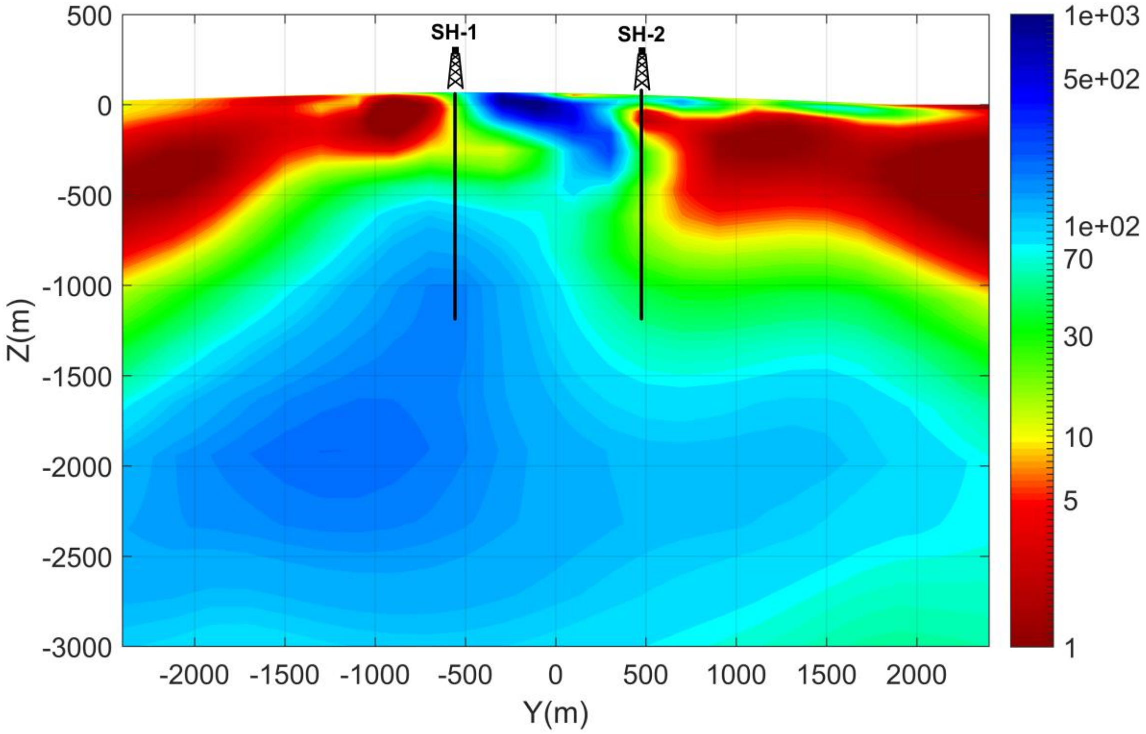
01_Introduction

02_Geothermal energy

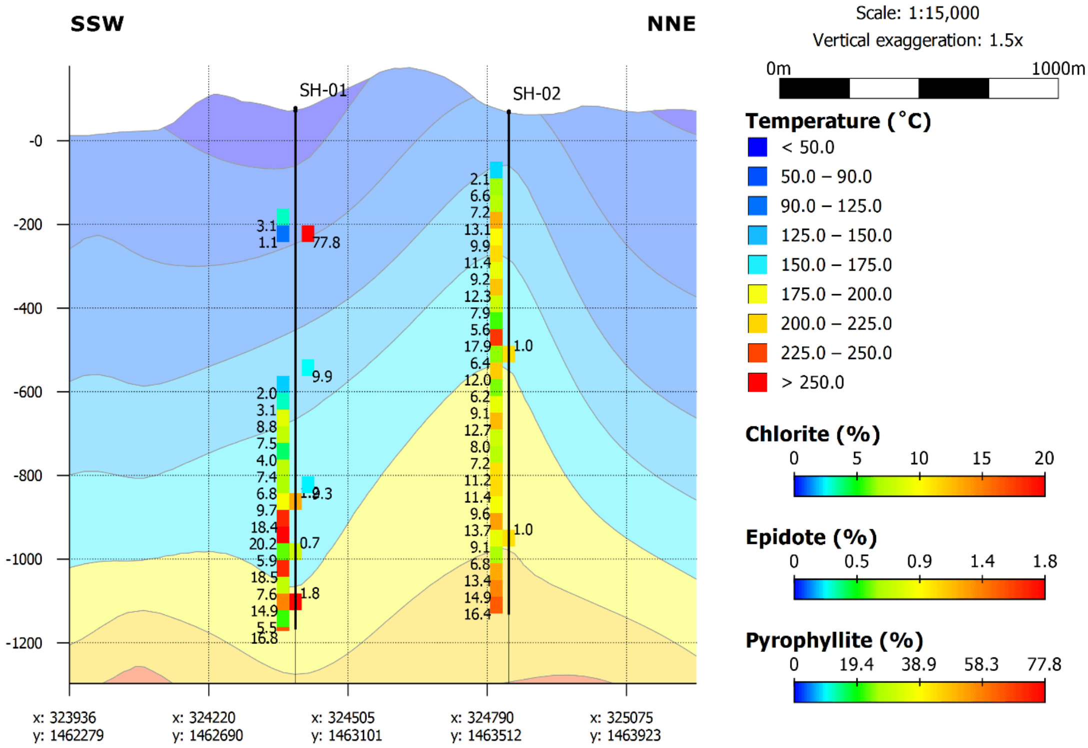
1. Define geothermal energy in your own words.
2. How is geothermal energy utilized? Describe the types of geothermal systems utilizing geothermal energy.
3. Describe the main elements and their function of any geothermal system
4. Describe the main types of geothermal plays. What is this categorization based on?
5. Is there another categorization possible? Which one? Describe the advantages and disadvantages of both categorizations.

