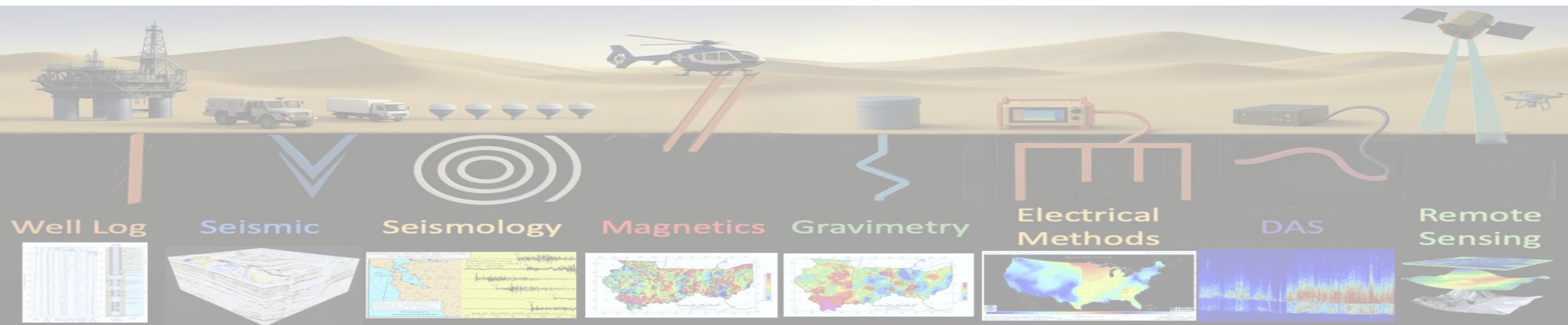


重磁电数据处理与解释

第七讲 电磁数据正反演、数据处理

中国石油大学（北京）地球物理学院
陈 涛

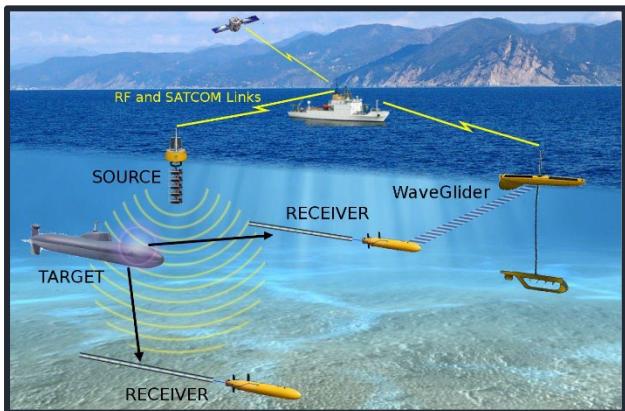
GeoGoku



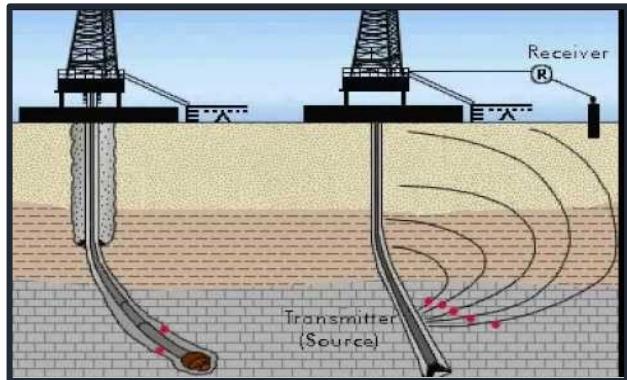
课前知识

GeoGoku

海洋



井中

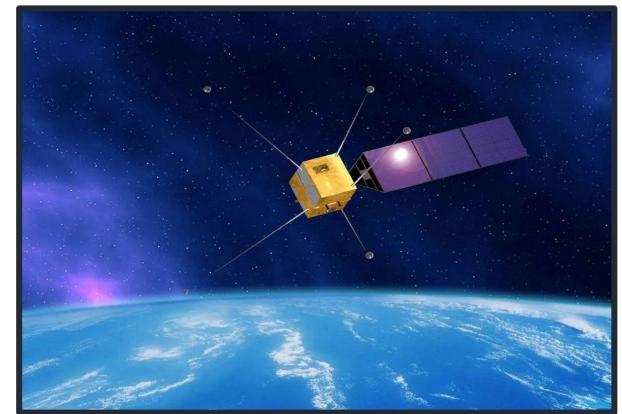


航空



电磁探测

卫星



地面





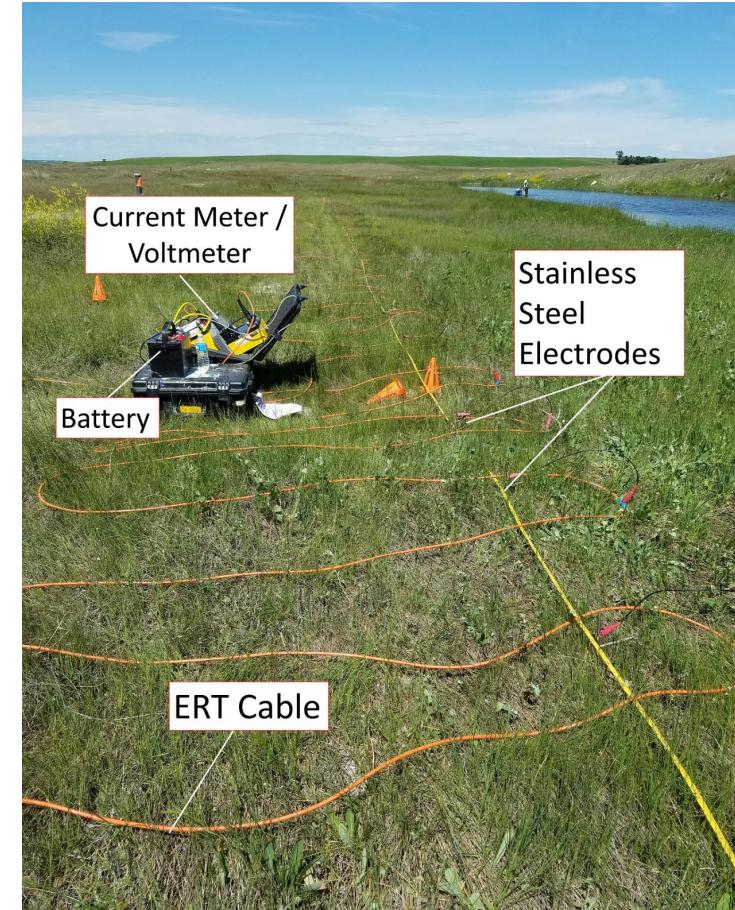
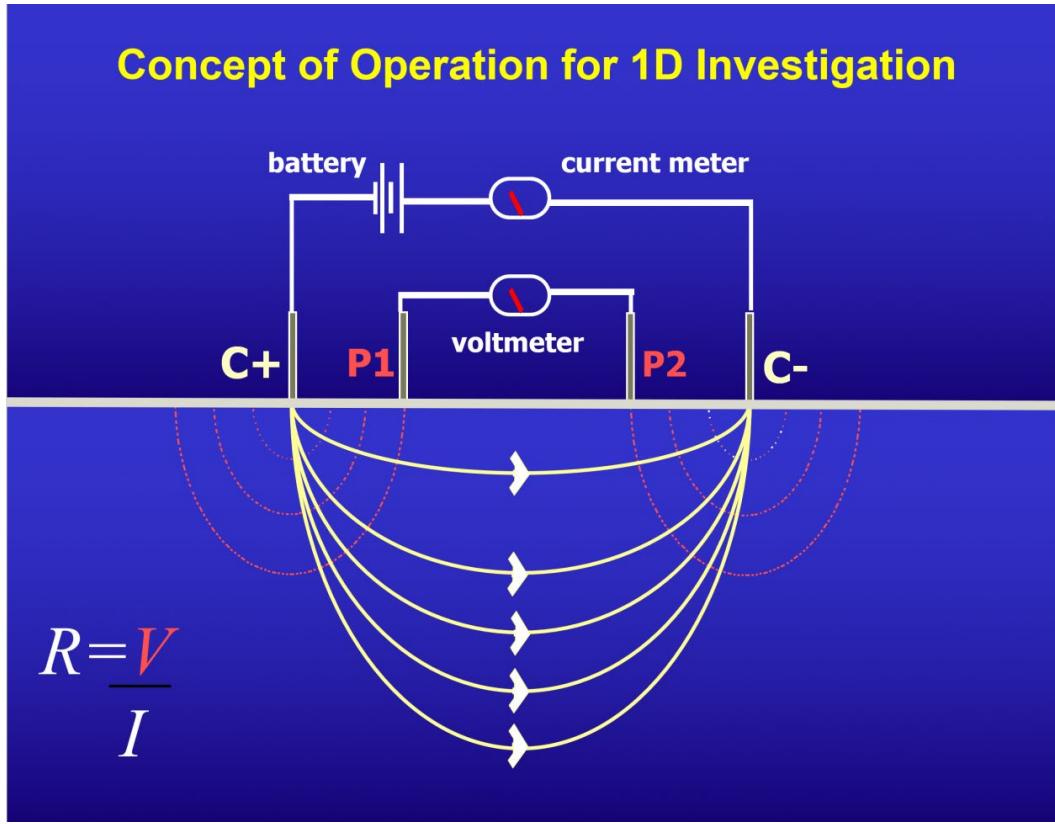
目 录

GeoGoku

第一节 电法正演基本理论

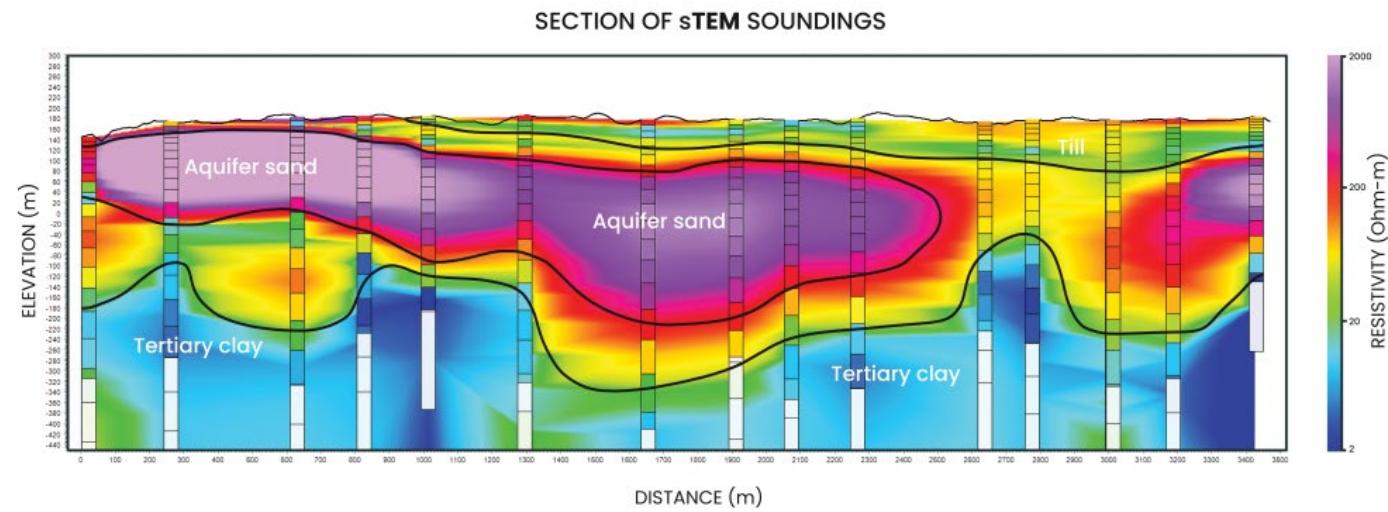
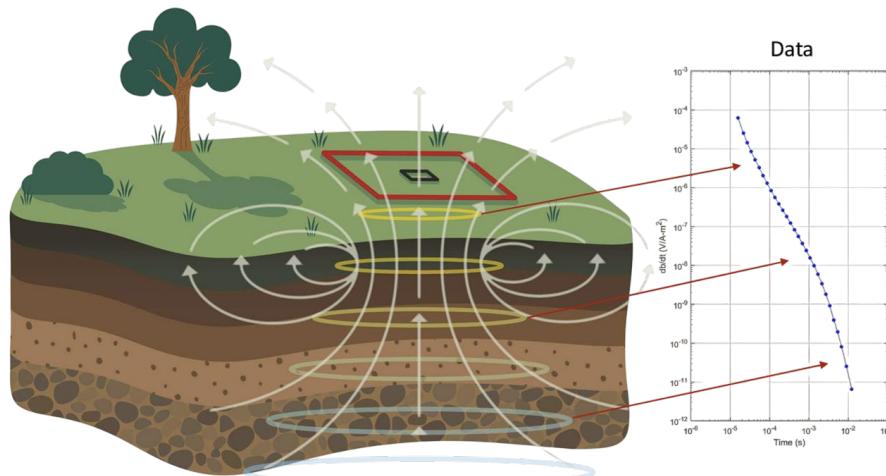
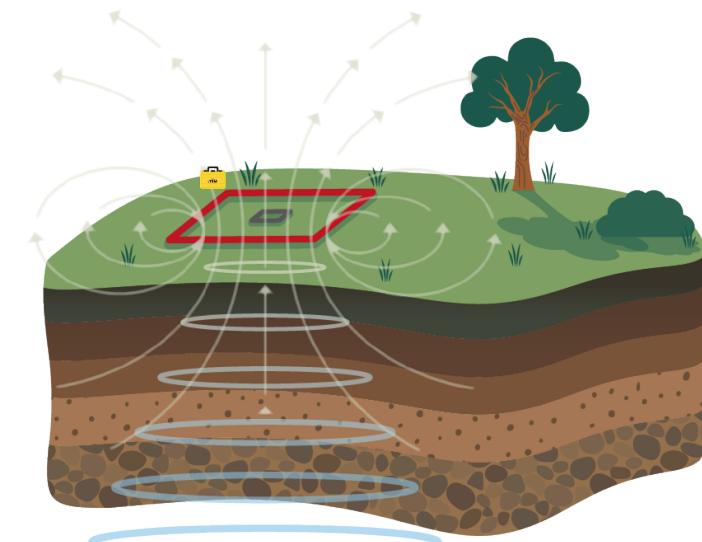
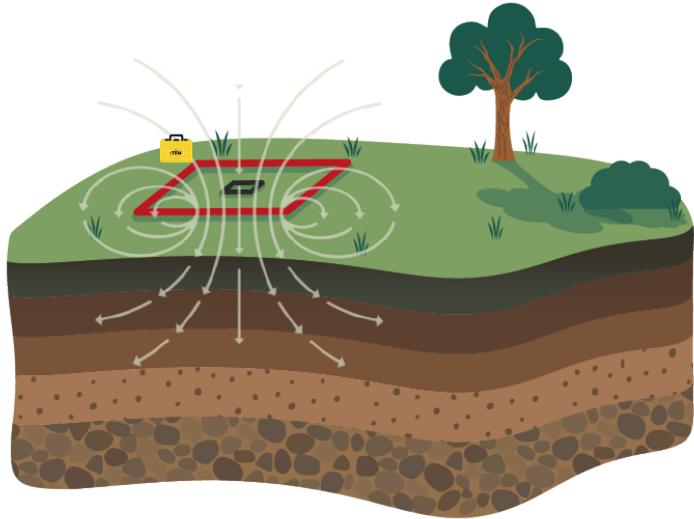
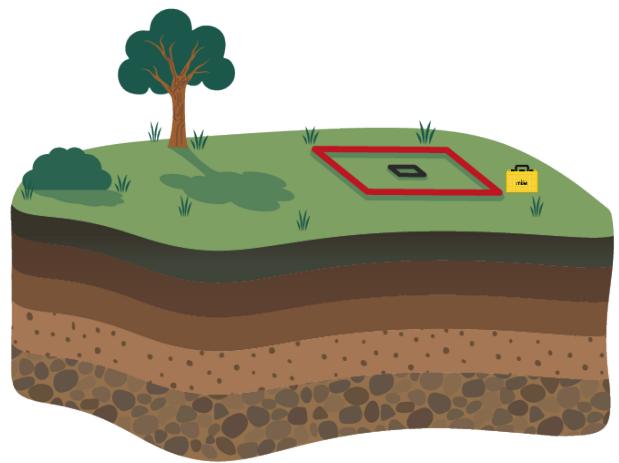
Electrical Resistivity

GeoGoku



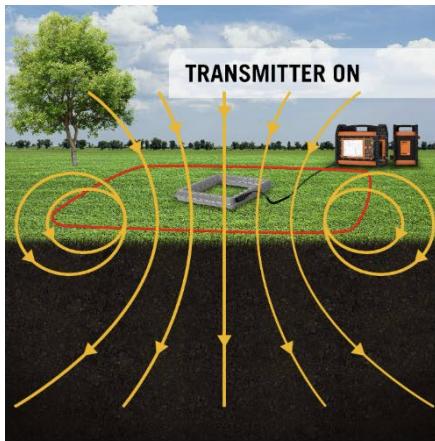
Time-Domain/Transient Electromagnetics

GeoGoku

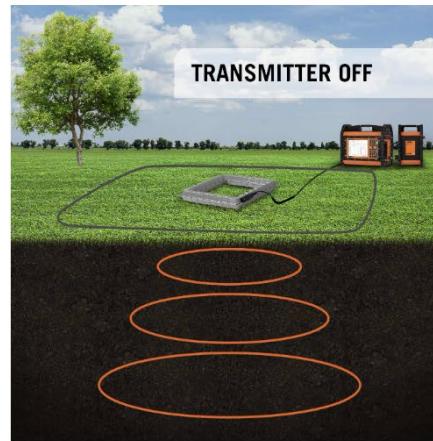


Time-Domain/Transient Electromagnetics

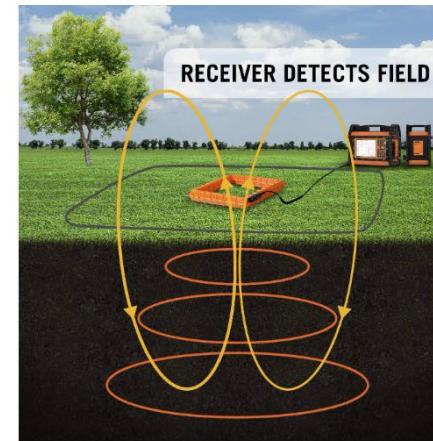
GeoGoku



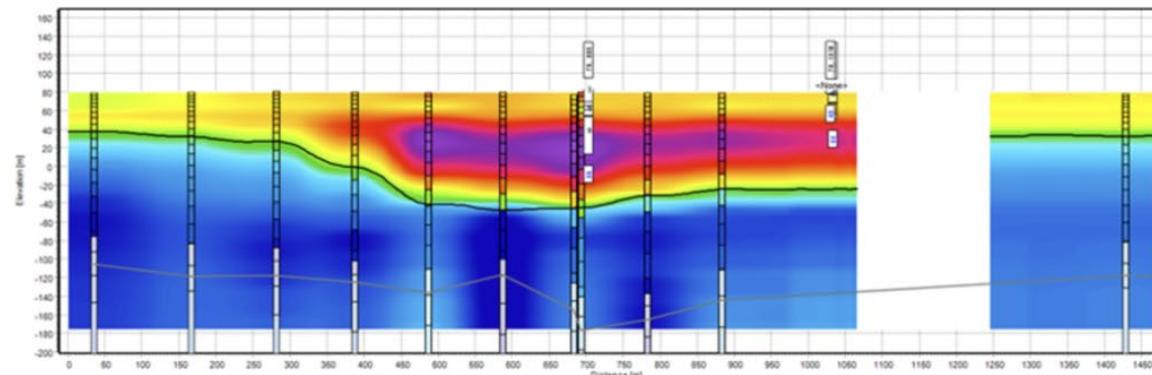
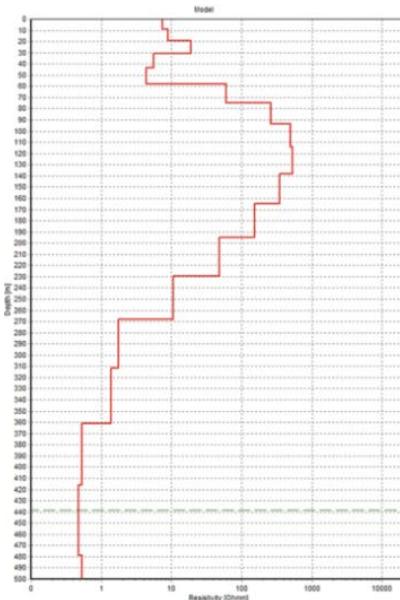
Current flowing through TX Loop (red)
create a magnetic field (yellow)



