Abandoned Wells Near the Student Dormitory of SUSTech

Name:

Student ID:

1. Setup

The HSE Office of SUSTech was notified by the former owner of the campus that some wells were abandoned and left untreated when they were moving out. Those wells, located near now the student dormitory buildings, were cased by steel pipes and remains open. However, the landscaping work during the construction of the university unknowingly covered those wells by lawns. For the safety of students living nearby, those wells need to be located and filled back.

Initially the HSE staff attempted to retrieve information from archives, but the documents about those wells are lost. The person who were responsible for those wells can only provide approximate locations as most landmarks have been demolished. In order to avoid extensive digging or trenching, the HSE office reached out to the earth science department and asked if geophysics can help. The key information they would like to obtain is the exact location of the wells. If possible, they are also interested in how deep the wells go vertically. Here is a list of their wishes:

1. Confirm whether any steel pipes exist under the lawn
2. Determine the number of pipes and their overall distribution
3. Determine the horizontal position (precision about ten centimeters)
4. Determine the vertical extent if possible
5. Be quick and cheap but with sufficient information for the follow-up excavation

Questions:

Those requirements are from the HSE Office, and they would like you to propose a geophysical survey justified by a feasibility study. Do you think their expectations are realistic? Or how confident are you of solving those problems? Why? Provide your answers below. You may come back and revise your answers when you finish this worksheet.

Your answers:

1.
2.
3.
4.
5.

---

2. Properties

Geophysical methods only work if there is a contrast in physical properties.

Questions:

Please list at least three physical properties that you think may be used to distinguish a vertical carbon steel pipe and the surrounding media. Also provide comments on whether these properties can be practically used in this project.

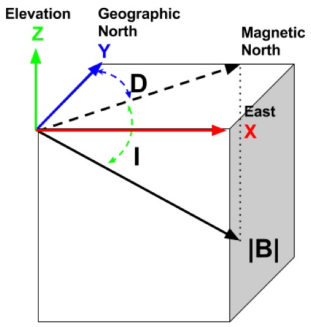
Your answers:

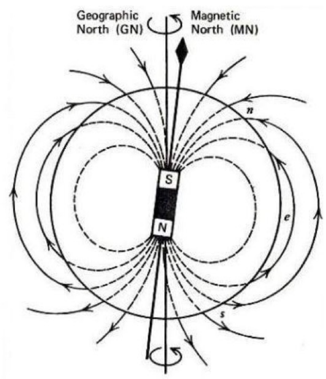
1.
2.
3.

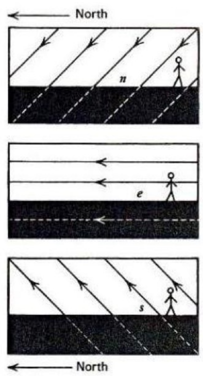
Carbon steel, compared to other common earth materials, are highly magnetized. There are two types of magnetization in a carbon steel pipe, remanent and induced magnetization.

1. Induced magnetization

The earth produces a very strong magnetic field that appears like from a bar magnet at the center of the earth, or so-called a dipole field. At any locations on the earth, the dipole field is a vector specified by three quantities: inclination (I), declination (D) and intensity or magnitude (|B|).







Questions:

Find the three quantities of the geomagnetic field ($\mathbf{B}_0$) at Shenzhen.

Your answers:

- Inclination =
- Declination =
- Intensity =

Carbon steel is magnetically susceptible, which means a small piece of carbon steel has the ability of becoming a small magnet (a magnetic dipole) under the influence of an external field. The direction of this induced magnetization is the same as the local geomagnetic field. The strength of the dipole and its field are associated with an intrinsic property: susceptibility κ (unitless). The magnetization intensity of a small piece quantifies how many bar magnets (unit dipole moment) are in a unit volume, and is given by

$$M = \kappa H_0 = \kappa B_0/\mu_0,$$

where $\mu_0 = 4\pi \times 10^{-7} H/m$ is the magnetic permeability in free space. So the total magnetic moment (total number of small bar magnet) of the small piece is

$$m = MV,$$

where V is the volume.

The observed dipole field from that small piece at a certain distance ($\mathbf{r}$) is

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi}\left(\frac{3\mathbf{r}(\mathbf{m}\cdot\mathbf{r})}{r^5} - \frac{\mathbf{m}}{r^3}\right),$$

where $\mathbf{r}$ and $\mathbf{m}$ are vectors of distance and induced dipole moment, respectively. When κ is not too large, superposition holds so the total effect of the entire pipe is the sum of many small pieces (dipoles).

Questions:

Find the susceptibilities of the following media.

Your answers:

1. Air =
2. Water =
3. Carbon steel =
4. Copper =
5. Sand =
6. Magnetite =
7. Granite =

2. Remanent magnetization

Materials at high temperatures are non-magnetic. When a pipe is cooled down during manufacturing, it picks up the orientation of local geomagnetic field and memorize it. A fixed and permanent magnetic field is then attached to the pipe and moves or rotates with the pipe even the pipe is displaced.

