Deconvolution of u-channel paleomagnetic data near geomagnetic reversals and short events

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[1] The deconvolution scheme of *Oda and Shibuya* [1996], designed for half-core data from the pass-through magnetometer aboard the *Joides Resolution*, has been adapted for treatment of u-channel data. The program was tested using u-channels from Ocean Drilling Program (ODP) Site 1090. A significant increase in resolution of the u-channel data can be achieved by deconvolution, resulting in data comparable with that obtained by continuous discrete sampling. Large amplitude changes of the magnetization vector revealed by the deconvolution treatment are in good agreement with the results obtained on discrete samples extracted from the same u-channels. Application of this procedure to u-channel data from ODP Sites 983 and 984, over a short time interval around 1.255 Ma, permitted enhanced definition of the so-called Bjorn geomagnetic event. *INDEX TERMS:* 1594 Geomagnetism and Paleomagnetism: Instruments and techniques; 1535 Geomagnetism and Paleomagnetism: Reversals (process, timescale, magnetostratigraphy); 1513 Geomagnetism and Paleomagnetism: Geomagnetic excursions. **Citation:** Guyodo, Y., J. E. T. Channel, 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.

1. Introduction

[2] An increasing number of high-resolution sedimentary paleomagnetic studies have been published in the past decade, due in part to the development of pass-through cryogenic magnetometers allowing fast, automatic, and continuous measurement of sediment cores [e.g., *Channell et al.*, 1998; *Channell and Kleiven*, 2000; *Guyodo et al.*, 2001; *Stoner et al.*, 2000; *Tauxe and Shackleton*, 1994; *Valet and Meynadier*, 1993]. The 2G Enterprises pass-through magnetometers have orthogonal pick-up coils permitting simultaneous measurement of magnetization along three axes. The shape of the pick-up coil response functions results in an averaging of the remanent magnetization contributed by sediment within the response functions. In the case of the pass-through magnetometer aboard the Ocean Drilling Program (ODP) research vessel, *Joides Resolution*, the response functions have a half-peak width of ~8 cm. A few studies have attempted to correct for the smoothing inherent in the pass-through magnetometer data by developing deconvolution procedures [e.g., *Constable and Parker*, 1991; *Oda and Shibuya*, 1996]. Aboard ship, ODP core sections, 6.6 cm in diameter and 1.5 m in length, are measured as half-cores after splitting along their length. The resulting non-circular cross-section and non-centered position of the sample in the pass-through magnetometer, lead to undesirable cross-talk between measurement axes of the magnetometer that complicates efforts to deconvolve the data [*Parker et al.*, 1998].

[3] U-channel samples, typically encased in $2 \times 2 \times 150$ cm plastic containers with a square cross-section [*Tauxe et al.*, 1983], have become increasingly popular due to the availability of small-access pass-through magnetometers designed to measure them [*Weeks et al.*, 1993]. The pick-up coils in these magnetometers have narrower response functions than those of the magnetometer aboard the *Joides Resolution*, and the centering of the u-channel sample in the measurement space is better. Nevertheless, u-channel magnetometers still provide data integrated over a few centimeters, which is a problem for the study of rapid geomagnetic excursions that may be recorded over only a few centimeters. It is worth exploring whether the deconvolution of u-channel data could improve resolution over intervals characterized by rapid variations in their magnetization. For that purpose, we use the three-dimensional numerical code recently developed for data from the *Joides Resolution* by *Oda and Shibuya* [1996]. In this scheme, the magnetization vector is modeled as a smoothly changing function with a degree of smoothness obtained by minimizing the Akaike's Bayesian Information Criterion (ABIC). This method differs from that proposed by *Constable and Parker* [1991], which was based on a comparison between model residuals and observational errors. The *Oda and Shibuya* [1996] protocol treats the three components of magnetization (X, Y, and Z) simultaneously, and incorporates interactions between components. The reliability of this deconvolution program was originally tested by comparing discrete samples data with deconvolved data obtained aboard the *Joides Resolution* at ODP Site 769 [*Oda and Shibuya*, 1996; *Oda et al.*, 2000]. The deconvolution procedure was estimated to yield an effective spatial resolution of about 2 cm, and good agreement was found between deconvolved and discrete sample data [*Oda and Shibuya*, 1996; *Oda et al.*, 2000]. The discrete samples were, however, collected at 5-cm intervals down-core, and therefore a high-resolution comparison between discrete samples and deconvolved data was not performed.