The collapsing magnetic field creates
electrical currents in the ground (orange)



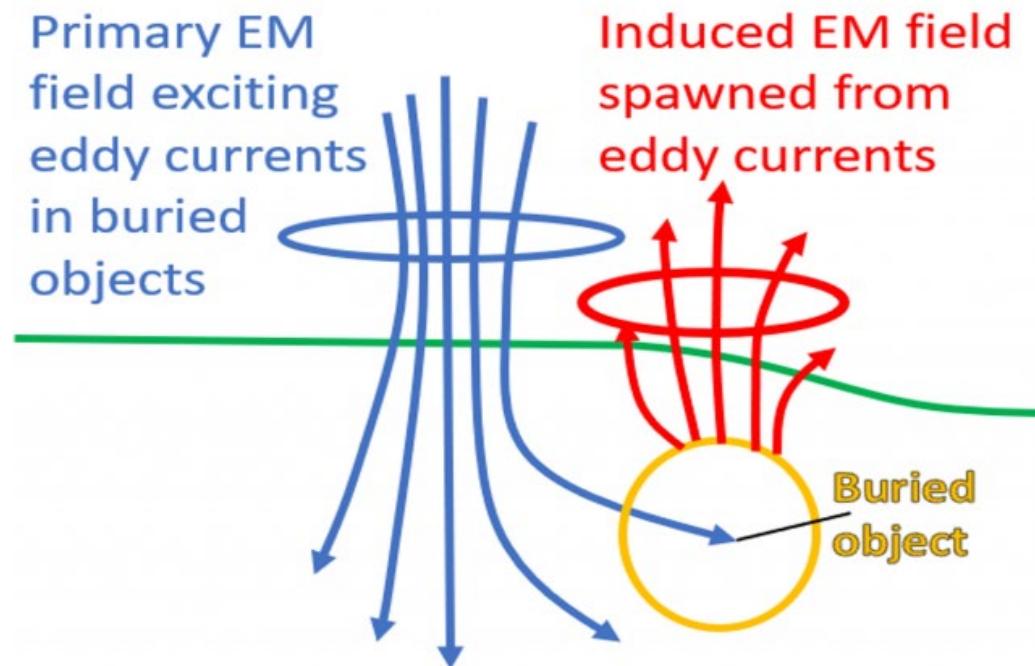
Ground currents create a secondary
magnetic field (yellow) recorded by the RX
coil (centre)





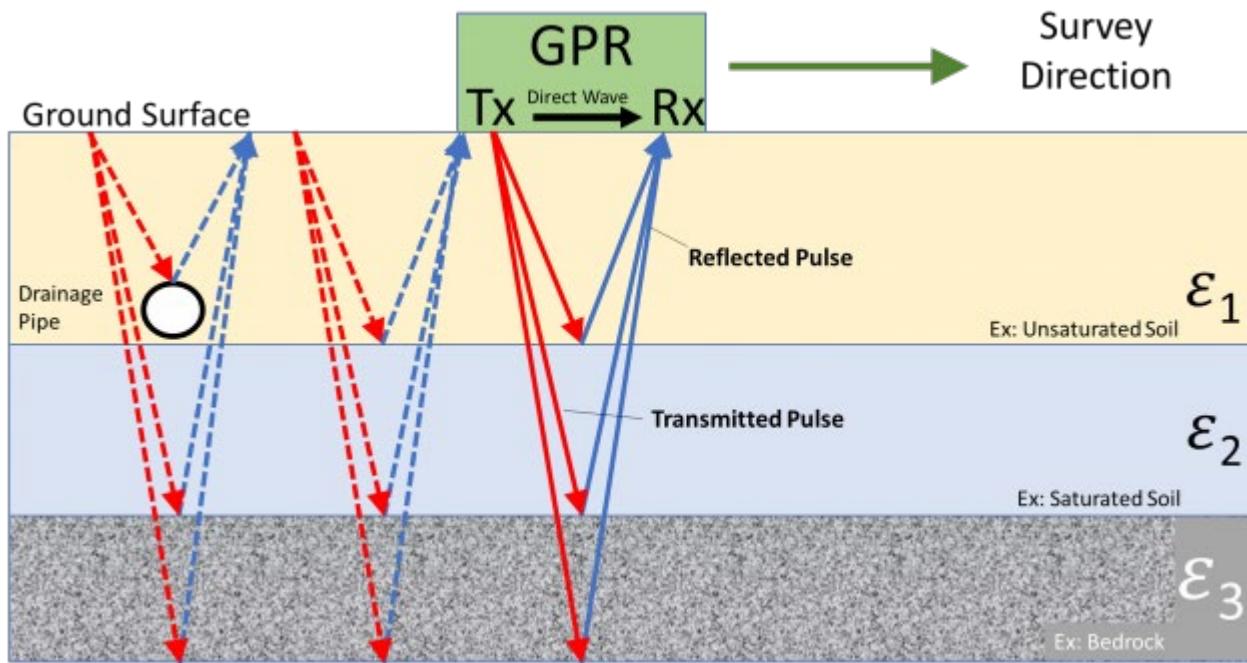
Frequency Domain Electromagnetic

GeoGoku



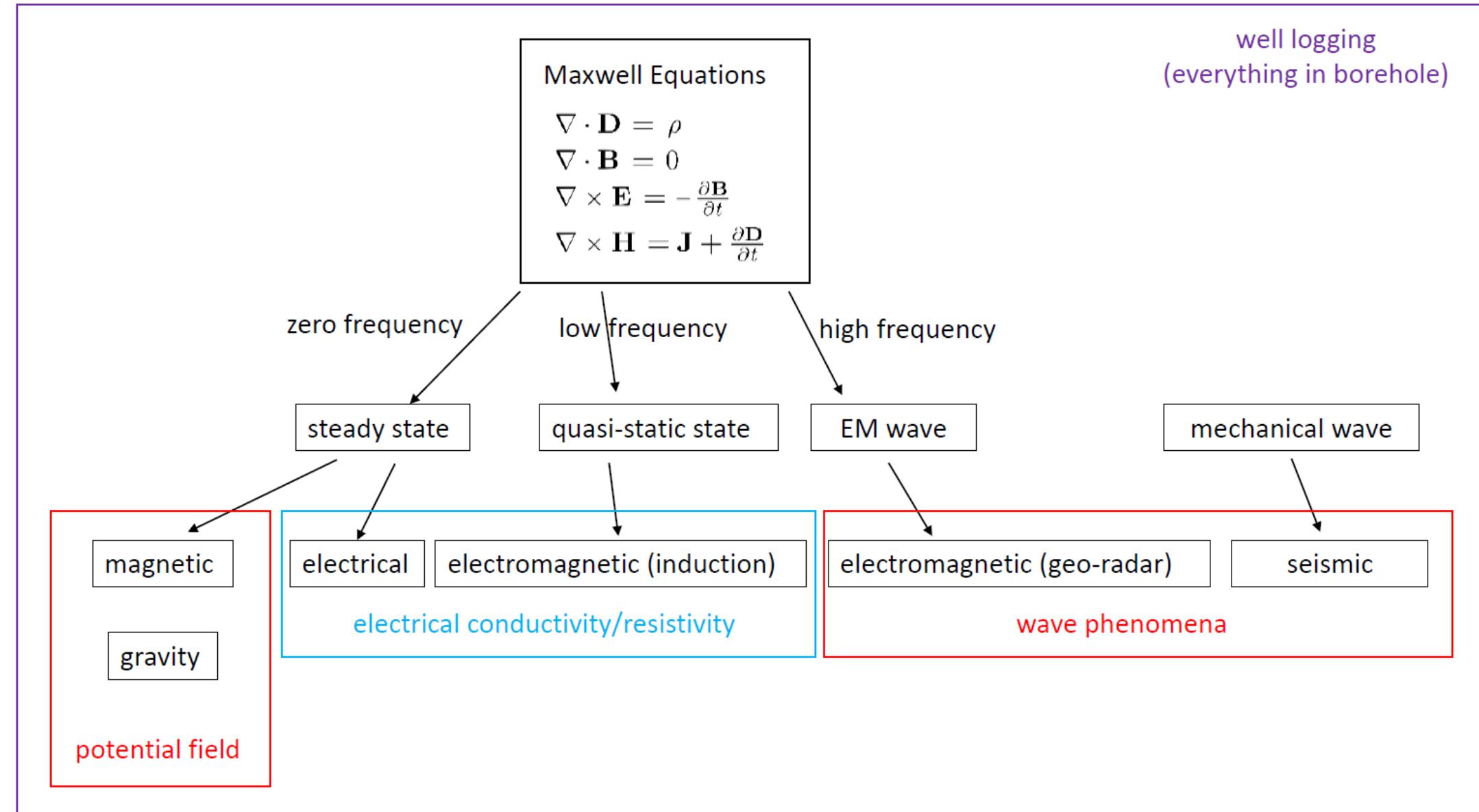
Ground Penetrating Radar (GPR)

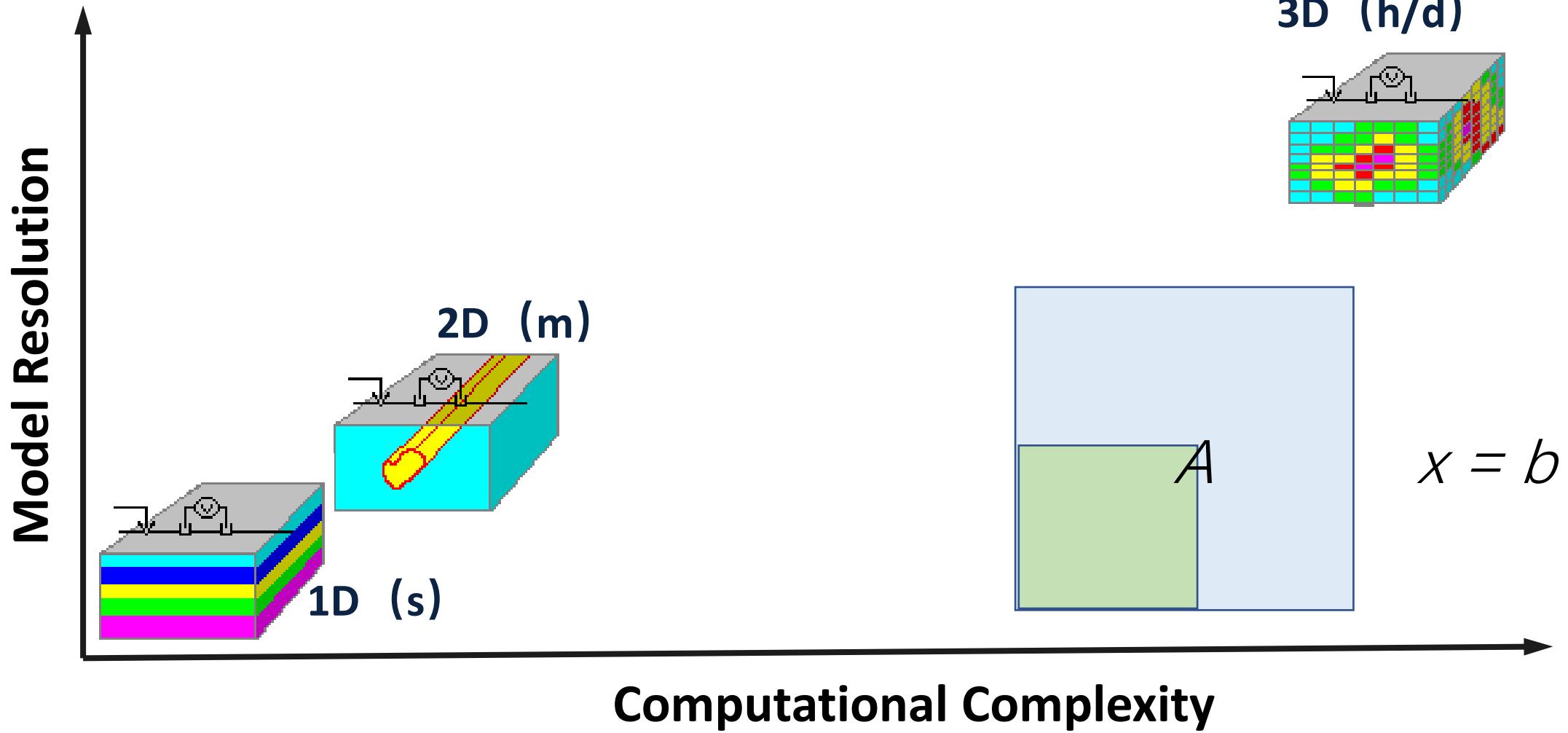
GeoGoku



基本公式

GeoGoku





基本公式

GeoGoku

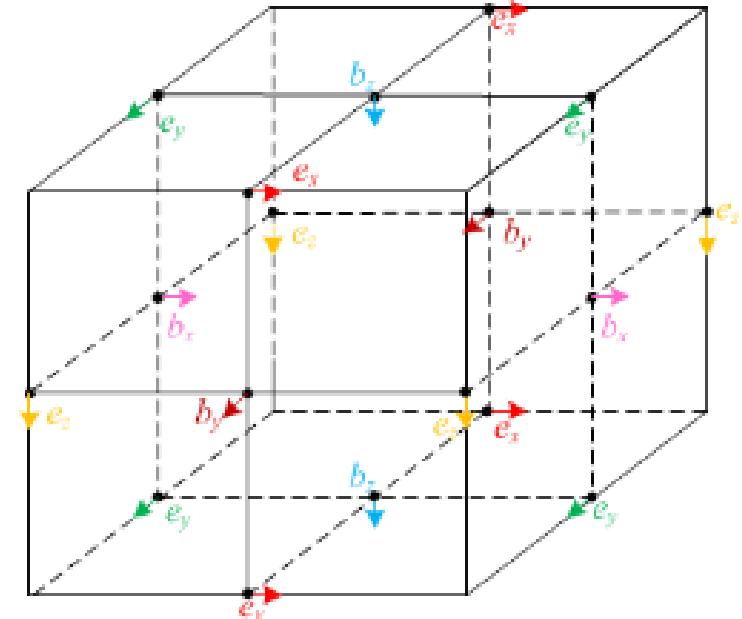
$$\nabla \times \mathbf{E} + \mu \frac{\partial \mathbf{H}}{\partial t} = 0$$

$$\nabla \times \mathbf{H} - \sigma \mathbf{E} = \mathbf{J}_s(t)$$

其中: \mathbf{E} : 电场强度, \mathbf{H} : 磁场强度, σ : 电导率,
 μ : 磁导率, \mathbf{J}_s : 源电流密度。

时间上的离散使用向后差分(隐式)的格式, 空间上, 使用交错网
格离散(Yee晶胞):

$$\begin{pmatrix} \mathbf{A}(\mathbf{m}, \delta t_1) & & \\ -\gamma(\delta t_2) \mathbf{I} & \mathbf{A}(\mathbf{m}, \delta t_2) & \\ \ddots & \ddots & \ddots \\ \ddots & \ddots & \ddots \end{pmatrix} \begin{pmatrix} \mathbf{B}^1 \\ \mathbf{B}^2 \\ \vdots \\ \vdots \end{pmatrix} = \begin{pmatrix} \mathbf{q}^1(\mathbf{m}) + \gamma(\delta t_1) \mathbf{h}^0 \\ \mathbf{q}^2(\mathbf{m}) \\ \vdots \\ \vdots \end{pmatrix} \quad \xrightarrow{\hspace{1cm}} \quad \mathbf{A}^{i+1}(\mathbf{m}, \delta t^{i+1}) \mathbf{B}^{i+1} = u(\mathbf{J}_s^{i+1}, \mathbf{B}^i, \mathbf{m}, \delta t^{i+1})$$





目 录

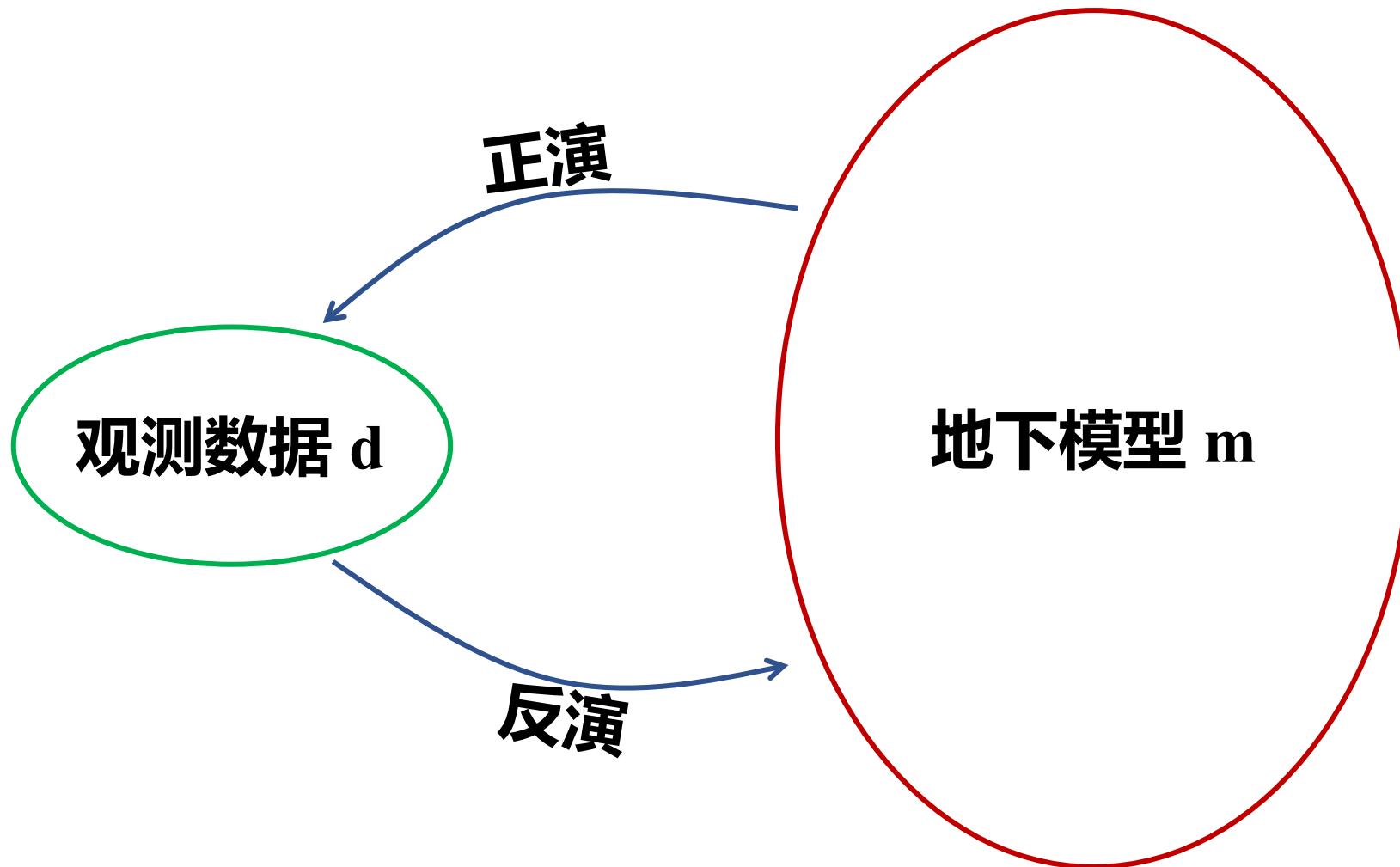
GeoGoku

第一节 电法正演基本理论

第二节 电法反演基本理论

1. 反演基本理论

GeoGoku



1. 反演基本理论

GeoGoku

- 广义度量目标函数:

$$\phi = \phi_d + \lambda \phi_m$$

$$\phi_d = \|\mathbf{C}_d(\mathbf{d}^{obs} - \mathbf{d}^{pre})\|_p^p,$$

$$\phi_m = \|\mathbf{C}_m(\mathbf{m} - \mathbf{m}^{pri})\|_p^p.$$

距离度量方法

- \mathbf{C}_d 是一个对角矩阵，其元素是观测噪声标准差估计的倒数。
- \mathbf{C}_m 是一个模型特征提取算子，一般由一阶或者二阶差分算子构成。

