Expedition 305 (Midatlantic Ridge) – Measurements with the Goettingen Borehole Magnetometer (GBM)

(Data processing by Erich Steveling, Goettingen)

This is a brief report on the latest of the data processing for internal purposes only. Finalised are the static calibration of the magnetic field sensors and the determination of the temperature dependent drift of the 3 fibre optic gyros (FOG). Particularly the determination of the drift was very time consuming. The procedure included 21 experiments in the Gauss House where the magnetometer had been heated up. The total registration time accumulated to 362 hours.
The data shown in the following figures 1-6 have been processed as follows (in brackets you find the used programme names) (file names: 1309d_no, 1309u_no):

1. Correction of value ranges in data header (GBMCON29)
2. Insert depth, registered by third system (GBMCON34)
3. Correction of Bz values (due to unknown reasons single Bz values have been transmitted erroneously when the tool rotated very quickly) (gbmcon38)
4. Split inclination and temperature values (GBMCON2)
5. Split Rx and Ry FOG data (GBMCON24)
6. Applied shift to Ry of 0.5s (GMBCON26)
7. Cut-out of lines at beginning and end (GBMCON11)
8. Drift correction of gyro data (GBMCON16)
9. Apply depth scale of meters below sea floor and depth correction (GBMCON3)
10. Split down-log and up-log (GBMCON6)
11. Cut-out lines (GBMCON11)

All figures are reduced to the open hole section 160-860 mbsf.

Figure 1: Down-log magnetic field components (not oriented). Bx and By vary in the range of approx. ±28,000 nT. It is caused by tool rotation (approx.20 rotations in this depth interval) in a 27,479 nT horizontal field at the drilling location. Furthermore, the two curves appear to have a wide-range noise, which will be discussed later. In Bz one cannot observe an impact of the tool rotation on data quality; apparently the borehole was not significantly deviated. The vertical dashed lines in the figure mark the components of the Earth’s magnetic reference field at the drilling location. The Bz values are close to the reference line, as it is supposed to be.

Figure 2: Down-log, gyro Rx, Ry, Rz (drift eliminated), inclination Nx, Ny, and temperatures T1, T2.
According to the inclinometer data Nx, Ny one can infer that at 160 mbsf the inclination of the borehole was 1.5 degree. It reduces down to 340 mbsf and finally increases slowly to 2.5 degree at total depth. At the same time Rx and Ry show only little variation, which mean the tool rotated mainly around the vertical axis. This rotation is obviously seen in Rz. Also, Rz and Bx, By (Fig.1) show a strong correlation. Rz shows a strong noise as well. T1 is the temperature of the gyros (additional heating), T2 is approximately the temperature of the tool body and hence close to the temperature of the drilling mud.

***Figure3*:** Up-log magnetic field components (not oriented).

For the up-log data the same clarifications hold as for the down-log (see Fig.1). The tool rotated about 15 times around the vertical axis. The Bz measurements from down- and up-log agree very well, which means that the small spikes (anomalies) in the curves are more than likely caused by rock magnetism!

Figure 4: Up-log, gyro Rx, Ry, Rz (drift eliminated).
For the up-log data the same clarifications hold as for the down-log (see Fig.2). In the temperature curve T1 and T2 the maximum of >70 ºC only occurs in the up-log at 820 mbsf (T2) and 740 mbsf (T1) and not, how it would be expected, at the bottom of the hole. This might be related to a delayed reaction of the temperature sensors within the probe.

Figure 5: Up-log magnetic field components (not oriented). 540-580 mbsf
Figure 5 zooms into the interval 540-580 mbsf of Figure 3. Here, one can clearly see that the apparent noise in Bx and By data is in fact a periodic oscillation of a little less than 1m, which translates to a time period of 10s when logging speed is at 0.1m/s. In Bx the double amplitude of the oscillation reaches up to 40,000 nT, which is very strong!

Figure 6: Up-log , gyro Rx, Ry, Rz (drift eliminated), inclination Nx, Ny, and temperatures T1, T2.
The gyro curves in this figure relate to the magnetic components in Figure 5. In Rz one can see the same oscillation as in Bx and By. Rz oscillates with 90º double amplitude, which means the tool experienced strongly oscillating rotations around the z axis. These tool rotations within the horizontal Earth magnetic field cause the observed Bx and By oscillations. Furthermore, due to the hole inclination the tool oscillation causes the oscillation in the inclinometer parameters Nx and Ny.

Following the above listed processing steps 1-8 the data have been further processed as follows (file names: 1309d_ro.dat, 1309u_ro.dat):

9. During the data registration the magnetic field data have been filtered with a 3s-low pass filter. Therefore, the data are transformed with FFT into a frequency domain, then multiplied with a filter function and finally transformed back into the time domain with an inverse FFT. (GBMCON25)
10. Re-orientation of the magnetic field components using the gyro data on an x (North) – y (East) – z (vertically downwards) coordination system. (GBMCON27)
11. Split down-log and up-log (GBMCON6)
12. Depth correction to mbsf (GBMCON30)

Figure 7: Up-log magnetic field components (re-oriented). 540-580 mbsf
The magnetic field data from Figure 5 (Bx, By, Bz) were re-oriented using the data from the gyro (Rx, Ry, Rz) seen in Figure 6. Principally, the re-orientation seems successful, Bx is slightly below, Bz slightly above and By on the components of the reference field data. (dashed lines). The long periodic tool rotation is, as expected, eliminated through the re-orientation; but unfortunately the short periodic oscillation is not. From the about 40,000 nT oscillation double amplitude (Figure 5) about 10,000 nT remain in Bx and By after the re-orientation. Bz now appears ‘rougher’ compared to Figure 5.

Figure 8: Down-log magnetic field components (re-oriented).
Here, the re-oriented magnetic field components from Figure 1 are presented. Re-orientation was performed with gyro data from Figure 2. Again, in principal the re-orientation was successful, however, particularly in the upper section significant deviation from the reference field can be observed. Not satisfying are the remaining high-frequency oscillations in Bx and By, which are visible as apparent noise below 440 mbsf

Figure 9: Up-log magnetic field components (re-oriented).
These are the re-oriented up-log magnetic field components from figure 2. They are equally noisy as the down-log data seen in figure 8. Bx and By show nearly no agreement between up-log and down-log.