[4] In the present study, we test the application of this deconvolution scheme to u-channel samples measured at a spacing of one centimeter. Results of the deconvolution treatment are compared with data obtained on 1 cm-thick

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slices of the same u-channels. Subsequently, the deconvolution program is applied to paleomagnetic data obtained from ODP Sites 983 and 984.

2. Response Functions

[5] The numerical code developed by *Oda and Shibuya* [1996] has been adapted to the type of data generated by the 2G-Enterprises 760R u-channel magnetometer at the University of Florida. The program was modified to permit uploading of data obtained from u-channel samples measured every centimeter, with a leader and a trailer of 10 cm. The protocol requires also the input of a file containing the response functions of the magnetometer sensors determined with the sampling resolution used for the u-channel measurements [*Oda and Shibuya*, 1996]. These measurements were performed with a 4-mm-edge plastic cube containing a point source with a magnetic moment of 2.3×10^{-7} Am^2, placed on the vertical wall of a plastic holder fixed to the sample tray of the magnetometer. A 4-cm^2, nine-nodes-grid was drawn on the vertical wall of the holder such that the plastic cube could be positioned at nine locations in the sensing region of the magnetometer, which permitted the measurement of the response function in a region corresponding to the cross-section of a u-channel. The response functions of the nine locations were subsequently integrated to reflect the average response of the sensors in the region occupied by the u-channel during its measurement. This procedure accounts for possible lateral non-homogeneity of the response function of the magnetometer, in the region of measurement. The response curves were measured in the X, Y, and Z directions when the cube was oriented in X, Y, and Z, respectively, and normalized by the Z intensity peak value (Figure 1). The deconvolution procedure also incorporates the cross terms between the X and Z coils [*Oda and Shibuya*, 1996]. These were introduced in the initial program to account for the vertical off-center position and shape of the samples in the shipboard magnetometer. These are not as critical here, since the u-channels are better centered relative to the pick-up coils than for half-cores in the shipboard magnetometer. The half-peak widths of the u-channel magnetometer response functions are ~4.5 cm on the X and Y axes, and ~5.5 cm on the Z axis.

3. Deconvolution of U-Channels and Comparison with Discrete Samples

[6] We selected two u-channels among those sampled from the piston cores recovered at ODP Site 1090 in the sub-Antarctic South-Atlantic. The nannofossil/diatom oozes carry a well-defined characteristic magnetization component and a pristine Eocene to Miocene polarity record [*Channell et al.*, 2002a]. The two u-channel samples were collected from core sections 1090D-17H-1 and 1090E-22H-6. The former (1090D-17H-1) records the reversal at the young end of polarity chron C7n (Late Oligocene). The latter (1090E-22H-6) records a short normal polarity chron that is either at the young end of C11r or part of C11n (Early Oligocene). Both u-channels have been stepwise alternative field (AF) demagnetized with AF peak values up to 100 mT. For each demagnetization step, the natural remanent magnetization (NRM) was measured every centimeter, with a leader and a trailer of 10 cm. The complete paleomagnetic study of the samples collected at Site 1090 is to be published elsewhere [*Channell et al.*, 2002a].