- l_p -norm
- M -measure of Huber (1964):
$$\rho(x) = \begin{cases} x^2 & |x| \leq c, \\ 2c|x| - c^2 & |x| > c, \end{cases}$$
- l_p -norm of Ekblom (1987):
$$\rho(x) = (x^2 + \varepsilon^2)^{p/2}$$
- Support measure last and Kubik (1983) and Portniaguine and Zhdanov (1999) :

$$\rho(x) = \frac{x^2}{x^2 + \varepsilon^2}.$$

参考 Farquharson (2008)

1. 反演基本理论

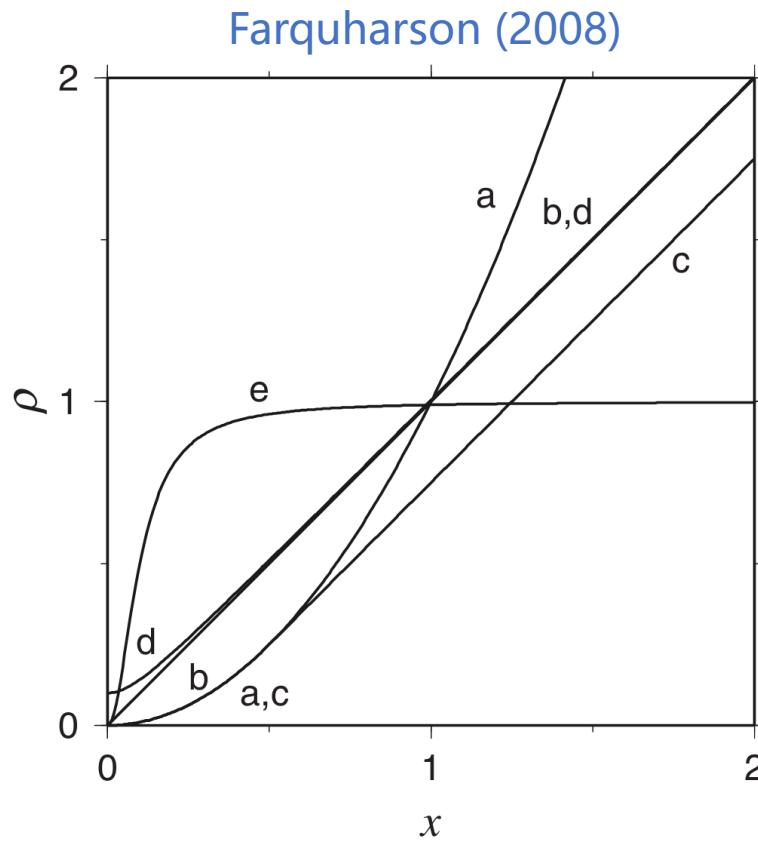
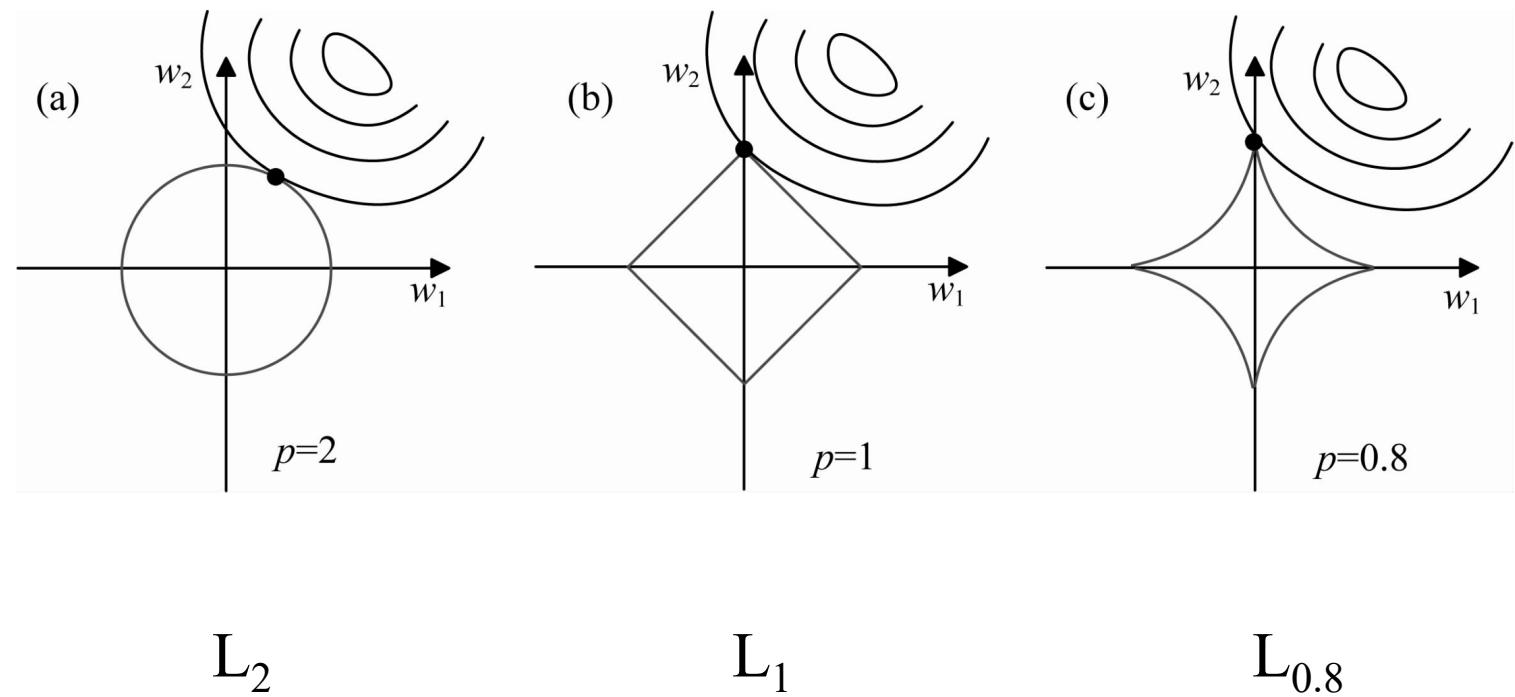


Figure 1. The behavior of the function ρ for various measures: (a) the l_2 -norm; (b) the l_1 -norm; (c) the Huber M -measure with $c = 0.5$; (d) the Ekblom measure with $p = 1$ and $\varepsilon = 0.1$; (e) the support measure of equation 10 with $\varepsilon = 0.1$.

- 不同范数的度量特征



- 不同范数正则化解的特征

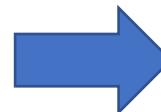
1. 反演基本理论

- 目标函数的梯度:

$$\mathbf{g}_i = -\mathbf{J}^T \mathbf{C}_d^T \mathbf{R}_d \mathbf{C}_d (\mathbf{d}^{obs} - \mathbf{d}_{i-1}^{pre}) + \lambda \mathbf{C}_m^T \mathbf{R}_m \mathbf{C}_m (\mathbf{m}_{i-1} - \mathbf{m}^{pri}).$$

- 高斯-牛顿方程:

$$\begin{aligned}\mathbf{d}_i^{pre} &= \mathbf{d}_{i-1}^{pre} + \mathbf{J} \delta \mathbf{m}, \\ \mathbf{m}_i &= \mathbf{m}_{i-1} + \delta \mathbf{m}.\end{aligned}$$



$$\begin{aligned}&(\mathbf{J}^T \mathbf{C}_d^T \mathbf{R}_d \mathbf{C}_d \mathbf{J} + \lambda \mathbf{C}_m^T \mathbf{R}_m \mathbf{C}_m) \delta \mathbf{m} \\ &= \mathbf{J}^T \mathbf{C}_d^T \mathbf{R}_d \mathbf{C}_d (\mathbf{d}^{obs} - \mathbf{d}_{i-1}^{pre}) \\ &\quad + \lambda \mathbf{C}_m^T \mathbf{R}_m \mathbf{C}_m (\mathbf{m}^{pri} - \mathbf{m}_{i-1}).\end{aligned}$$

If $p = 2$, $R_{jj} = 2$; $p = 1$, $R_{jj} = (x_j^2 + \varepsilon^2)^{-\frac{1}{2}}$, Ekblom (1987)



1. 反演基本理论

- 伴随正演:

$$\mathbf{K}\mathbf{E} = \mathbf{S} \quad \rightarrow \quad \frac{\partial \mathbf{K}}{\partial m_k} \mathbf{E} + \mathbf{K} \frac{\partial \mathbf{E}}{\partial m_k} = \frac{\partial \mathbf{S}}{\partial m_k}$$

\mathbf{L} 为从解向量到任意一点数据值的插值算子

$$\mathbf{J}_k = \frac{\partial \mathbf{d}}{\partial m_k} = \frac{\mathbf{L} \partial \mathbf{E}}{\partial m_k} = \mathbf{L} \mathbf{K}^{-1} \left(\frac{\partial \mathbf{s}}{\partial m_k} - \frac{\partial \mathbf{K}}{\partial m_k} \mathbf{E} \right).$$

$$\mathbf{G}_k = \frac{\partial \mathbf{s}}{\partial m_k} - \frac{\partial \mathbf{K}}{\partial m_k} \mathbf{E}, \quad \rightarrow \quad \mathbf{J} = \mathbf{L} \mathbf{K}^{-1} \mathbf{G} \quad \rightarrow \quad \mathbf{J}^T = \mathbf{G}^T \mathbf{K}^{-T} \mathbf{L}^T$$

$$\mathbf{Jv} = \mathbf{Lb}$$

$$\mathbf{J}^T \mathbf{u} = \mathbf{G}^T \mathbf{w}$$

$$\mathbf{Kb} = \mathbf{Gv}$$

$$\mathbf{K}^T \mathbf{w} = \mathbf{L}^T \mathbf{u}$$

1. 反演基本理论

Algorithm 1. BFGS for geo-electromagnetic inversion.

Require: \mathbf{m}_0 : Initial model.

Require: \mathbf{H}_0 : Initial inverse of Hessian matrix.

Require: K : Maximum number of iterations.

- 1) Initializing iteration index $i = 0$ and regularization factor λ .
 - 2) Calculating η_0 and \mathbf{g}_0 .
 - 3) **while** $\eta_i > 1.0$ and $i < K$ **do**
 - 5) Set $\mathbf{u}_i = \mathbf{H}_i \mathbf{g}_i$ and find the appropriate step length α_i to update model by $\mathbf{m}_{i+1} = \mathbf{m}_i + \alpha_i \mathbf{u}_i$;
 - 6) Calculate η_{i+1} and \mathbf{g}_{i+1} . If η_{i+1} decreases too slowly, update λ using cooling approach
 - 7) Update the approximation of inverse of Hessian matrix by

$$\mathbf{H}_{i+1} = (\mathbf{I} - \boldsymbol{\rho}_i \mathbf{s}_i \mathbf{y}_i^T) \mathbf{H}_i (\mathbf{I} - \boldsymbol{\rho}_i \mathbf{y}_i \mathbf{s}_i^T) + \boldsymbol{\rho}_i \mathbf{s}_i \mathbf{s}_i^T, \text{ where } \boldsymbol{\rho}_i = 1/(\mathbf{y}_i^T \mathbf{s}_i),$$

$$\mathbf{s}_i = \mathbf{m}_{i+1} - \mathbf{m}_i, \text{ and } \mathbf{y}_i = \nabla \phi(\mathbf{m}_{i+1}, \mathbf{d}) - \nabla \phi(\mathbf{m}_i, \mathbf{d})$$

$$i = i + 1$$
 - 8) **end while**
 - return** \mathbf{m}_i .
-

Algorithm 2. Adam (Kingma and Ba, 2015) for geo-electromagnetic inversion. Recommended settings for hyperparameters: $\beta_1 = 0.5$, $\beta_2 = 0.999$, and $\epsilon = 10^{-5}$. The values β_1^i and β_2^i denote β_1 and β_2 to the power of i .

Require: α : Step size.

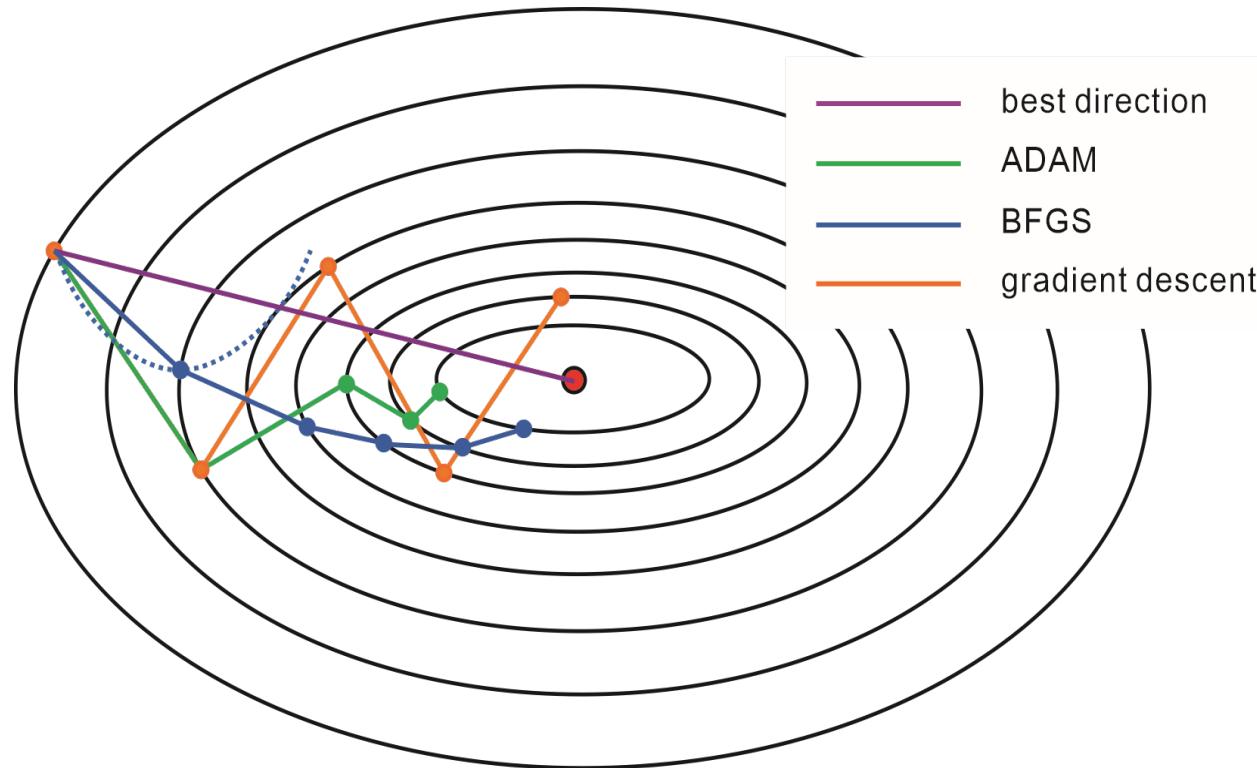
Require: $\beta_1, \beta_2 \in (0, 1]$: Exponential decay rates for the moment estimates.

Require: K : Maximum number of iterations.