03_Factors affecting resistivity

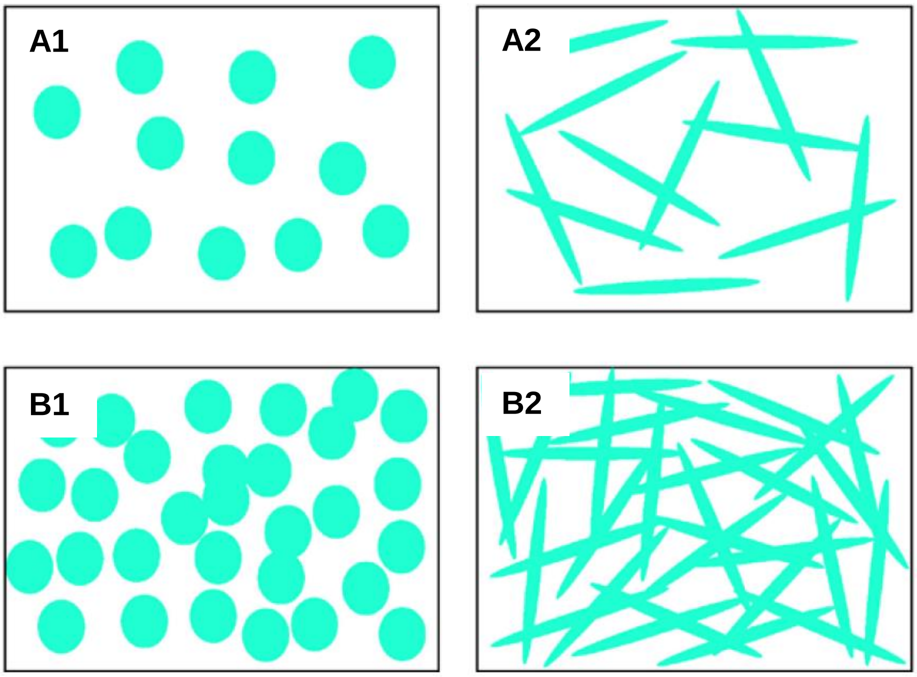
1. Which factors affect the subsurface resistivity? How?
2. Given the categorization of geothermal plays following Moeck (2014), rank the driving factors for resistivity of the two main categories. Motivate
3. Hydrothermal clay alteration plays a significant role in the resistivity response of a geothermal system. Consider the resistivity cross-section below and draw isotherms on the resistivity cross-section using Figure 1.2 in the course notes.



4. Given the temperature cross-section below orientated along the resistivity cross-section of question 2, would you maintain the isotherms or interpreted the resistivity cross-section differently?



