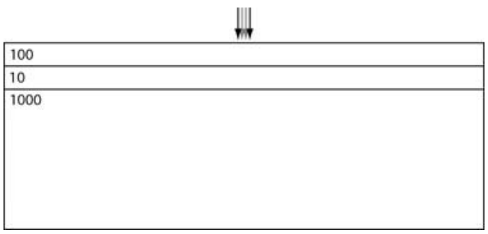
<u>325 C4 Electric current flow in a multi-layer Earth</u>

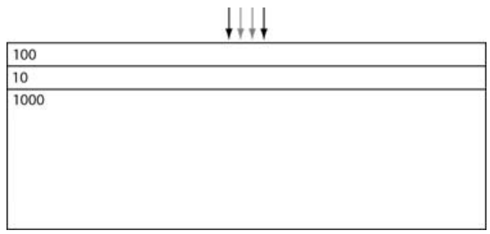
C4.1 Qualitative solution for apparent resistivity

Consider the following models with $h_1 = h_2 = 10$ m. Sketch the approximate current flow patterns on the diagram and estimate the apparent resistivity.

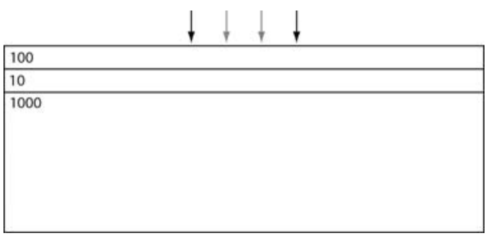
Remember that apparent resistivity can be considered as the average resistivity over the region in which the current flows.