- 1) Initial states for the moment parameter vectors: $\mathbf{v}_0 = 0$, $\mathbf{r}_0 = 0$.
 - 2) Initializing iteration index $i = 0$ and regularization factor λ .
 - 3) Calculating η_0 and \mathbf{g}_0 .
 - 4) **while** $\eta_i > 1.0$ and $i < K$ **do**
 - 5) $i = i + 1$
 - 6) $\mathbf{v}_i = \beta_1 \mathbf{v}_{i-1} + (1 - \beta_1) \mathbf{g}_i$ (update biased first momentum)
 - 7) $\mathbf{r}_i = \beta_2 \mathbf{r}_{i-1} + (1 - \beta_2) \mathbf{g}_i \otimes \mathbf{g}_i$ (update biased second momentum)
 - 8) $\tilde{\mathbf{v}}_i = \mathbf{v}_i / (1 - \beta_1^i)$ (Bias correction for the first momentum)
 - 9) $\tilde{\mathbf{r}}_i = \mathbf{r}_i / (1 - \beta_2^i)$ (Bias correction for the second momentum)
 - 10) $\mathbf{m}_i = \mathbf{m}_{i-1} - \alpha \tilde{\mathbf{v}}_i / (\sqrt{\tilde{\mathbf{r}}_i} + \epsilon)$ (model updates)
 - 11) Calculate η_i and \mathbf{g}_i . If η_i decreases too slowly, update λ using cooling approach
 - 12) **end while**
 - return** \mathbf{m}_i .
-

1. 反演基本理论

GeoGoku



- 一阶梯度类优化算法收敛路径

1. 反演基本理论

GeoGoku

- 模型上下限约束: $a_k < m_k < b_k$

Step 1: $x_k = \log(m_k - a_k) - \log(b_k - m_k)$

Step 2: $\mathbf{J}_k = \frac{\partial \mathbf{d}}{\partial x_k} = \frac{\partial \mathbf{d}}{\partial m_k} \frac{\partial m_k}{\partial x_k},$

$$\frac{\partial m_k}{\partial x_k} = \frac{(b_k - a_k) \exp(x_k)}{[1 + \exp(x_k)]^2}$$

Step 3: $m_k = \frac{a_k + b_k \exp(x_k)}{1 + \exp(x_k)} \quad k = 1, 2, \dots, M.$

- 稀疏变换:

Step 1: $\tilde{\mathbf{m}} = \mathbf{W}_w \mathbf{m},$

Step 2: $\tilde{\mathbf{J}} = \mathbf{J} \mathbf{W}_w^{-1}.$

- 关于稀疏系数的GN方程:

$$(2\tilde{\mathbf{J}}^T \mathbf{C}_d^T \mathbf{C}_d \tilde{\mathbf{J}} + \lambda \mathbf{R}) \delta \tilde{\mathbf{m}} \\ = 2\tilde{\mathbf{J}}^T \mathbf{C}_d^T \mathbf{C}_d (\mathbf{d}^{obs} - \mathbf{d}^{pre}) + \lambda \mathbf{R} (\tilde{\mathbf{m}}^{pri} - \tilde{\mathbf{m}}_{i-1}),$$

$$R_{jj} = [(\tilde{\mathbf{m}}^{pri} - \tilde{\mathbf{m}}_{i-1})_j^2 + \varepsilon^2]^{-\frac{1}{2}}.$$

Step 3: $\mathbf{m}^n = \mathbf{m}^{n-1} + \mathbf{W}_w^{-1} \delta \tilde{\mathbf{m}}.$

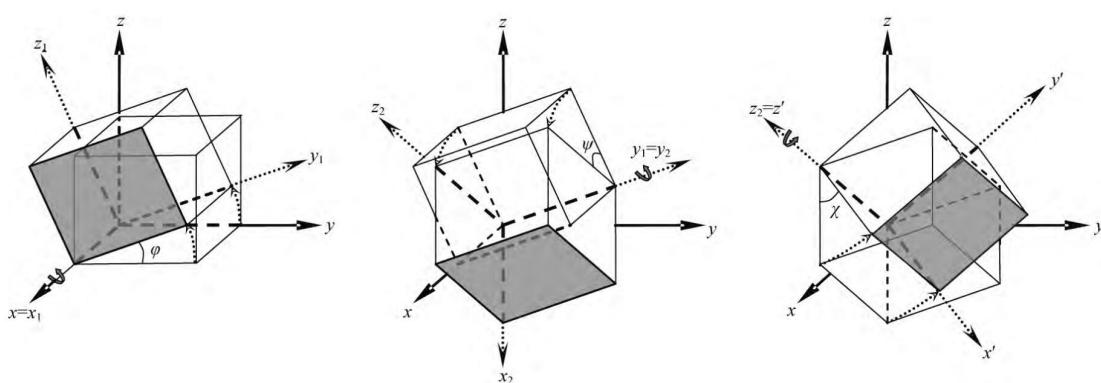
1. 反演基本理论

- 各向异性电导率：

$$\underline{\underline{\sigma}} = R_x(\alpha)R_y(\beta)R_z(\gamma) \begin{pmatrix} \sigma_x & & \\ & \sigma_y & \\ & & \sigma_z \end{pmatrix} R_z^T(\gamma)R_y^T(\beta)R_x^T(\alpha)$$

$$\mathbf{R}_x(\alpha) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \alpha & -\sin \alpha \\ 0 & \sin \alpha & \cos \alpha \end{pmatrix} \quad \mathbf{R}_y(\beta) = \begin{pmatrix} \cos \beta & 0 & \sin \beta \\ 0 & 1 & 0 \\ -\sin \beta & 0 & \cos \beta \end{pmatrix} \quad \mathbf{R}_z(\gamma) = \begin{pmatrix} \cos \gamma & -\sin \gamma & 0 \\ \sin \gamma & \cos \gamma & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

- 旋转示意图



(Liu and Yin, JAG, 2014)

- 伴随问题：

$$\mathbf{J}_k = \frac{\partial \mathbf{d}}{\partial m_k} = \frac{\mathbf{L}_z \partial \mathbf{E}}{\partial m_k} = \mathbf{L}_z \mathbf{K}^{-1} \left(- \int_{\Omega} \mathbf{N}_i \left(\frac{\partial \underline{\underline{\sigma}}}{\partial \mathbf{m}_k} \right) \mathbf{N}_j d\Omega \mathbf{E} \right)$$

$$\frac{\partial \underline{\underline{\sigma}}}{\partial m_1} = \mathbf{R} \frac{\partial \Lambda}{\partial m_1} \mathbf{R}^T = \mathbf{R} \begin{pmatrix} 1 & & \\ & 0 & \\ & & 0 \end{pmatrix} \mathbf{R}^T \quad \frac{\partial \underline{\underline{\sigma}}}{\partial m_2} = \mathbf{R} \frac{\partial \Lambda}{\partial m_2} \mathbf{R}^T = \mathbf{R} \begin{pmatrix} 0 & & \\ & 1 & \\ & & 0 \end{pmatrix} \mathbf{R}^T$$

$$\frac{\partial \underline{\underline{\sigma}}}{\partial m_3} = \mathbf{R} \frac{\partial \Lambda}{\partial m_3} \mathbf{R}^T = \mathbf{R} \begin{pmatrix} 0 & & \\ & 0 & \\ & & 1 \end{pmatrix} \mathbf{R}^T$$

$$\frac{\partial \underline{\underline{\sigma}}}{\partial m_4} = \frac{\partial \mathbf{R}_x(\alpha)}{\partial m_4} \mathbf{R}_y \mathbf{R}_z \Lambda \mathbf{R}^T + \mathbf{R} \Lambda \mathbf{R}_z \mathbf{R}_y \frac{\partial \mathbf{R}_x^T(\alpha)}{\partial m_4}$$

$$\frac{\partial \underline{\underline{\sigma}}}{\partial m_5} = \mathbf{R}_x \frac{\partial \mathbf{R}_y(\beta)}{\partial m_5} \mathbf{R}_z \Lambda \mathbf{R}^T + \mathbf{R} \Lambda \mathbf{R}_z \frac{\partial \mathbf{R}_y^T(\beta)}{\partial m_5} \mathbf{R}_x$$

$$\frac{\partial \underline{\underline{\sigma}}}{\partial m_6} = \mathbf{R}_x \mathbf{R}_y \frac{\partial \mathbf{R}_z(\gamma)}{\partial m_6} \Lambda \mathbf{R}^T + \mathbf{R} \Lambda \frac{\partial \mathbf{R}_z^T(\gamma)}{\partial m_6} \mathbf{R}_y \mathbf{R}_x$$



目 录

GeoGoku

第一节 电法正演基本理论

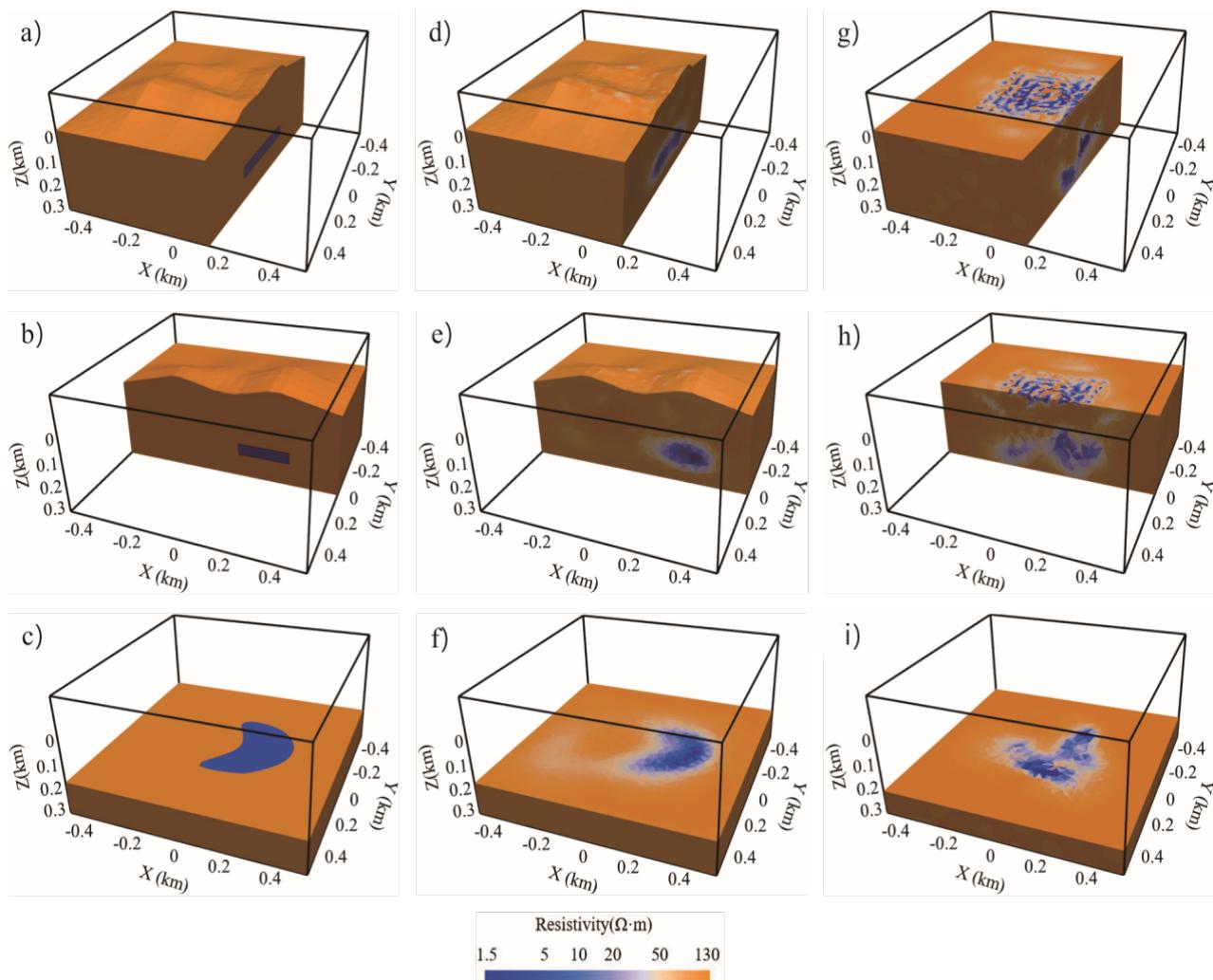
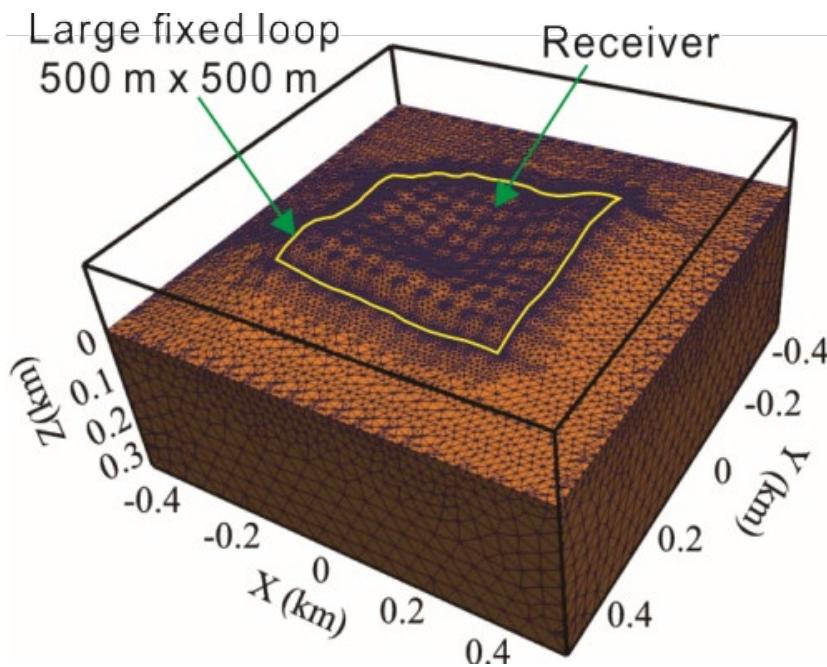
第二节 电法反演基本理论

第三节 电法反演应用

2. 反演应用

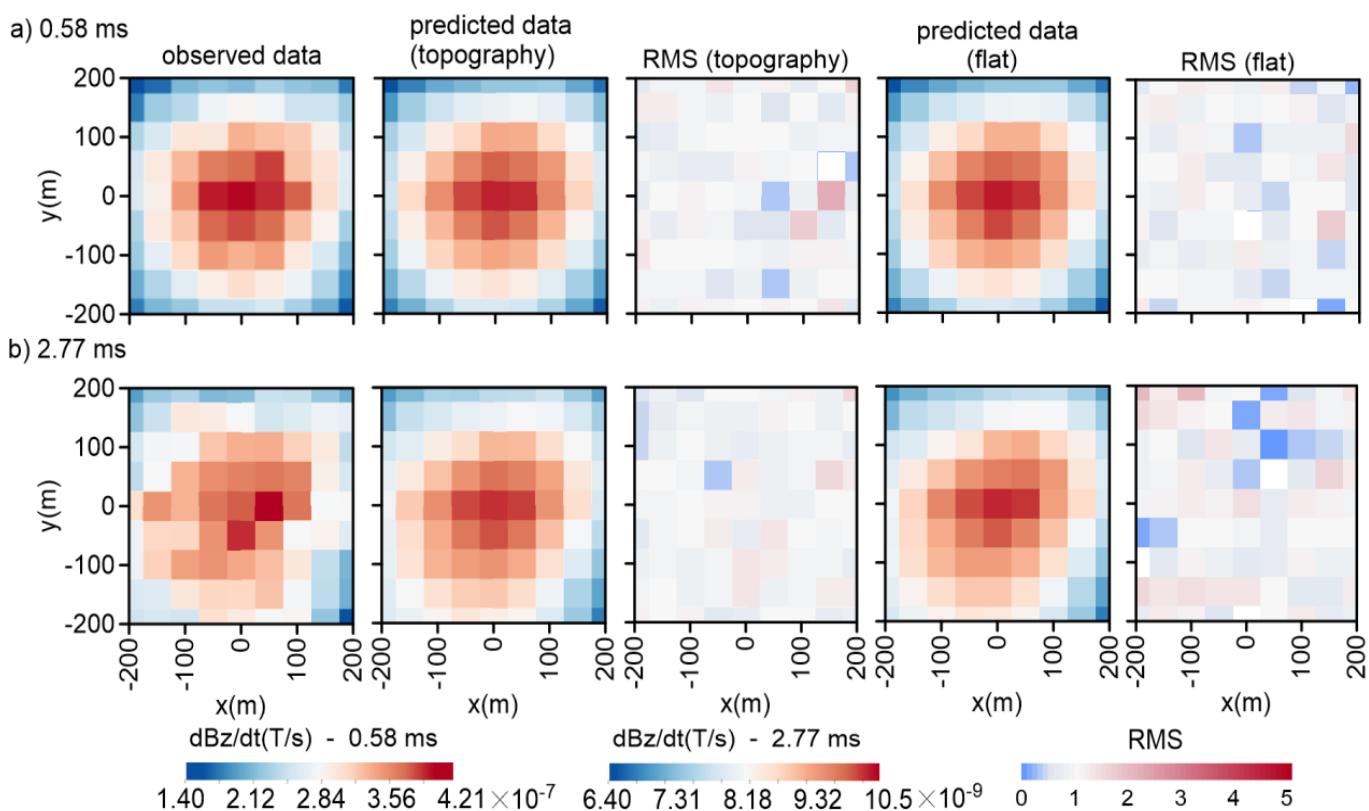
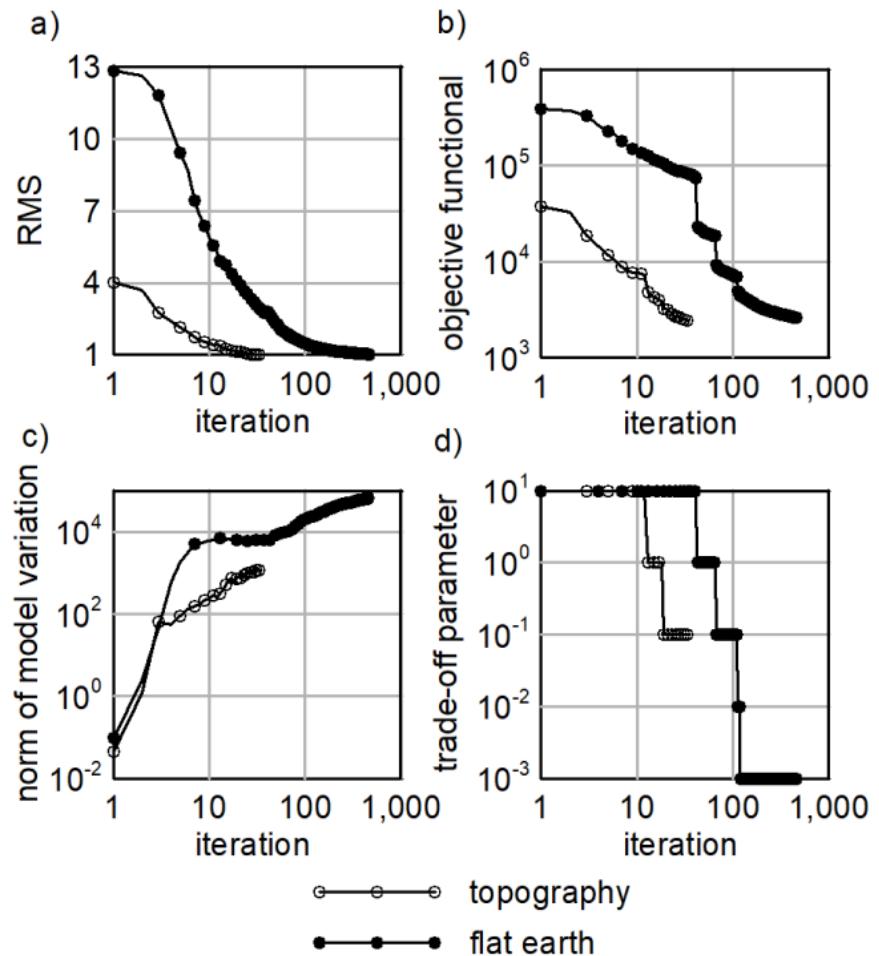
GeoGoku

- $9 \times 9 = 81$ 数据集;
- 342863 未知数(带地形); 318373 未知数(不带地形);
- 29个时间道, 0.012 – 10.4 ms;
- 一次正演计算时间 6 min