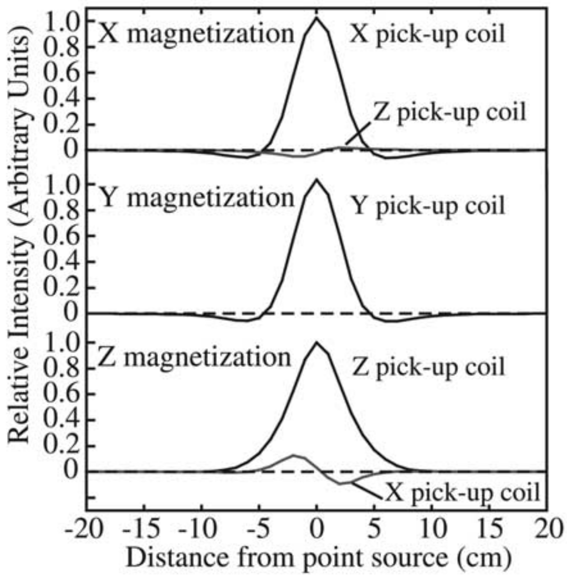

Figure 1. Normalized response functions of the u-channel magnetometer. Black lines depict the response of the X, Y, and Z pick-up coils when the magnetization is oriented in the X, Y, and Z directions, respectively. Gray lines depict the response of the Z coil to a magnetization oriented in the X direction (top), and of the X coil to a magnetization oriented in the Z direction (bottom).

[7] The discrete sub-samples were extracted from the portions of the u-channels that are not part of the composite section at Site 1090. The sampling was performed between 0 and 122 cm for section 1090D-17H-1, and between 76 and 150 cm for section 1090E-22H-6. These samples were obtained by cutting 1 cm-thick slices of the sediment contained in the u-channels. A few samples, corresponding to intervals with coarser-grained sediment, were damaged during the sampling and were excluded from this study. The discrete samples were measured in eight orientations on a three-axis discrete magnetometer located at the University of Florida (Figure 2). The u-channels were also measured in eight orientations prior to deconvolution and comparison with the discrete samples (Figure 2). Differences among u-channel measurements are small, with standard errors of ~4% and ~2% for inclination and intensity, respectively. These are noticeable only at the u-channel edges and over intervals with large magnetization gradients, where biases introduced by the response functions are the most important (Figure 2). The internal consistency of the u-channel measurements made using eight sample orientations indicates that, at the resolution of our measurements, the samples are centered in the measurement space and that cross talk is minimized. Improvements in the accuracy of the u-channel position in the magnetometer could reduce the error where the magnetization rapidly changes. For the *2G-Enterprises 760R* u-channel magnetometer, the position is determined by the stepper motor counts and may vary by up to a few millimeters due to changes in the friction between sample

