EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Center for Applied Geoscience

Group Report Magnetics

Geophysics

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1 Introduction

The aim of the following report is to locate a gas pipe in a 20 x 20 m field and to investigate effects of this pipe in the ground on the Earth's magnetic field. The question is how the pipe is aligned to the Earth's magnetic field and how deep the pipe lies in the ground. In the course of the measurement different magnetometers are used. The field is located near the Campus Morgenstelle and the measurements were taken on the 25th of May between 2 pm and 7 pm. The coordinates as well as the orientation of the field can be seen in figure 1. Furthermore, the exact basic structure of the field can be seen in figure 2. Difficulties during the measurement were caused by a larger pile of wood (P1) as well as construction site fences and other objects at the edge of the field (P2).

Figure 1: Field side from above.

Figure 2: Field side with chosen coordinate system.

2 Methods

To successfully survey a 20 x 20 m area under which a pipe is suspected, it must first be measured. An angle prism and several measuring tapes can be used for this purpose. The x-axis, which has already been laid out with a measuring tape, is fixed at both ends with alignment rods. Measuring tapes are laid out in the y-direction at a distance of 4 meters from each other with the help of the angle prism. For this, the alignment rods of the x-axis must be visible on the left and right in the angle prism, as well as the meter display on the x-axis and a third alignment rod on the y-axis. If all four markings in the angle prism are on one line, the x and y axes are at right angles to each other. After successfully laying out four measuring tapes at right angles, another measuring tape can be laid out parallel to the already existing x-axis. The measurement takes place at a distance of one meter in both directions, where a measurement is also made at 0 m so that a quantity of 441 measuring points is achieved in the end.
The measurement was done with two different instruments: a Fluxgate magnetometer (figure 3, right) which measures the vertical gradient and an Overhauser magnetometer (figure 3, left) which measures the variation of the Earth's magnetic field and the total field. The measuring instruments as well as the geophysical theory will be explained in the following.
As already mentioned the Fluxgate magnetometer measures the vertical gradient of the magnetic field, that means the change of the magnetic field in nT. The total earth magnetic field in Tübingen has a value of about 48 000 nT. A fluxgate magnetometer can detect very small changes down to 1 nT. The measurement is based on two circuits with a primary current and a secondary current. A low frequency current in kHz is induced into the primary current. If the magnetic currents are in equilibrium, they cancel each other out and are balanced. An external field, such as the Earth's magnetic field, causes an imbalance between the primary and secondary currents, which can be measured as an output voltage which is proportional to the strength of the component of the Earth's magnetic field. The Fluxgate magnetometer can measure all three spatial directions, wherein an alignment must be made in the respective spatial direction.[1] In our research, we are only interested in the vertical component, which is why only this was measured. Disadvantages of the measurement with a fluxgate magnetometer are that the ouput is a voltage, which must be calibrated in terms of magnetic field and it does not yield absolute field values.[2]
The Overhauser magnetometer measures the total magnetic field. Here it is important to record a reference measurement with the respective time before each row along the y-axis. The Earth's magnetic field is subject to relatively fast temporal changes which can be eliminated with the help of the reference measurement during the evaluation. The measurement principle is based on the principle of proton precession, consisting of a liquid with hydrogen atoms surrounded by a coil. In this process, the protons are aligned by a strong artificial external magnetic field. This artificial magnetic field is induced by the alternating coil with a certain frequency. Once the protons are aligned, the artificial magnetic field is removed and the protons are subject only to the weak earth magnetic field. Due to the different alignment of the magnetic fields, their spin direction changes and they are brought to Larmor precession, emitting a radiation which in turn

induces a voltage in the applied coil. The decreasing alternating voltage with a certain frequency equals the precession frequency, which in turn is sensitive to the total external field. This results in the relationship

$$\omega = \gamma_p \cdot |B| \tag{1}$$

ω = precision frequency $[\frac{1}{\mathrm{s}}]$
γ_p = gyromagnetic ratio $[\frac{1}{\mathrm{s}\cdot\mathrm{T}}]$
$|B|$ = total external field [T]