Figure 10: Up-log magnetic field components (re-oriented) and horizontal component H.
In the left column is the non-corrected Bx and By data plotted (like in Figure 5). In the middle column the horizontal component is plotted. It is calculated using the following formula: $H = \sqrt{B_x^2 + B_y^2}$ As to be expected, H is close to the reference field (dashed line). However, the curve should be equally smooth like the vertical component Bz, and the anomalies seen in Bz should be seen in H. It appears the high-frequency oscillations cover the assumed anomalies.

The oscillations are a serious problem when investigating the data. The problems can be summarised as follows:

1. During the logging operation a long periodic and fairly constant rotation of the tool around the vertical axis can be observed. In the open hole section the rotation period is about 40m (spatially) which translates to 400s (time). This rotation is easily registered by the gyros and used for correction for the re-orientation.
2. The long periodic rotation is overlaid by a short periodic oscillation of about 1m, or 10s respectively. It is observed in the magnetic field data as well as in the gyros and the inclinometer data, hence it is real. It is unclear what causes these oscillations.
3. The oscillation in the magnetic components correlates with the ones in the gyro, but not as well so that they can be eliminated by the oscillation in the gyro data.
4. Attempts to eliminate the oscillations with a low-pass filter were so far unsuccessful. The magnetic anomalies show signatures which are in the same frequency range as the oscillations.
5. The Bz component is not affected by oscillation because of the near-vertical nature of the drill hole. The down-log and up-log run of Bz agree very well, and Bz can be used to determine magnetised layers. However, for that the not-oriented Bz should be used.
6. As long as it is not possible to eliminate the oscillations one should not use the data to calculate rock magnetisation.

At the moment we can only assume why the oscillations cannot be eliminated:

1. The programme for re-orientation GMBCON27 could be faulty. Not supporting this theory is the successful elimination of the long periodic rotation and the position of the re-oriented magnetic field components which are close to the reference field.
2. Erroneous readings of the magnetic field sensors or the gyros during data registration. It seems that the error lies rather in the magnetic sensors than in the gyros: the curve of H, which is calculated from Bx and By, should be much smoother!
3. The only way the H curve becomes smoother is when the low-pass filter function (3s low-pass) is the same for Bx and By. Hence, erroneous filters could be a cause.
4. The components Bx, By, Bz, Rx, Ry, and Rz are not recorded exactly at the same time, but successively. In principle there are phase shifts between the components. If they are not considered during the interpretation or if they are larger than expected, resulting short-periodic oscillations can be the problem.
5. The change in the magnetic field per time unit could have been to fast for the digitising sequence of 2 values per second. This might be particularly the case for the magnetic field data. The sampling theorem would have been invalidated and the true time sequence could not be reproduced. This is currently cause of major concern!
6. Future borehole measurements with the GBM make only sense if it is possible to stop such tool rations for example with a centraliser.

It is generally essential to test the low-pass filter. As soon as that is technically feasible measurements should be done accordingly.

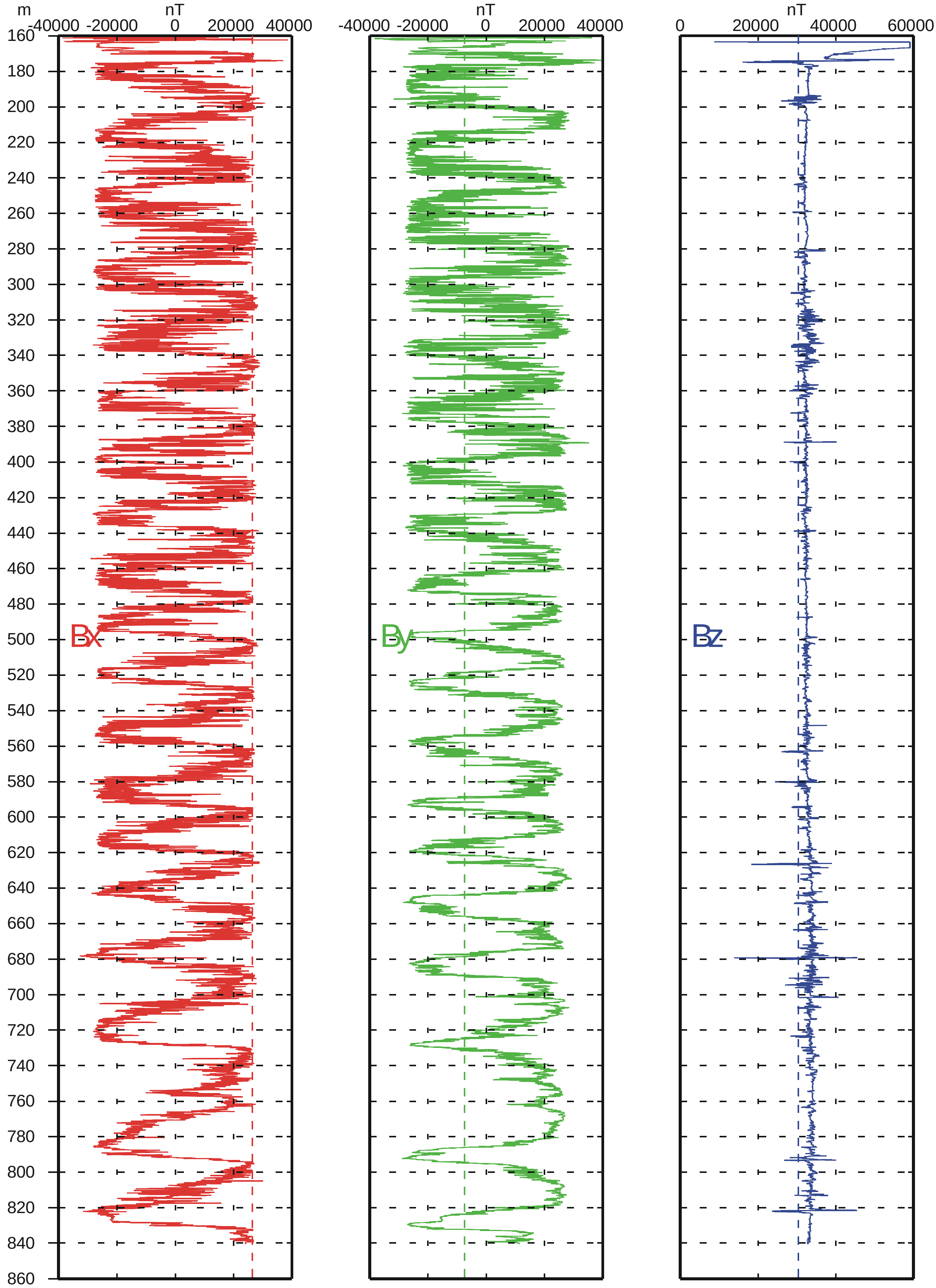

Figure 1: Down-log magnetic field components (not oriented), depth given in mbsf.

