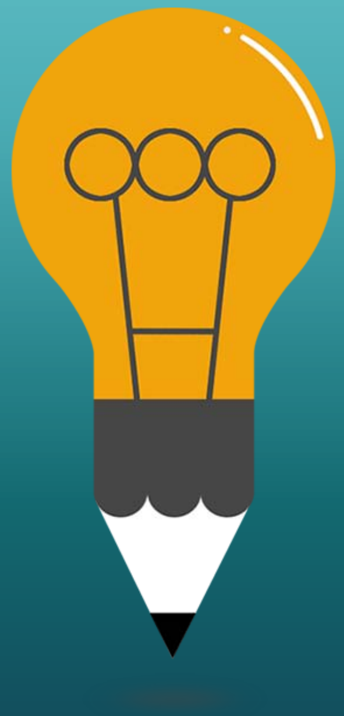
2020應用地質技術研討會，台中(2020/11/20)



地質模型不確定性

董家鈞
國立中央大學應用地質研究所
地震災害鏈風險中心E-DREaM

Acknowledgement

➢ **Research team of Shackleton Project**

地質模型不確定衍生之風險：工程、環境、水資源、和地質災害之探討

Geological uncertainty and societal risk:
the perspectives of engineering,
environment, and geohazards

focused on: (i) geological uncertainty; and (ii) uncertainty propagation

Shackleton Program (MOST108-2638-E-008-001-MY2)

MOST 科技部 Ministry of Science and Technology

Endurance 沙克爾頓計畫

學校　中央大學地球科學院院學士班演講，2020/9/28

Seminar, NTU, 2020/10/16

地球科學聯合會，工程地質論壇，2019/5/16

第十八屆大地工程學術研討會特邀演講，墾丁，2020/9/2　學術研討會

專業活動

環保署土基會教育訓練，2020/2/12

政府部門

高速公路局，國道工程日，2020/4/24

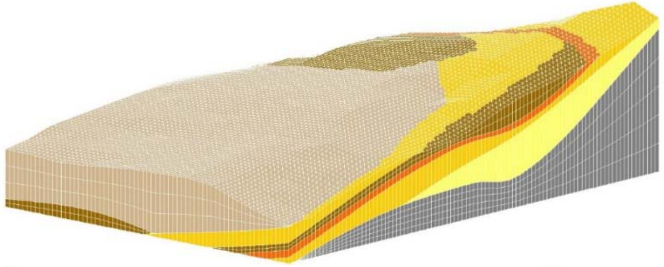
專業期刊

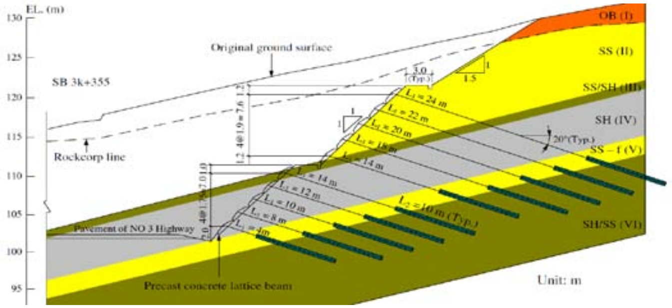
知之為知之，不知為不知，是知也!!

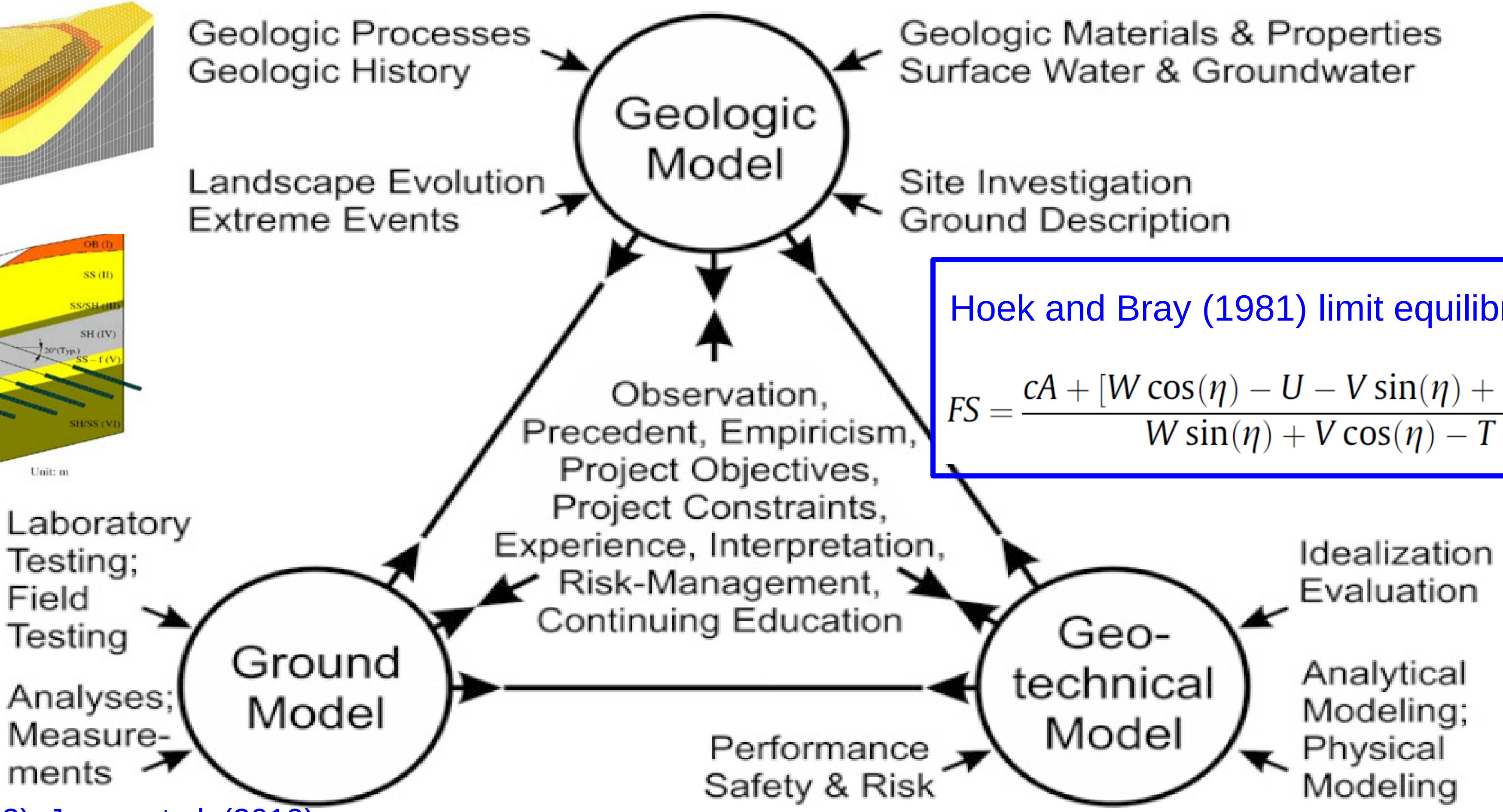
黑色星期五，2019/12/13

Burland's (1987) soil mechanics triangle (modified by Keaton, 2013)