5. Explain the difference between porosity and permeability. How are they correlated?



6. Consider the figure above. Rock is white and pores are green. Is there a difference in porosity between A1 and A2? And in A1 and B1? Is the permeability of B1 and B2 different? If so, which one is higher?
7. What porosity is required to explain a resistivity of 5 Ωm? Assume a water saturation of 100% and a water resistivity of 0.3 Ωm. Try different values in the range 1 to 2 of the cementation factor 'm'.
8. Following Archie, in case the porosity is very small, what happens to the resistivity? Is this realistic?

9. Using Archie's law, estimate the porosity of the Röt Fringe Sandstone Member in well KDK-01 which has an average resistivity of 25 Ωm. Assume a water saturation of 100% and a water resistivity of 0.3 Ωm. Experiment with different values in the range 1 to 2 of the cementation factor 'm'. Based on the porosity estimates, does this sandstone make a good geothermal reservoir?
10. Using the porosity-permeability relation shown below. Predict the permeability of the Röt Fringe Sandstone Member in well KDK-01. Assume a cementation factor of 1.5. Based on the permeability estimate, does this sandstone make a good geothermal reservoir?
11. Apply the RGPZ model to the data. Assume a grain diameter of 0.10 mm. How does the RGPZ predicted permeability 'k' compare to the permeability predictions based on Archie's laws and the porosity-permeability relation? Hint: 1 Darcy = 10^{-12} m^2.