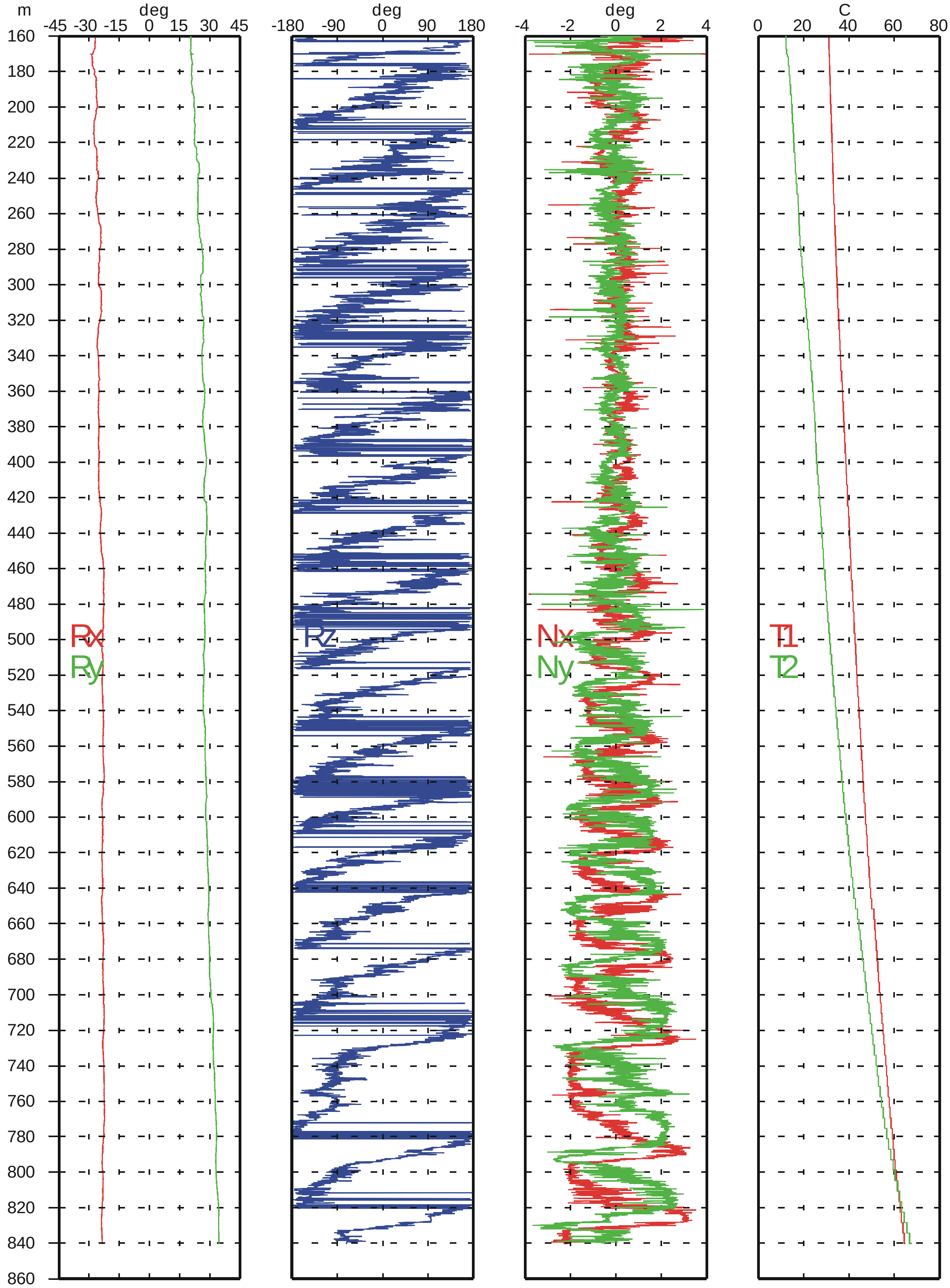

Figure 2: Down-log, gyro Rx, Ry, Rz (drift eliminated), inclination Nx, Ny, and temperatures T1, T2. Depth given in mbsf.