"If the Geologic Model is wrong, then neither the Ground Model nor the Geotechnical Model can be correct." --- Keaton (2013)







Hoek and Bray (1981) limit equilibrium model:

$$FS = \frac{cA + [W\cos(\eta) - U - V\sin(\eta) + T\cos(\theta)]\tan\phi}{W\sin(\eta) + V\cos(\eta) - T\sin(\theta)}$$

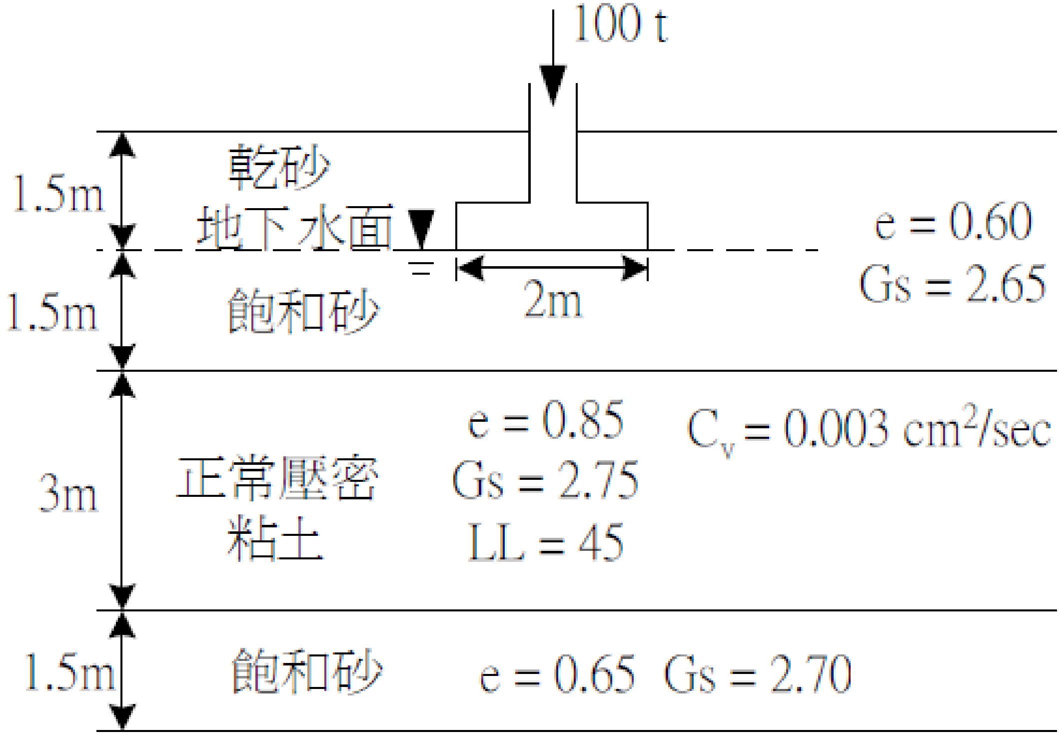
Burland (1987), Keaton (2013), Juang et al. (2019)

二、有一 2m×2m 之獨立基腳承受 100 t 之上部載重，置於如下圖所示之土層。

求[redacted]粘土層之主要壓密沈陷量(cm)。(15 分)

[redacted]當粘土層沈陷 6.1 cm 時所需時間（天）。(10 分)

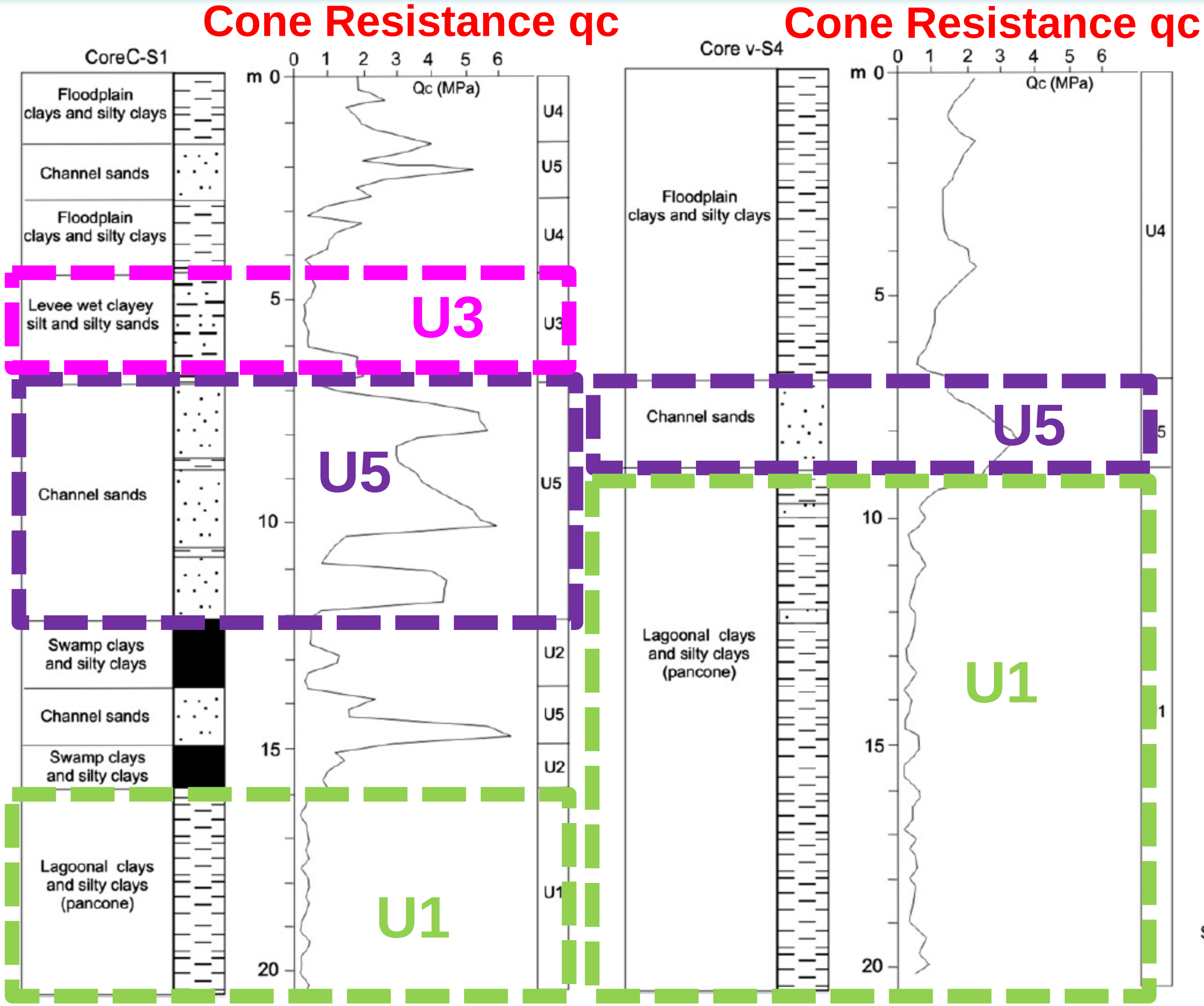
（壓密度與時間因素的關係列於右表）



壓密度(%)	時間因素
0	0
10	0.008
20	0.031
30	0.071
40	0.126
50	0.197
60	0.287
70	0.403
80	0.567
90	0.848
100	∞