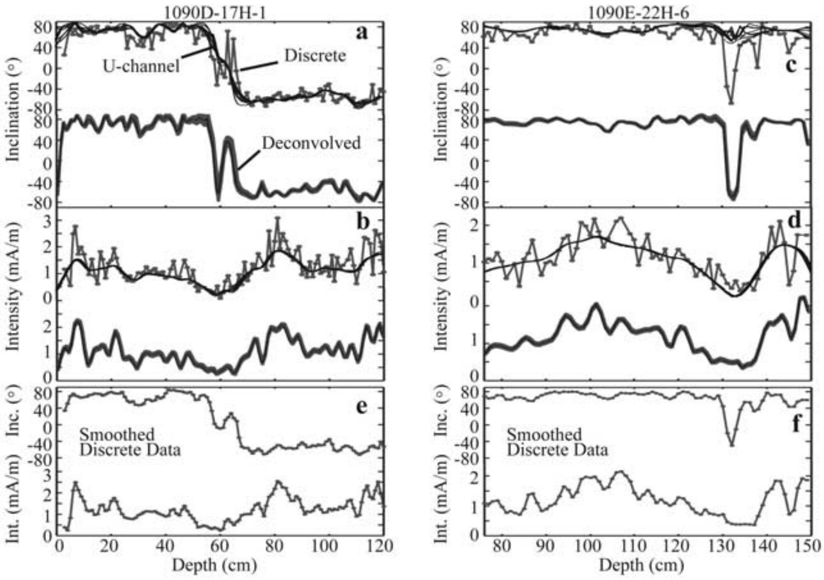

Figure 2. Deconvolved and discrete sample inclination (a, c) and intensity (b, d). Gray squares depict discrete sample data. Black lines superimposed to the discrete sample curves depict initial u-channel data. Deconvolved data are plotted at the base of each subfigure. Gray shadings depict the 95% confidence interval on the deconvolutions determined from measurement of the u-channels in eight orientations. Errors associated with the discrete data are smaller than the size of the symbols used to plot the data. (e, f) Discrete samples inclination (top) and intensity (bottom), after cubic spline smoothing of the data to reduce their resolution.

tray and guide rail. An optical encoded sample carrier would improve accuracy of the sample position.

[8] In Figure 2, the deconvolved u-channel inclination and intensity variations (averaging eight deconvolutions) are compared to the results obtained on the discrete samples. Since the discrete sub-samples were taken after the u-channels had been stepwise demagnetized up to 100 mT, the u-channel and discrete sample data in Figure 2 are the NRM after demagnetization at 100 mT. The most noticeable observation is that small amplitude features in the u-channel data are considerably amplified by the deconvolution. For instance, the small inclination modulation at about 60 cm in the u-channel data of section 1090D-17H-1 corresponds to an abrupt change of about 100° in the deconvolved data (Figure 2a). Similarly, in section 1090E-22H-6, the small directional change, at about 130 cm, becomes what might be interpreted as a short geomagnetic event after deconvolution (Figure 2c). These changes are in good agreement with those recorded by the discrete samples, which attests to the validity of the deconvolution results over these two intervals (Figure 2). Overall, the deconvolved data have a lower resolution than the discrete data, and direct comparison between the two data sets is not always obvious. When the resolution of the discrete sample data is reduced by cubic spline smoothing to simulate what would be obtained with standard 7 cm^3 discrete samples taken continuously (Figures 2e and 2f), discrete and deconvolved variations are in better agreement, except for a few features of small amplitude. These differences may be due to slight disturbances of the discrete samples, and/or to small stratigraphic errors of a few millimeters occurring during sub-sampling. Alternatively, they could indicate inaccuracies in the deconvolution results. The addition of other cross-terms of the response function, in future versions of the deconvolution code, could improve the results.

[9] We subsequently applied the deconvolution scheme to u-channel data collected from cores recovered in the North Atlantic at ODP Leg 162 at Sites 983 and 984. The high sedimentation rates at these sites, higher than 10 cm/ky, allowed the recovery of detailed paleomagnetic records spanning the last ~2 My [e.g., *Channell et al.*, 1998; *Channell and Kleiven*, 2000]. Recently, *Channell et al.* [2002b] reported the presence of several geomagnetic excursions in the directional paleomagnetic record of the Matuyama Chron at these two sites. One of those, which was named the Bjorn event, appeared as a rapid change in the direction of magnetization at 1.255 Ma, prior to the Cobb Mountain event. The age of the event was based on the match of susceptibility and oxygen isotope records to a reference oxygen isotope curve [*Channell et al.*, 2002b]. The virtual geomagnetic pole (VGP) latitudes calculated from the component directions of the u-channel NRM [*Channell et al.*, 2002b] are shown in Figure 3 for a time interval encompassing this event. The Bjorn event represents a good candidate for deconvolution, since it is recorded within less than 30 cm of sediment. It is nearly synchronous at both sites, indicating well constrained age models, although the shape of the excursion is somewhat different from one record to another. This is partly due to the slight difference in resolution of the two records. Site 983 and Site 984 have mean sedimentation rates of ~14 cm/ky and ~10 cm/ky over this interval, respectively. The u-channel data, the NRM after demagnetization at peak AF values ranging from 20 to 140 mT, were treated with the deconvolution program over the interval encompassing the event. Component directions were then calculated from the deconvolved output, for the 25–140 mT demagnetization interval. Overall, these component directions are well defined, as demonstrated by the low values of the maximum angular