2. 反演应用

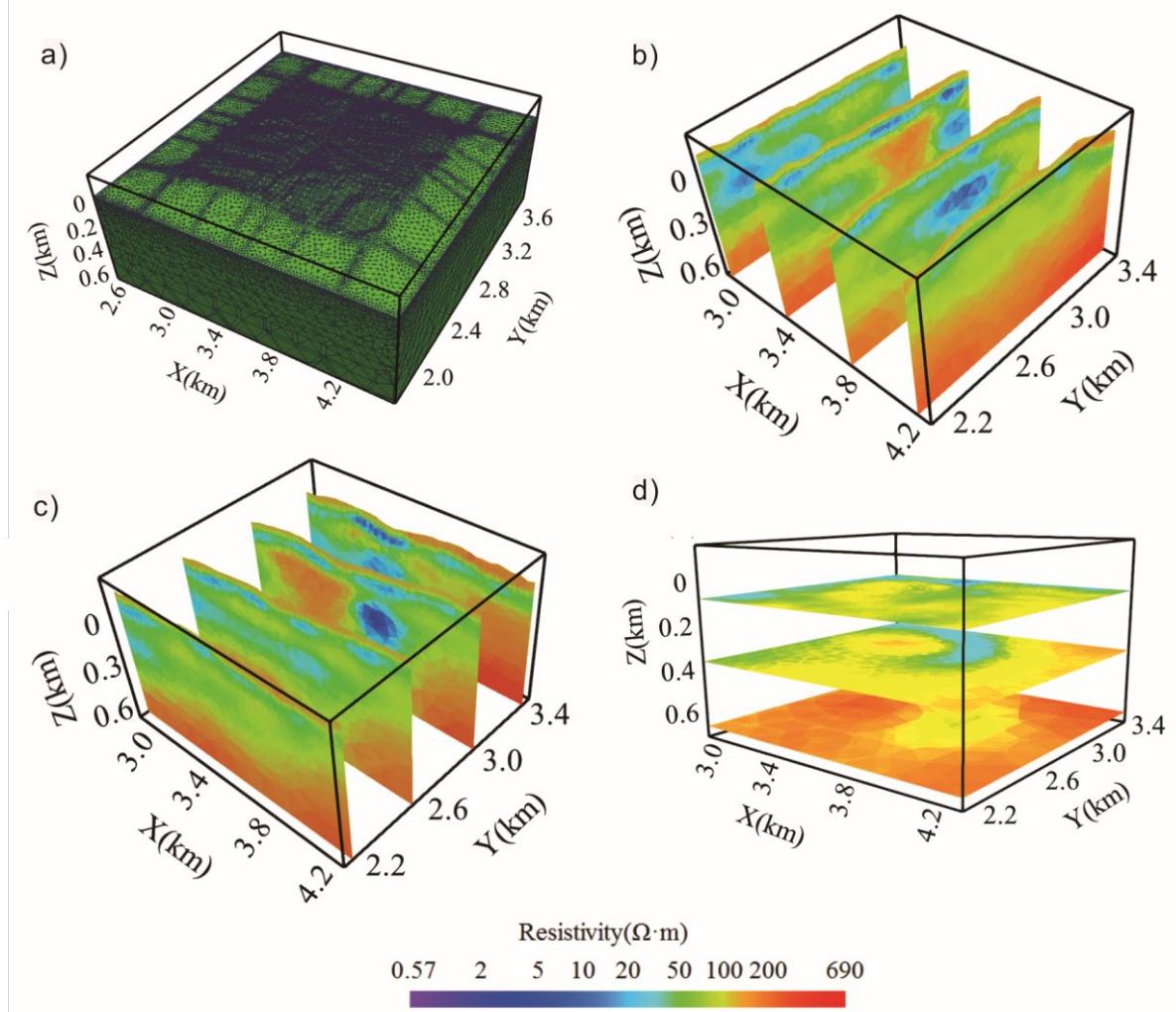
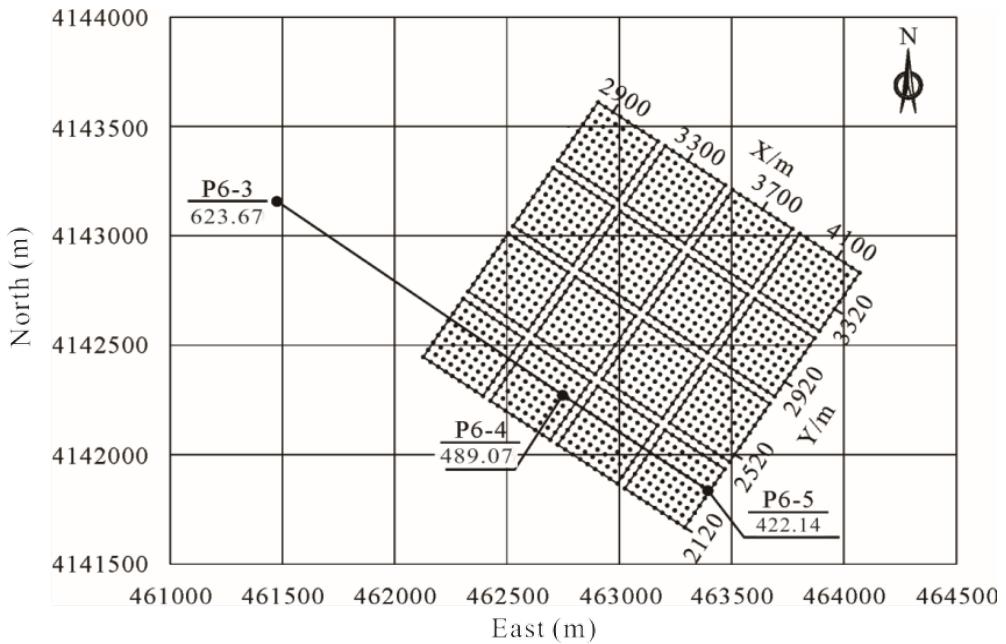
GeoGoku



2. 反演应用

GeoGoku

- $9 \times 9 \times 15 = 1215$ 数据集;
- 534225 未知数;
- 29个时间道, 0.1 – 10 ms;
- 一次正演计算时间 70 min





目 录

GeoGoku

第一节 电法正演基本理论

第二节 电法反演基本理论

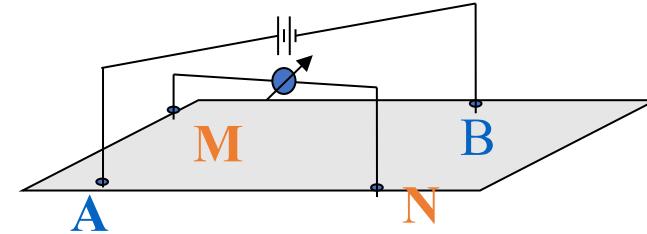
第三节 电法反演应用

第四节 电法数据处理

■ 半空间地下电阻率的确定

地面水平，地下为均匀、无限、各向同性介质，将A、B两供电电极与电源相连，并向地下供入电流强度为I的电流时，则地表任意两测量电极M和N的电位：

$$\begin{cases} U_M = \frac{\rho I}{2\pi} \left(\frac{1}{AM} - \frac{1}{BM} \right) \\ U_N = \frac{\rho I}{2\pi} \left(\frac{1}{AN} - \frac{1}{BN} \right) \end{cases}$$



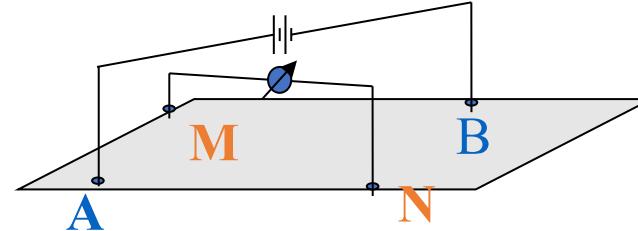
$$\begin{aligned} \Delta U_{MN} &= U_M - U_N \\ &= \frac{\rho I}{2\pi} \left(\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN} \right) \end{aligned}$$

■ 半空间地下电阻率的确定

得到用点电极测量均匀大地电阻率的表达式：

$$\rho = \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}} \frac{\Delta U_{MN}}{I} = K \frac{\Delta U_{MN}}{I}$$

$$K = \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}}$$



K 称为电极排列系数（装置系数），其单位为米，是一个仅与各电极间空间位置有关的量。

■ 半空间地下电阻率的确定

$$\rho = K \frac{\Delta U_{MN}}{I}$$

地面水平，地下为均匀、无限、
各向同性介质

实际工作中常常不能满足这些条件，地形往往起伏不平，
地下介质也不均匀，各种岩石相互重叠，断层裂隙纵横
交错，或者有矿体充填其中。

■ 半空间地下电阻率的确定

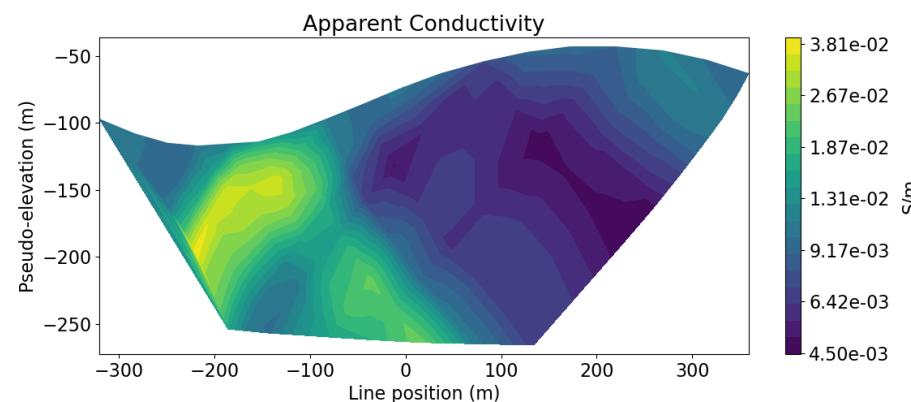
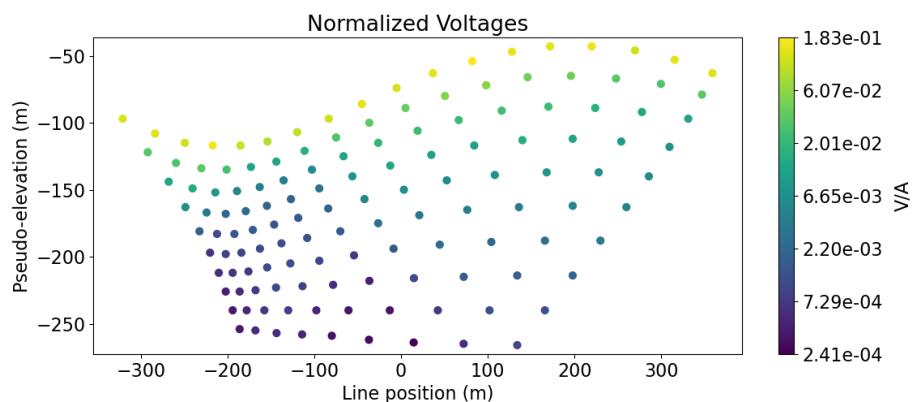
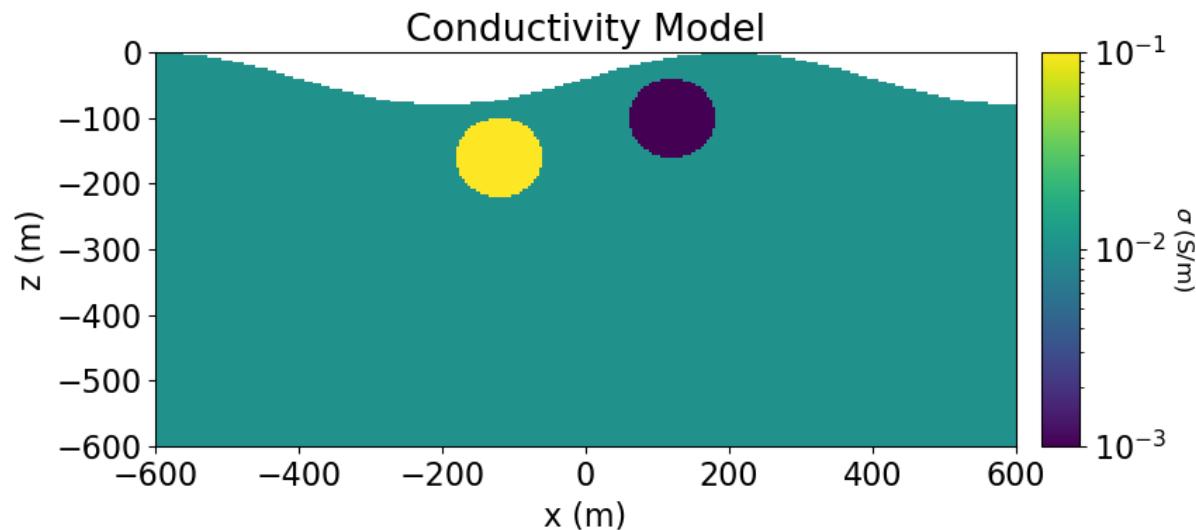
$$\rho = K \frac{\Delta U_{MN}}{I}$$

地面水平，地下为均匀、无限、各向同性介质

$$\rho_s = K \frac{\Delta U_{MN}}{I}$$

地面水平，虽然不是岩石的真电阻率，但却是地下电性不均匀体和地形起伏的一种综合反映。

■ 视电阻率



■ 常见装置的视电阻率

两极装置（单极-单极装置）

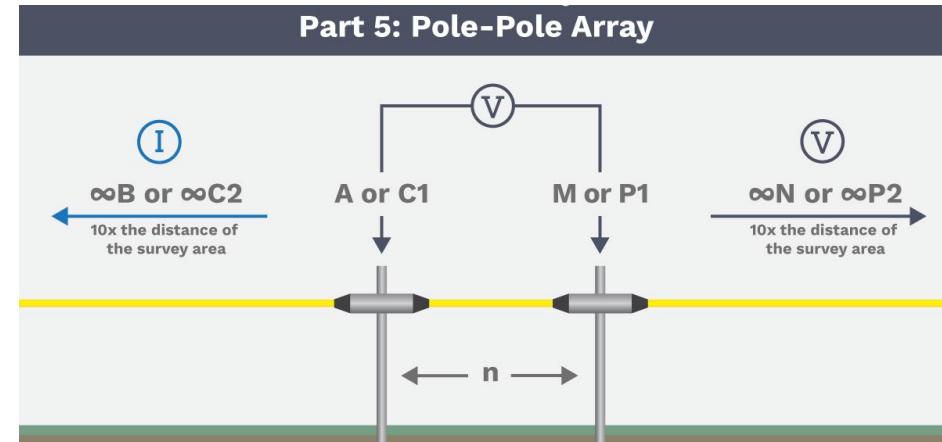
供电电极 B 和测量电极 N
均置于“无穷远”处接**地**。

这里所指的“无穷远”具有相对概念，如对 B 极而言，若相对 A 极在 M 极产生的电位小到实际上可以忽略时，便可视 B 极为无穷远；对 N 极而言，若 A 极在 N 极产生的电位相对 M 极很小以至可以忽略时，便认为 N 极位于无穷远，并取那里的电位为零。因此，二极装置实际是一种测量电位的装置。

$$\rho_s = K \frac{\Delta U_{MN}}{I}$$

$$K = \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}}$$

$$K_{AM} = 2\pi AM$$



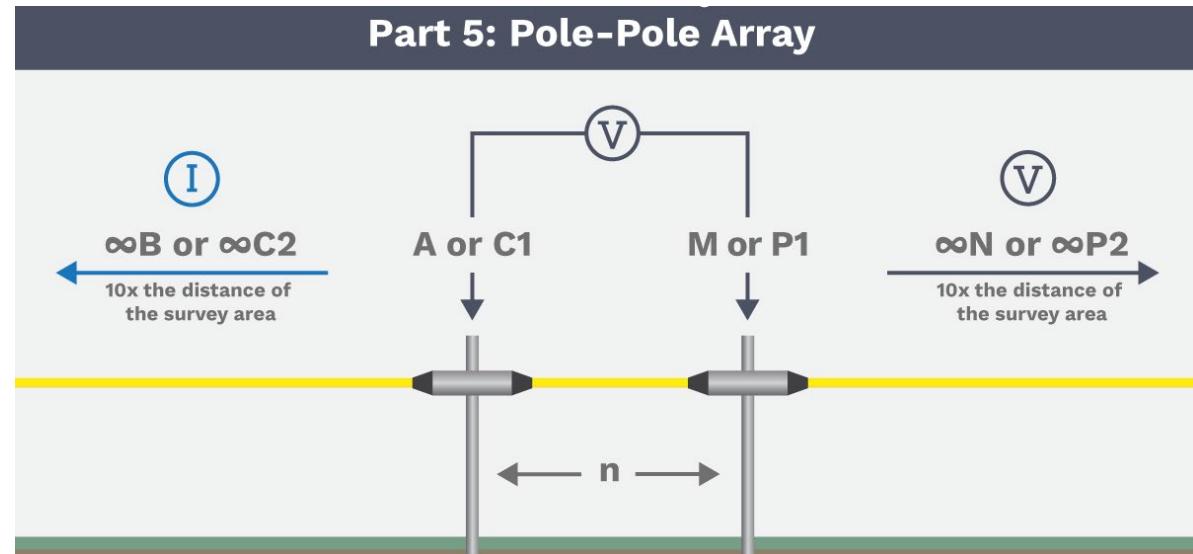
■ 常见装置的视电阻率

装置描述：供电电极 A 和测量电极 M 位于地表，而另一个供电电极 B (电流回线) 和另一个测量电极 N (电位参考) 被放置在无穷远 (实际上是足够远以至于它们对测量结果的影响可以忽略不计)。

装置系数 K ：

$$K = 2\pi \cdot AM$$

其中 AM 是供电电极 A 和测量电极 M 之间的距离。



■ 常见装置的视电阻率

装置描述：供电电极 A 和 B 组成一个偶极子，测量电极 M 和 N 组成另一个偶极子。两个偶极子之间的距离是 r ，每个偶极子的长度（极距）通常相等，设为 a 。通常 $AB = MN = a$ ，且 $r = na$ (n 为整数)。