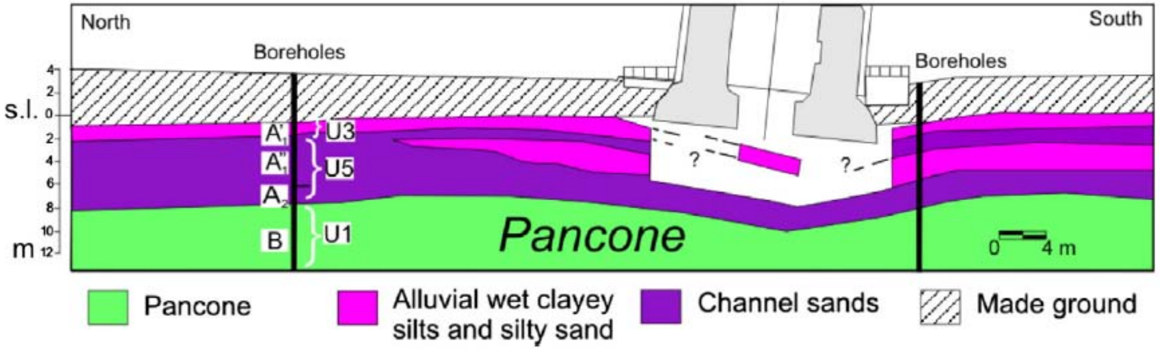
How to obtain this profile for engineering practice?

92專技高考考題



為何需要地質師?

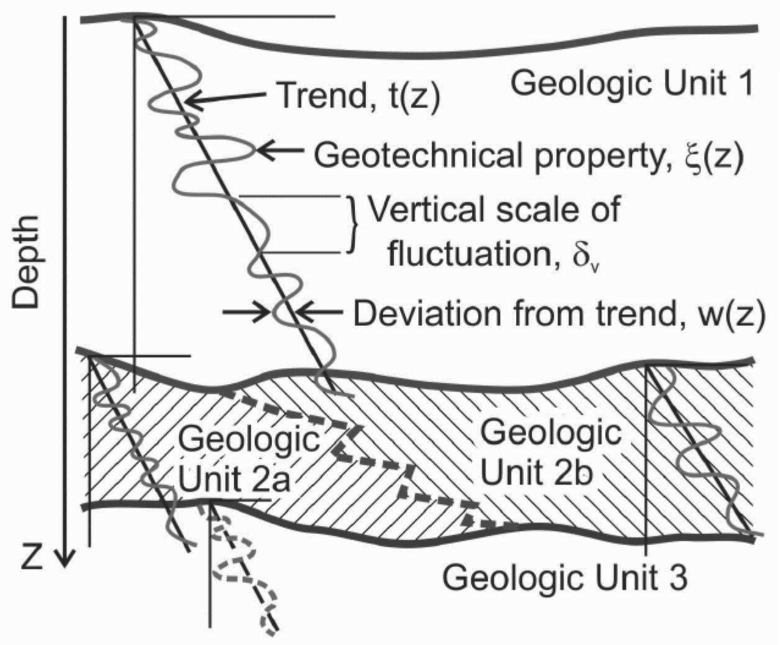
建立地質模型需要地質學知識



Sarti et al., 2012, Sedimentary Geology

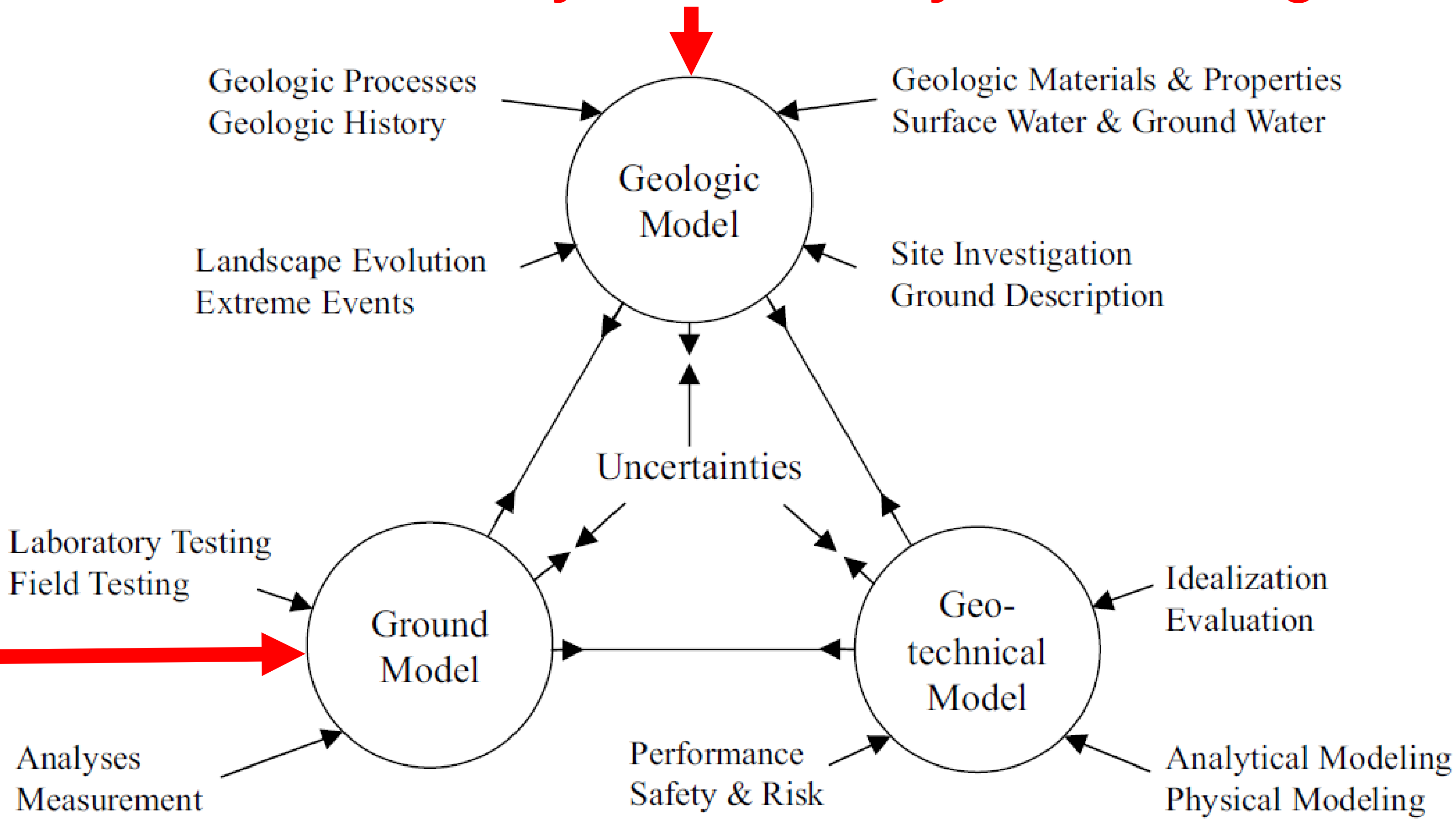
大地工程可靠度設計推動對工程設計參數不確定性掌握之需求

Uncertainties of geological model are poorly studied, not to say the reliability-based design!!