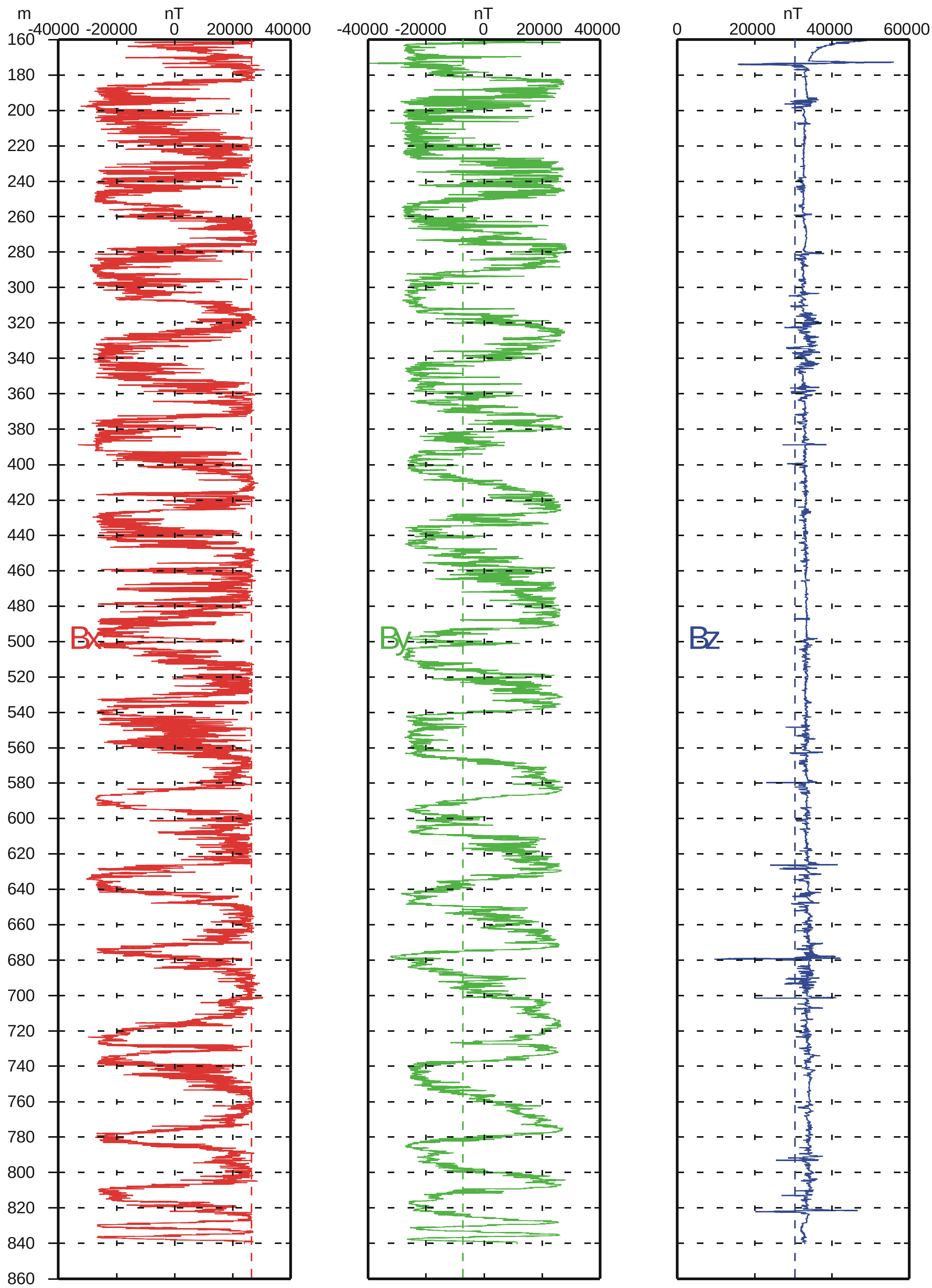

Figure 3: Up-log magnetic field components (not oriented). Depth in mbsf.

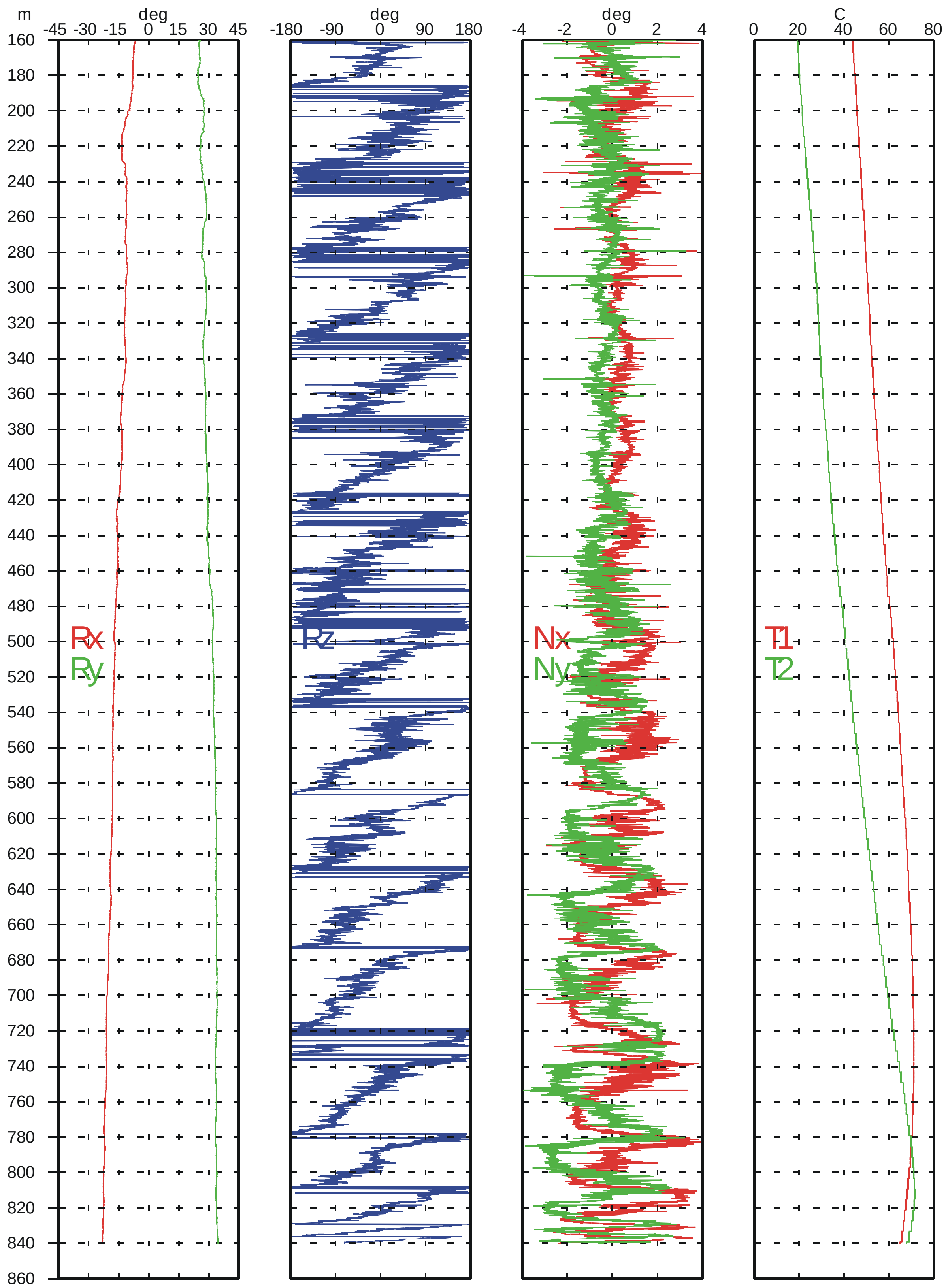

Figure 4: Up-log, gyro Rx, Ry, Rz (drift eliminated), inclination Nx, Ny, temperatures T1, T2, depth in mbsf.