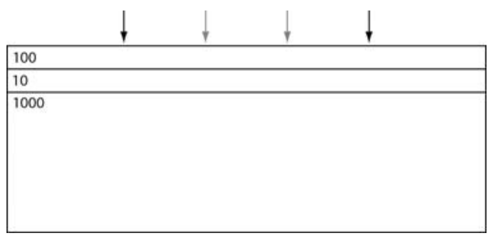
a =0.1m



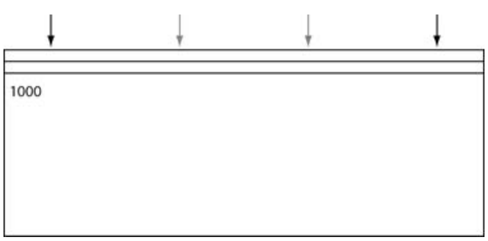
a=3 m



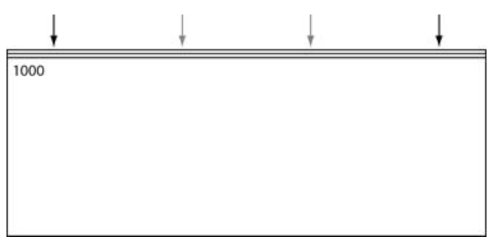
a=10 m



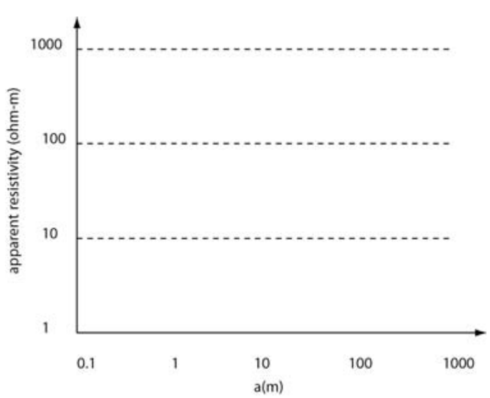
a = 30 m



a=100 m

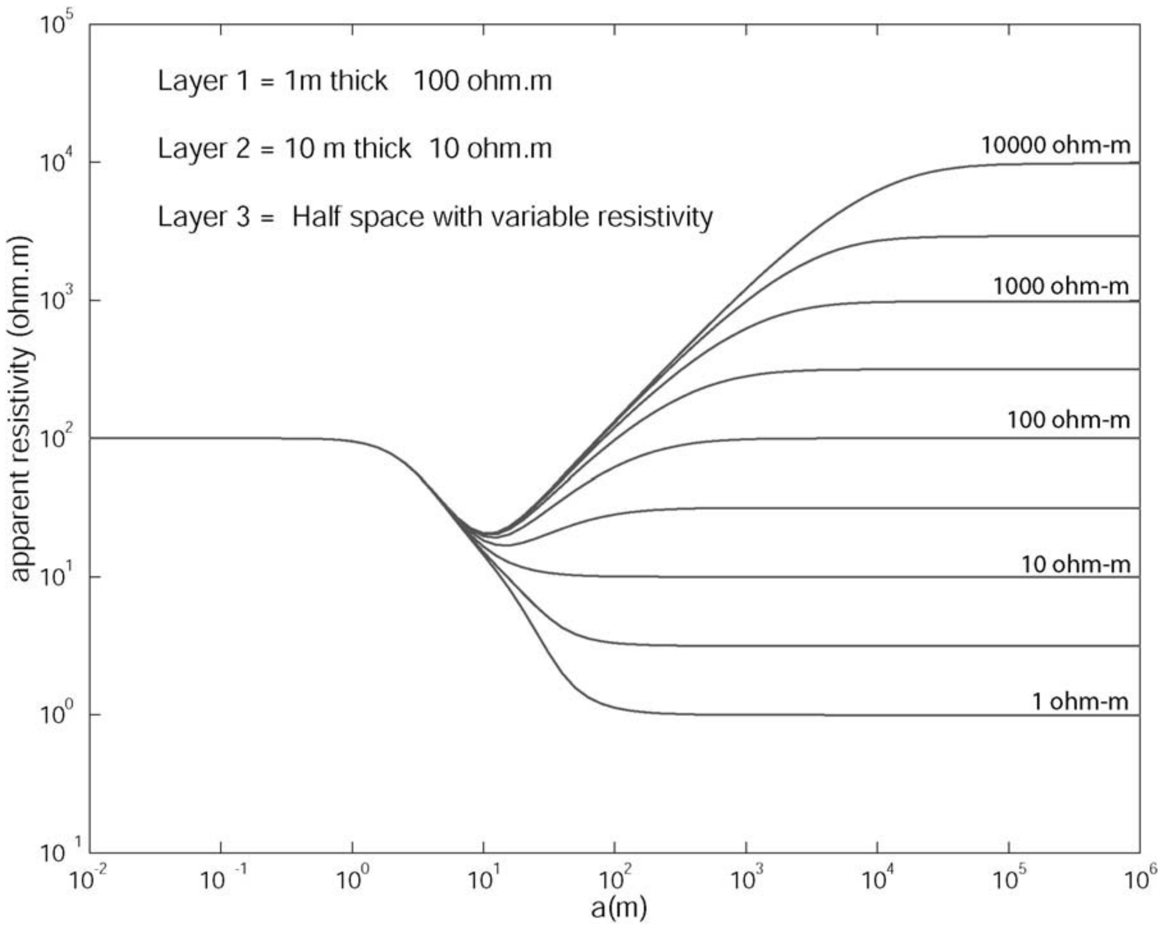


a = 1000m



C4.2 Quantitative solution for apparent resistivity

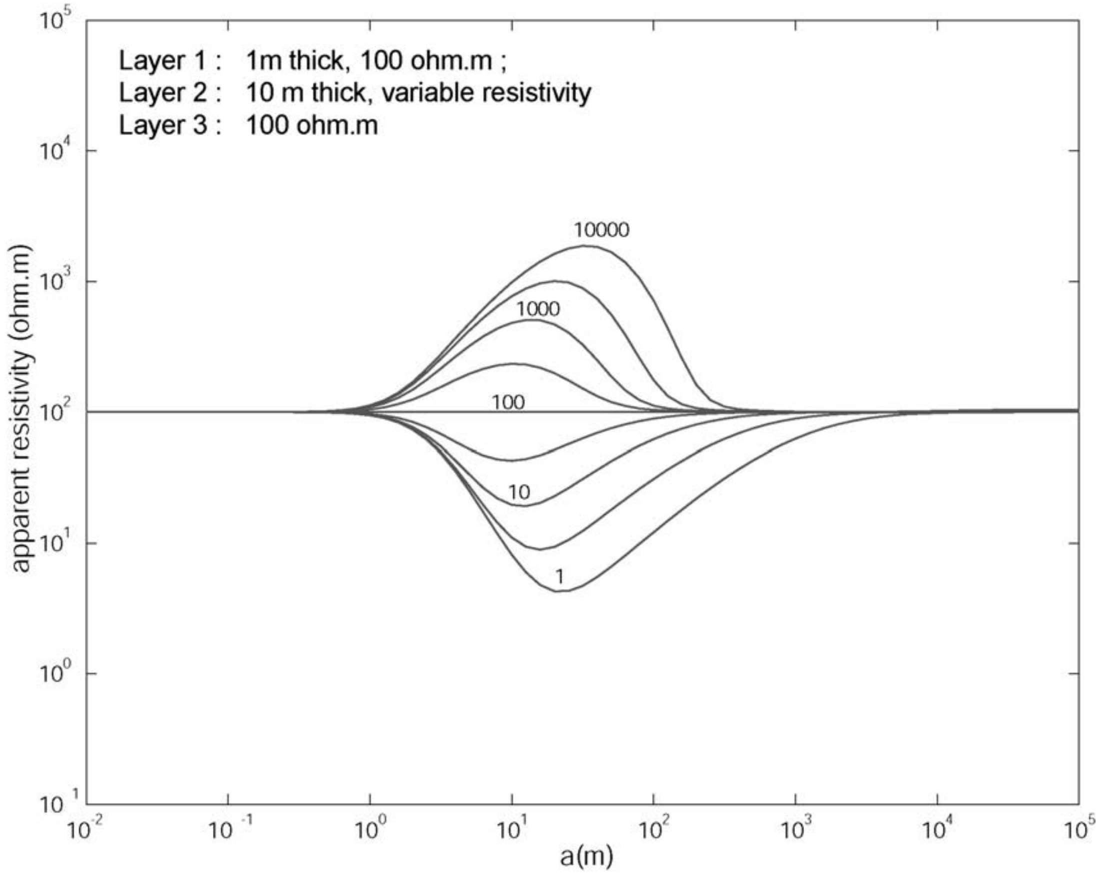
The following figures were generated using a simple MATLAB script **wenner3lay.m** which uses a power series expansion to compute ρ_a as a function of *a*-spacing. Note that a lot of terms must be included in the summation to get convergence.



Note

- All the apparent resistivity curves are identical until the third layer is detected with *a* ~10 m.

- At very large values of *a*-spacing, the apparent resistivity value is that of the lowest (3rd) layer. These very large values cannot be measured in practice.