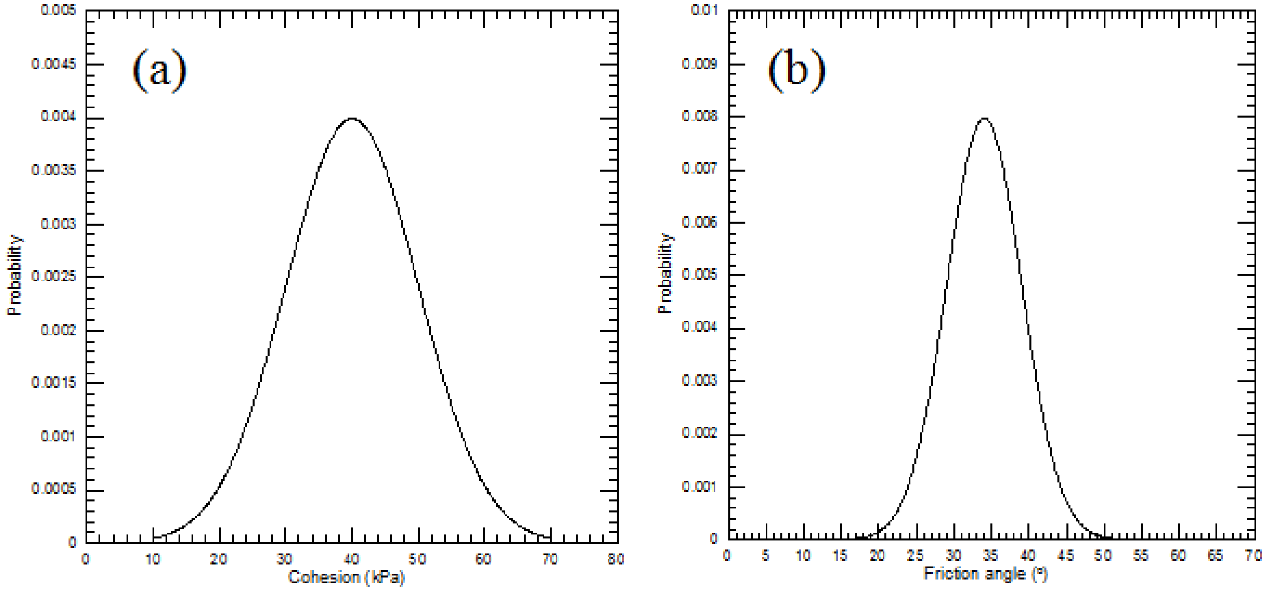
Phoon et al. (1995)

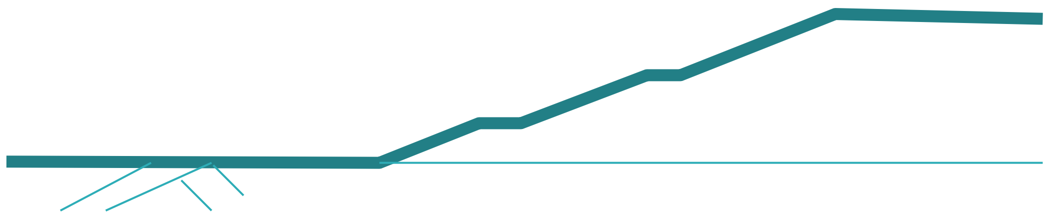
Uncertainty of geotechnical properties



Reliability-based design

Uncertainty of geotechnical properties: Slope stability as an example

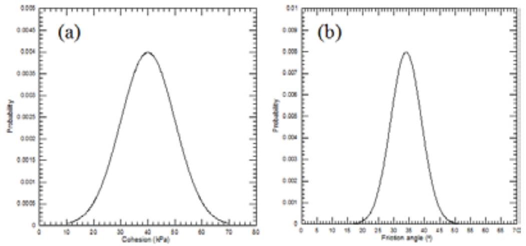




	Cohesion (kPa)	Friction angle (˚)
Mean	40.0	34.0
S.D.	10.0	5.0

Failure probability of a slope

***Rosenblueth* point estimation method (Rosenblueth, 1975)**



- **Two parameters:** C_+ C_- ϕ_- ϕ_+
- **Mean value of FS (factor of safety)**

$$F.S.[avg] = P_{++}F.S(C_+,\phi_+) + P_{+-}F.S(C_+,\phi_-) + P_{-+}F.S(C_-,\phi_+) + P_{--}F.S(C_-,\phi_-)$$

$$P_{++} = (1+\rho_{c,\phi})/4;\ P_{+-} = (1-\rho_{c,\phi})/4;\ P_{-+} = (1-\rho_{c,\phi})/4;\ P_{--} = (1+\rho_{c,\phi})/4$$

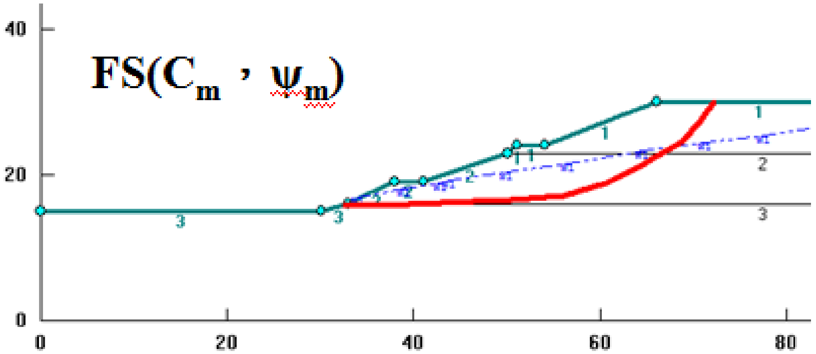
$\rho_{c,\phi} = -0.5$ correlation coefficient of cohesion and friction angle