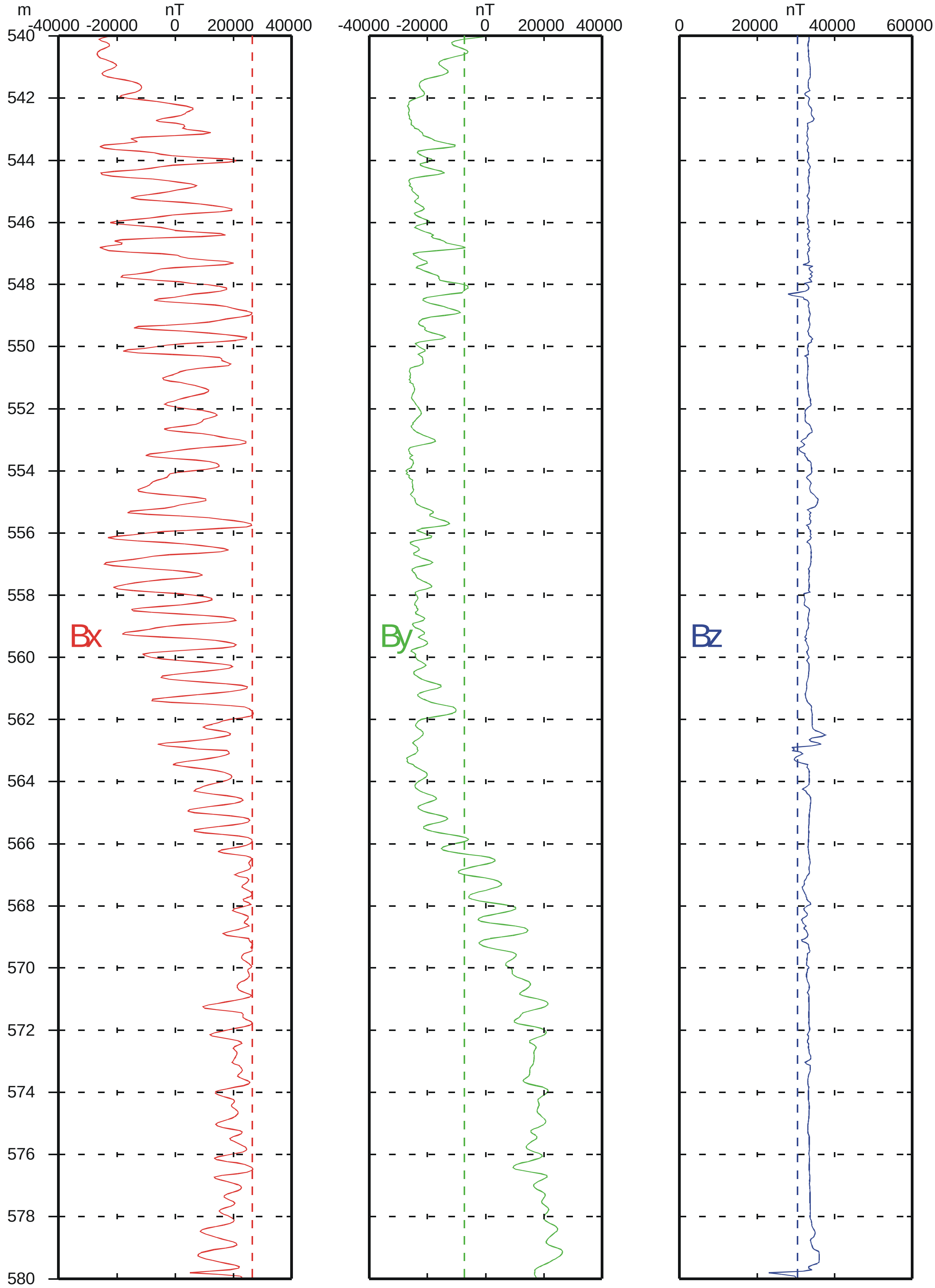

Figure 5: Up-log magnetic field components (not oriented), depth in mbsf.