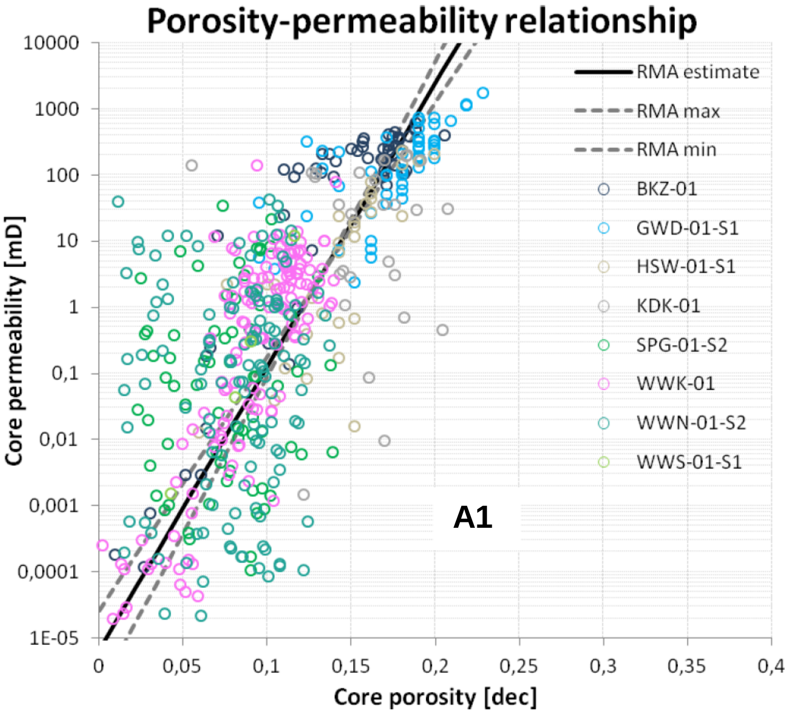


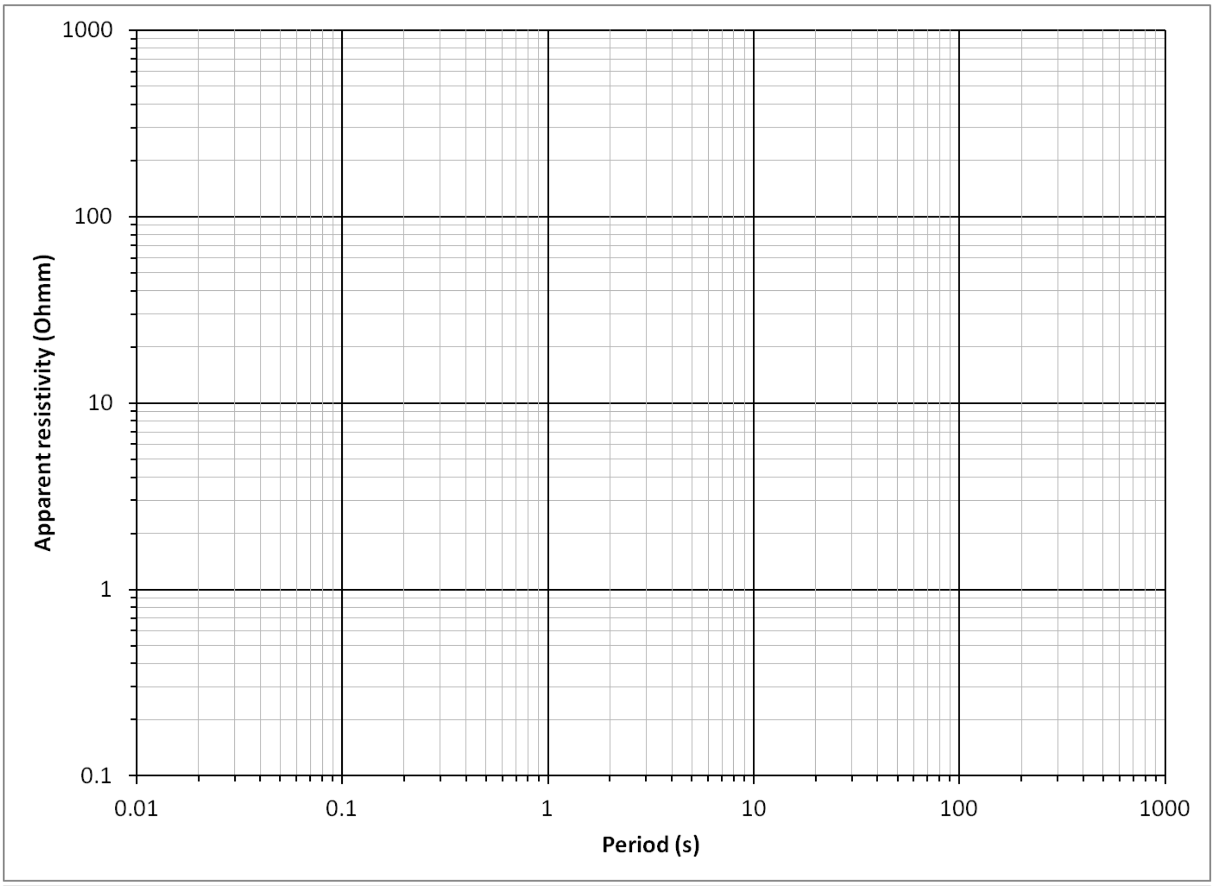
Figure 4.2 Porosity-permeability relationship of the Röt Fringe Sandstone Member. Also plotted are the asymptotes of the 95% confidence intervals of the regression coefficients.

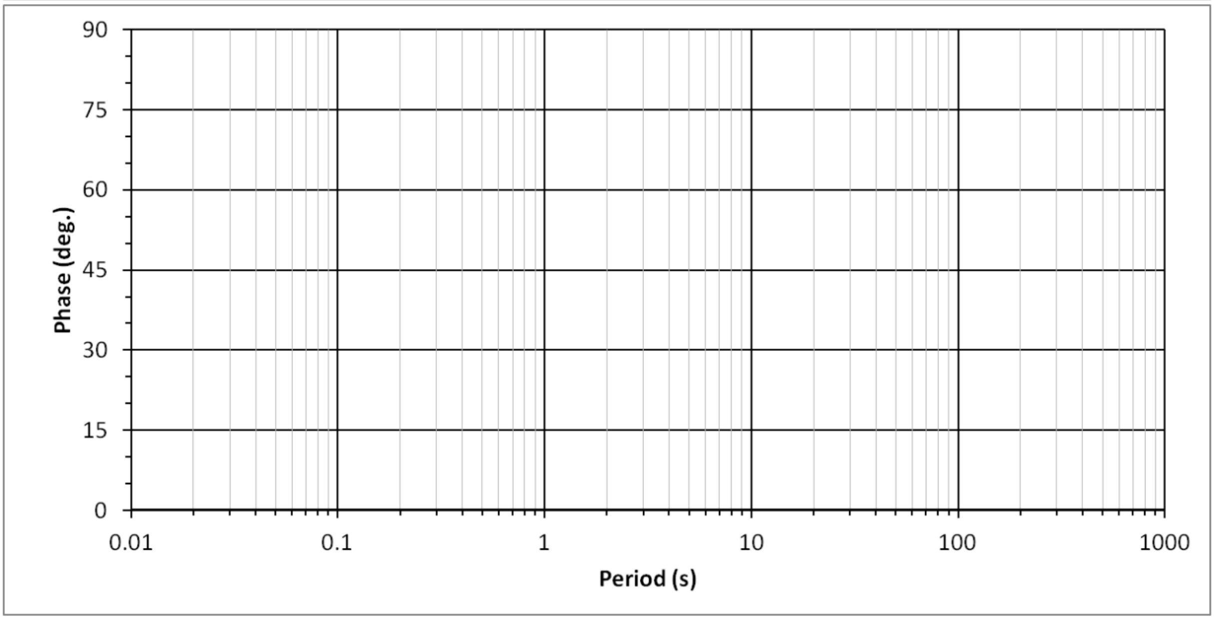
04_Magnetotellurics in geothermal exploration