- **Standard deviation of the FS** $\sigma(y) = \sqrt{E[y^2] - (E[y])^2}$

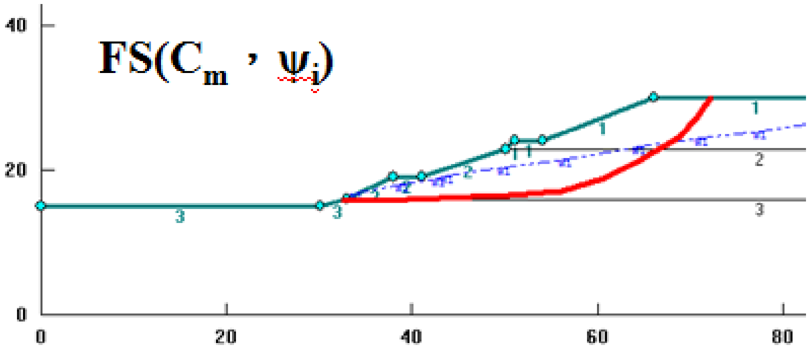
$$E[y^2] = P_{++}F.S^2{}_{++} + P_{+-}F.S^2{}_{+-} + P_{-+}F.S^2{}_{-+} + P_{--}F.S^2{}_{--}$$

$$E[y] = F.S.[avg]$$

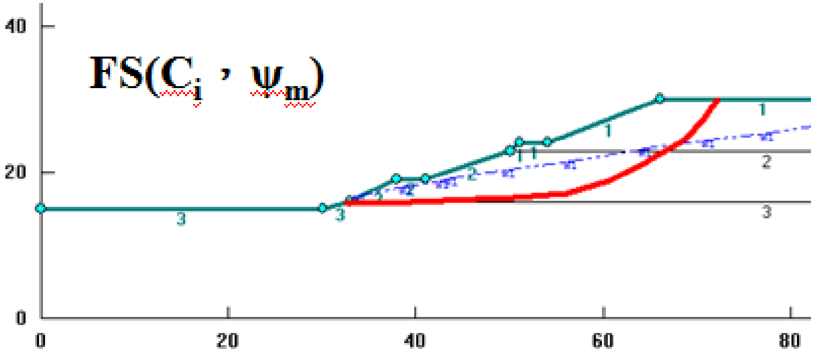
同樣平均值，標準差越大破壞機率越高



PCSTABL5M/si FSmin=3.39
Factors of Safety Calculated by Janbu Method



PCSTABL5M/si FSmin=2.78
Factors of Safety Calculated by Janbu Method



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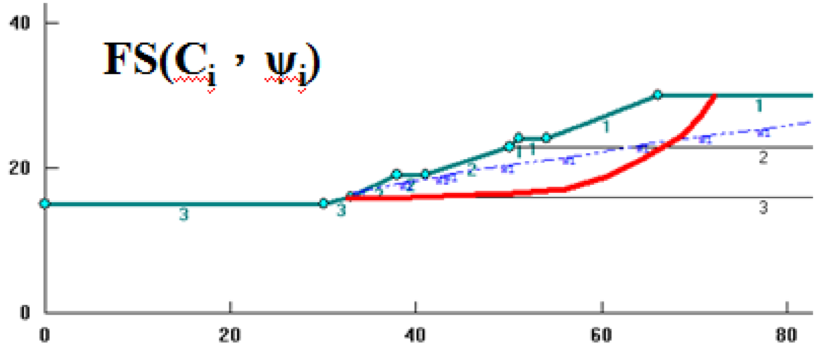
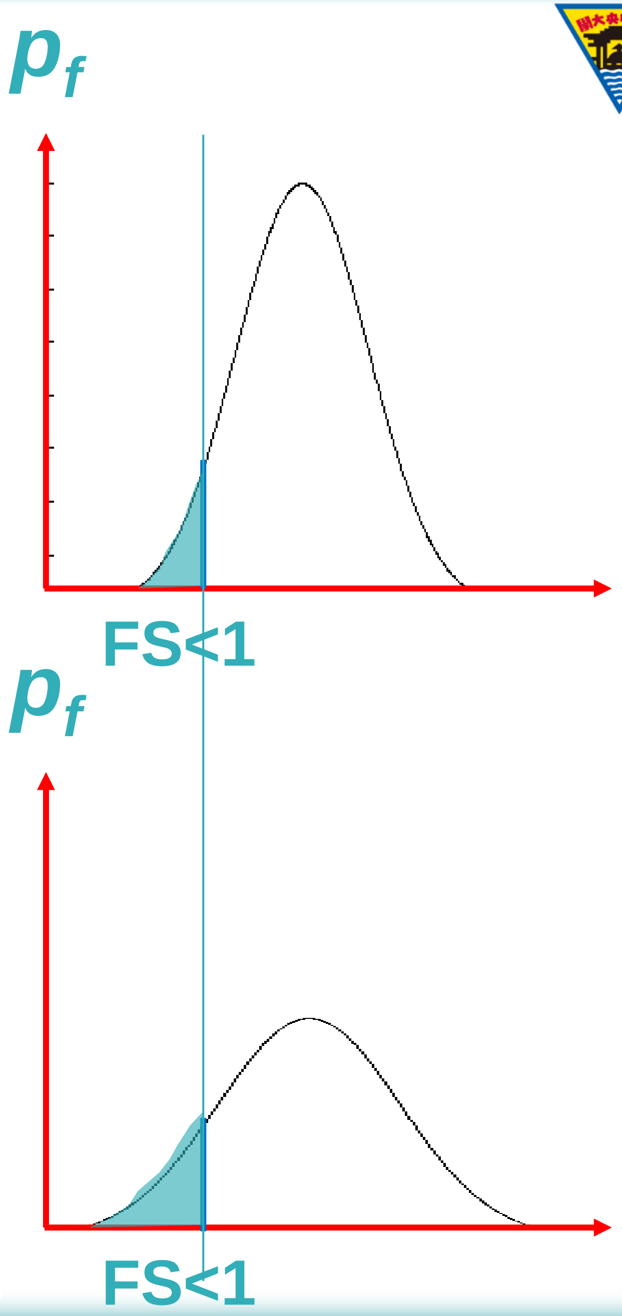
Factors of Safety Calculated by Janbu Method



PCSTABL5M/si FSmin=2.28
Factors of Safety Calculated by Janbu Method

FS(C_m，ψ_m)	FS(C_m，ψ_i)	FS(C_i，ψ_m)	FS(C_i，ψ_i)	FS mean	FS S.D.
3.39	2.78	2.89	2.28	2.835	0.28



Uncertainty characterization of geological, ground, geotechnical models uncertainty; Impact of uncertainties, Value of uncertainty reduction

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Probabilistic methods for unified treatment of geotechnical and geological uncertainties in a geotechnical analysis