装置系数 K ：

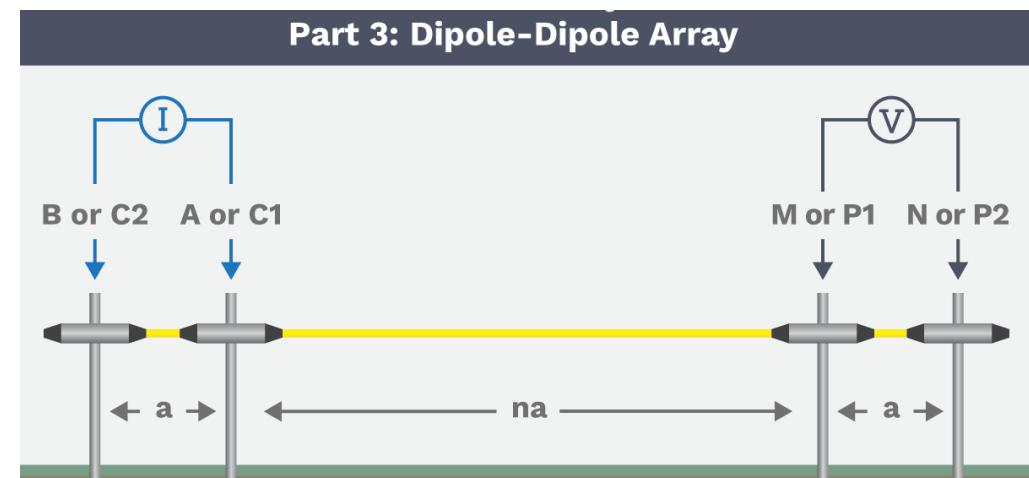
$$K = \pi \cdot n(n+1)(n+2) \cdot a$$

或者更通用的表达式（基于 r 和 a ）：

$$K = \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}}$$

当 $AB = MN = a$ 且 $BM = r$ 时，上式可近似为：

$$K \approx \pi \cdot \frac{r^3}{a^2}$$



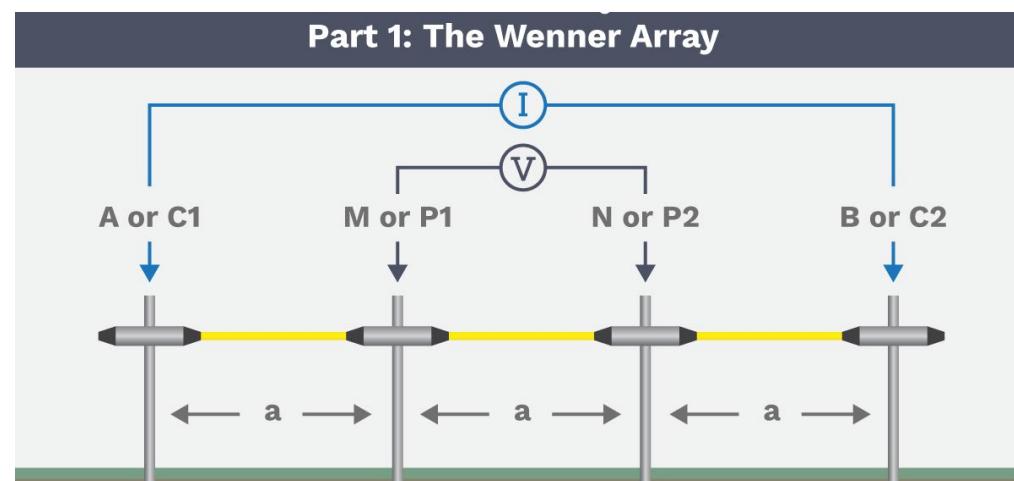
■ 常见装置的视电阻率

装置描述：四个电极 A, B, M, N 沿一条直线等间距排列，且 $AM = MN = NB = a$ 。

装置系数 K ：

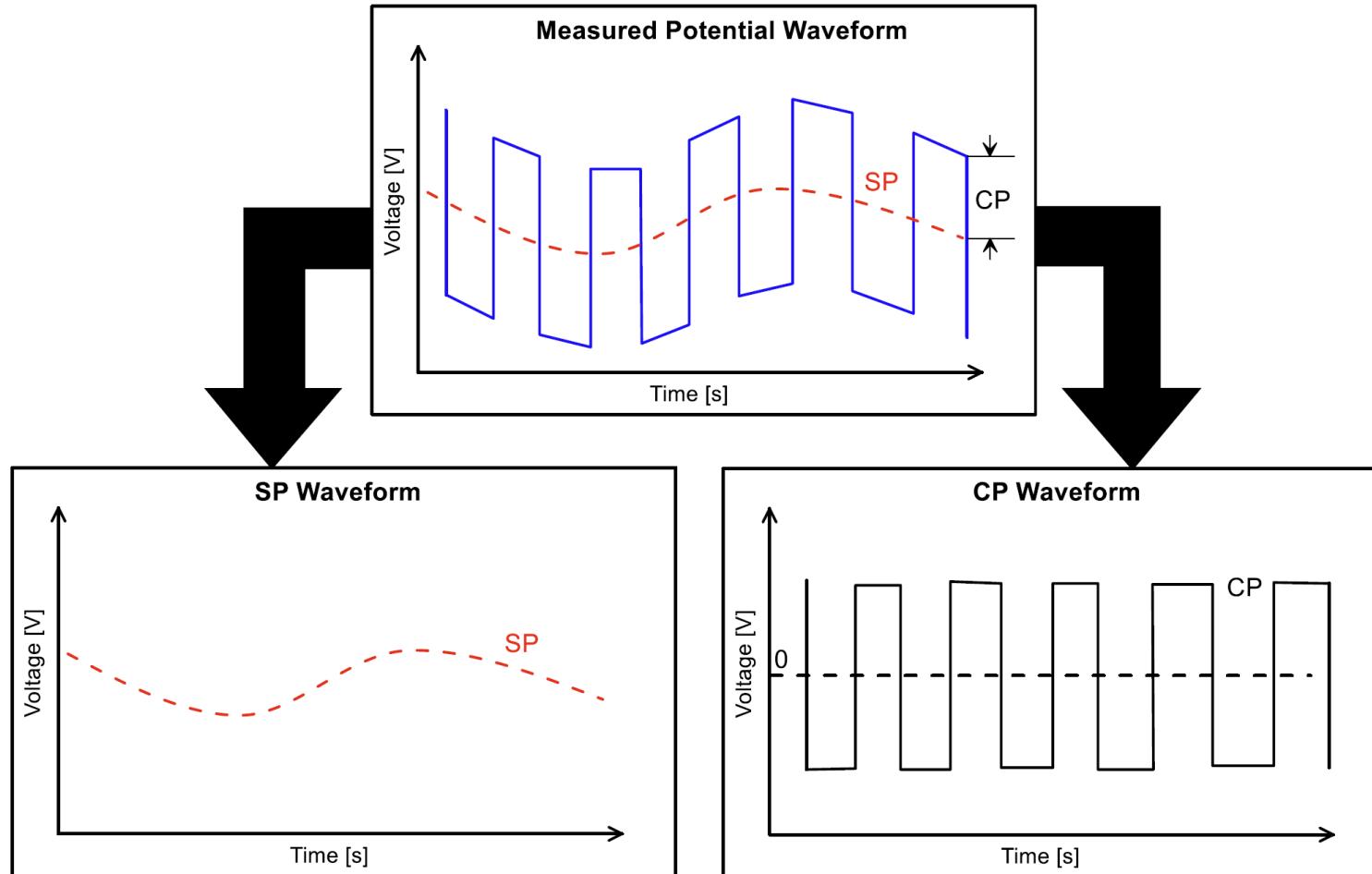
$$K = 2\pi \cdot a$$

其中 a 是相邻电极之间的距离（**极距**）。



直流电法数据中电场分离

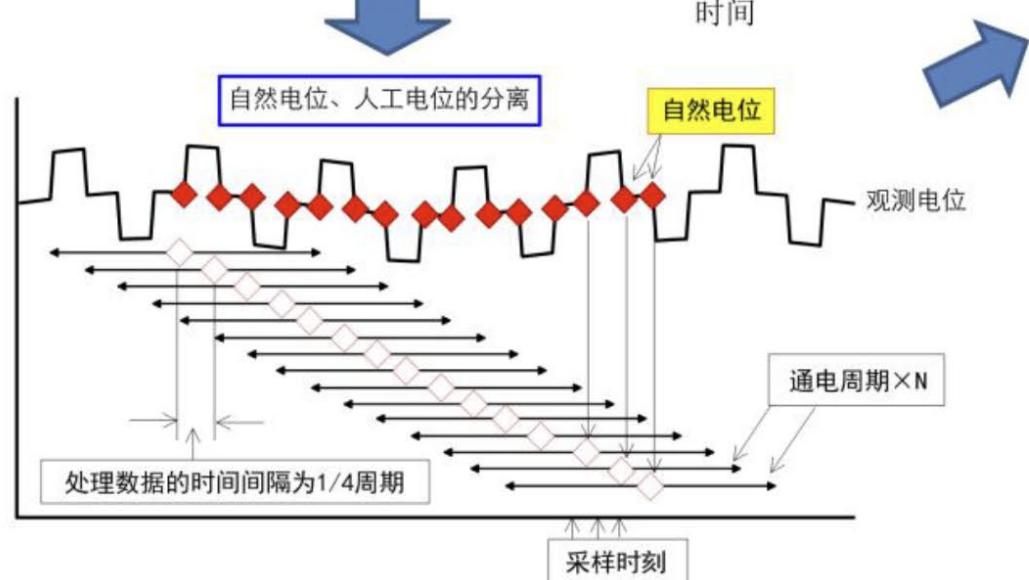
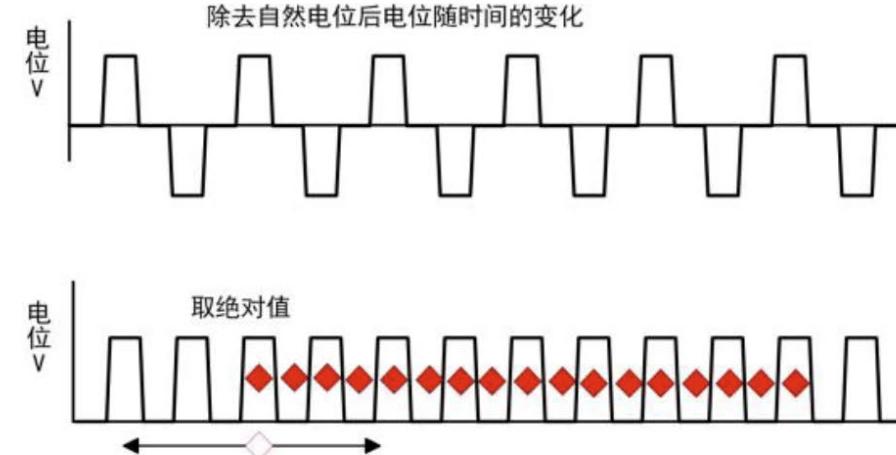
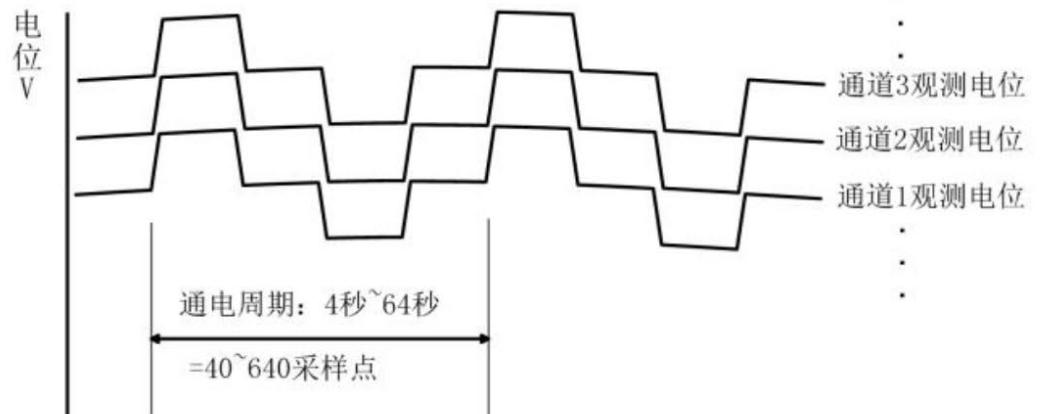
GeoGoku



直流电法数据中电场分离

GeoGoku

人工电位与自然电位的分离



$$SP(i) = \frac{\sum_{j=i-n+1}^i X(j)}{n}$$
$$CP(i) = X(i) - SP(i)$$



目 录

GeoGoku

第一节 电法正演基本理论

第二节 电法反演基本理论

第三节 电法反演应用

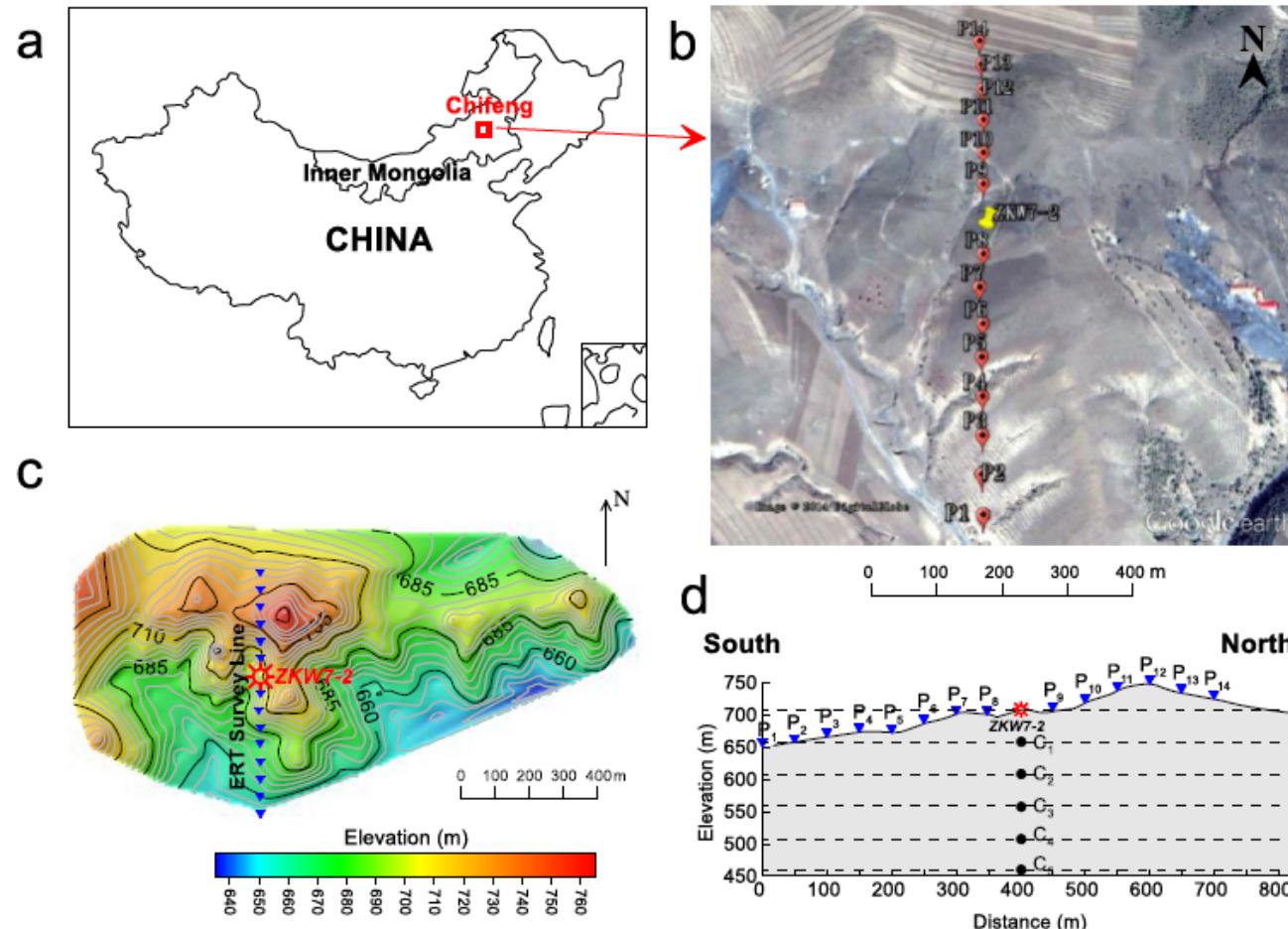
第四节 电法数据处理

第五节 电法应用

5. 电法应用

GeoGoku

■ 金属矿勘探

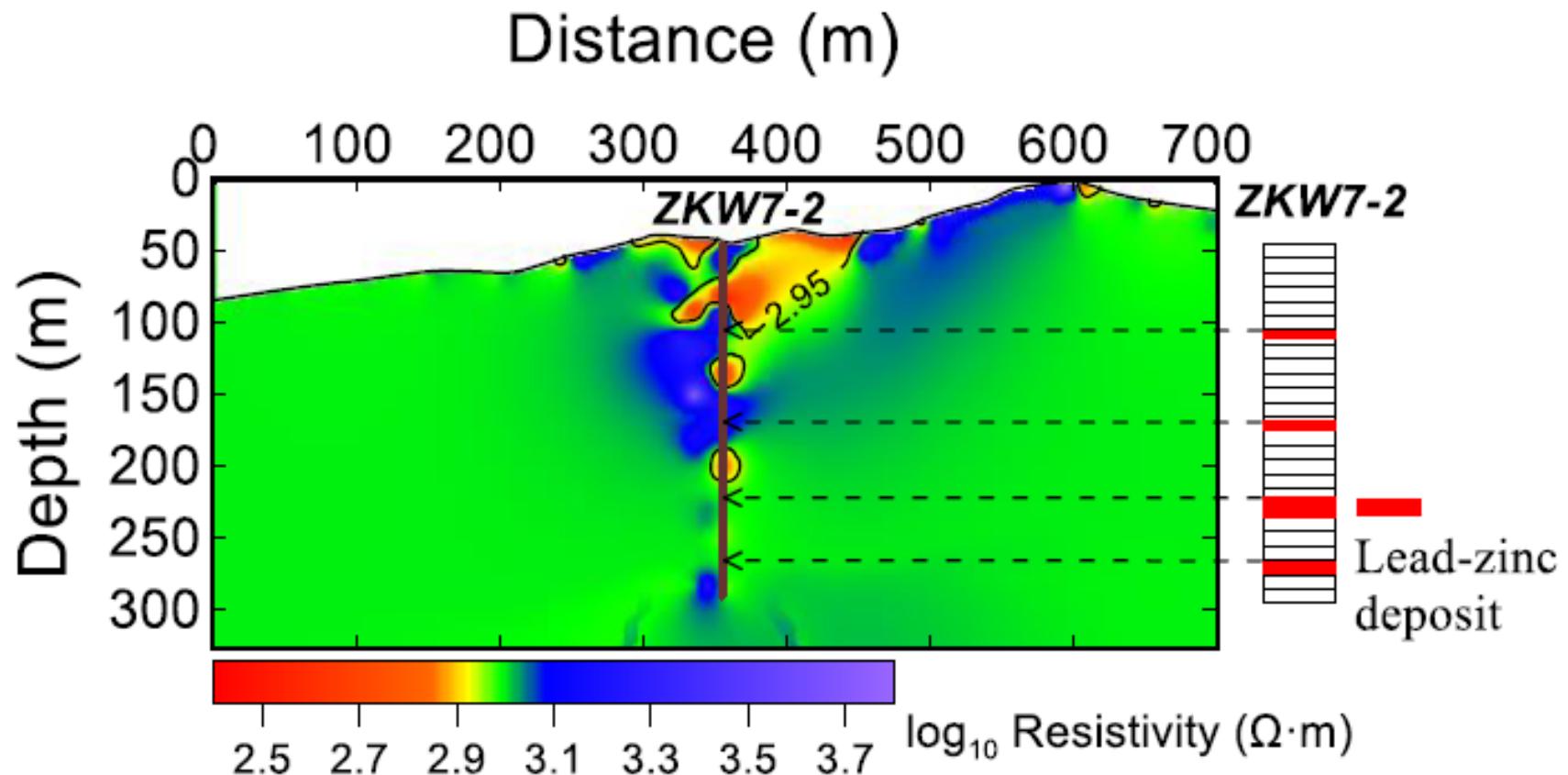


测区位置(a, b)、测区地形(c)及电极装置布设(d)