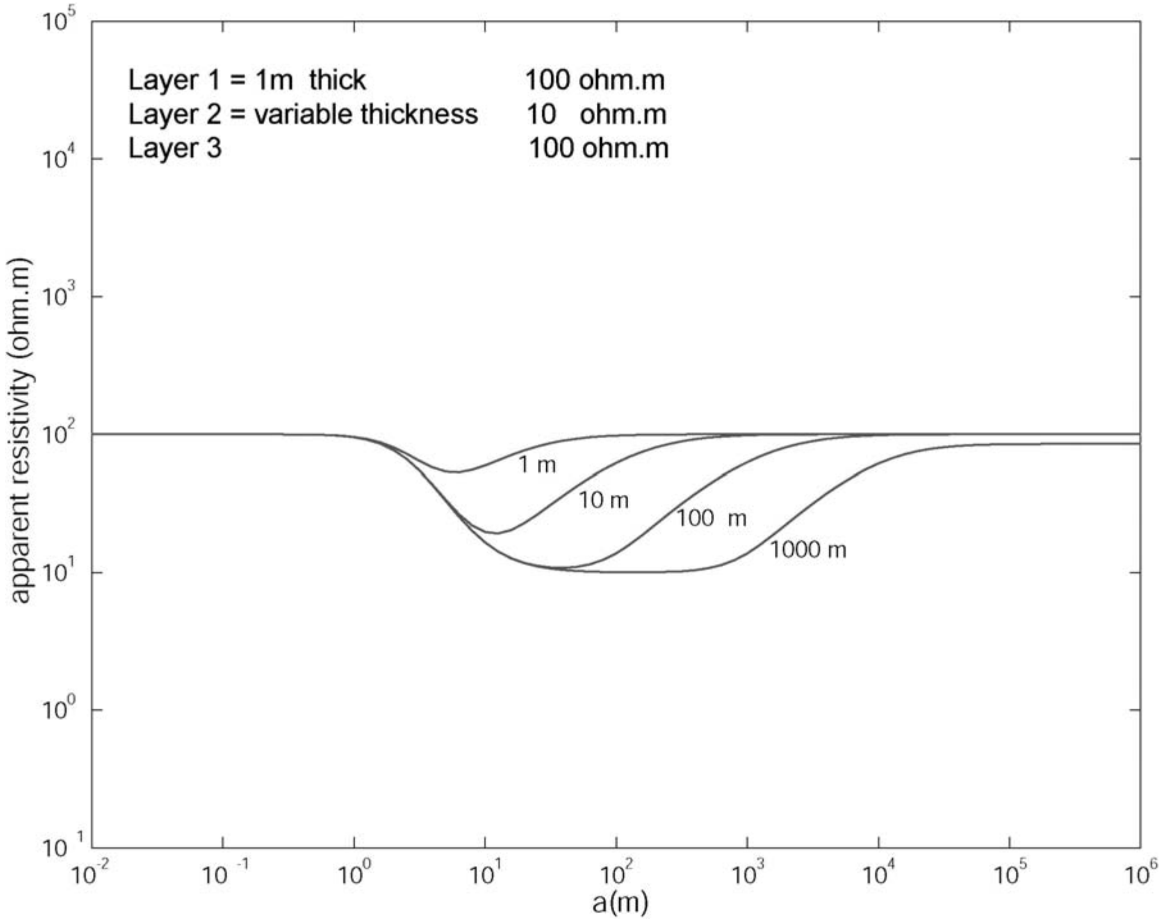


Note

- As the *a*-spacing increases and the middle layer is detected. If this layer is a conductor, then ρ_a falls quickly as *a*-spacing increases. This is because electric current flows preferentially in a conductor.

- Similarly, when the middle layer is a resistor, ρ_a increases more slowly as electric current tends to flow in the overlying conductor (Layer 1).

- Resistor and conductor are relative terms.



Note

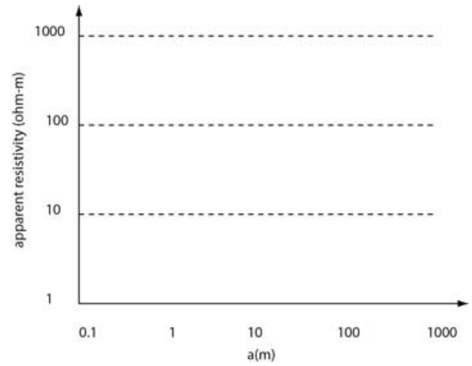
- When Layer 2 is thin, ρ_a never reaches the true value of ρ_2 since there is never a situation where all (or even a majority) of the electic current flows in Layer 2.

- When Layer 2 is very thick, ρ_a approaches the true value of $\rho_2 = 10\ \Omega m$