C. Hsein Juang[a,b], Jie Zhang[c,*], Mengfen Shen[d], Jinzheng Hu[c]

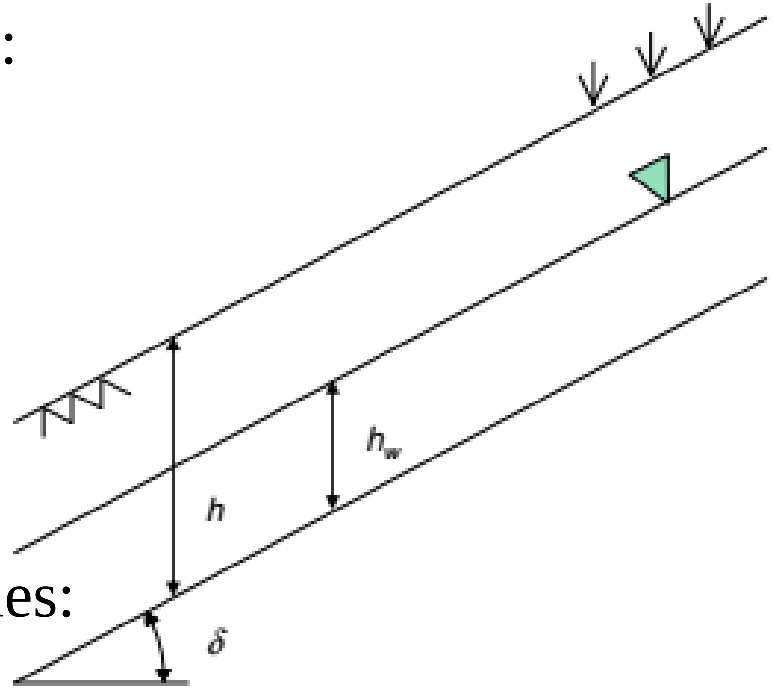
[a] *Departmnet of Civil Engineering, National Central University, No. 300, Zhongda Road, Zhongli District, Taoyuan City 320, Taiwan*
[b] *Glenn Department of Civil Engineering, Clemson University, Clemson, SC 29634, USA*
[c] *Department of Geotechnical Engineering, Key Laboratory of Geotechnical and Underground Engineering of Ministry of Education, Tongji University, 1239 Siping Road, Shanghai 200092, China*
[d] *College of Civil Engineering and Architecture, Zhejiang University of Technology, Hangzhou 310014, China*

Impact of geological, ground, and geotechnical models uncertainty: infinite slope

$$g(\boldsymbol{\theta}) = \frac{c + \left[\gamma(h-h_w) + (\gamma_{sat} - \gamma_w)h_w\right]\cos^2\delta \tan\varphi}{\left[\gamma(h-h_w) + \gamma_{sat}h_w\right]\sin\delta\cos\delta} \qquad F_S = g(\boldsymbol{\theta}) + \varepsilon$$

Wu & Abdel-Latif (2000）

- Geological model uncertainties:
  - h
  - h_w
- Ground model uncertainties:
  - c
  - φ
- Geotechnical model uncertainties:
  - Model error ε



Reliability analysis: First Order Reliability Method (**FORM**)

Calculate the reliability index and failure probability

Reliability index and failure probability

Deterministic variables

δ (°)	h_w (m)	γ_s (kN/m^3)	γ (kN/m^3)	γ_w (kN/m^3)
35	1.825	19	17	9.8

Performance function / **Reliability analysis**

$g(\boldsymbol{\theta})$	F_s	F_s-1	β	p_f
1.000	1	-6E-09	1.841	0.033

Random variables

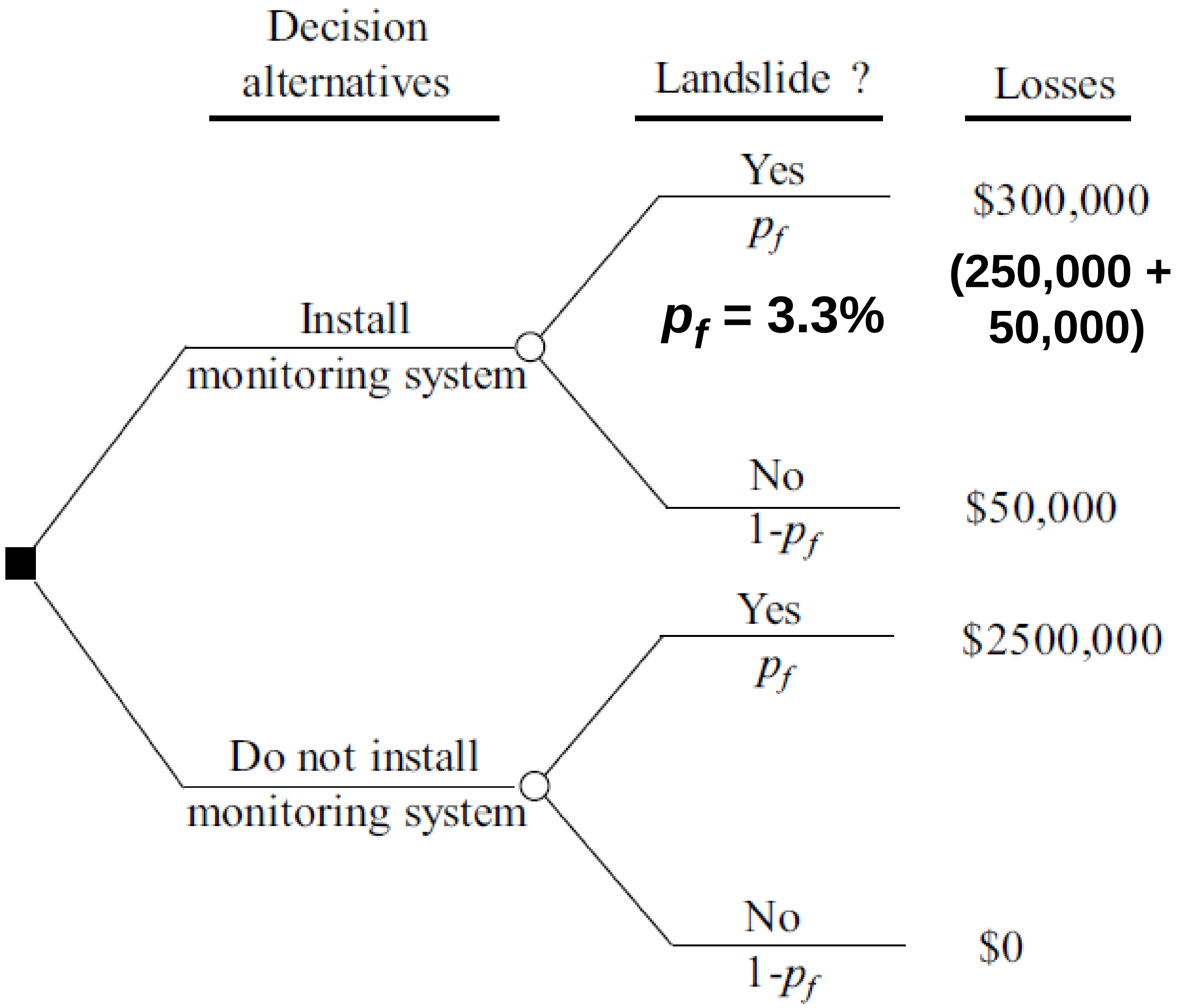
	c (kPa)	φ (°)	m	h (m)	ε
$\boldsymbol{x}$	7.572	36.049	0.525	3.476	0
μ_x	10	38	0.5	3	0.02
σ_x	2	2	0.05	0.6	0.07
$\boldsymbol{y}$*	-1.214	-0.976	0.501	0.793	-0.286

$\mathbf{R_y}$

1	0	0	0	0
0	1	0	0	0
0	0	1	0	0
0	0	0	1	0
0	0	0	0	1

Notes: (1)This spreadsheet calculates the reliability index of the infinite slope. (2)The setting in Solver is "minimize N6 by changing values in cells E13:I13, subjected to M6 = 0"