5. 电法应用

GeoGoku

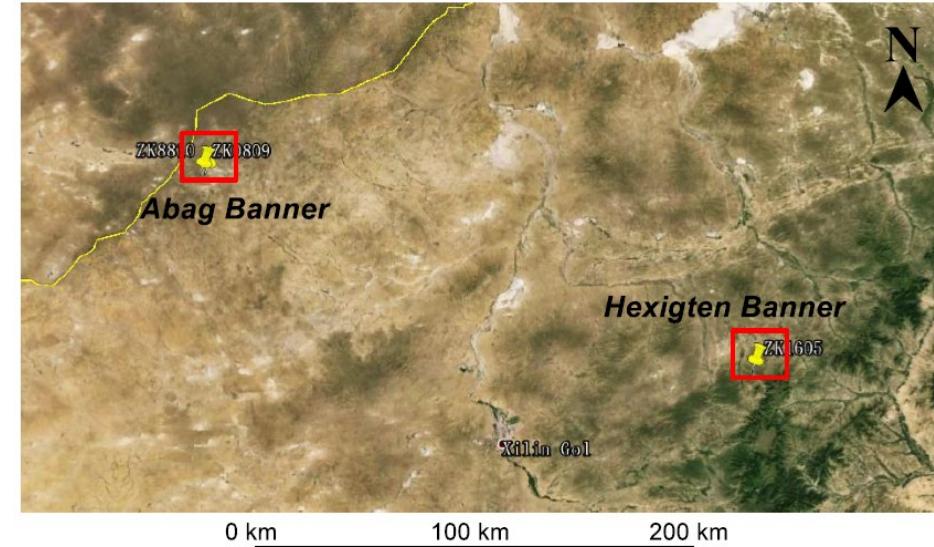
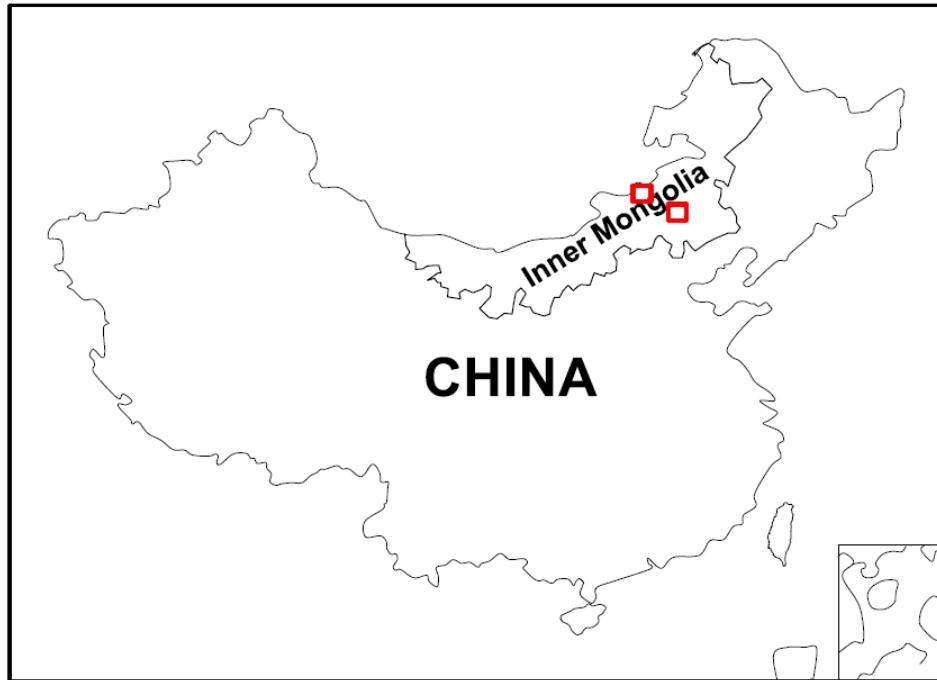
■ 金属矿勘探



5. 电法应用

GeoGoku

■ 金属矿勘探

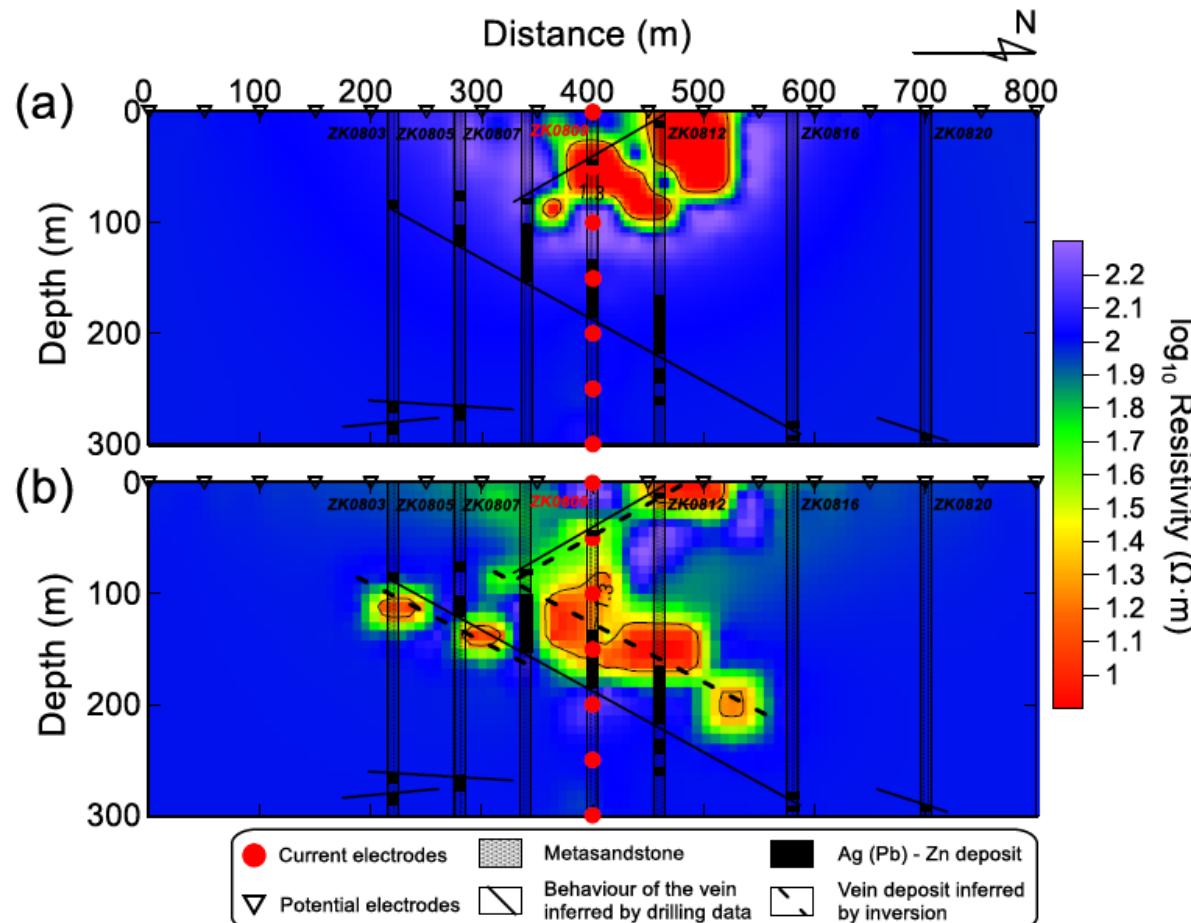


阿巴嘎旗与克什克腾旗测区位置

5. 电法应用

GeoGoku

■ 金属矿勘探



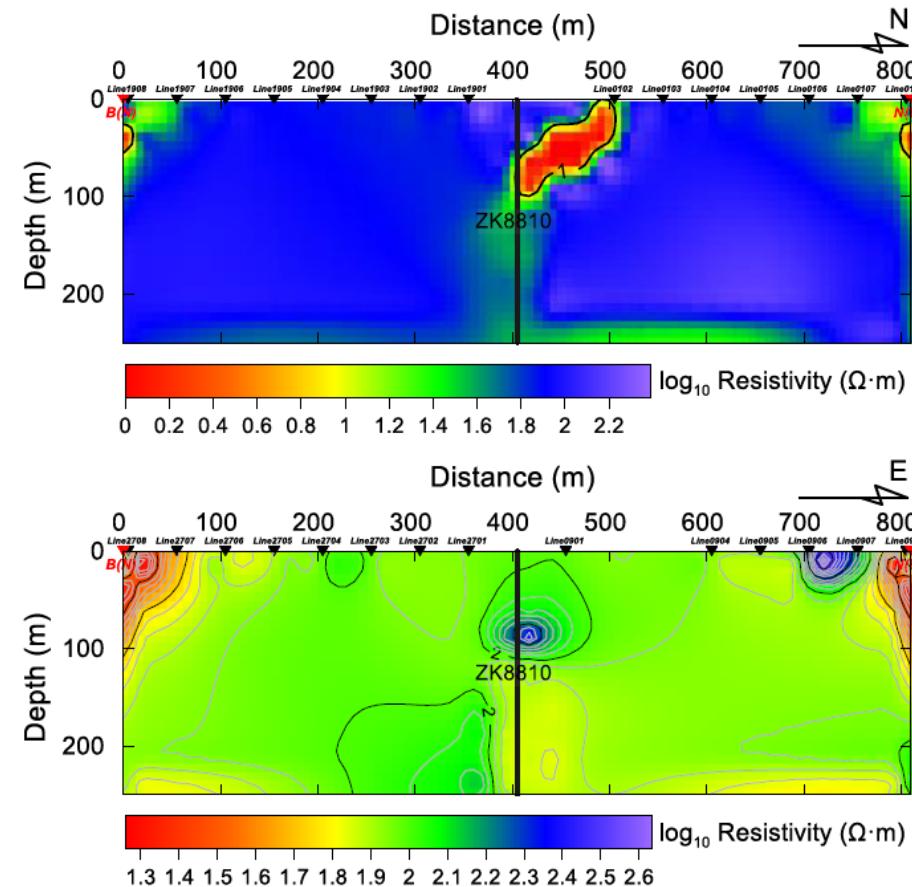
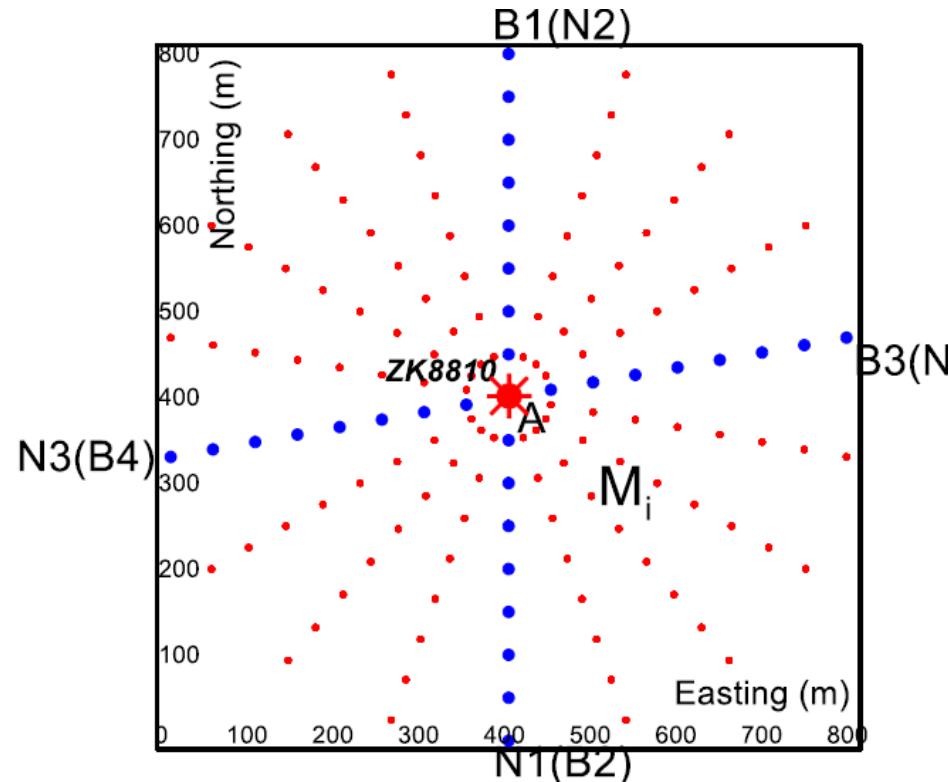
反演结果中所圈定的矿脉信息与钻孔资料所推断的矿脉信息在0m~200 m之间有很好的一致性，而反演结果在250 m以下区域则很难揭示出更多的矿脉信息。对比两种反演结果可以看出，加入先验信息约束的反演可以更准确的圈定地下矿脉的信息。

电阻率法反演结果(a)未加入约束条件反演(b)加入约束条件的反演

5. 电法应用

GeoGoku

■ 金属矿勘探

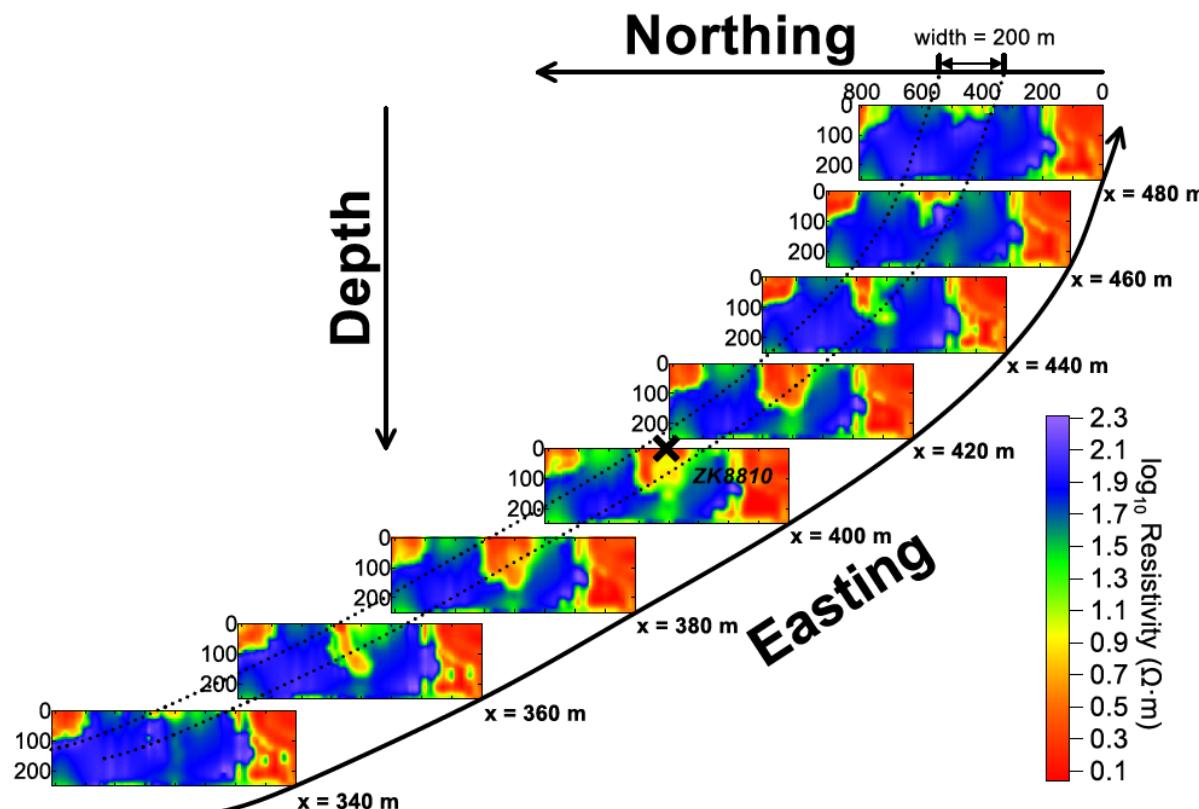


从南北方向测线反演结果可以看出矿脉向南倾，倾角大约 45° ，而从东西方向测线反演结果中无法获取更多的矿脉信息。从两条测线反演结果可以推断矿脉规模较小，而为了获取地下更详细的信息，我们布设了面积性测网采用同样的电极装置如图5-13所示进行了三维反演解释。

5. 电法应用

GeoGoku

■ 金属矿勘探



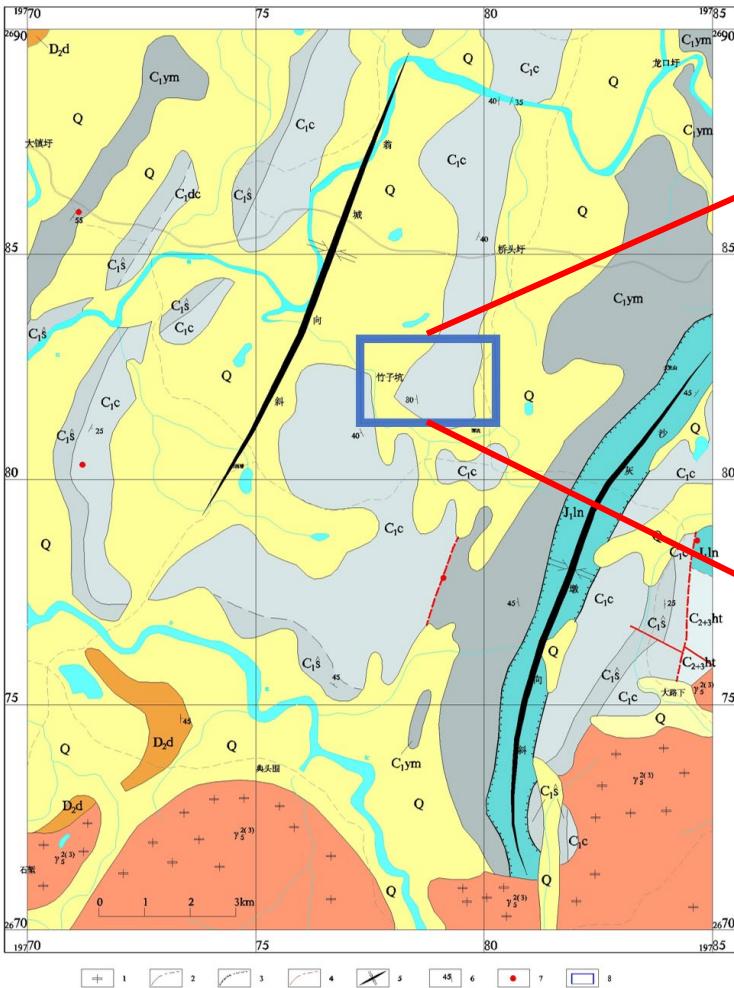
在x方向上x=340 m~480 m处有小规模低阻体聚集于井口附近。走向上跨度为140 m，倾向上跨度为200m左右。由于可能存在边界效应影响，所以在测区南部边界上聚集的低阻带信息为不可靠信息，可以进一步对该测区南部进行更细致法勘探工作已验证是否存在大规模的矿藏资源。

5. 电法应用

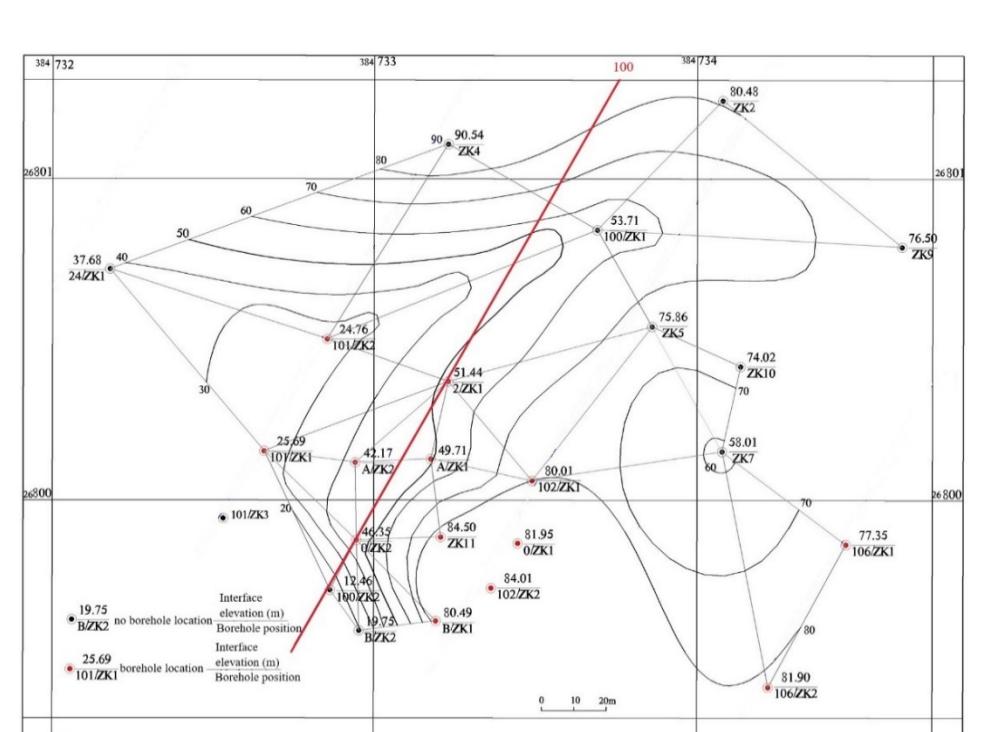
GeoGoku

■ 瞬变电磁

接地长导线源实测数据反演



Q - 第四系：由砂质粘土组成
C₁c - 下石炭统测水组：石英粉砂岩
C₁s - 下石炭统石磴子组：纹层灰岩 1.中粒似斑状花岗岩
2.正常岩层地质界线 3.不整合地质界线 4.断裂构造 5.褶皱构造 6.岩层产状 7.褐铁矿点 8.矿区勘测区域