There are **four** possible types of 3-layer apparent resistivity curves

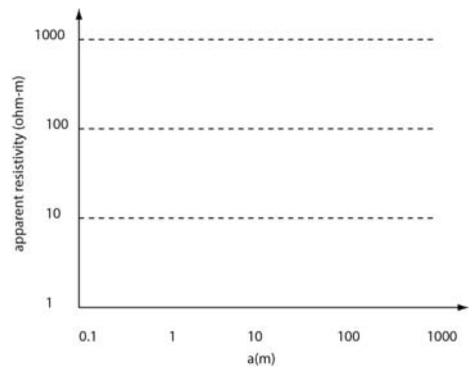
A-type $\rho_3 > \rho_2 > \rho_1$

e.g. ρ_1 =10Ωm; ρ_2 =100 Ωm; ρ_3 =1000 Ωm



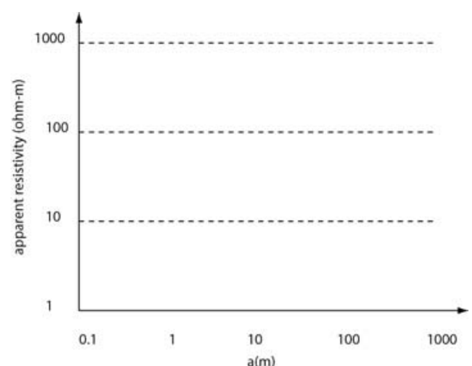
Q-type $\rho_3 < \rho_2 < \rho_1$

e.g. ρ_1 =100 Ωm; ρ_2 =10 Ωm; ρ_3 =1 Ωm



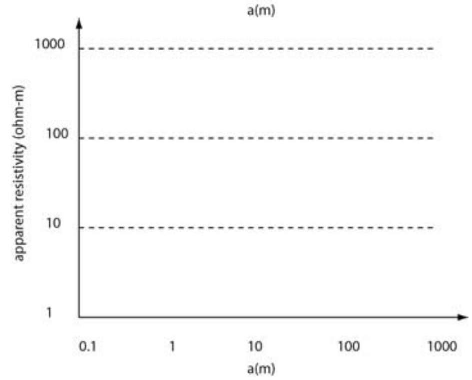
H-type $\rho_3 > \rho_2 < \rho_1$

e.g. ρ_1 =100 Ωm; ρ_2 =10 Ωm; ρ_3 =1000 Ωm



K-type $\rho_3 < \rho_2 > \rho_1$

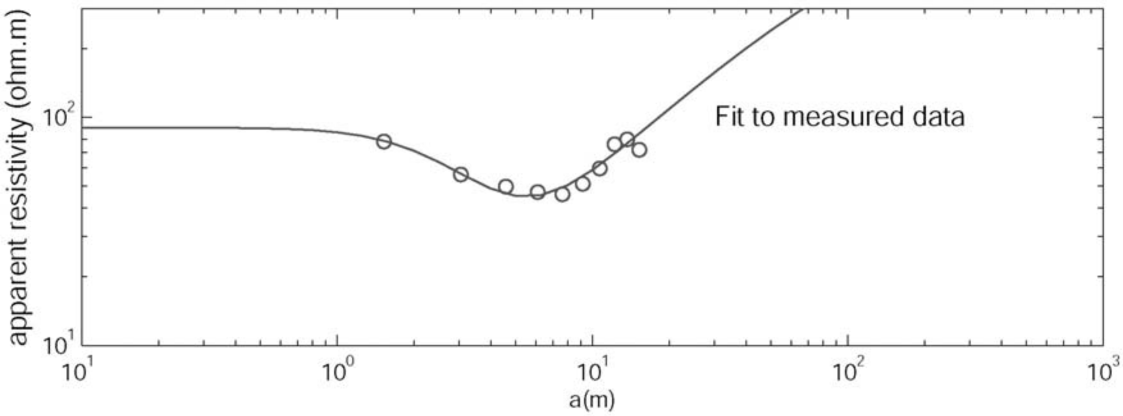
e.g. ρ_1 =100 Ωm; ρ_2 =1000 Ωm; ρ_3 =10 Ωm

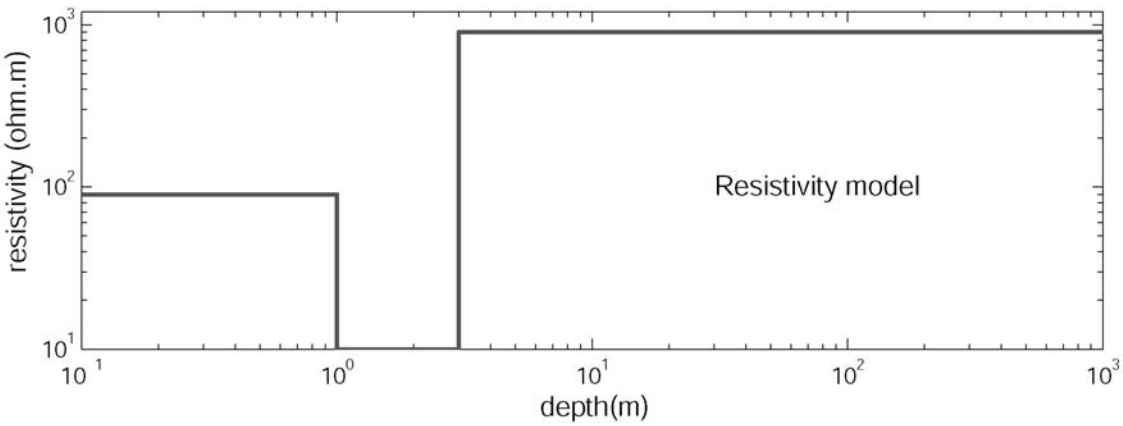


Sketch the apparent resistivity curves when h_1=3 m and h_2 = 10 m.

Question: Consider the A-type and Q-type resistivity curves. Would it always be obvious from these curves that there are 2 or 3 layers present?