The Overhauser magnetometer also has a sensitivity of about 0.1 nT, this is sensor dependent.[1] Measurement deviations can occur if the Fluxgate and the Overhauser magnetometer measure too close to each other, or if any devices such as smartphones or keys are still in the pocket, as the electromagnetic waves can falsify the measured value. Furthermore, it is very important to measure at the same height throughout the measurement with each of the magnetometers, because of the fall off in magnetic field strength with the third power of distance.
We expect to find an induced magnetic dipole due to the gas pipe in the north-south direction, this would result in a magnetic anomaly with a minimum and a maximum in north-south direction. Since we are in the northern hemisphere, the dipole moment runs parallel to the Earth's magnetic field into the ground.

Figure 3: Overhauser magnetometer (left) and Fluxgate magnetometer (right).

3 Results

The results are shown in plots with the total field strength (Figure 4) respectively the vertical gradient (Figure 5) at every measurement point. To make clear at which points there was no measured data, there are black dots at every point of data collection. The points where there is a lack of data were locations where it was not possible to measure. One example was a woodpile at location ($x = 3$, $y = 7$) and ($x = 4$, $y = 7$) also marked as P1 in Figure 1 or 2. In order to obtain a continuous graph, the measurement points were interpolated using Matlab. The field strength of the total field, measured with the Overhauser magnetometer, was plottet in relation to the reference measurements that were made before measuring each y-row. For this purpose, the values of the reference measurement were each subtracted from the values of the continuously measured field strength. The first plot (Figure 4, left) shows that there was a big distraction at point P2 of the measurements. At this location there were big metal objects just next to the measurement area. Because of that, there is the second plot (Figure 4, right) which was corrected in the area where the distraction was located. For this purpose, the interfering data were eliminated and the empty places were filled with help of the nearest neighbour interpolation.

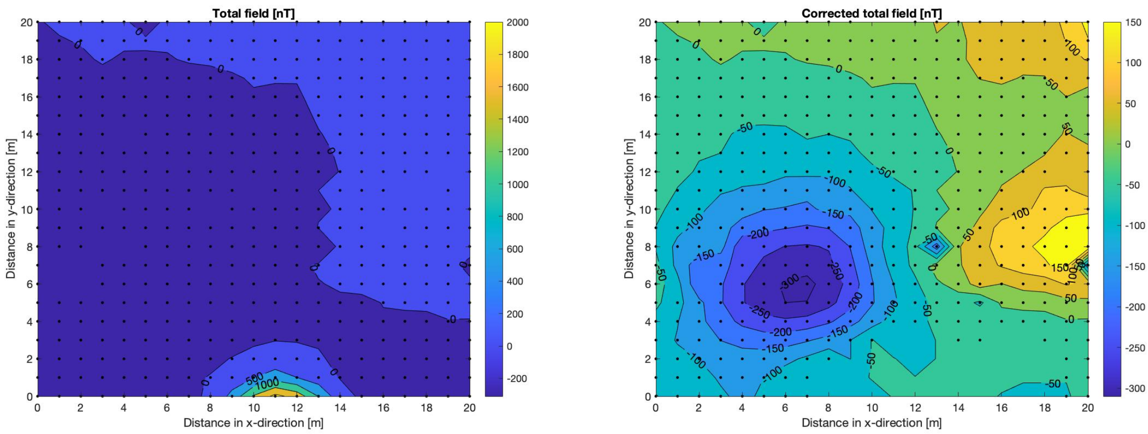

Figure 4: Contour maps of the total field strength (left) and corrected values (right) measured with the Overhauser magnetometer.

The measured values for the vertical gradient were also plotted completely at first (Figure 5, left) and corrected for the disturbances at the edge in the second graph (Figure 5, right).