Decision tree to evaluate the value of monitoring



$$R_i = C_{i1} p_f + C_{i2}(1 - p_f)$$

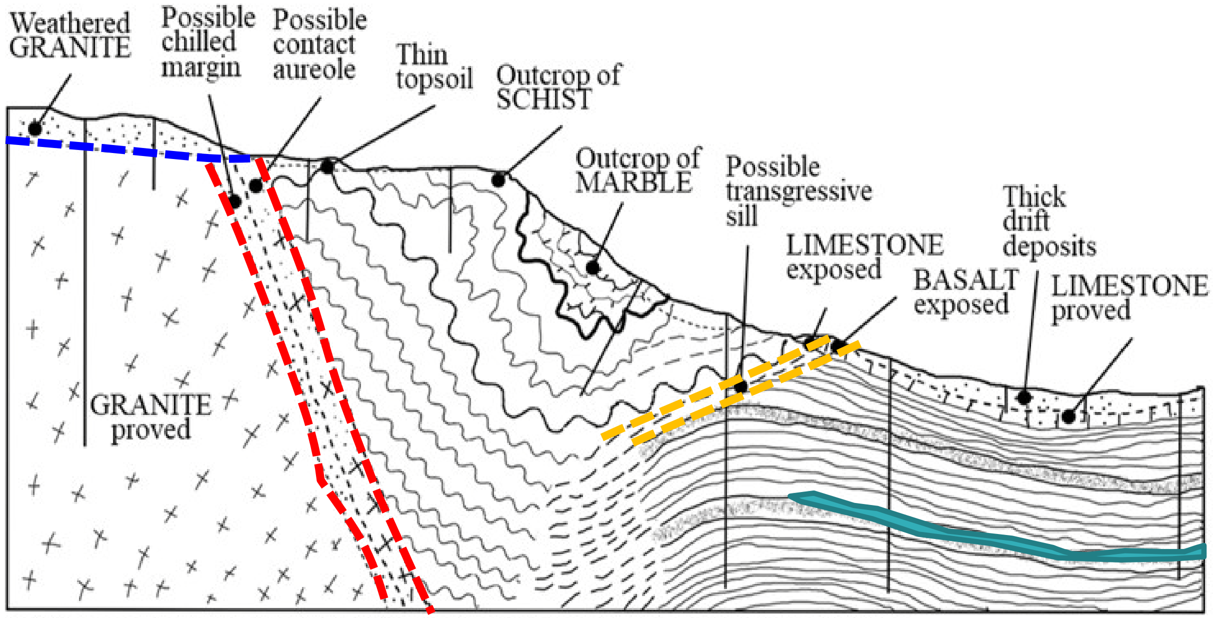
$$R_1 = \$58,250$$

$$R_2 = \$82,500$$

地質調查價值何在?浪費錢?如何說服業主增加調查經費?

Geological model uncertainties are critical…

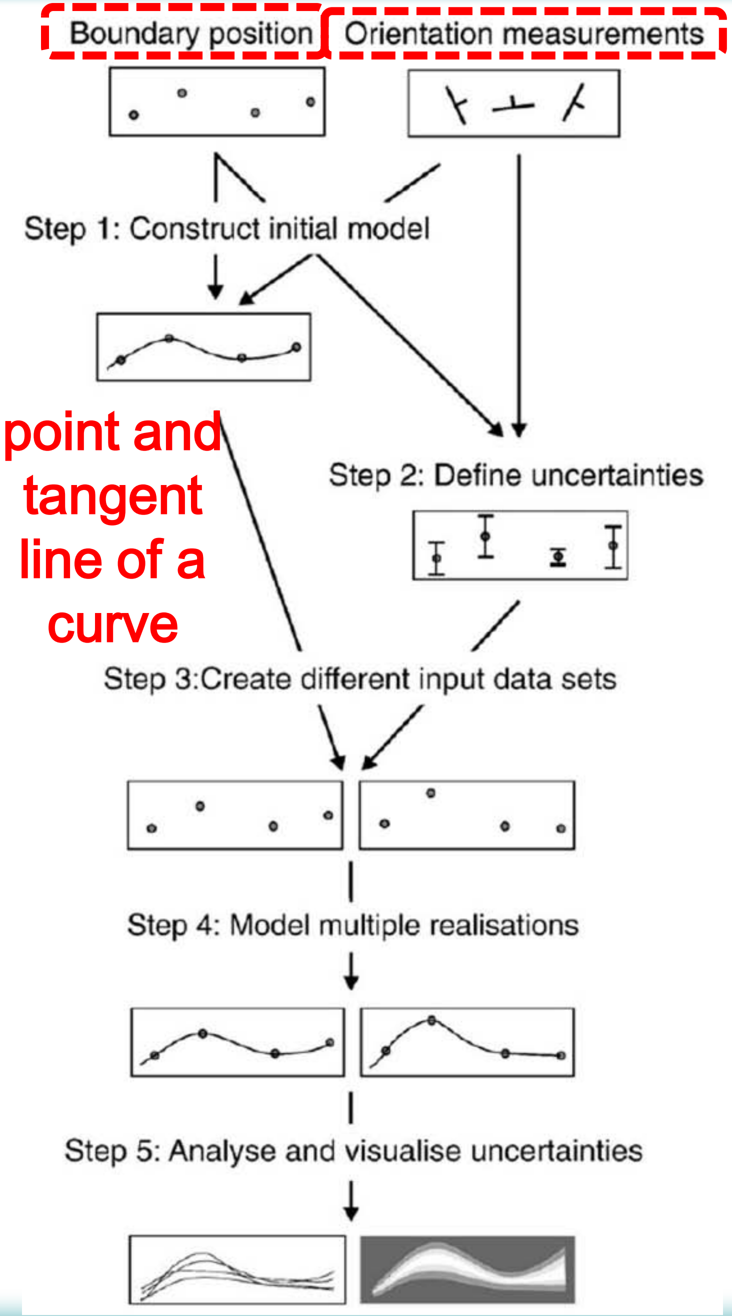
How to evaluate the GM uncertainty and uncertainty propagation of prediction?