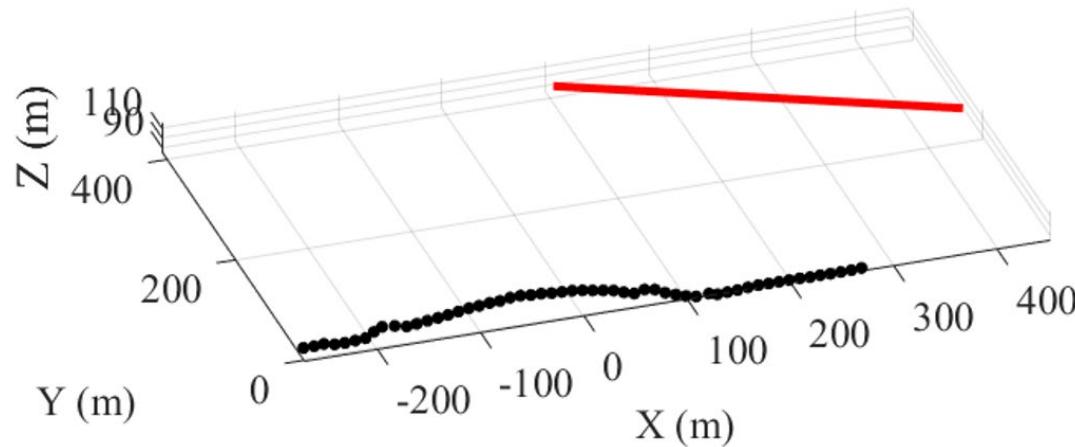
- ◆ 接地长导线源：378.5m，斜坡波形，下降沿0.05ms，发射电流1A
- ◆ 100号测线接收点间距10m，共55个接收点
- ◆ 在地表接收数据，每个测点观测从发射电流关断后0.0311ms到24.3ms

5. 电法应用

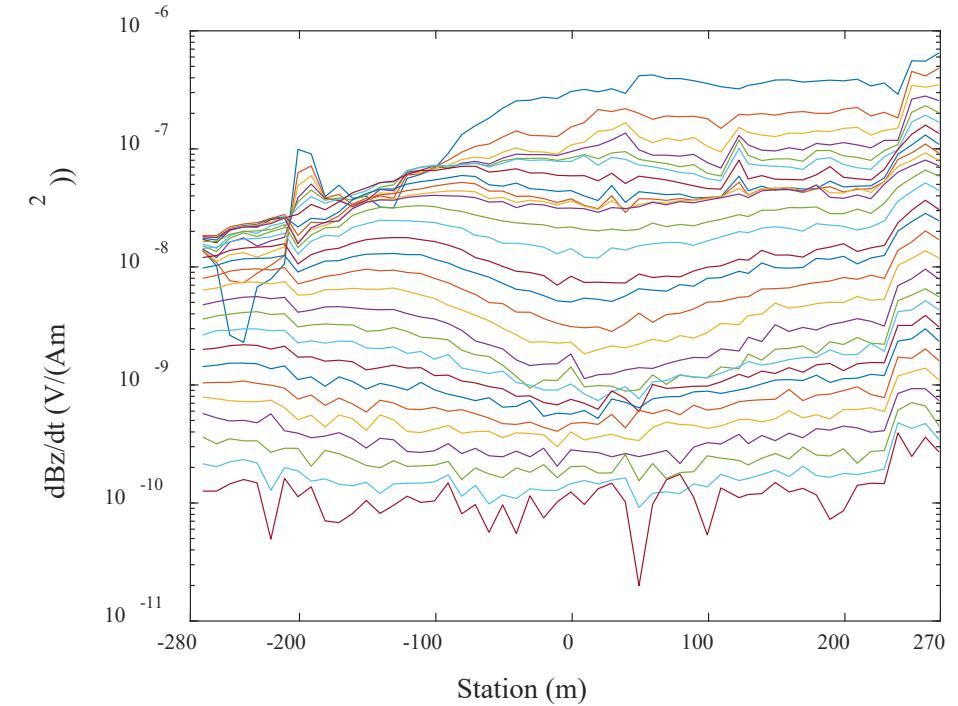
GeoGoku

■ 瞬变电磁

接地长导线源实测数据反演



测点与源相对位置，红色表示源，黑色点表示接收点

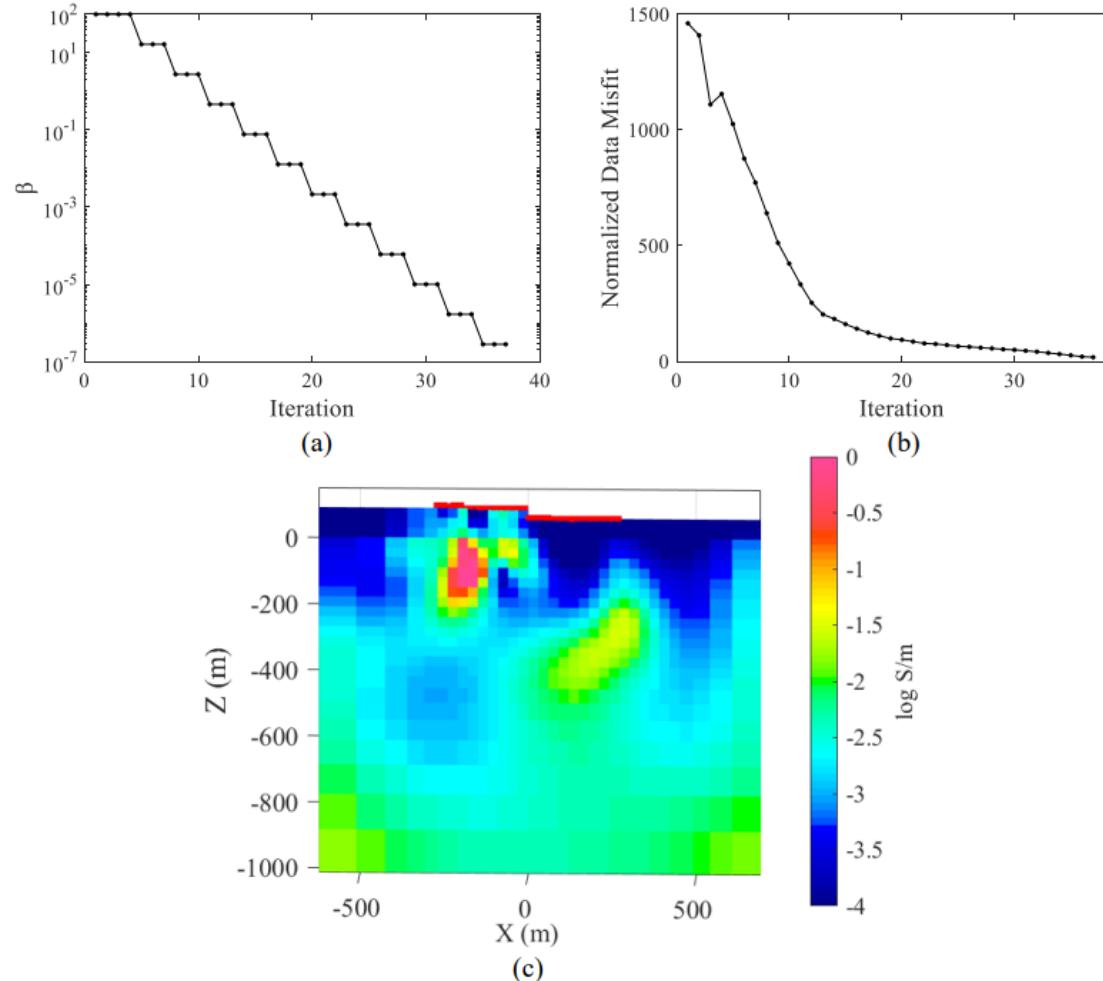


100号测线所有归一化观测数据

5. 电法应用

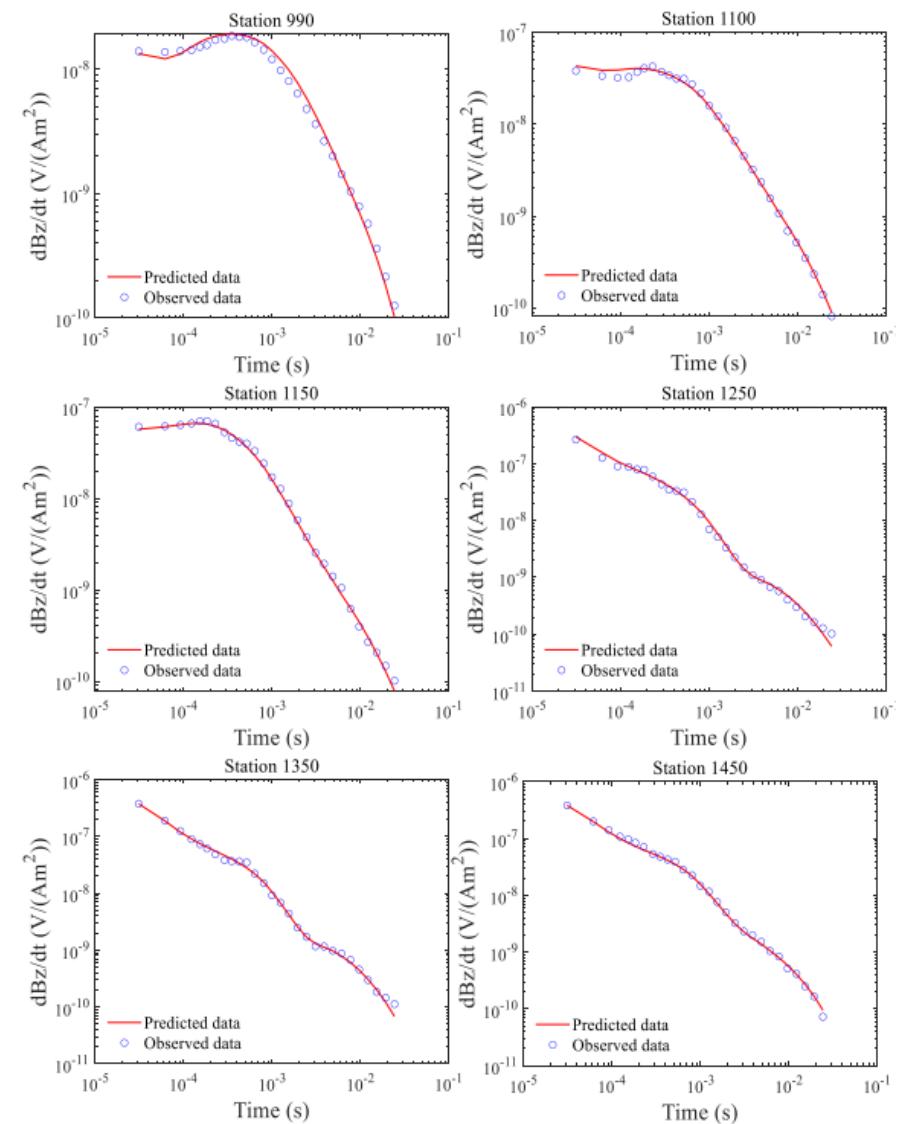
GeoGoku

■ 瞬变电磁



(a) 正则化因子变化曲线; (b) 归一化的数据RMS;
(c) $Y=0$ 处三维反演结果电导率切片, 红色的点代表接收测点

接地长导线源实测数据反演

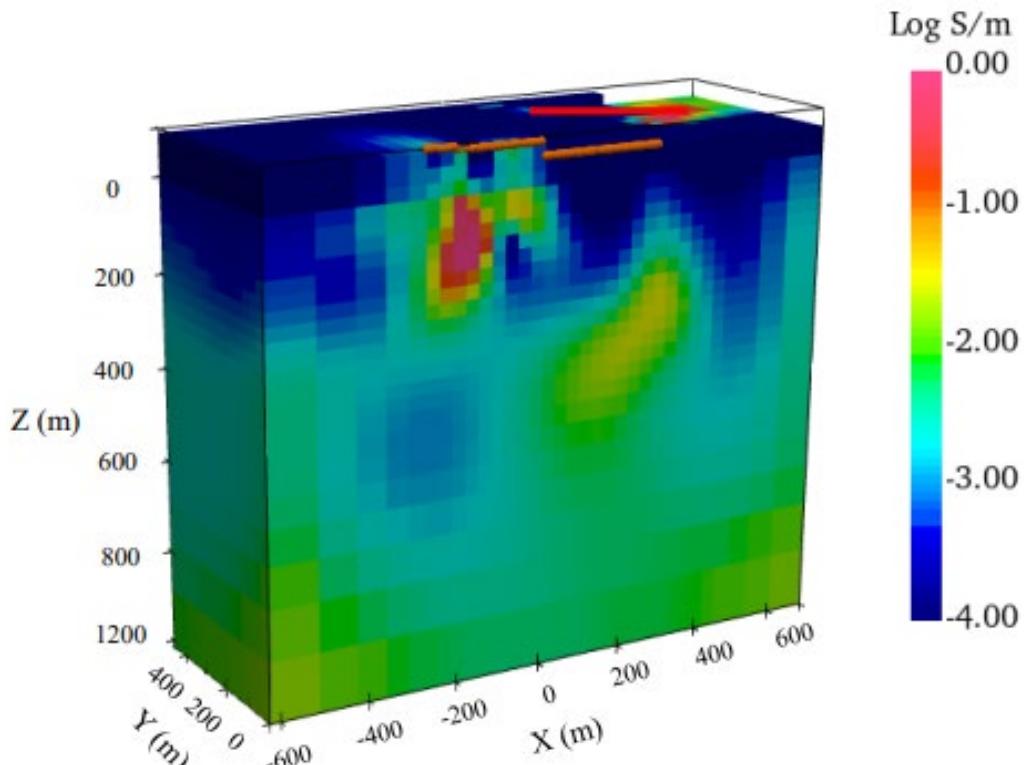


“热启动” 反演共经历37次迭代, 数据拟合。

5. 电法应用

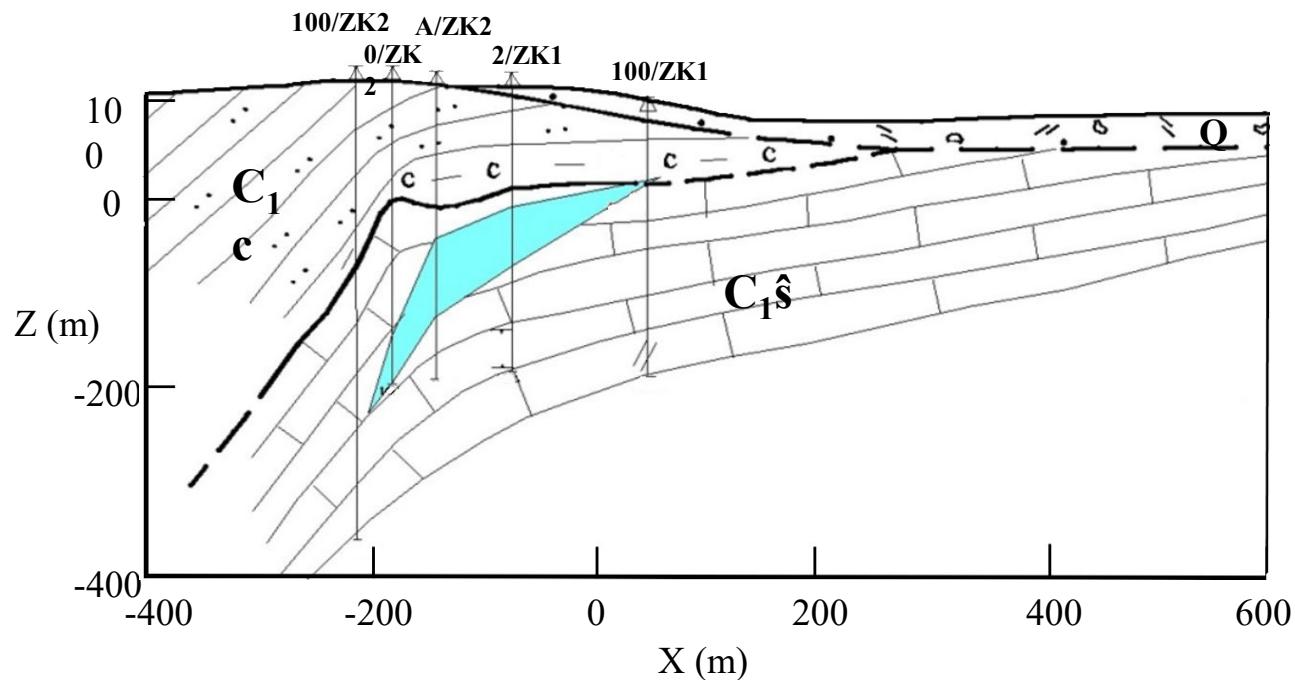
GeoGoku

■ 瞬变电磁 接地长导线源实测数据反演

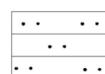


高导矿体位置：

X方向-200 m至0 m; Z方向0 m至-200 m。



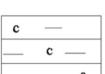
Q - 第四系：粉砂质粘土； C_1c - 下石炭统测水组：粉砂岩；
 C_1s - 下石炭统石磴子组：纹层灰岩



风化粉砂岩

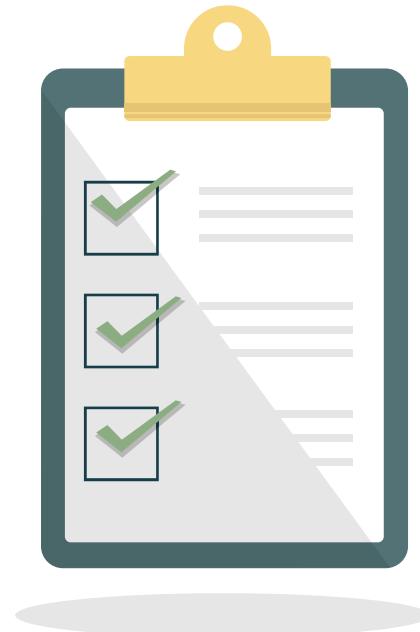


灰岩



风化炭质泥岩

- 解释的原则
- 重磁在地学中的应用



- 识别断裂构造标志
- 磁法为什么可以识别沉积盆地基底





课程结束

陈涛

图片来自沈金松