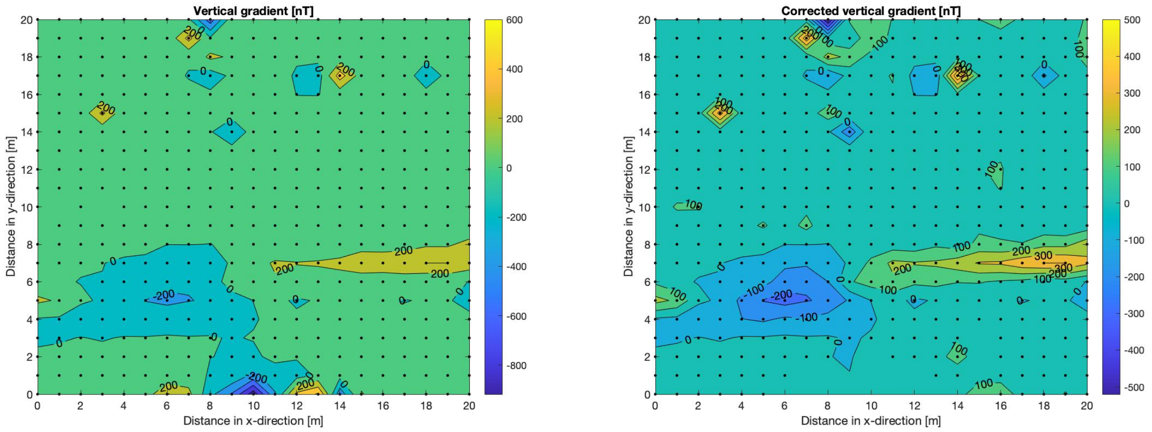

Figure 5: Contour maps of the vertical gradient (left) and corrected values (right) measured with the Fluxgate magnetometer.

The following plot (Figure 6) shows the reference measurements over time with a linear regression. The course suggests whether there was a drift during the measurement, which must be taken into account. Since the measured values vary by a maximum of 30 nT, which corresponds to a change by 0,06 % of the total field strength, a correction for the time variation is not needed.

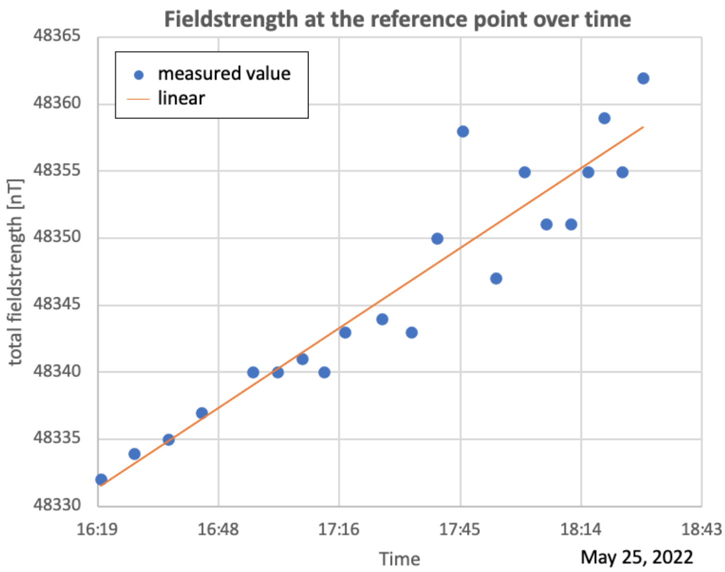

Figure 6: Total field strength at the reference point over time.

To figure out the depth of the pipe there is the halfwith defined. To find out, a side view of the anomaly (Figure 7) was created with y-values up to 13 to exclude the outlier peaks. The orange line marks approximately the fieldstrength without the pipe. For the determination the first peak is used, because it is shown completely in the plot.

