運用淺地表地球物理探勘技術之注意事項

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從一則專業笑話談起

有一天，某個大學地球科學系決定要增聘一個助理教授，於是登報公開徵求適合人選。在經過一番激烈的篩選淘汰後，評選委員們決定邀請一位地球化學博士、一位地質博士、和一位地球物理博士前來面試。

首先評審委員面試了地球化學博士，在一番熱切的閒談後，地球化學博士開口問了:"所以，你們有那些問題想問我呢?"。委員們說:"是的，喔對了，可否請你告訴我2+2是多少呢?"地球化學博士回答:"這還要取決於量測儀器的校正程度與誤差，但我會說 2+2=4.0000+/-0.00000001"。

接下來評審委員面試的是地質博士，在閒聊後，評審委員們也問了同樣的問題" 2+2是多少?"。地質學家回答:"我會說應該答案是介於3跟5之間啦~"

最後評審委員面試的是地球物理博士，同樣的在一陣閒聊後，委員們問到:"可不可以請你告訴我們2+2等於多少?"只見地球物理博士上身前傾橫跨過桌子，小聲地回答說："你們要它等於多少?"

省思:

有些地球物理探測，因為探測深度深達數十公里乃至數百公里，因此難以被實際驗證其正確性與準確性。但，淺地表地球物理(near surface geophysics)技術，幾乎是立即或是稍後會被鑽井或開挖驗證。如何提升淺地表地球物理探測的分析，從”你想要什麼”，到”大約在……與……..之間”，再提升到”我會說是xxxxxx +/-0.0000000x”，需要對於地球物理技術施測的計畫、過程、訊號處理、反演算、解釋分析等工作上進行嚴謹且小心的品質控制QC/品質保障QA程序，方能提升解釋的正確性與準確性。

淺地表地球物理分析解釋出錯原因歸納

- 刻意騙局 (Blatant Scams)
- 科學誤導 (misguided science)
- 過度解釋 (over-selling) (Greg Hodges, Furgo Airbone Survey, Canada)
- 儀器問題 (Instrument issues)
- 雜訊汙染 (Noise contaminations)
- 不適切的量測方式(Inadequate measuring procedures)
- 不恰當的資料處理 (Improper data processing)
- 錯誤解釋 (Misinterpretation)
- 數學/物理錯誤 (Mathematical/Physical error)
- 不恰當的反演假象 (Inadequate inversions)

刻意騙局（Blatant Scams）

某些公司或私人宣稱其研發的地球物理儀器如何如何神奇，可以精準直接知道地下物體的濃度與體積。但是談到這些儀器的物理原理以及精確度，卻都稱正在申請專利中，也無法提出在專業期刊論文發表相關原理與量測驗證的佐證。因為是專業機密，所以連儀器都也不便讓人仔細檢視，必須要經過內部訓練的專業人員方可接觸操作。

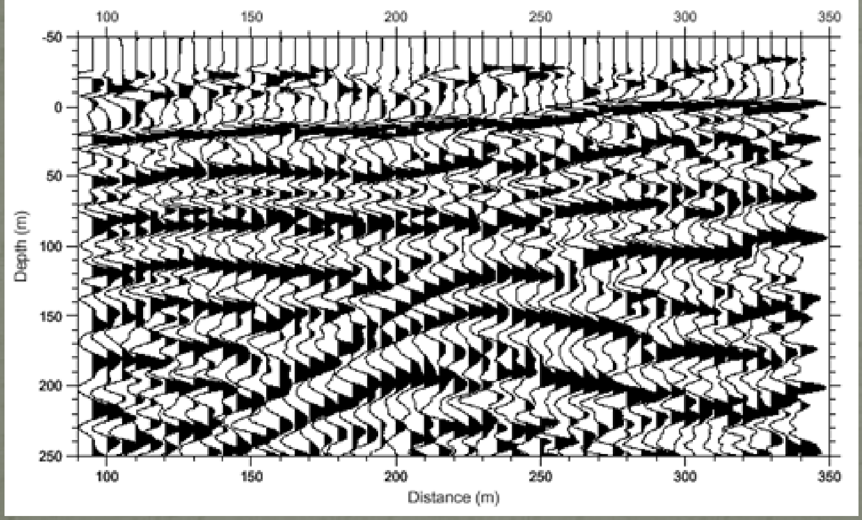
1979年有一位名叫波拿所立的義大利人通過中間人的介紹，接觸了法國石油公司Elf Aquitaine，宣稱發明了一套通過空中重力波偵測，可以探測油氣的設備。Elf的經理於是把波拿所立的設備(包在厚厚的遮蔽簾幕下)帶上飛機，飛越已知的油氣田。而該儀器在正確的時刻與地點響起了偵測到物體的聲音，並且在螢幕上顯示不明的條紋影像。(不幸的是該測試竟然是在沒有任何該公司科學家的參與，也無法仔細檢視儀器的情況下進行的。)。Elf很快的跟波拿所立簽了一個8千萬美元的初期合約，而且竟然還承諾不需知道任何儀器的原理。更神奇的是，在多次重複測試發現無法正確顯示油氣位置後，波拿所立解釋是因為儀器過於靈敏，Elf還又跟他再簽了一個1 億3千萬美元的後續授權合約。但是最後，Elf開始產生了懷疑，於是要求波拿所立讓他們檢視儀器。波拿所立答應讓Elf技術人員很短的檢視他的儀器外觀並拍照。結果該公司的技術人員檢視後，懷疑他們看到的僅是一個很簡單的訊號產生器而已。最後Elf公司乾脆請來著名的物理學家哈露維茲，哈露維茲要求波拿所立重新展示它儀器的部分功能，也就是穿牆偵測能力，哈露維茲將一隻尺放在牆的一側，結果波拿所立的儀器在偵測後，準確的呈現了一個直方體的形狀---只是哈露維茲在放尺的時候，故意把尺凹折了90度..............結果是騙局被拆穿，波拿所立逃到外國，但Elf也因為草率投資而慘痛損失1億5千萬美金。

科學誤導 (misguided science)

用的是成熟且經過科學印證的物理原理儀器，但是使用者或者是不了解技術的物理原理，或是刻意誇大它的用途與功效。最常見的例子就是像透地雷達，使用的是電磁波，也有堅實的理論基礎，但如果有人告訴你他可以用透地雷達看到地下數百公尺深的構造，便是科學誤導，誇大了透地雷達的功效。因為理論上透地雷達功率衰減的快，一般只能穿透到地下10-20公尺深度，在地下水位面很淺的台灣，因為電磁波在飽和含水地層中衰減的快，速度也慢，因此往往只有5-7公尺的穿透深度。所以要用透地雷達看到10-20公尺以上深度，以現在技術而言是做不太到的(除非是在北極冰層或地下水很深的沙漠)。

過度解釋（over-selling）

亦即過度誇大儀器的訊號解釋與解析能力。例如在波速斷面反演算的過程中，由於透地雷達波、地震波都是遵循波動力學，因此就訊號處理的解析度來說，要分離兩個波所代表的反射面，需要波峰與波峰的間距大於1/2波長，也就是說訊號處理技術理論上最小能解析的地層厚度，要在雷達波或地震波長的1/2以上。有時某些研究的波速斷面反演算，來自於地震或雷達波探測資料，但仔細一算波長就知道該種地球物理技術解析度沒法解析到那麼薄的地層，但是往往還看到解釋者在波速斷面反演算時分成很薄的數層，並計算出在該層中的波速側向變化，其實都是一種過度解釋。



If the data collection / forward model has limited resolution, the solution needs only limited resolution.