1. [Insert some models to interpret of several examples…case studies from IGA conference database. When?]

05_Electromagnetic principles

1. Considering a 2-layer model with a top layer of 1,000 m thick with a resistivity of 10 Ωm and a basement of 100 Ωm.
    a. What will be the skin depth at a sounding period of 0.1 s? Plot the apparent resistivity at this period in the apparent resistivity vs period plot below.
    b. What will be the skin depth in the upper layer at 1 s? Plot the apparent resistivity at this period in the apparent resistivity vs period plot below.
    c. What will be the skin depth in the upper layer at 10 s? Plot the apparent resistivity at this period in the apparent resistivity vs period plot below.
    d. What will be the skin depth in the upper layer at 100 s? Plot the apparent resistivity at this period in the apparent resistivity vs period plot below.





2. The phase response can be approximated using the equation: $\Phi = \frac{\pi}{4}(1 - \frac{\partial \log \rho_a}{\partial \log T}))$.

   Sketch for the periods 0.1 to 100 s for the 2-layer case of the previous question, the phase response in the figure above. Hint: consider the behavior of Φ, not the absolute values.

06_The magnetotelluric transfer function

See forward exercises

07_Distortion, dimensionality and noise

See forward exercises

08_Data acquisition

1. Open in Google Earth kml-file MtPancar.kml with the planned (A)MT stations. Assess the planned station locations on basis of the Google Earth satellite images. Would you propose to shift stations, why? Propose new locations.
2. Given the forecast of the Space Weather Services, what would be the optimal moment to conduct our field school the coming week?

09_Estimation of the magnetotelluric transfer function.
Answer the question below for a single MT station of the recorded field school data. Process the other stations using the approach.

1. Load time series data and assess the time series recorded at all sampling rates at different time spans (use TSviewer). Answer the following questions:
    a. How many samples are recorded at each sampling rate?
    b. What is the highest frequency recorded? And the lowest frequency?
    c. If present, indicate a few examples of noise on the raw time series. Try to estimate the signal-to-noise ratio of the time series. Motivate you answer (e.g. by adding some figures)
    d. Can you observe a correlation between Hx and Ey channels and between the Hy and Ex channels? Motivate you answer (e.g. by adding some figures)
2. Compute the power spectrum of the time series (at different sampling rates) and answer the following questions (use TSviewer in SSMT2000).
    a. How can you recognize noise in a power spectrum?
    b. Do the power spectra suggest equal quality data at all sampling rates? Motivate you answer (e.g. by adding some figures).
    c. If present, at what frequencies do you observe recorded noise? Motivate you answer (e.g. by adding some figures).
    d. Can you observe a correlation between Hx and Ey channels and between the Hy and Ex channels? Motivate you answer (e.g. by adding some figures)
    e. Plot the Ex-Hy and Ey-Hx coherence. What does this plot tell you? Do the same for the Ex-Ey and Hx-Hy coherences, what does this plot tell you?
    f. Do you expect that remote reference processing will improve the estimate of the MT transfer function? Why?
3. Estimate the magnetotelluric transfer function with and without remote reference station (use SSMT2000 and MTeditor).
    a. Do you observe a difference in the estimated MT transfer function? Which estimate gives the best station response? Motivate.
4. Save the best MT transfer function as EDI and import in Geotools™
    a. Does the station response show static shift?
    b. Describe the behavior of apparent resistivity and phase of the station response. What does this tell about the dimensionality of the data?
    c. Rotate the data to its principal axis. Again, Describe the behavior of apparent resistivity and phase of the station response. What does this tell about the dimensionality of the data?
    d. What is the TE and what is the TM-mode. Is there a difference, what does this tell you?