Borehole Electrical Resistivity

In a water-filled, horizontal borehole, electrical borehole measurements with different electrode configurations are to be carried out. Based on the borehole measurement data, the layer boundaries of a sulfidic ore zone in the Freiberger grey gneiss are to be determined.

Experimental Setup

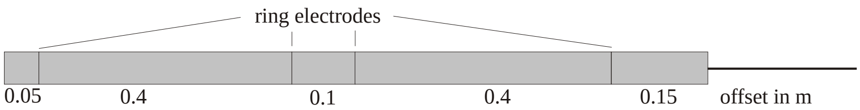

Figure 1: Setup of the borehole probe

On the used borehole probe (Figure 1), 4 ring electrodes are attached at different distances. Therefore, the four configurations shown in Figure 2 can be realized.

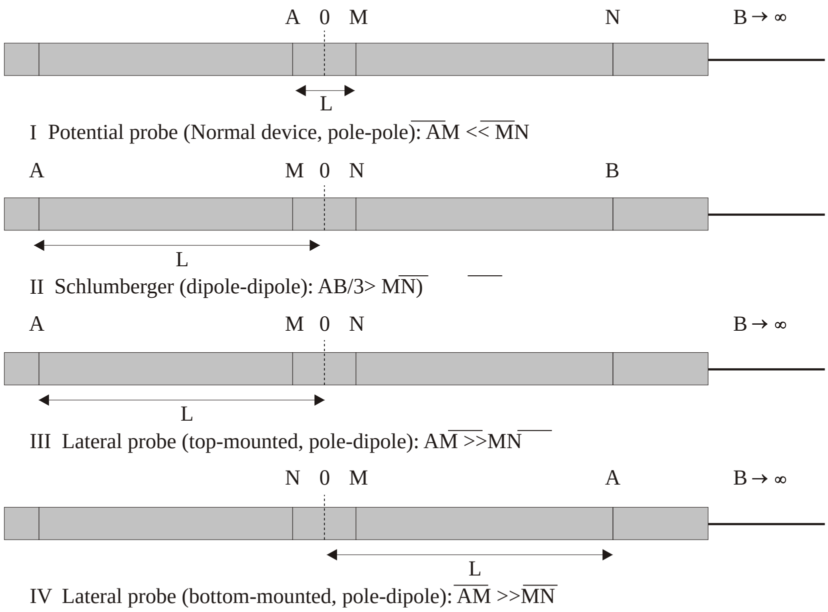

Figure 2: Electrode configurations; A,B - electrodes for current injection; M,N - electrodes for voltage measurement; L - spacing

The reference point 0 of the probe is the same for all configurations, and the measured value of the electrical resistance R is assigned to it. The probe spacing L is a measure of the effective depth of investigation (defining the radial range from which the measurement still collects information from the surrounding rock) of the respective configuration. For the potential and gradient probes, the current electrode $B \rightarrow \infty$ is grounded at a large distance from the wellhead.