(by P. B. Stark in U.C. Berkeley)

儀器問題（Instrument issues）

地球物理儀器會有讀數飄移(Reading shift)或故障現象，可能原因有:

●溫度變化(Temperature variation)

●電路老化(Circuit aging)

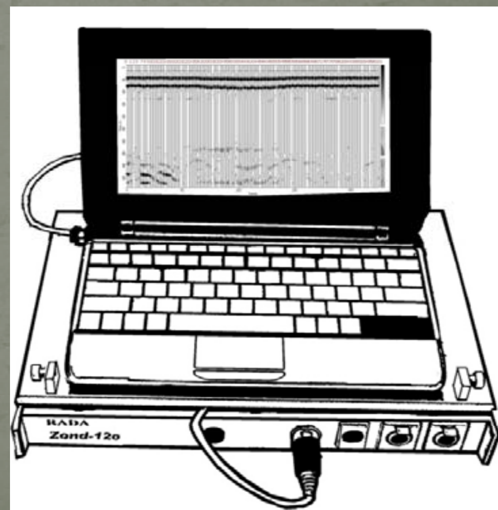
●短路或故障(Short-circuit or malfunction)

●訊號傳輸線故障或接觸不良(broken transmission cables)

●不當操作下的人為故障(Human error)

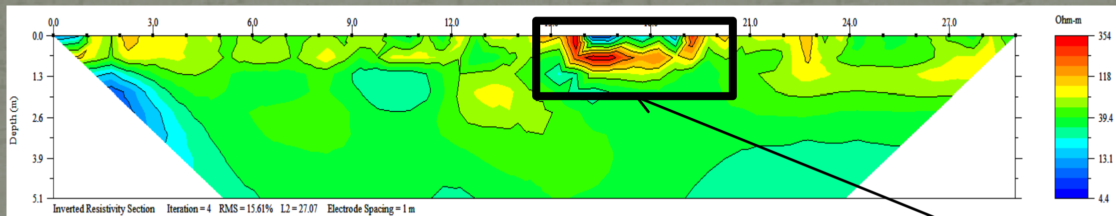
減低及防止儀器問題的作法

- 按操作手冊進行例行實驗室儀器校正程序
- 選擇適當地點建立測試標準場址
- 建立例行標準場址測試與校正作業程序
- 建立實驗室儀器校正與標準場址校正追蹤紀錄
- 建立人員操作與訓練記錄
- 建立各儀器送修、故障、排除與維修紀錄

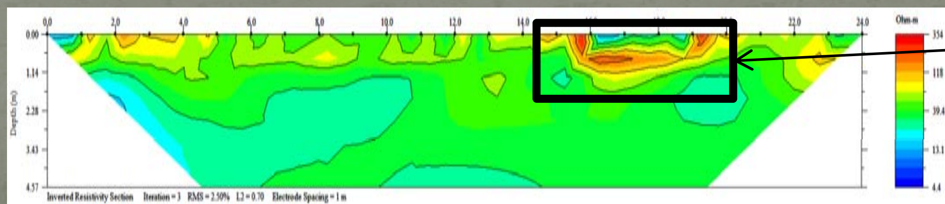


海洋大學校內地電阻儀器測試場

AGI SuperSting R1/IP地電阻影像剖面圖



Lippman 4 point Light hp 地電阻影像剖面圖。



Known structure

雜訊汙染 (Noise contaminations)

地球物理儀器雜訊來自於:

● 自然環境雜訊(潮汐、地磁場、太陽活動、大地電流(含銅、鐵礦區域)............)

● 人為雜訊:

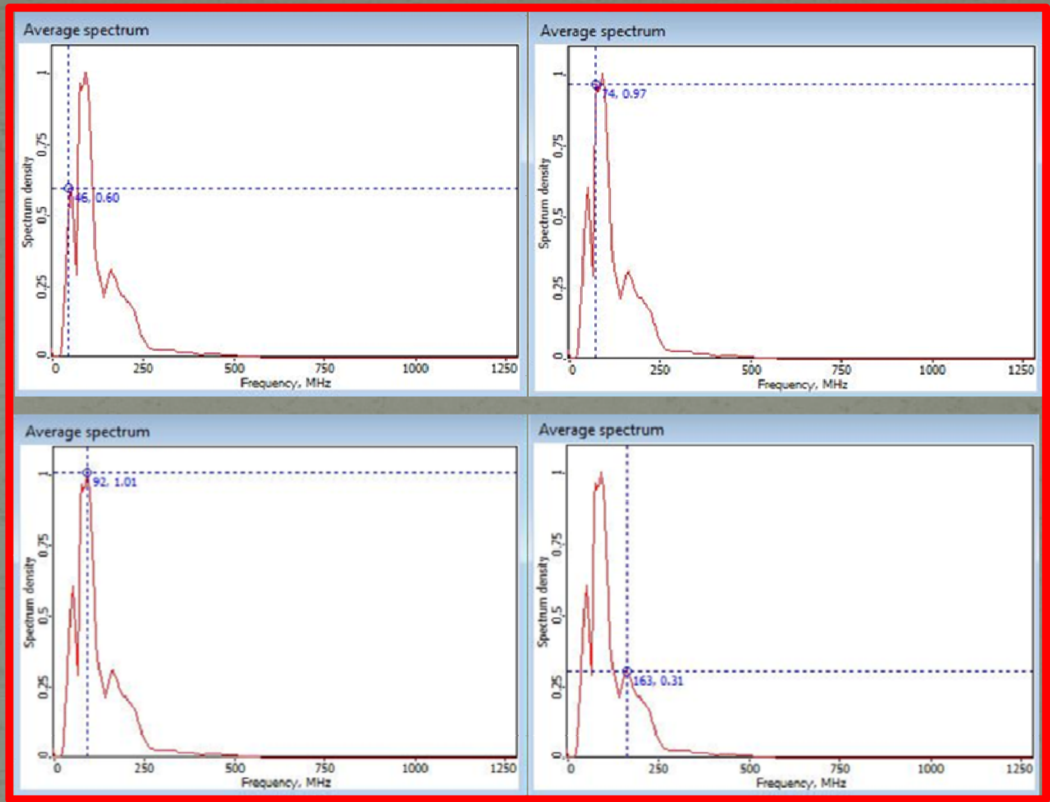
➢ 隨機不固定源(車輛震動、車輛引擎高壓電路、大哥大、無線電通訊...............)

➢ 持續固定源(道路、地下管線、房宅、鐵路、高鐵、水井、高壓電線、工廠高壓裝置與電路、廣播電台、氣象或軍事雷達.................)

➢ 隨機固定源(工廠機台低頻震動、軍民用或漁業通訊電台、抽水馬達...........)

案例:基隆和平島透地雷達探測之資料頻譜分析

西北-東南向測線頻譜峰值分佈位置



西南-東北向測線頻譜峰值分佈位置

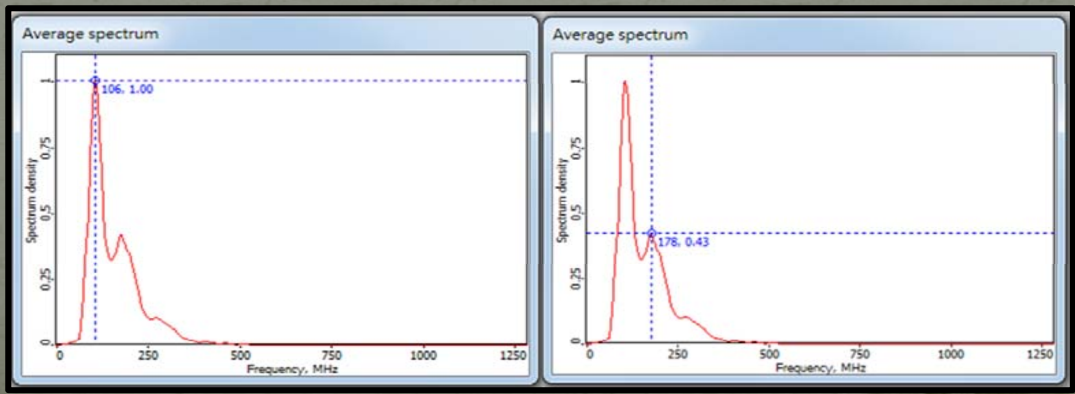


表 6、各類業務主要使用電磁波頻段

項目	用途	使用單位	使用狀況	主要使用頻段
1	公眾通信中繼網路	電信事業	1.局間中繼電路	150,200,450,900（MHz）
2	公眾無線電叫人業務	電信事業	無線電叫人系統	160,280（MHz）
3	公眾船舶通信業務	電信事業	船岸通信系統	4,6,8,12,16,22,25,160（MHz）
4	有線電話無線主副機	開放供民眾使用	用戶自備設備	1.6,46,49,1900（MHz）
5	船舶通信	客、貨、漁船、農委會	水上行動通信	2-26,156-174,450（MHz）
6	船舶導航	港務局	水上行動通信	140,150（MHz）
7	氣象測報	氣象局	1.一點對多點通信 2.定點通信 3.氣象雷達	5,6,7,8,9,13,40,400（MHz） 1.5,2（GHz）
8	警察及維持治安	警政、司法機關、保全公司	1.行動通信 2.定點通信 3.無線中繼系統	4,5,140,150,160,170,410,480,490,500,900（MHz）
9	無線電遙控、監視、定位、測震	研究機構、水利	1.一點對多點通信 2.定點通信	35,40,50,210,410（MHz）

和平島透地雷達雜訊可能的來源

不適切的量測方式(Inadequate measuring procedures)

■錯誤的儀器選擇(發射能量、天線形式、接收線圈形式、電極型式、儀器形式..............)