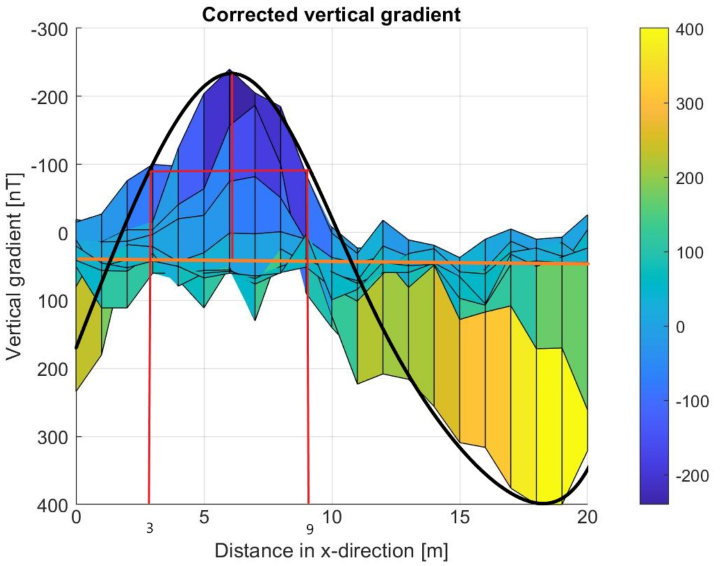

Figure 7: Graphical determination of the halfwidth with a side profile.

This results in a halfwidth of 6 m. With the help of the magnetic dipole applet of the jupyter notebook (Figure 8), the depth can be estimated. For this purpose, the data for the inclination and declination of Tübingen were inserted. The depth thus corresponds approximately to the halfwidth of the anomaly. As can be seen in the following, with a halfwidth of 6 m, the depth of the object can be assumed to be approximately 5 meters.

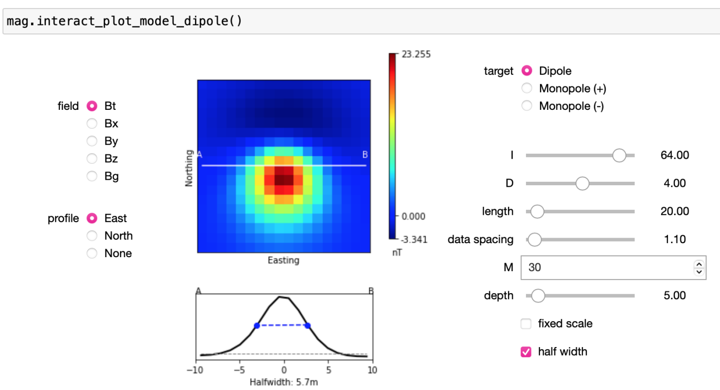

Figure 8: Estimation of the depth with the forward model [3].

4 Discussion

When looking at the figures from chapter 3 it can be seen from the blue maxima (negative values) and yellow minima (positive values) that we were able to measure an anomaly of the total magnetic field within our measurement area, which means a deviation of the total magnetic field from the Earth's magnetic field. Thus, we can assume an existing magnetized object in the subsurface. The results of the measurement with the Overhauser magnetometer as well as with the Fluxgate magnetometer match very well. Both return a maximum of the anomaly approximately at point ($x = 7, y = 5$) and a minimum at point ($x = 19, y = 7$) (see Figures 4 and 5 on the right). As described in chapter 2, we expected to detect a magnetic anomaly with maximum and minimum in the north-south direction by our measurements. However, our results do not meet these expectations. In Figure 1 it can be seen that our chosen x-axis of the measurement area is oriented approximately in the east-west direction. In both figures 4 and 5, a maximum as well as minimum of the field strength can be seen relatively parallel to the x-axis. By induced magnetization of an object such an anomaly in east-west direction cannot arise. Therefore, in our case, a remanent magnetization must be present, which, in the case of a metallic pipeline, may have arisen during the cooling process of the production. A remanent magnetization makes the interpretation difficult, since one does not know in which direction the dipole moment of the remanent magnetic field is oriented. ([2], page 267) What can be assumed, however, is that there is a narrow, longitudinal object in the subsurface on a line between the maximum and minimum, as indicated by the red bars in Figure 9. This could be a pipeline. However, it is difficult to conclude from this graphic whether or not the object extends beyond the survey area. In the side view of the anomaly of the vertical gradient from Figure 7 with an approximated curve, it can be seen that the anomaly resembles the shape of a sine curve that extends beyond the measurement area. This would be a possible indication that there is indeed a continuous pipe in the subsurface and not just an object with two ends. Since a pipeline must be built from several individual pieces, it could be that our measurement area lies exactly over one of these pieces. You can see on the left edge of the graph that the anomaly is approaching a minimum again, which can be an indicator that at the reversal point between positive and negative values a new piece of the pipe starts. Using the halfwidth, the depth of the object below the measured maximum was estimated to be approximately 5 m. As can be seen in Figure 7, the curve of the minimum is not completely within our measurement range. However, one can guess that the halfwidth of the minimum is larger than that of the maximum, which would result in a larger depth of the pipeline. Therefore, it could be that the pipeline is not exactly horizontal in the ground, but has a slight slope towards the increasing x-values.