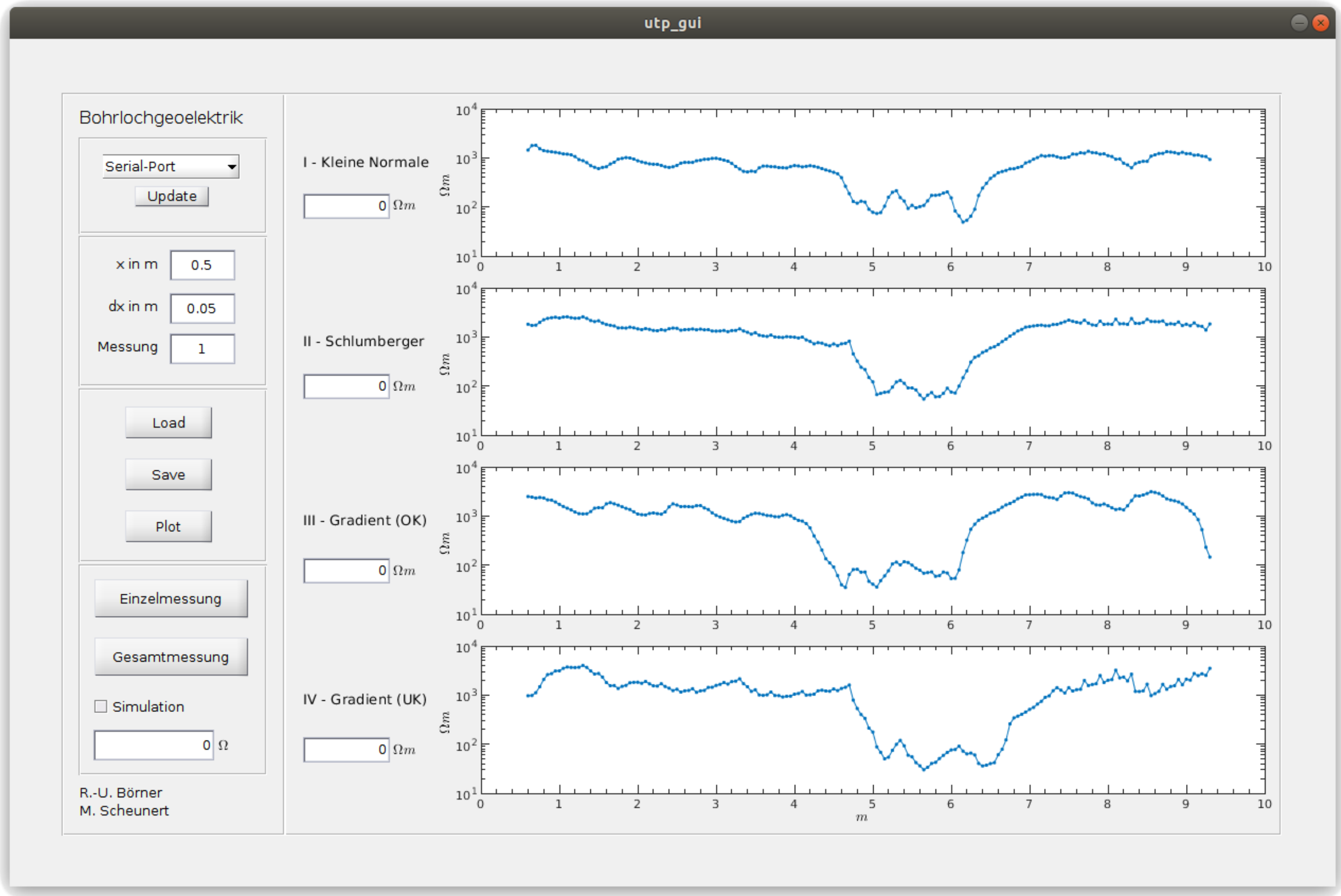

Figure 3: Graphical user interface of the MATLAB program `utp_gui`

The measurement configurations can be selected via a switch box (Table 1).

The measuring device used is the *Terrameter*. For each measurement, a selectable, constant current I is injected and the voltage drop ΔU is measured. The electrical resistance is given by:

$$R = \frac{\Delta U}{I}. \tag{1}$$

Nr.	Configuration
I	Normal device
II	Schlumberger
III	Top-mounted lateral probe
IV	Bottom-mounted lateral probe

Table 1: Configuration selection at the switch box

Group	`x in m`	`dx in m`
1	0.6	0.2
2	0.65	0.2
3	0.7	0.2
4	0.75	0.2

Table 2: Overview of starting depths and measurement point spacing for the groups

The MATLAB program `utp_gui` calculates the *apparent resistivity* ρ_s for each configuration according to Neumann's formula:

$$\rho_s = Rk \tag{2}$$

from the electrical resistance R and configuration factor k. That is, the apparent resistivity is the resistivity value that would be measured in a homogeneous half-space with the same electrode configuration and resistance value. The configuration factor k for the full space is given by:

$$k = 4\pi \left(\frac{1}{\overline{AM}} - \frac{1}{\overline{AN}} - \frac{1}{\overline{BM}} + \frac{1}{\overline{BN}} \right)^{-1}. \tag{3}$$

For each measurement configuration, the measurement curve is graphically displayed and the current measurement value is shown (Figure 3). It is possible to measure all four configurations one after the other as part of a `Gesamtmessung` or to start a `Einzelmessung`. Under `Messung`, a number between 1 and 4 must be specified, with the configurations numbered in the order of their graphical representation. To determine the location of the measurement points, the parameters `x` as the first depth for the probe reference point and the measurement point spacing `dx` must be entered. The electrical borehole probe is inserted into the borehole using a push rod. The apparent resistivity $\rho_{s,1}$ to $\rho_{s,4}$ in Ωm for the respective measurement configuration are recorded. The corresponding starting depths and the measurement point spacing for all groups can be found in Table 2.