■錯誤的施測設計(電極或施測間距、施測陣列方式、儀器通入地下能量大小、抗雜訊措施........)

■錯誤的測線幾何與方位(待測目標物位於測線上之相對位置、方位......)

■錯誤的施測時間及季節

例子說明:透地雷達施測前，天線頻率的選擇

有關天線頻率之選擇，一般而言高頻訊號（高頻天線）衰減較快、探測深度淺，解析度較高；低頻訊號（低頻天線）衰減較慢、並可傳遞至地層較深處但解析度較低。在選擇使用之天線頻率時的最優先考慮為穿透深度以及解析度，但也需考量空間解析能力以及雷達訊號經不均勻物質反射程度的散射限制(Clutter)。利用以下經驗公式可輔助天線頻率之選擇：

（1）空間解析度： $f_c^R > \frac{75}{\Delta z\sqrt{K}}$ （MHz）

（2）散射限制：$f_c^C < \frac{30}{\Delta L\sqrt{K}}$ （MHz）

（3）探測深度：$f_c^D < \frac{1200\sqrt{K-1}}{D}$（MHz）

（4）選擇適當天線頻率：$f_c^R < f_c < \min\left(f_c^D, f_c^C\right)$

（Davis & Annan,1989）

其中f_c^R、f_c^C、f_c^D、f_c為天線中心頻率（MHz），Δz、ΔL 為欲解析的空間寬度大小（m），D 為欲達探測之深度（m），K 為介電常數。

例子說明:透地雷達施測前，天線頻率的選擇

不同天線頻率對介電常數之穿透深度（取自ASTM D6432-11）

K / f	1	5	10	15	25	80
25 MHz	12.0	5.36	3.8	3.08	2.4	1.36
50 MHz	6.0	2.68	1.88	1.56	1.2	0.68
80 MHz	3.76	1.68	1.20	0.96	0.76	0.40
100 MHz	3.0	1.36	0.96	0.76	0.6	0.32
200 MHz	1.52	0.68	0.48	0.40	0.32	0.16
300 MHz	1.0	0.44	0.32	0.24	0.20	0.12
500 MHz	0.6	0.28	0.20	0.16	0.12	0.08
900 MHz	0.32	0.16	0.12	0.08	0.08	0.04

不恰當的資料處理（Improper data processing）

■不恰當的濾波方式、標準與頻段

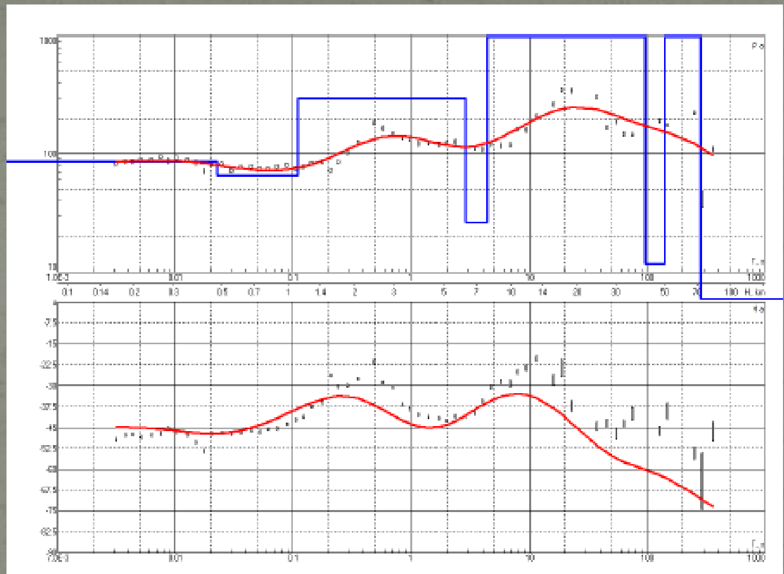
■不恰當的雜訊門檻

■未進行重覆量測(Repeated or static measurements)以及互換量測(Reciprocal measurements)

■採用錯誤的後處理物理假設與模型

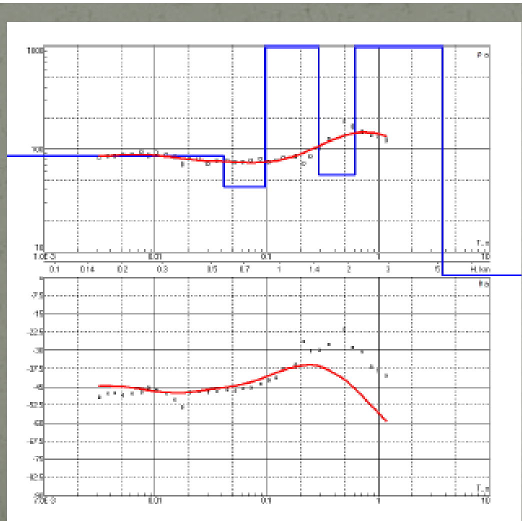
C地的大地電磁觀測資料

全資料反演算



RMS: 18.8%

濾除低頻誤差大
的資料後反演算



RMS: 8.67%

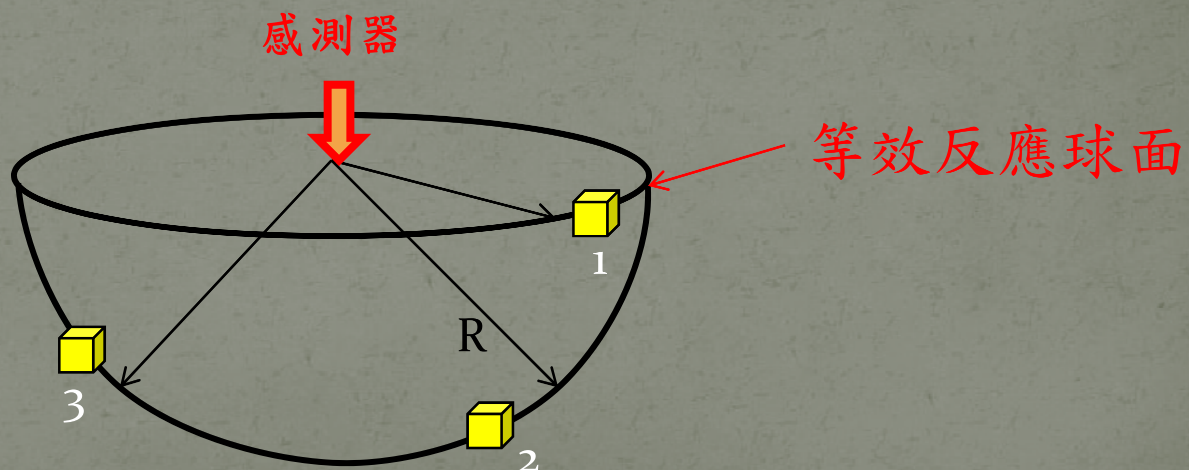
數學/物理錯誤 (Mathematical/Physical error)