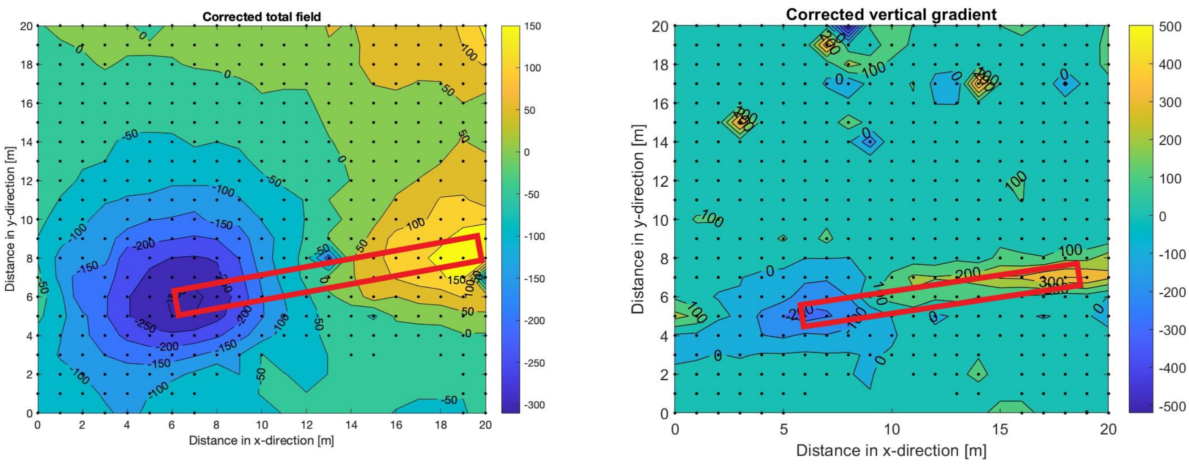

Figure 9: Contour maps of the corrected total field and vertical gradient with estimated position of the pipeline.

In addition, it should be mentioned that our measurement procedure has many sources of error. First of all, there may have been inaccuracies in the determination of the measurement area and the placement of the orthogonal lines along which the measurements were made. For example, not all measurement points have always been exactly 1 m away from their four neighbouring ones or angles have not been exactly 90 degrees. In addition, the measuring instruments must always be used to measure at the same height, whereby deviations of a few centimeters may have occurred. Furthermore, additional influences of metallic objects besides the already considered construction fences at location P2 in the surrounding of the measurement cannot be excluded.

5 Conclusion

In conclusion we were able to identify a gas pipeline in our mapped area. It lies at a depth of approximately 5 metres and runs roughly in east-west direction relatively parallel to the x-axis. We expected a magnetic anomaly with a minimum and a maximum in north-south direction due to the gas pipeline. However, this expectation did not agree with our result that there is an east-west orientation of the minima and maxima. Therefore, we conclude that there must be a remanent magnetisation of the pipe. That is why it is likely that on the line between minima and maxima a narrow longitudinal object, our pipeline, is located.
To find the depth of the pipe, there is a halfwidth defined. Using a side view of the anomaly, it can be seen that the anomaly resembles the shape of a sine curve that goes beyond the measurement range. Because of that it is not entirely clear how far it extends beyond our area. In addition we expect that the pipe is not completely horizontal in the ground due to the greater curve of the minimum.

References

[1] Telford et al. *Applied Geophysics*. second. Cambridge Univ. Pr. Cambridge, 1998.

[2] William Lowrie. *Fundamentals of Geophysics*. second. Cambridge Univ. Pr. Cambridge, 2007.

[3] URL: `https://notebooks.gesis.org/binder/jupyter/user/geoscixyz-geosci-labs-761iv0jy/notebooks/notebooks/mag/MagneticDipoleApplet.ipynb` (visited on 06/03/2022).