4.3 Fitting Wenner array resistivity data with a two-layer resistivity model





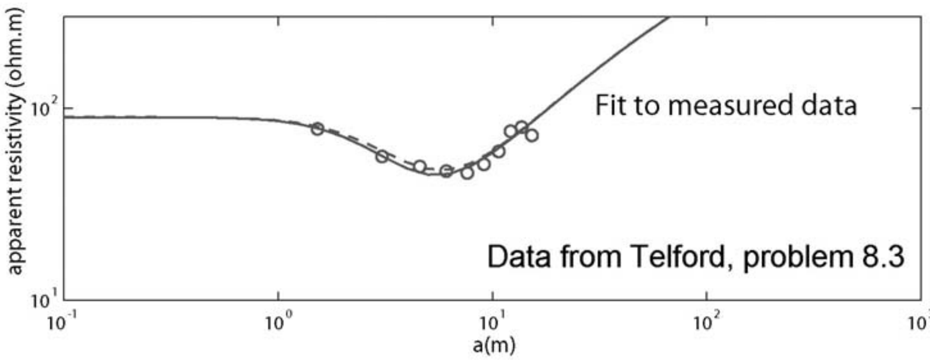
Simple trial and error forward modeling (**wenner3lay_fit.m**) can be used to find a 3-layer model that will fit the Wenner array data plotted above. These data can be found in Telford Table 8.3.

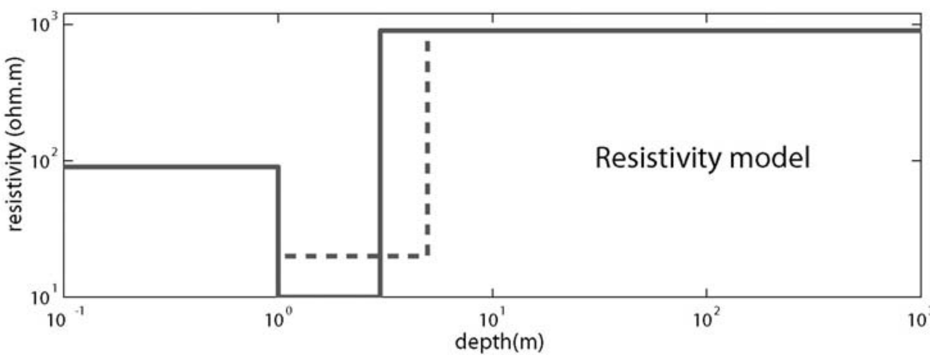
Note that in this case, the range of *a*-spacing values are quite limited. We don't have one that is small enough to sample just the upper layer (1), or a long enough spacing to sample just the lower layer (3).

Master curves could also be used to interpret these Wenner array data. However, this is more complicated than for the two layer geometry considered on Assignment 3.

All possible combinations of the five model parameters [h_1, h_2, ρ_1, ρ_2, ρ_3] cannot be displayed on a single graph. Thus a book showing many master curves is needed and analysis can become time-consuming.

C4.4 Equivalence and non-uniqueness





Model 1: $h_2 = 2$ m and $\sigma_2 = 0.01$ S/m

Model 2: $h_2 = 4$ m and $\sigma_2 = 0.02$ S/m

In addition to the model shown in C4.3, other 3 layer models can be found that will fit the same Wenner array data. This is another example of **non-uniqueness** in geophysical data interpretation.

The models shown above have the same values of ρ_1, ρ_3 and h_1. However the values of ρ_2 and h_2 are different. Both models fit the measured data and the predicted apparent resistivity curves are virtually identical. However, note that for both models, Layer 2 has the same ratio h_2 / ρ_2 . This quantity is termed the **conductance**, C, and

$$C = \quad h_2 / \rho_2 = h_2 \sigma_2 = 2 \text{ x } 0.1 = 4 \text{ x } 0.05 = 0.02 \text{ Siemens (S)}$$

where σ_2 is the electrical conductivity of the layer and h_2 is the layer thickness. DC resistivity exploration can determine the conductance of the layer reliably. However in this situation, DC resistivity cannot distinguish between various combinations of h_2 and σ_2 that give the same conductance. The two models that both fit the data are said to be **equivalent**.

Can you think of a similar situation in gravity data analysis?

Another problem with interpreting DC resistivity data can be that a thin layer may not resolved, especially when it's conductance is much less than adjacent layers. This phenomenon is called suppression.

Also consider the case of the A and Q-type curves listed above. A model may have 3 layers, but the curve will not show this.

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