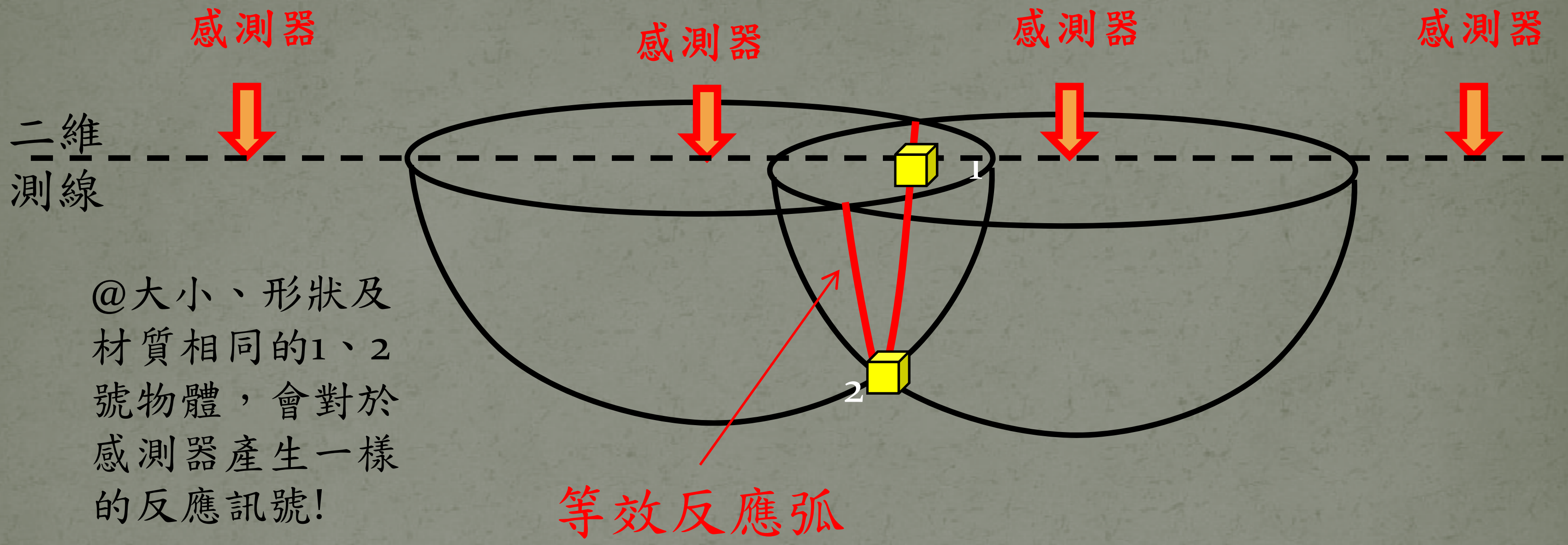
■以一維模型與反演算解釋含有大量二維訊號之施測資料

■以二維模型與反演算解釋含有大量三維訊號之施測資料

■以密度不足的量測資料，嘗試進行二維或三維空間的反演算

@大小、形狀及材質相同的1、2、3號物體，會對於感測器產生一樣的反應訊號!

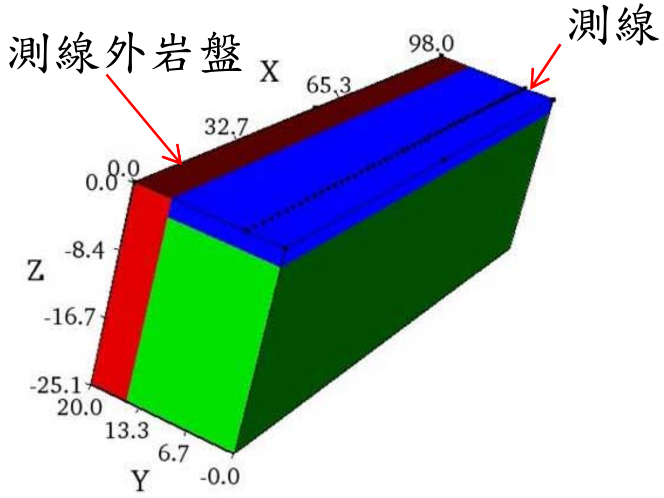




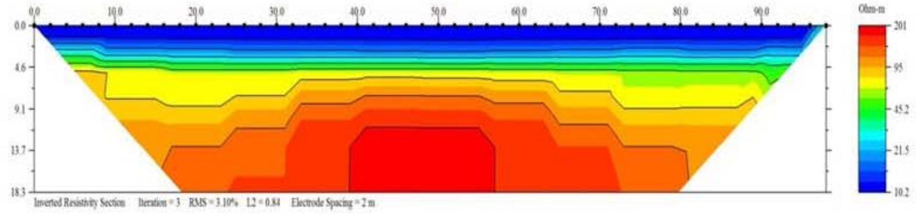
@大小、形狀及材質相同的1、2號物體，會對於感測器產生一樣的反應訊號!

➢在一維或二維測線外的物體，卻對一維/二維施測的結果產生訊號的貢獻，結果出現在一維/二維測線的垂直剖面解釋中，但實際的位置卻偏離測線，稱之為陰影效應(Shadow effect)。這個物理現象幾乎出現於所有的淺地表地球物理施測中，須謹慎小心以對!!!!

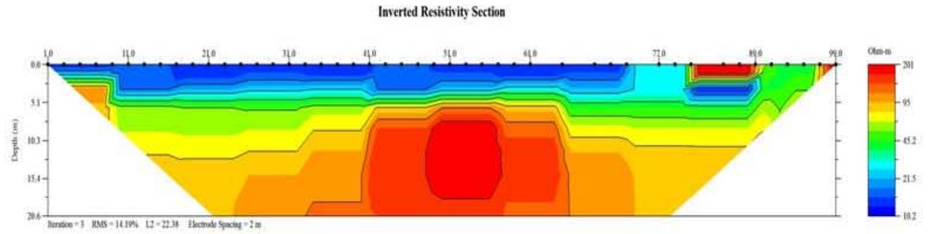
Shadow effect: 地電阻施測實例



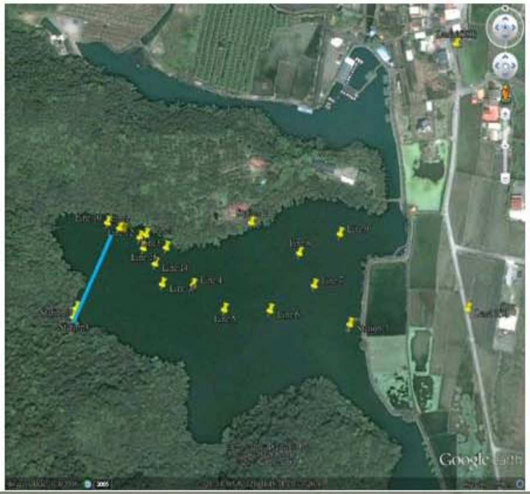
Forward model 正演模擬結果



測線 Line 10



實際測線反演算結果



實際測線幾何位置

不恰當的反演算（Inadequate inversions）

不恰當的反演算常常讓產生的資料帶有較大的誤差，甚至讓產生的資料帶有假象(artifacts)。不恰當的反演算設定包括:

■不恰當的邊界條件(Neumann(constant flux)邊界、Dirichlet (constant potential) 邊界、mixed邊界...........)