Questions:

Find an object with remanent magnetization (nails, steel rod, re-bar, etc.) and figure out the orientation of its remanent magnetization using the 3-axis magnetometer on your smart phone (Physics Toolbox App). Describe the direction of magnetic field lines relative to the object.

Your answers:

-

3. Survey

In most exploration problems where the geomagnetic field is assumed constant in a local survey area, the induced and remanent magnetization or their combination are the source of magnetic anomalous data. The geomagnetic field is a vector field that can point to any direction in a 3D space. While it is possible to measure all three components, a typical form of magnetic data is the total magnetic intensity (TMI), which can be easily measured by the proton precession magnetometer or cesium vapor magnetometer.

To illustrate TMI data, we consider an object embedded in the earth generating an anomalous magnetic field ($\vec{B}_A$) due to the induced magnetization. Based upon the earth magnetic field ($\vec{B}_0$), we define a unit vector $\hat{B}_0$ for the earth field as

$$\hat{B}_0 = \frac{\vec{B}_0}{|\vec{B}_0|}$$

We measure both earth and anomalous magnetic field such that

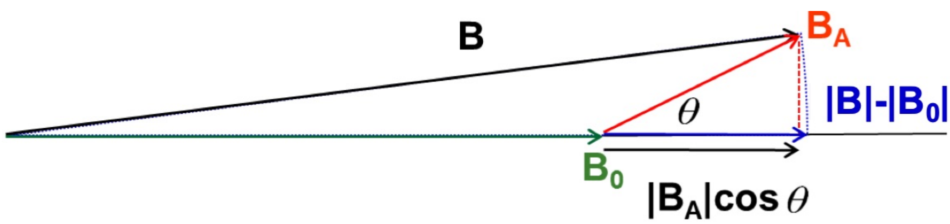
$$\vec{B} = \vec{B}_0 + \vec{B}_A$$

Total field anomaly, $\triangle\vec{B}$ can be defined as

$$|\triangle\vec{B}| = |\vec{B}| - |\vec{B}_0|$$

If $|\vec{B}| \ll |\vec{B}_0|$, then the **scalar** total field (TMI) anomaly $|\triangle\vec{B}|$ is the projection of the anomalous field onto the direction of the earth field:

$$|\triangle\vec{B}| \simeq \vec{B}_A \cdot \hat{B}_0 = |\vec{B}_A| cos\theta$$



Questions:

Suppose we are at the magnetic north pole with a vertical geomagnetic field pointing down. A susceptible cubic object of $\kappa = 1$ and $V = 1m^3$ is buried 10 m below the surface. Calculate the TMI anomaly data directly above the object on the surface. Compare the value with the geomagnetic field and verify the validity of the approximation above.

Your answers:

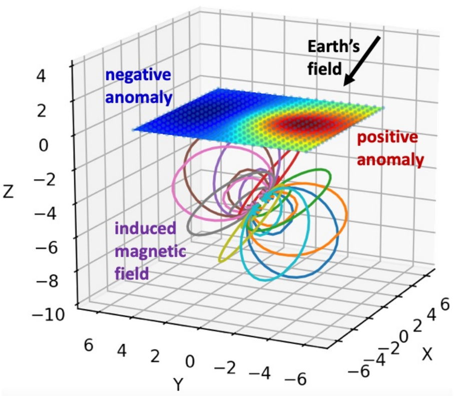
-

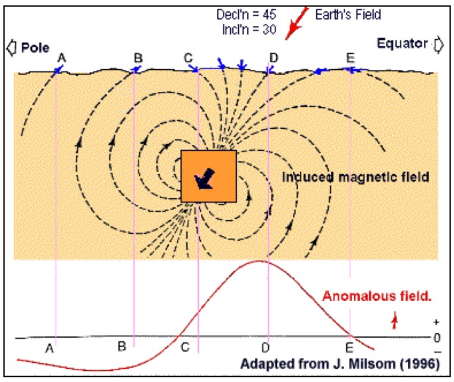
---

4. Data

Similar to the gravity data, magnetic data are often acquired along survey lines or over a survey grid on the surface. For the same magnetic object, its TMI anomalous data pattern can be quite different depending on the background (inducing) geomagnetic field.

The figures below illustrate the anomalous magnetic field lines from a susceptible object in 3D and its anomalous TMI data. The block only has the induced magnetization, and is relatively small so the anomalous field from it appears like a dipole field. For magnetic, it is important to note the peak of anomaly does not necessarily corresponds to the location of object.





Questions:

Under what circumstances, does the peak of anomaly directly indicate the location of object?

Your answers:

-

Magnetic Dipole Anomaly App

Play around with the interactive app below to understand the TMI responses observed on the surface due to a small susceptible object. The object is sufficiently small, so its field appears like from an magnetic dipole.