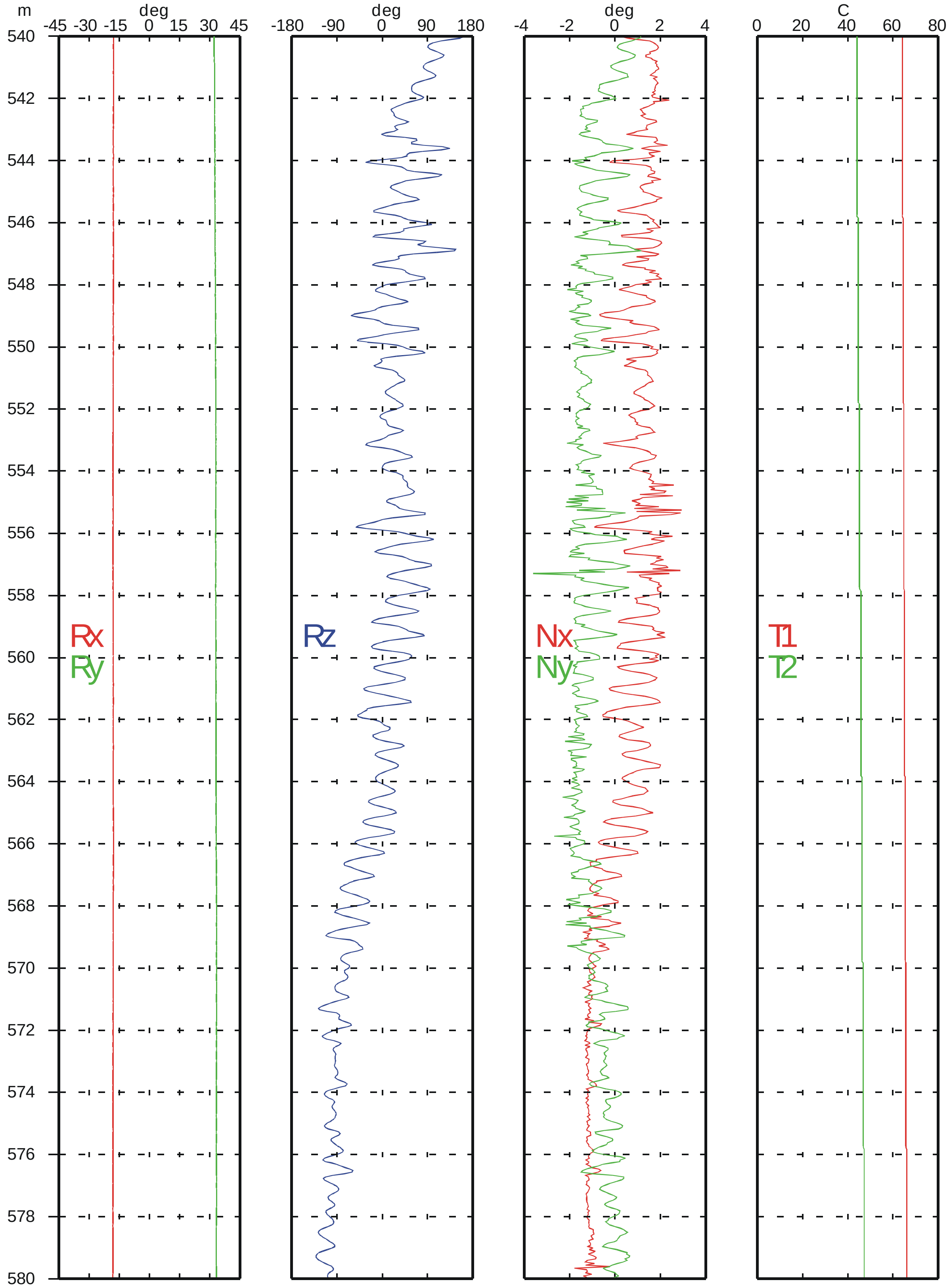

Figure 6: Up-log , gyro Rx, Ry, Rz (drift eliminated), inclination Nx, Ny, temperatures T1, T2, depth in mbsf.

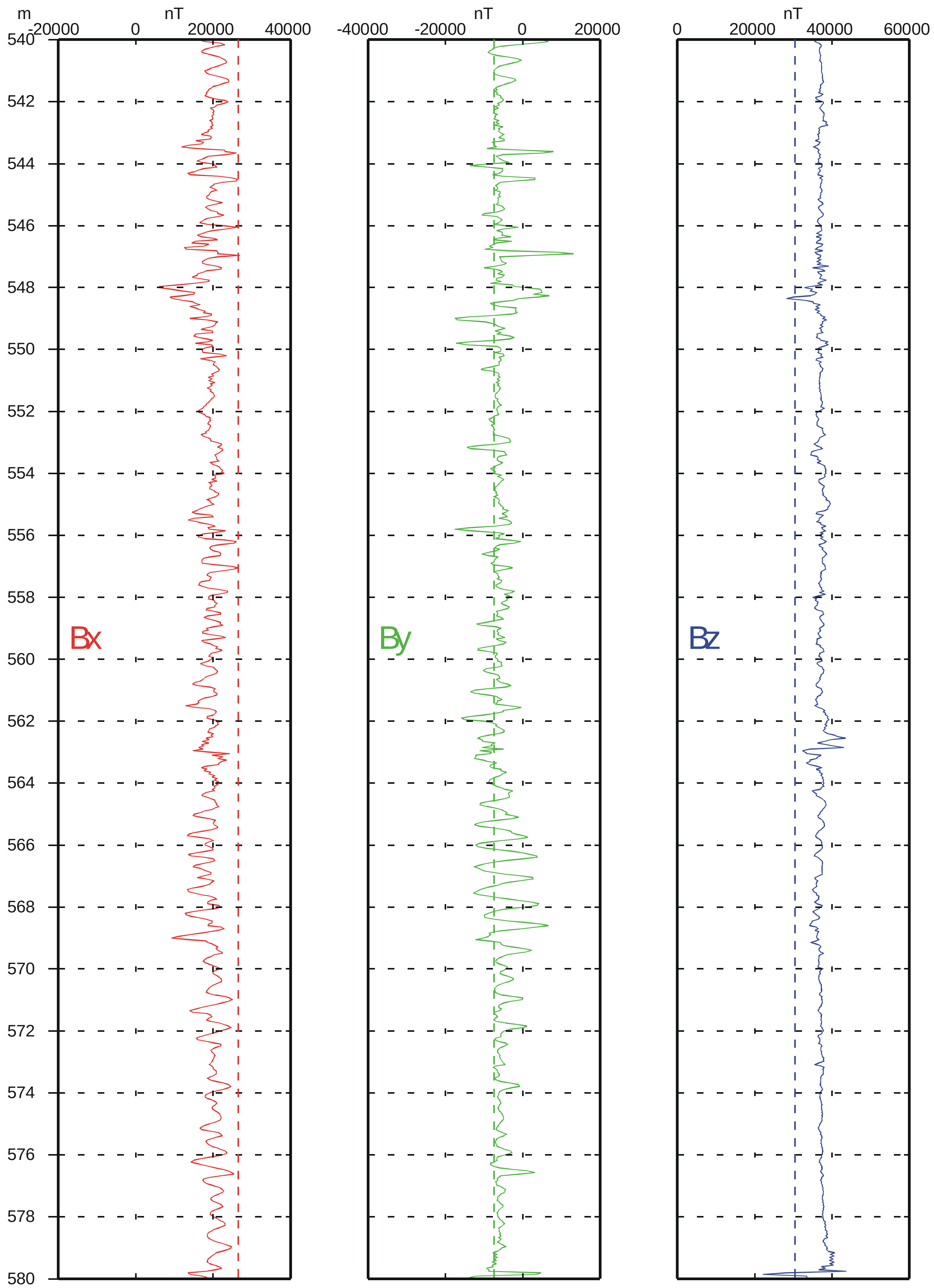

Figure 7: Up-log magnetic field components (re-oriented), depth in mbsf.