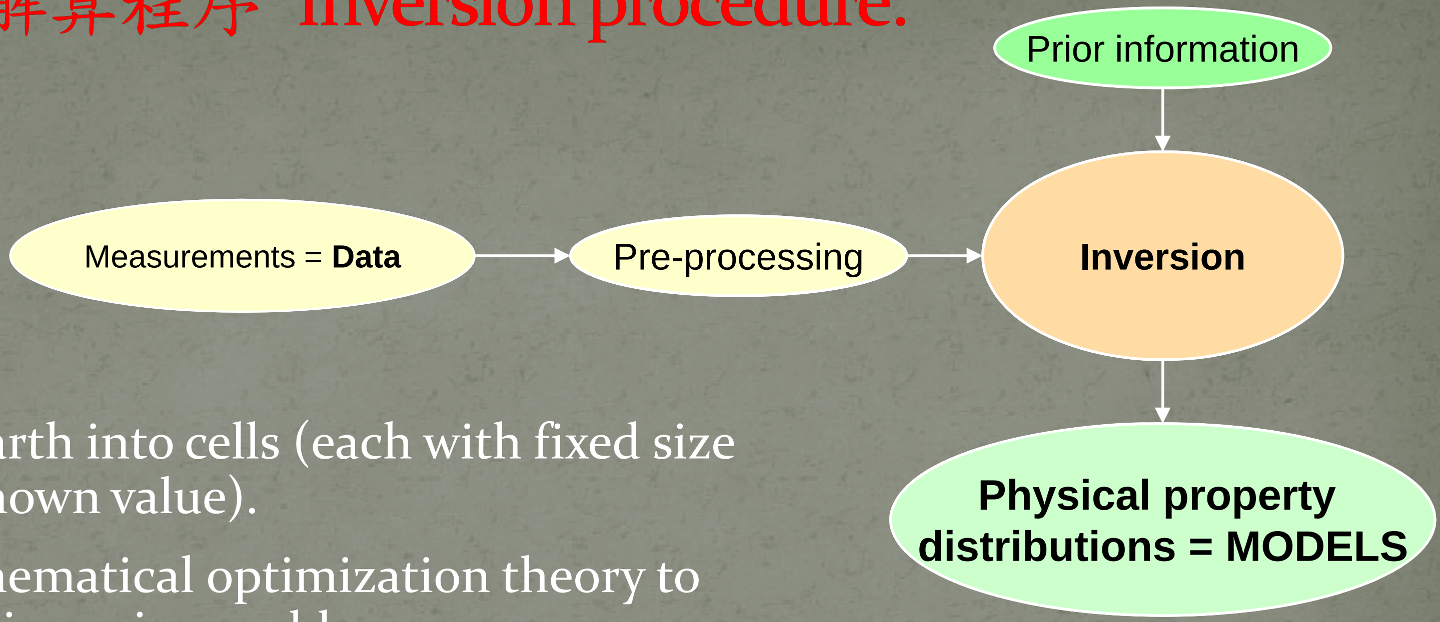
■不恰當的初始條件/模型

■不恰當的網格分割

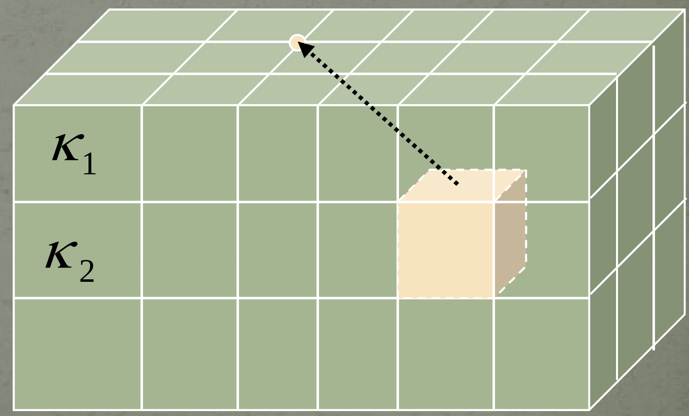
■不恰當的反演參數設定(平滑參數、解析參數、反演終止條件、反演與正演迴圈數目、穩定阻尼參數..............)

■不恰當的演算法選用(最小平方法、平滑模型、穩健法、蒙地卡羅法、基因演算法、最大相似法..........)

反演算解算程序 Inversion procedure:

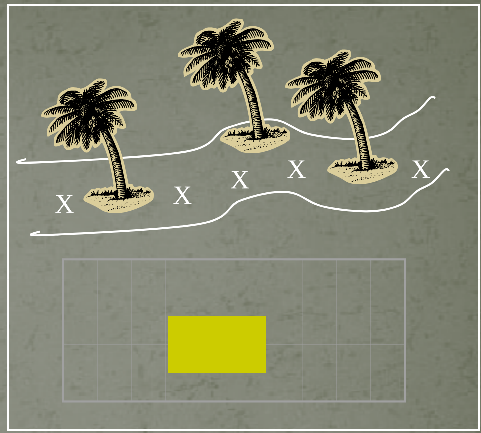


- Divide Earth into cells (each with fixed size and unknown value).
- Use mathematical optimization theory to solve the inversion problem
- Inversion: find values for cells such that data are explained.
- Difficulties:
  - Solution is non-unique.
  - Computationally demanding.



3D, and ~ 10^5 cells

反演(算)問題= 由量測資料推論物理系統架構的作法



- *資料永遠帶有誤差(data uncertainties)*
- *物理的理論須要假設及簡化*
- *幾乎有無限組的模型可以符合量測的資料結果(non-uniqueness)*
- *物理的理論有可能是不準確的(theoretical uncertainties)*
- *正演的模型可能是高度非線性的(增加計算時間及難度)*
- *我們永遠僅會有有限的量測資料數目*

進一步的問題還有:

- 我們的資料有多準確?
- 我們如何解正演的問題?
- 對於模型空間我們有哪些先驗訊息(a priori information)?

例子說明:地電阻反演算的演算法影響

地電阻正演算公式:電流能量守恆

$$\frac{\partial}{\partial x}\left(\sigma\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial z}\left(\sigma\frac{\partial V}{\partial z}\right)-k^2\sigma V=-I\cdot\delta(x)\cdot\delta(z)$$

where V is the scalar electrical potential in the Fourier transform domain, and I is the electric current source. k is the wavenumber in the transform domain. σ is electrical conductivity as a function of (x, z).

例子說明:地電阻反演算的演算法影響

反演算方法(1): 阻尼最小平方法(Damped Least Square method, DLS)

目標式:

$$\mathbf{S}(\mathbf{m}) = (\mathbf{d}_{obs} - g(\mathbf{m}))^{T}\,\mathbf{W}_{d}\,(\mathbf{d}_{obs} - g(\mathbf{m}))$$

d_{obs} is the observed data, g(m) is the calculated data. W_d is a data weighting matrix.

矩陣解:

$$\left(\mathbf{J}^{\mathrm{T}}\mathbf{W}_{\mathrm{d}}\mathbf{J} + \lambda\mathbf{I}\right)\Delta\mathbf{m} = \mathbf{J}^{\mathrm{T}}\mathbf{W}_{\mathrm{d}} \cdot \left(\mathbf{d}_{\mathrm{obs}} - \mathrm{g}(\mathbf{m})\right),$$

Where $\mathbf{J} = \frac{\partial \mathrm{g}(\mathbf{m})}{\partial \mathbf{m}}$ **is Jacobian (sensitivity) matrix. λ is a damping factor whose effect is to ensure that the inversion resolves primary features at the early iterations.**

例子說明:地電阻反演算的演算法影響

反演算方法(2): 平滑模型反演法(Smooth Model Inversion, SMI)

目標式:

$$\mathbf{S}(\mathbf{m}) = (\mathbf{d}_{obs} - g(\mathbf{m}))^T \mathbf{W}_d (\mathbf{d}_{obs} - g(\mathbf{m})) + \alpha \cdot \mathbf{m}^T \mathbf{R}\mathbf{m}$$

α is a Lagrange multiplier and a stabilizing factor. It determines the amount of model roughness imposed on the model during the inversion. R is a roughness operator.

例子說明:地電阻反演算的演算法影響

反演算方法(3): 穩健反演法(Robust Inversion, RI)

目標式: $$S(m) = |d_{obs} - g(m)|$$

Both least squares inversion and smooth model inversion are based on a L2-norm criterion. Robust inversion is based on the assumption of exponential distribution of data errors and minimizes an L1-norm of combined data misfit and model stabilizing functional.

例子說明:地電阻反演算的演算法影響

反演算方法選用:

阻尼最小平方法(Damped Least Square method, DLS)
資料品質較好時一般選用，易受帶有較高的誤差的單筆資料影響
較小的L-2norm
較好的解析度，呈現較明顯的電阻率空間變化

平滑模型反演法(Smooth Model Inversion, SMI)
資料雜訊高時選用
較大的L2-norm，解答穩定
較差的解析度，但有較好的構造延伸呈現

穩健反演法(Robust Inversion, RI)
欲呈現明顯(Sharp)變化的邊界時採用
影像易有鋸齒假象或明顯邊界假象
資料雜訊高時可以選用，較不易帶有較高的誤差的單筆資料影響

錯誤解釋 (Misinterpretation)

■對施測的方法所具有的解析度誤判

■對待測目標物或背景的物理性質的誤判

■對於會影響所採用的地球物理方法參數的土壤/岩石物理原理缺乏了解

■對於可能的現地干擾來源缺乏認知

適當的淺地表地球物理施測作法

■資料收集
■定義待測目標與待測區域
■選擇施測地球物理方法
■評估其他選項(解析度要求、儀器敏感度、地區可能自然或人為雜訊、QA/QC要求、經費............等)
■選擇施測參數、解析度等儀器設定
■現地施測(重複施測、互換施測)
■檢視現地施測參數(決定是否調整或重測)
■資料處理與雜訊濾除
■反演算(選擇適當的反演算參數、演算法等)
■解釋與建議