- **Inclination** (I) and **declination** (D) describe the orientation of the Earth's ambient field. Positive inclination implies you are in the northern hemisphere, and positive declination implies that magnetic north is to the east of geographic north.
- **length** changes the size of the square survey area. The default is 72 m on a side.
- **data spacing** changes the distance between measurements. The default is a 2-metre grid.
- **M** is the total dipole moment in Am^2. M is assumed to be only from the induced magnetizations, whose direction is the same as the geomagnetic field and magnitude can be calculated using susceptibility and volume.
- **depth** changes the depth (in metres) to the centre of the buried object.
- **Bt, Bx, By, Bz, Bg** are the total field, X-component (positive northwards), Y-component (positive eastwards), Z-component (positive down) and gradient of the anomalous field respectively.
- **fixed scale** fixes the colour scale so that the end points of the colour scale are minimum and maximum values for the current data set.
- **profile** specifies the direction of the survey profile.
- **half width** marks the half width of the anomaly, providing an estimation of the depth of burial.
- All measurements are taken 1m above the surface. The gradient data **Bg** are taken at heights of 1m and 2m.
- Note: magnetic moment (M) for monopole mode is equal to the magnetic charge (Q).

In [10]:

```
from geoscilabs.mag.MagDipoleApp import MagneticDipoleApp
mag = MagneticDipoleApp()
mag.interact_plot_model_dipole()
```

Questions:

A susceptible object (1×1×1 m, κ = 1) is buried 10 m deep in Shenzhen. What does the TMI anomalous data on surface look like?

Answers:

- Set the parameters in the app above and save this notebook to keep the images of data.

Simulation of a Vertical Steel Pipe

In this feasibility study, you need to be able to numerically forward model the TMI response of a steel pipe and prove such signals can be detected for the purpose of locating the pipe.

Questions:

Please write a code to carry out this calculation.

- The pipe has an inner radius 8 cm and an outer radius 10 cm.
- The pipe is made of carbon steel with a nominal susceptibility $\kappa = 100$.
- The length of pipe is unknown. Please make your code flexible in modeling a variable length.
- The pipe is covered by a layer of soil and lawn, and the depth to the pipe head is about 20 cm.
- The strength and direction of remanent magnetization are unknown. Please make your code flexible in modeling a variable remanent magnetization.
- We assume that superposition holds in this scenario, so a long pipe can be approximated by a string of small pieces.
- TMI data are measured by a magnetometer 1 m above the surface.
- Make two plots: (1) TMI anomalous map over a data grid of your choice; (2) TMI anomalous data profile along a line across the pipe.

Your answers:

In [11]:

```
# Your code starts here

# Tip: you may want to encapsulate your simulation code into a function for use
 later

# Plan view

# Profile
```

5. Processing

In feasibility studies, synthetic noises can be added to the simulated data to test the reliability of processing and interpretation methods. A random noise is often characterized by a zero-mean Gaussian distribution with a standard deviation quantified by some reference values (e.g. a percentage of the peak or average TMI anomaly, the sensitivity threshold of the instrument, a fraction of the background geomagnetic field).

Questions:

Suppose there is a random ambient noise at the site. Please add a random noise of some different levels (e.g. 1 nT, 10 nT, 100 nT, ...) to the data you just simulated above and visualize them. Can you determine which noise level can seriously distort the TMI data anomaly and make the data useless? Let's assume the pipe is 10 m long and there is no remanent magnetization.

Your answers:

-

In [12]:

```
# Your code starts here

# Add noise

# Plan view (noisy data)

# Profile (noisy data)
```

6. Interpretation

With the capability of simulating the magnetic response of a vertically buried steel pipe, we are able to investigate the detectability of a surface TMI survey to the abandoned wells. Finish the following exercises by running your simulation code with different parameters.

Questions:

For objects made of steel, the remanent magnetization may be much greater than the induced magnetization. Use your code to investigate how the presence of remanent magnetization influences the TMI anomaly. And how does the remanent magnetization affect the search for the abandoned wells? Hint: Draw your own conclusions by varying the direction and magnitude of the remanent magnetization.

Your answers:

-

In [13]:

```
# Your code for the investigation on the remanent magnetization
```

Questions:

The HSE Office is very interested in knowing the vertical extents of the pipes. Do you think a TMI survey on the surface can provide such information? Use your code to help answer this question. Let's assume the direction of remanent magnetization is vertically upwards and its strength is 10 times stronger than that of the induced. Hint: You may run simulations for a variety of vertical length and then compare them.

Your answers:

-

In [14]:

```
# Your code for the investigation on detecting the pipe lengths
```

Questions:

The HSE Office is almost convinced. Before they grant the final approval, you need to provide a plan of survey. One of the most important parameters is the spacing between two measurement locations. Use your simulation code to determine the "optimal" spacing that has the best trade-off between precision and economy.

Your answers:

-

In [15]:

```
# Your code for planning the survey (spacing)
```

7. Synthesis

Congratulations! You just finished most of the feasibility study. Your plan looks quite feasible. But there are still some questions you can think about.

Questions:

1. One big unknown in this project is the parameters of remanent magnetization. Can you do anything to solve this problem?
2. What measures can be taken if the anomaly from pipes is too weak?
3. There may be other small scrap metals buried near surface at the site, and they may also interfere with the TMI data. What can you do to minimize their influence?

Your answers:

1.
2.
3.

End of Worksheet

In [ ]:

```

```