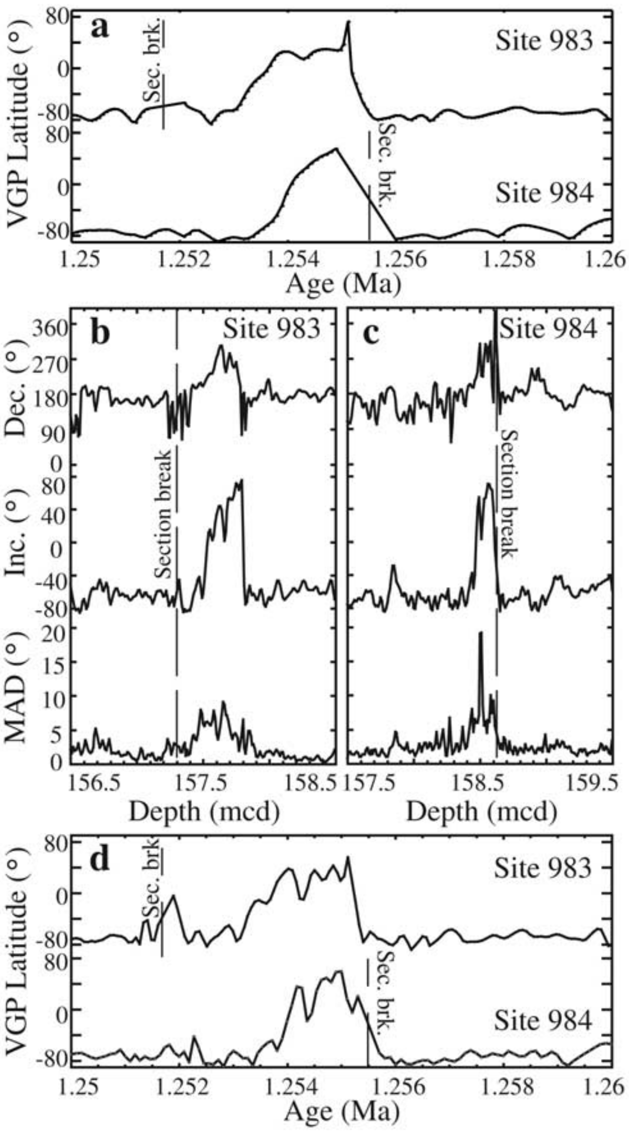

Figure 3. (a) VGP latitudes derived from u-channel component magnetization data at Sites 983 (top) and 984 (bottom). The excursion at 1.255 Ma is the Bjorn event reported by *Channell et al.* [2002b]. (b, c) Component declination (top) and inclination (middle), and associated maximum angular deviation (MAD) values (bottom) calculated from the deconvolved u-channel data at Sites 983 (b) and 984 (c). The depth scale is in meter composite depth (mcd). Dashed lines denote section breaks. (d) VGP latitudes computed from the deconvolved data at Site 983 (top) and 984 (bottom) in the vicinity of the Bjorn geomagnetic excursion.

deviation. During the Bjorn event, there is general agreement between the deconvolved data at the two sites, which is best observed when they are plotted in terms of VGP latitude versus age (Figure 3d).

4. Summary

[10] We investigated the possibility of applying the three-dimensional deconvolution scheme proposed by *Oda and Shibuya* [1996] to paleomagnetic data acquired from u-channel samples at intervals of one centimeter. Two u-channels characterized by abrupt changes in magnetization were deconvolved and the results compared with data obtained on discrete samples extracted from the same u-channels. Results indicate that deconvolved data have a spatial resolution close to what would be obtained from traditional 7 cm^3 paleomagnetic cubic samples. Large changes in the intensity and direction of the magnetization of discrete samples are reproduced by the deconvolved u-channel data. The numerical code was also applied to u-channel data from ODP Sites 983 and 984 containing a short geomagnetic excursion. A significant increase in the resolution of the directional record of this event is observed at both sites, with better agreement between the records after deconvolution.

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