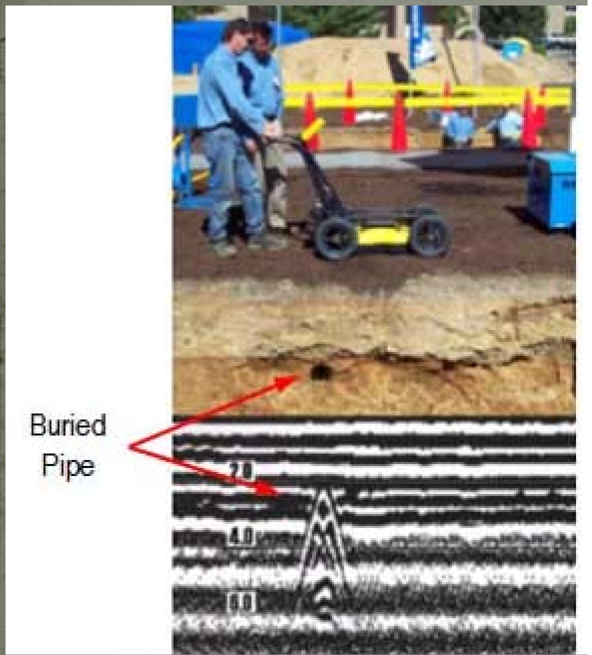
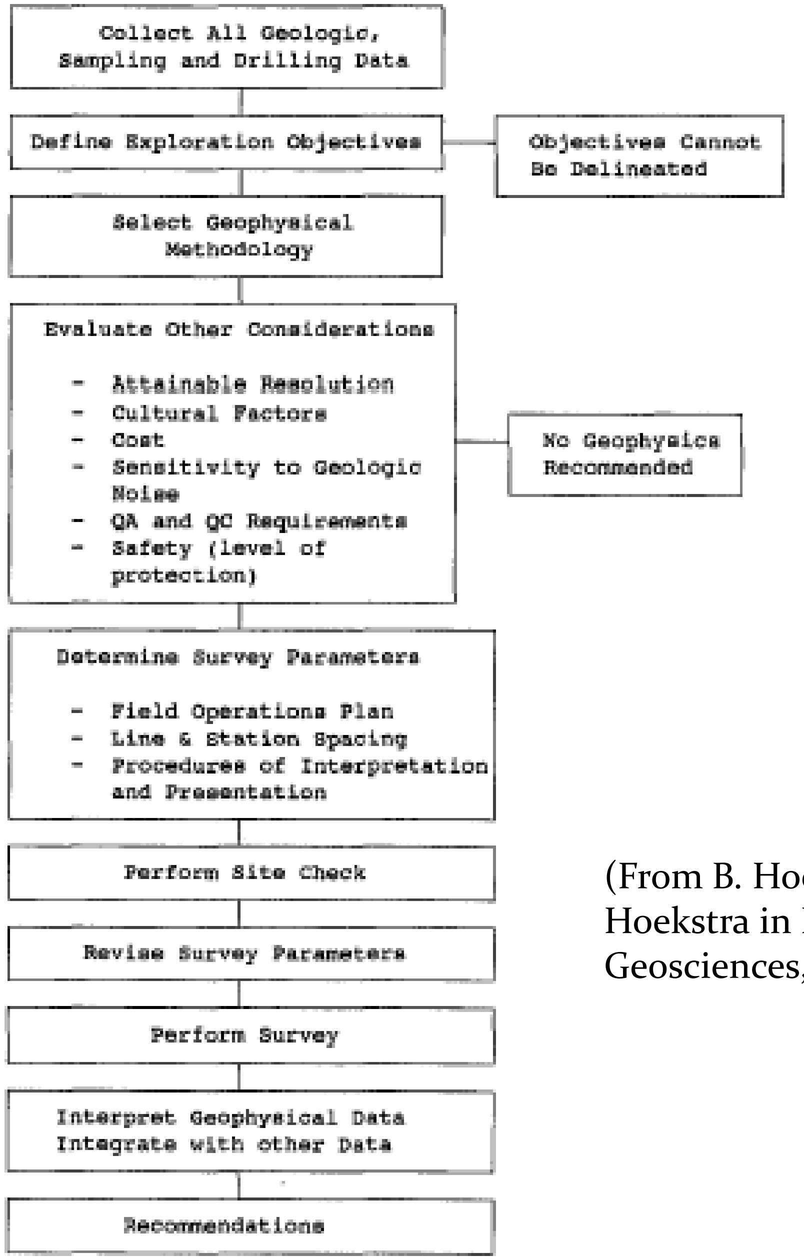


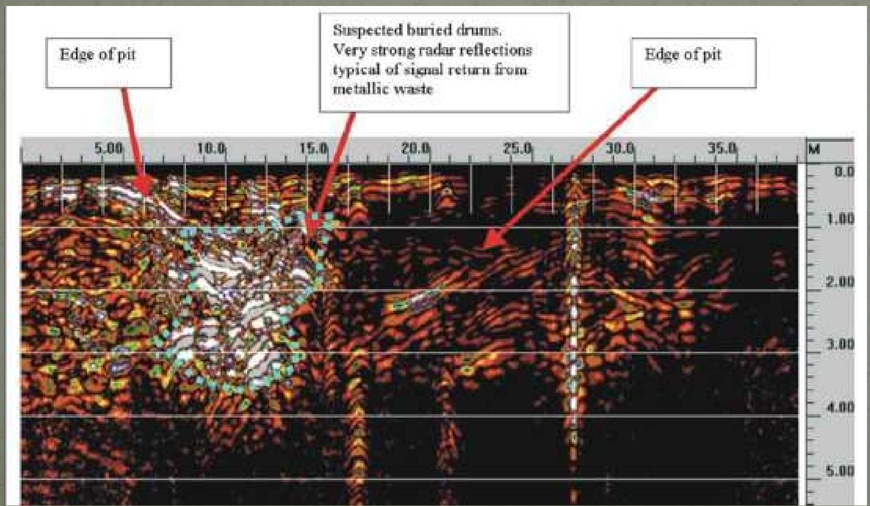
Figure 1
Planning a Successful Geophysical Survey

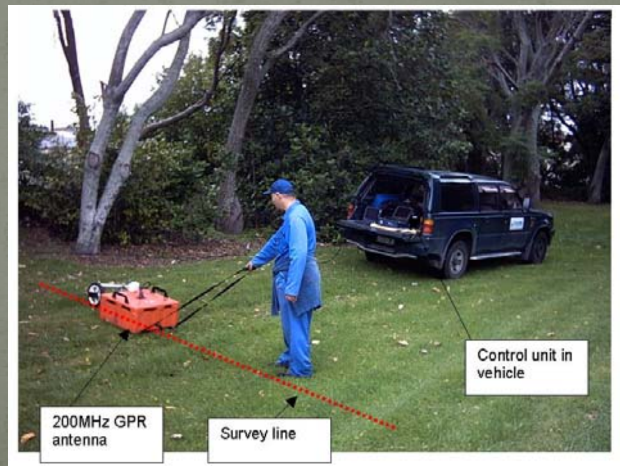


(From B. Hoekstra and P. Hoekstra in Blackhawk Geosciences, Inc.)

但是，

除了在儀器、處理程序上認知到可能的影響，對於地球物理技術施測的計畫、過程、訊號處理、反演算、解釋分析等工作上進行嚴謹且小心的品質控制QC/品質保障QA程序，改進提升淺地表地球物理探測的分析，從”你想要什麼”，到”大約在……與……..之間”，再提升到”我會說是xxxxxx +/-0.0000000x”之外。更重要的，其實是人員的專業教育與訓練………………..





地球物理專業人員施測教育與訓練

OVERVIEW OF PROFESSIONAL GEOPHYSICIST EXAMINATION OUTLINE

Content Area/*Subarea*	**Content Area Description**	**Percent Weight**
I. Preliminary Geophysical Project Design *Ia. Feasibility Study* 可行性研究 *Ib. Project Design* 施測規劃設計	This area assesses the candidate's ability to design a geophysical project that is consistent with the client's objectives.	43 *(25)* *(18)*
施測準備與施作 II. Fieldwork Preparation and Data Collection	This area assesses the candidate's ability to implement a geophysical design and/or workplan in the field.	14
III. Data Analysis and Interpretation 資料分析與解釋	This area assesses the candidate's ability to analyze, interpret, and communicate geophysical data and results.	34
IV. Safety 安全規劃與注意	This area assesses the candidate's ability to identify hazards and safely manage geophysical work and personnel.	9
Total		**100**

Note. The values for Subareas Ia and Ib are breakdown values of Content Area I and are not added to the total percentage.