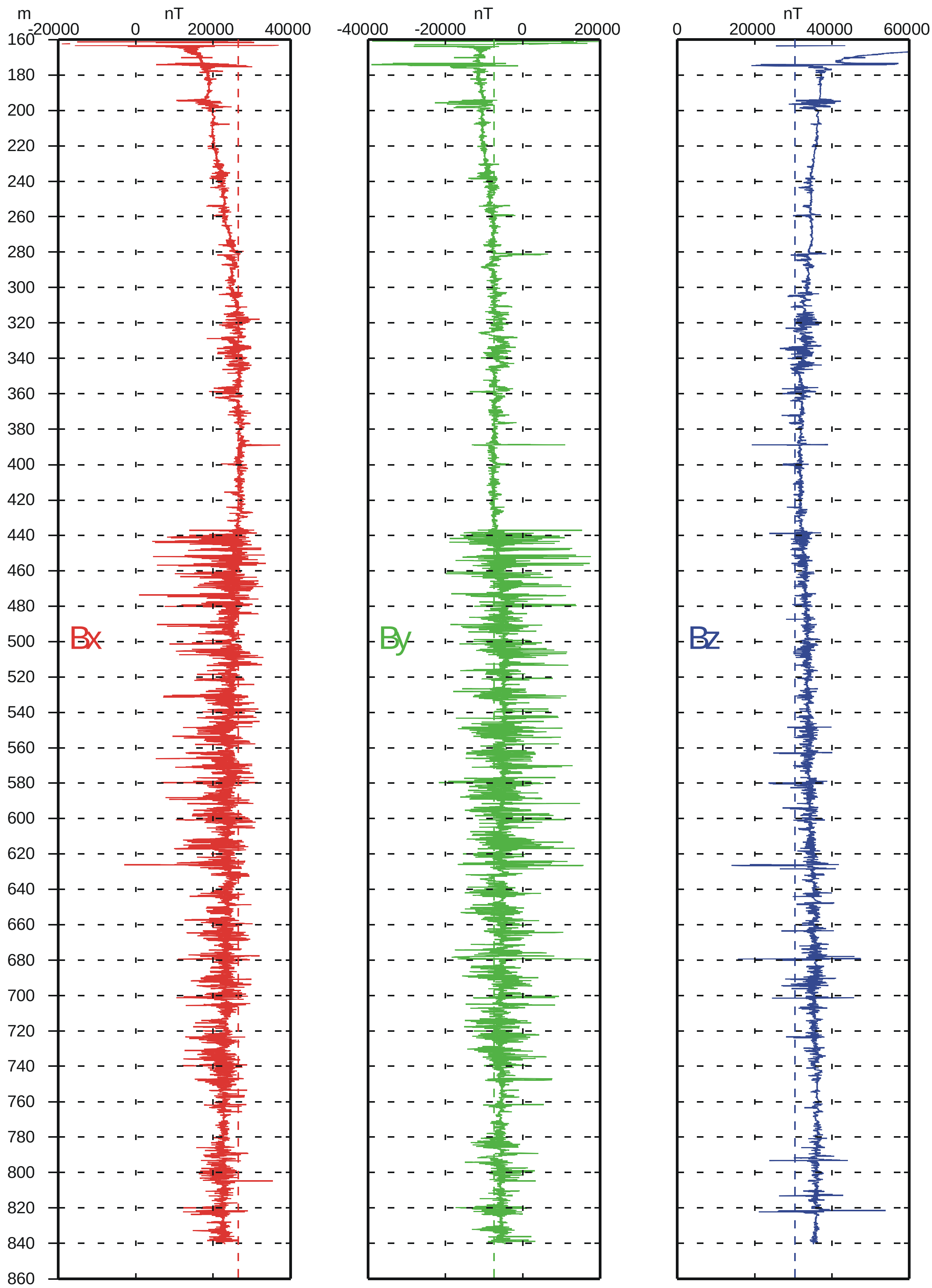

Figure 8: Down-log magnetic field components (re-oriented), depth in mbsf.

