u channel data over this 10 m interval (r = 0.98).

[13] The shipboard data from ODP Site 983 [*Shipboard Scientific Party*, 1996b] can be compared with u channel susceptibility measurements carried out at UF and at Laboratoire des Sciences du Climat et de l'Environnement (LSCE), Gif-sur-Yvette (France) (Figure 4). The u channel susceptibility track at LSCE employs a 45-mm diameter Bartington Instruments circular loop sensor, which was calibrated by comparison of u channel and discrete sample measurements (C. Kissel, personal

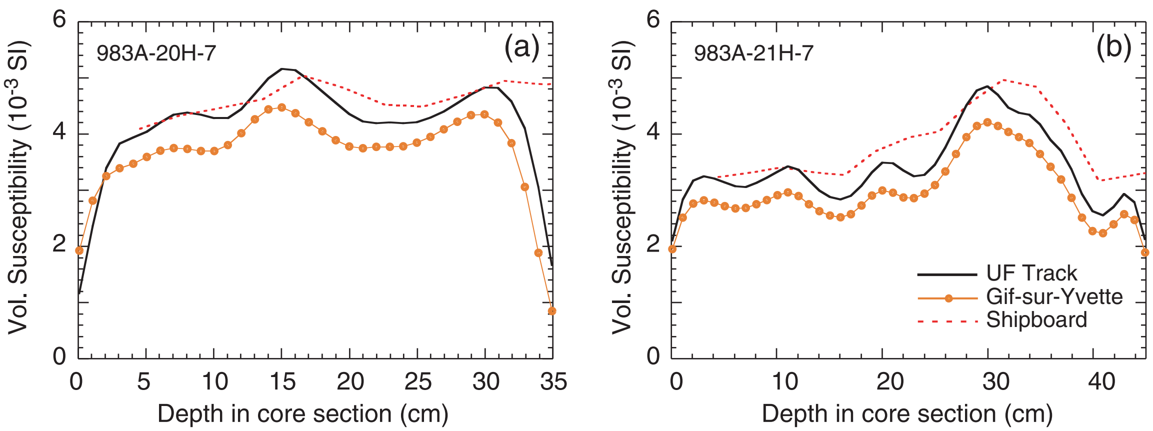

Figure 4. ODP Site 983: Sections 983A-20H-7 (a) and 983A-21H-7 (b), which have been measured for volume susceptibility aboard the *JOIDES Resolution*, at the University of Florida (UF) and at Gif-sur-Yvette (France). Ocean Drilling Program (ODP) shipboard data have been converted to SI units of magnetic susceptibility using a correction factor of 6.8 × 10^{-6}.

communication, 1999). Figure 4 shows a comparison between volume susceptibility data obtained on Sections 983A-20H-7 and 983A-21H-7. In these examples, the differences in average values between shipboard and land-based data range between 7% (UF, Section 983A-20H-7) and 25% (Gif, Section 983A-21H-7). As expected, the resolution of the u channel measurements (both for the UF and LSCE tracks) is enhanced relative to the results from the shipboard MST (Figure 4).

[14] A full list of components and suppliers used in the construction of the University of Florida u channel susceptibility track can be found at http://ess.geology.ufl.edu/susceptibility/index.html. The software can be downloaded from the same location.

Acknowledgments

[15] We thank Alain Mazaud and Catherine Kissel for supplying information concerning the calibration of the susceptibility measurement track at Gif-sur-Yvette (France). We thank Joe Stoner, John King, and Denis Kent for their comments on the manuscript. Construction of the susceptibility track at the University of Florida was supported by NSF grant EAR 96-17897. IRM contribution 0301.

References

Blum, P., Physical properties handbook: A guide to the shipboard measurement of physical properties of deep-sea cores [online], *Ocean Drill. Program Tech. Note*, *26*, 1997. (Available at http://www-odp.tamu.edu/publications/tnotes/tn26).

Guyodo, Y., J. E. T. Channell, and R. G. Thomas, Deconvolution of u-channel paleomagnetic data near geomagnetic reversals and short events, *Geophys. Res. Lett.*, *29*(17), 1845, doi:10.1029/2002GL014927, 2002.

Lide, D. R., et al. (Eds.), *Handbook of Chemistry and Physics* [online version], 83rd ed., CRC Press, Boca Raton, Fla., 2002.

Shipboard Scientific Party, Site 984, *Proc. Ocean Drill. Program Init. Rep.*, *162*, 169–222, 1996a.

Shipboard Scientific Party, Site 983, *Proc. Ocean Drill. Program Init. Rep.*, *162*, 139–167, 1996b.

Shipboard Scientific Party, Explanatory notes, *Proc. Ocean Drill. Program. Init. Rep.*, *172*, 13–29, 1998.

Shipboard Scientific Party, Explanatory notes, *Proc. Ocean Drill. Program. Init. Rep.* [CD-ROM], *177*, 1–57, 1999a.

Shipboard Scientific Party, Explanatory notes, *Proc. Ocean Drill. Program. Init. Rep.* [CD-ROM], *178*, 1–66, 1999b.

Tauxe, L., J. L. LaBrecque, R. Dodson, and M. Fuller, U-channels—A new technique for paleomagnetic analysis of hydraulic piston cores, *Eos Trans. AGU*, *64*, 219, 1983.

Weeks, R., C. Laj, L. Endignoux, M. Fuller, A. Roberts, R. Manganne, E. Blanchard, and W. Goree, Improvements in long-core measurement techniques: Applications in palaeomagnetism and palaeoceanography, *Geophys. J. Int.*, *114*, 651–662, 1993.