From: Board for Professional Engineers , Land Surveyors, and Geologists, State of California

I. Preliminary Geophysical Project Design (43%) - This area assesses the candidate's ability to design a geophysical project that is consistent with the client's objectives.

Task Statements		Knowledge Statements	
Subarea Ia. Feasibility Study			
T3	Identify public safety concerns and relevant local, state, and federal regulations and apply to the geophysical project. 收集並了解公共安全議題與法規的規範	K1	Knowledge of the types of projects (e.g., geohazard, geologic, geotechnical, environmental) that would benefit from geophysical investigations.
		K5	Knowledge of local, state, and federal regulations related to geophysical projects.
		K6	Knowledge of public safety issues that should be addressed when planning geophysical work.
T4	Develop a conceptual geophysical model for the geophysical project. 為地球物理施測計畫先建構一基礎概念模型	K2	Knowledge of geophysical investigation methods and their applications.
		K3	Knowledge of methods for obtaining existing geophysical, geological, and other relevant data.
		K7	Knowledge of physical characteristics of the site that impact expected geophysical findings.
		K8	Knowledge of methods used to calculate geophysical estimates.
		K9	Knowledge of conceptual geophysical model types and their applications.
		K14	Knowledge of physical characteristics that differentiate the target of a geophysical investigation from its surroundings.
T5	Identify geophysical investigation methods, including measurement types and equipment in accordance with site conditions, geology, and client objectives. 選擇恰當的適合現地狀況之地物儀器	K2	Knowledge of geophysical investigation methods and their applications.
		K3	Knowledge of methods for obtaining existing geophysical, geological, and other relevant data.
		K4	Knowledge of methods for reviewing existing geological, and other relevant data in preparation for geophysical projects.
		K9	Knowledge of conceptual geophysical model types and their applications.
		K10	Knowledge of types of measurement instruments and their applications for geophysical project design.
		K11	Knowledge of geophysical equipment limitations as related to project design.
		K13	Knowledge of interference sources that affect geophysical project design.
		K14	Knowledge of physical characteristics that differentiate the target of a geophysical investigation from its surroundings.
		K16	Knowledge of the limitations of geophysical survey design.

Subarea Ib. Project Design			
T6	Design a geophysical project based on site conditions, geology, regulations, and client objectives. 規劃適當的現地施測設計	K2	Knowledge of geophysical investigation methods and their applications.
		K4	Knowledge of methods for reviewing existing geological, and other relevant data in preparation for geophysical projects.
		K5	Knowledge of local, state, and federal regulations related to geophysical projects.
		K6	Knowledge of public safety issues that should be addressed when planning geophysical work.
		K7	Knowledge of physical characteristics of the site that impact expected geophysical findings.
		K11	Knowledge of geophysical equipment limitations as related to project design.
		K12	Knowledge of the components of a geophysical investigation design.
		K13	Knowledge of interference sources that affect geophysical project design.
		K14	Knowledge of physical characteristics that differentiate the target of a geophysical investigation from its surroundings.
		K16	Knowledge of the limitations of geophysical survey design.
T7	Develop quality assurance/quality control (QA/QC) plan(s)/procedures to ensure the validity of data gathered during the geophysical project. 規劃適當的QA/QC	K2	Knowledge of geophysical investigation methods and their applications.
		K5	Knowledge of local, state, and federal regulations related to geophysical projects.
		K8	Knowledge of methods used to calculate geophysical estimates.
		K10	Knowledge of types of measurement instruments and their applications for geophysical project design.
		K13	Knowledge of interference sources that affect geophysical project design.
		K14	Knowledge of physical characteristics that differentiate the target of a geophysical investigation from its surroundings.
		K15	Knowledge of quality assurance/quality control (QA/QC) requirements/procedures related to geophysical data.

Subarea Ib. Project Design			
T8	Identify the limitations of the geophysical project using available data. 了解採用的地物儀器與方法之可能限制	K5 K6 K7 K10 K11 K13 K14 K15 K16	Knowledge of local, state, and federal regulations related to geophysical projects. Knowledge of public safety issues that should be addressed when planning geophysical work. Knowledge of physical characteristics of the site that impact expected geophysical findings. Knowledge of types of measurement instruments and their applications for geophysical project design. Knowledge of geophysical equipment limitations as related to project design. Knowledge of interference sources that affect geophysical project design. Knowledge of physical characteristics that differentiate the target of a geophysical investigation from its surroundings. Knowledge of quality assurance/quality control (QA/QC) requirements/procedures related to geophysical data. Knowledge of the limitations of geophysical survey design.
T9	Prepare workplan(s) in accordance with geophysical project requirements. 規劃適當的現地施測工作流程	K5 K6 K7 K10 K11 K12 K13 K14 K15 K16 K17 K18	Knowledge of local, state, and federal regulations related to geophysical projects. Knowledge of public safety issues that should be addressed when planning geophysical work. Knowledge of physical characteristics of the site that impact expected geophysical findings. Knowledge of types of measurement instruments and their applications for geophysical project design. Knowledge of geophysical equipment limitations as related to project design. Knowledge of the components of a geophysical investigation design. Knowledge of interference sources that affect geophysical project design. Knowledge of physical characteristics that differentiate the target of a geophysical investigation from its surroundings. Knowledge of quality assurance/quality control (QA/QC) requirements/procedures related to geophysical data. Knowledge of the limitations of geophysical survey design. Knowledge of workplan requirements/components for geophysical projects. Knowledge of local, state, and federal workplan requirements.

II. Field work Preparation and Data Collection (14%) - This area assesses the candidate's ability to implement a geophysical design and/or workplan in the field.

Task Statements		Knowledge Statements	
T10	Calibrate instruments used in geophysical projects according to equipment specifications. 正確的校正地物儀器	K19	Knowledge of calibration requirements and techniques for instruments used in geophysical projects.
		K21	Knowledge of methods and procedures for using equipment for geophysical projects.
T12	Revise workplan(s) to accommodate actual conditions encountered in the field. 根據現場狀況調整現地施測工作流程	K24	Knowledge of methods for identifying interference(s) and instrument error(s) when collecting data for geophysical projects.
		K25	Knowledge of methods for modifying geophysical survey design to improve data quality to accommodate field conditions.
		K26	Knowledge of methods for minimizing interference(s) and instrument error(s) when collecting data for geophysical projects.
		K27	Knowledge of magnetic measurement methods and their applications.
		K28	Knowledge of seismic measurement methods and their applications.
		K29	Knowledge of gravity measurement methods and their applications.
		K30	Knowledge of electrical measurement methods and their applications.
		K32	Knowledge of electromagnetic measurement methods and their applications.
		K33	Knowledge of acoustic measurement methods and their applications.
		K34	Knowledge of radioactivity measurement methods and their applications.
		K35	Knowledge of downhole logging measurement methods and their applications.
		K36	Knowledge of methods for evaluating the quality of field data collected during geophysical projects.

T13	Record data using the measurement methods outlined in the workplan(s) or geophysical survey design. 採用工作流程收集資料	K20	Knowledge of basic field techniques (e.g., map reading, grid layout, compass use) and their applications for geophysical projects.
		K21	Knowledge of methods and procedures for using equipment for geophysical projects.
		K22	Knowledge of methods for implementing geophysical surveys.
		K23	Knowledge of survey techniques (e.g., GPS) and their applications.
		K26	Knowledge of methods for minimizing interference(s) and instrument error(s) when collecting data for geophysical projects.
		K27	Knowledge of magnetic measurement methods and their applications.
		K28	Knowledge of seismic measurement methods and their applications.
		K29	Knowledge of gravity measurement methods and their applications.
		K30	Knowledge of electrical measurement methods and their applications.
		K32	Knowledge of electromagnetic measurement methods and their applications.
		K33	Knowledge of acoustic measurement methods and their applications.
		K34	Knowledge of radioactivity measurement methods and their applications.
		K35	Knowledge of downhole logging measurement methods and their applications.