Data Analysis and Interpretation

For the interpretation of the borehole electrical resistivity curves, it should be mentioned that the Schlumberger configuration and the potential probe provide symmetric anomalies over electrical conductors. The curve progression of the gradient probes, on the other hand, is asymmetric, with the top-mounted and bottom-mounted probe each emphasizing a layer boundary of the poorly conductive gray gneiss. Furthermore, the measurement curve of the Schlumberger configuration can theoretically be derived from the arithmetic mean of the data from the gradient probes.

Tasks:

- Determine the four configuration factors of the measurement configurations used.
- Graphically represent the measurement curves of all four configurations.
- Show that the measurement curve of the Schlumberger configuration actually results from the average of the data of both gradient probes.
- Using the MATLAB function `getDike.m`, based on a program by T. Hanstein `dike2.m`, generate synthetic measurement curves and compare them with the measured data (set up own script according to template Figure 4).
- Discuss the differences between synthetic and measured curves.
- Using the borehole measurement curves and the synthetic measurement curves, determine the layer boundaries of the highly conductive ore zone.
- Furthermore, specify and evaluate the resistivity of the ore zone and the gray gneiss.

```
function MWE()
  % Script for comparing measured and analytical apparent resistivity.

  % Usage of the function dike2.m:
  % y = 0 corresponds to the top of the ore zone!
  % The wellhead is at y < 0
  % ***** COORDINATE SYSTEM for dike2.m *****
  %            y=0          y=thick        --->y-axis
  % -------------+------------+-----------------z=0
  %              |   <thick>  |
  %     rho1     |    rho2    |    rho1         x-axis = strike direction

  % Coordinates.
  %   -starting depth:spacing:end depth
  y = -...:...:...;

  % Dike.
  thick = ...;
  rho2 = ...;

  % Surrounding rock.
  rho1 = ...;

  [rhosKN, rhosSB, rhosOK, rhosUK] = getDike(rho1,rho2,y,thick);
end
```

Figure 4: Example script for calling `getDike.m`

Notes

- Handling of the measuring probe:
  - When extending, be sure to hold the rod in the borehole! Otherwise, it may happen that it loosens when attaching the new extension.
  - The reference point is not exactly in the middle of the probe, but in the middle of the ring electrodes
    - $x = 0.6$m when the end of the probe is flush with the wellhead
  - Depth measurements with the folding rule should always be taken

from the outermost end of the probe (or the last extension rod) to the wellhead

- Top-mounted lateral probe (pole-dipole): Since this was originally designed for the detection of high-resistance zones, it characterizes the top of a high-resistance deposit. That is, the bottom-mounted probe detects the top of the ore body, and the top-mounted probe detects its bottom!
  - Deviation of the arithmetic mean of both gradient probes from the measured Schlumberger == sign of measurement error
- Potential probe (pole-pole): The second potential electrode is located only at the outer edge of the probe, i.e., just a poor approximation for infinity
- Terrameter:
  - Device has to measure the resistance Ω!
    * Mode = Ω
  - Do not set stacking on the device (GUI cannot process it)
    * cycles = 1
  - For negative resistances, reverse electrodes (e.g., potential)
  - Current as low as possible (battery), <20mA (measurement with 5mA worked in previous years for all configurations)
  - Typical error messages:
    * error 6: increase current
    * error 12: low battery
    * error 1: reduce current
- Switch box:
  - Order == order of configurations in the script
  - Overall measurement in Matlab script == continuous measurement of all 4 configurations,
    * After 'beep', switch
    * Always pay attention to the display during measurement (errors also cause beep!)

- MATLAB script:
  - If `error` when controlling Terrameter: check access permissions for USB port under LINUX
  - If `NaN`, repeat via individual measurement (reset measurement values & pay attention to x)
- `getDike.m`
  - Analytical solution based on dike in half-space (equivalent to 3-layer case in full space)