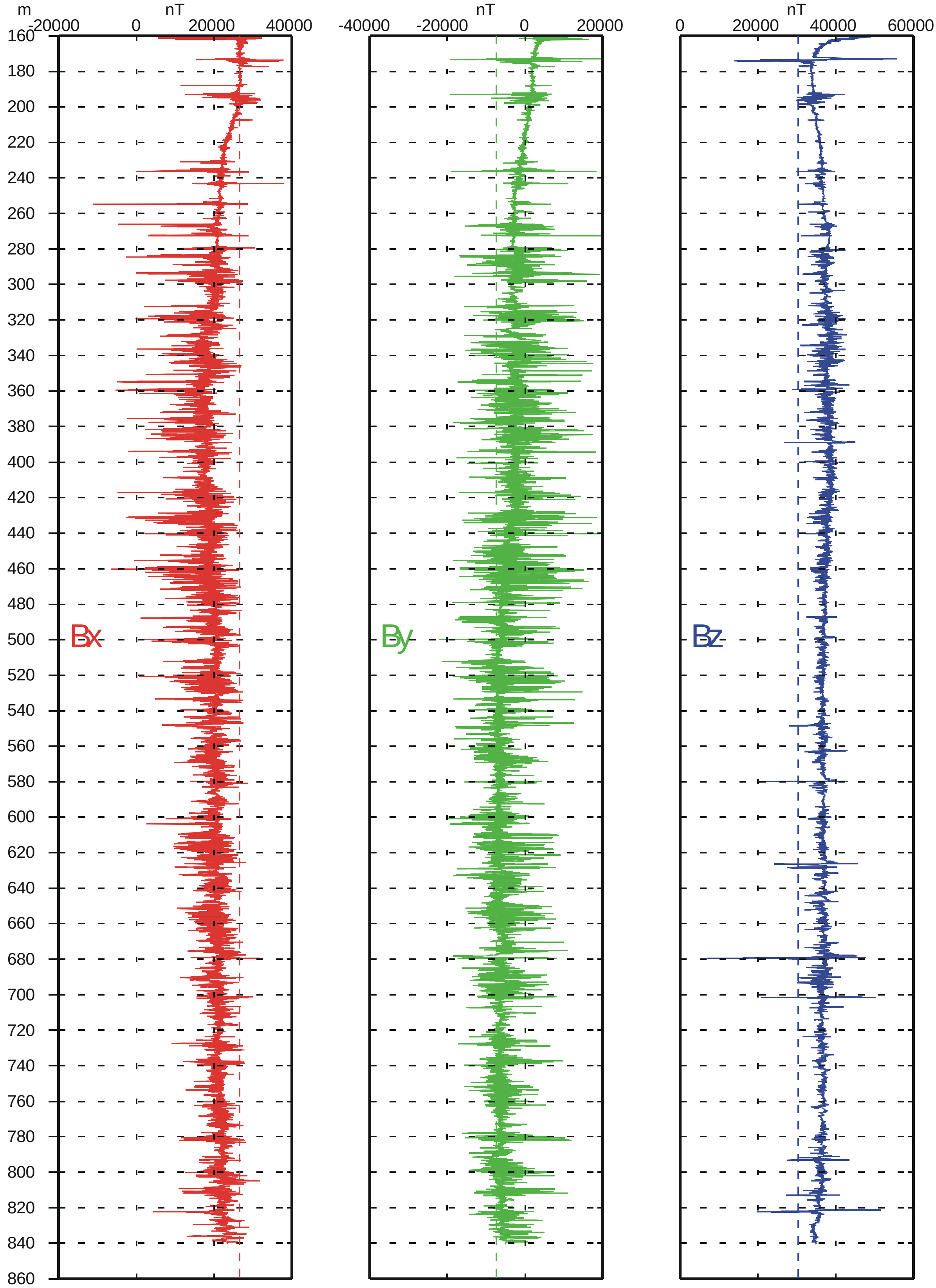

Figure 9: Up-log magnetic field components (re-oriented), depth in mbsf.

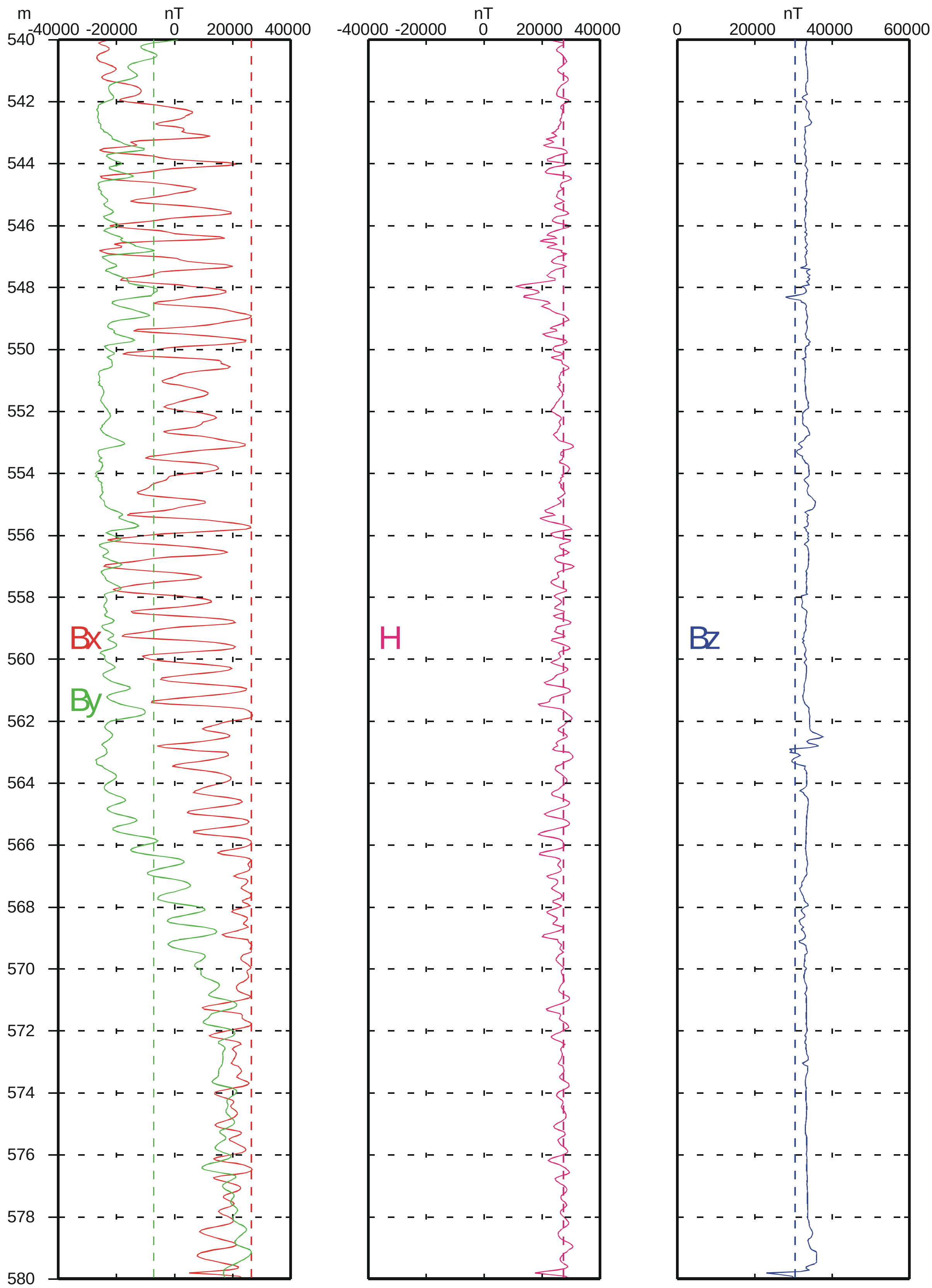

Figure 10: Up-log magnetic field components (re-oriented) and horizontal component H, depth in mbsf.