T14	Verify that the geophysical measurements/data are collected in accordance with applicable standards and workplan(s). 初步驗證資料品質	K19	Knowledge of calibration requirements and techniques for instruments used in geophysical projects.
		K20	Knowledge of basic field techniques (e.g., map reading, grid layout, compass use) and their applications for geophysical projects.
		K21	Knowledge of methods and procedures for using equipment for geophysical projects.
		K22	Knowledge of methods for implementing geophysical surveys.
		K23	Knowledge of survey techniques (e.g., GPS) and their applications.
		K24	Knowledge of methods for identifying interference(s) and instrument error(s) when collecting data for geophysical projects.
		K27	Knowledge of magnetic measurement methods and their applications.
		K28	Knowledge of seismic measurement methods and their applications.
		K29	Knowledge of gravity measurement methods and their applications.
		K30	Knowledge of electrical measurement methods and their applications.
		K32	Knowledge of electromagnetic measurement methods and their applications.
		K33	Knowledge of acoustic measurement methods and their applications.
		K34	Knowledge of radioactivity measurement methods and their applications.
		K35	Knowledge of downhole logging measurement methods and their applications.
		K36	Knowledge of methods for evaluating the quality of field data collected during geophysical projects.
		K37	Knowledge of methods for processing field data for geophysical projects.

III. Data Analysis and Interpretation (34%) - This area assesses the candidate's ability to analyze, interpret, and communicate geophysical data and results.

Task Statements		Knowledge Statements	
T15	Prepare geophysical data for analysis. 資料準備與驗證	K38	Knowledge of methods for preparing geophysical data for analysis.
		K39	Knowledge of geophysical software program applications for data analysis and processing.
		K40	Knowledge of geophysical software program limitations for data analysis and processing.
T16	Process data using applicable geophysical techniques. 資料處理	K38	Knowledge of methods for preparing geophysical data for analysis.
		K39	Knowledge of geophysical software program applications for data analysis and processing.
		K40	Knowledge of geophysical software program limitations for data analysis and processing.
		K41	Knowledge of methods for manually processing geophysical data.
		K42	Knowledge of data analysis techniques for geophysical projects.
		K44	Knowledge of mathematical principles related to geophysical projects.
		K45	Knowledge of physics principles related to geophysical projects.
		K47	Knowledge of factors that influence the interpretation of geophysical data.
		K49	Knowledge of methods for integrating nongeophysical (e.g., geological) information into geophysical findings.
T17	Analyze data using applicable geophysical principles. 資料分析	K38	Knowledge of methods for preparing geophysical data for analysis.
		K39	Knowledge of geophysical software program applications for data analysis and processing.
		K40	Knowledge of geophysical software program limitations for data analysis and processing.
		K41	Knowledge of methods for manually processing geophysical data.
		K42	Knowledge of data analysis techniques for geophysical projects.
		K43	Knowledge of geological principles related to geophysical projects.
		K44	Knowledge of mathematical principles related to geophysical projects.
		K45	Knowledge of physics principles related to geophysical projects.
		K46	Knowledge of methods for interpreting geophysical project results.
		K47	Knowledge of factors that influence the interpretation of geophysical data.
		K48	Knowledge of factors that warrant modification of the original conceptual geophysical model.

T18	Interpret geophysical results by integrating geological information, site conditions, and project objectives. 利用地質及相關資料進行解釋	K39	Knowledge of geophysical software program applications for data analysis and processing.
		K40	Knowledge of geophysical software program limitations for data analysis and processing.
		K42	Knowledge of data analysis techniques for geophysical projects.
		K43	Knowledge of geological principles related to geophysical projects.
		K44	Knowledge of mathematical principles related to geophysical projects.
		K45	Knowledge of physics principles related to geophysical projects.
		K46	Knowledge of methods for interpreting geophysical project results.
		K47	Knowledge of factors that influence the interpretation of geophysical data.
		K48	Knowledge of factors that warrant modification of the original conceptual geophysical model.
		K49	Knowledge of methods for integrating nongeophysical (e.g., geological) information into geophysical findings.
T19	Prepare technical document(s) to communicate the finding(s) of the geophysical investigation. 準備相關技術文件	K39	Knowledge of geophysical software program applications for data analysis and processing.
		K40	Knowledge of geophysical software program limitations for data analysis and processing.
		K42	Knowledge of data analysis techniques for geophysical projects.
		K43	Knowledge of geological principles related to geophysical projects.
		K44	Knowledge of mathematical principles related to geophysical projects.
		K45	Knowledge of physics principles related to geophysical projects.
		K46	Knowledge of methods for interpreting geophysical project results.
		K47	Knowledge of factors that influence the interpretation of geophysical data.
		K49	Knowledge of methods for integrating nongeophysical (e.g., geological) information into geophysical findings.
		K50	Knowledge of methods to document and explain geophysical results.
		K51	Knowledge of methods for preparing data visualizations (e.g., digital presentations, maps, cross-sections) to depict results of geophysical projects.
		K52	Knowledge of client/regulatory requirements for reporting geophysical findings.
		K53	Knowledge of methods for communicating geophysical findings to the public.

IV. Safety (9%) - This area assesses the candidate's ability to identify hazards and safely manage geophysical work and personnel.			
Task Statements		Knowledge Statements	
T20	Identify environmental and operational hazards that are relevant to geophysical fieldwork. 了解與現場工作可能的災害與危險	K54 K57 K59 K61	Knowledge of types of operational and environmental hazards on geophysical project sites. Knowledge of site safety plan(s)/procedures related to geophysical projects. Knowledge of methods for assuring the safe operation of tools and equipment used in geophysical projects. Knowledge of Cal/OSHA (California Occupational Safety and Hazard Act) laws and regulations related to geophysical work.
T21	Implement the site safety plan(s)/procedures to minimize hazards during geophysical projects. 訂定現場工作安全守則	K54 K55 K56 K57 K58 K59 K61	Knowledge of types of operational and environmental hazards on geophysical project sites. Knowledge of methods for minimizing hazardous site conditions. Knowledge of safety-related local, state, and federal requirements related to geophysical project sites. Knowledge of site safety plan(s)/procedures related to geophysical projects. Knowledge of types of personal protective equipment (PPE) used for geophysical projects and their applications. Knowledge of methods for assuring the safe operation of tools and equipment used in geophysical projects. Knowledge of Cal/OSHA (California Occupational Safety and Hazard Act) laws and regulations related to geophysical work.
T22	Manage fieldworkers in accordance with applicable laws and regulations. 執行並管理現場工作安全守則，以符合當地法令	K54 K55 K56 K57 K58 K59 K61	Knowledge of types of operational and environmental hazards on geophysical project sites. Knowledge of methods for minimizing hazardous site conditions. Knowledge of safety-related local, state, and federal requirements related to geophysical project sites. Knowledge of site safety plan(s)/procedures related to geophysical projects. Knowledge of types of personal protective equipment (PPE) used for geophysical projects and their applications. Knowledge of methods for assuring the safe operation of tools and equipment used in geophysical projects. Knowledge of Cal/OSHA (California Occupational Safety and Hazard Act) laws and regulations related to geophysical work.
T23	Report geohazard findings to clients and/or governmental agencies. 報告發現的潛在安全危害	K56 K61 K62 K63	Knowledge of safety-related local, state, and federal requirements related to geophysical project sites. Knowledge of Cal/OSHA (California Occupational Safety and Hazard Act) laws and regulations related to geophysical work. Knowledge of how geohazards impact human occupancy, infrastructure, and the environment. Knowledge of responsibilities for reporting geohazards to governmental agencies and clients.

結論

影響近地表地球物理施測的分析與解釋的因素很多，也因此往往在施測解釋上會與後來的鑽井及開挖驗證結果有不小的出入。但是，若能適度了解各種地球物理儀器的限制、設計與執行嚴謹的施測工作，並評估可能的干擾與雜訊來源，仔細的選擇與採取合理的資料處理及反演算作法，並廣泛收集現地資料，作出合理的分析解釋。可以在相當的程度尚避免上述的困擾。然而，人員的持續專業教育與訓練，才是讓地球物理技術的分析解釋提升準確性與正確性的根本之道。

Questions?