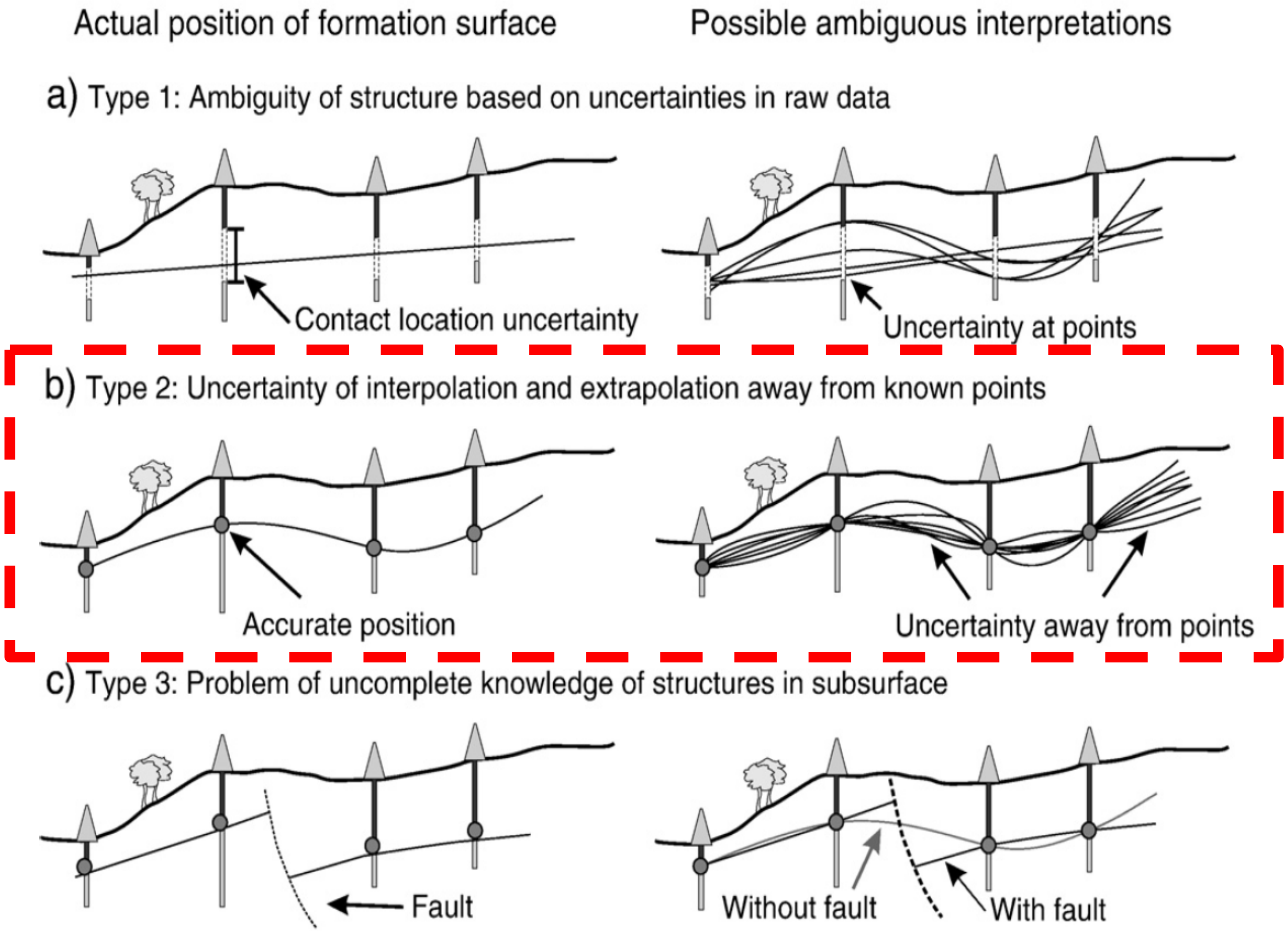
(a) Some potential misinterpretations of geology of (b) from borehole evidence

(after Fookes, 1997)

Different realizations of GM for geotechnical analysis



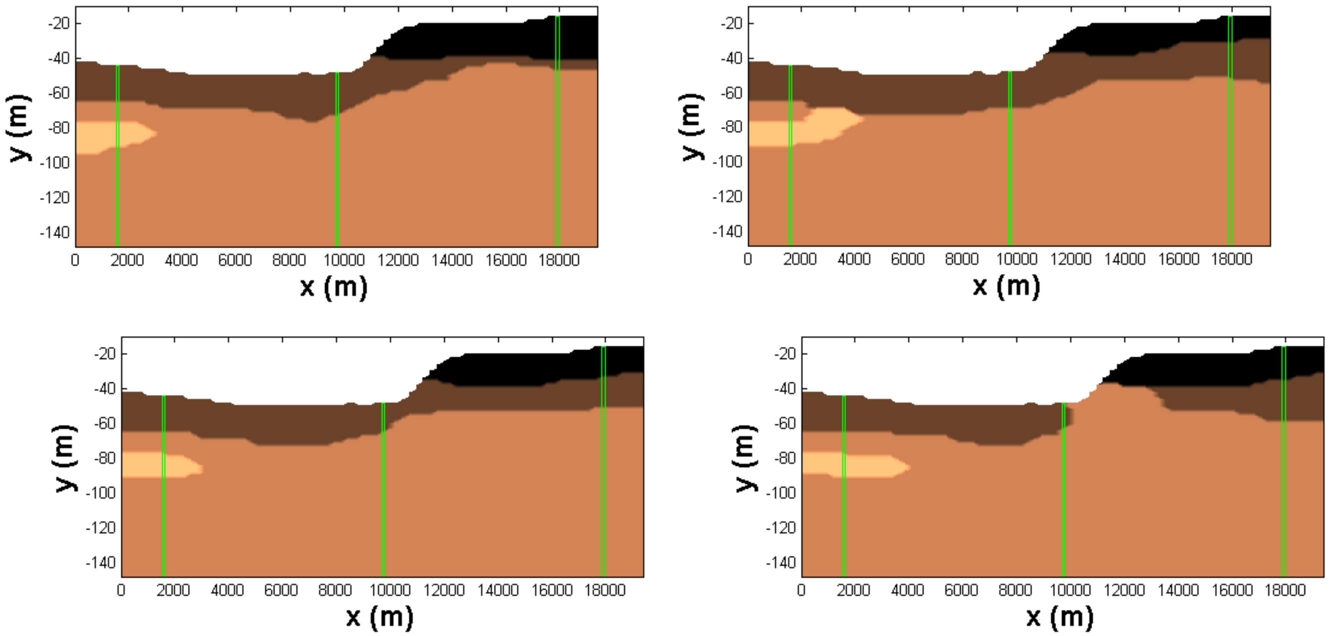
point and tangent line of a curve



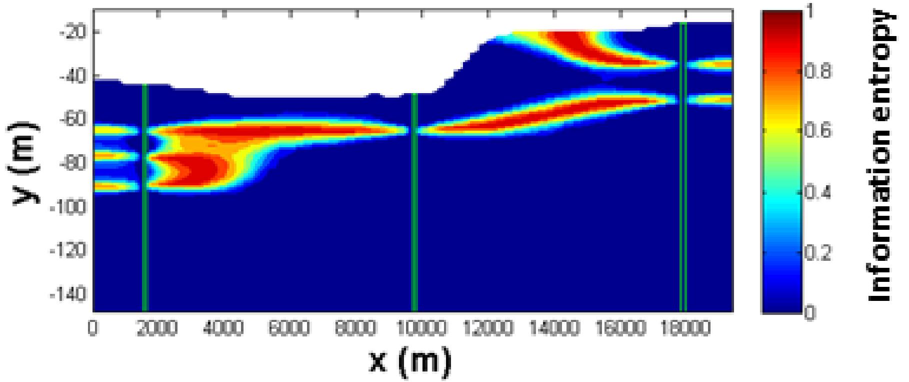
Quantify stratigraphic uncertainties: Markov random field

Source:徐雅涵等人，2020

4 possible GM



500 Realizations from 3 boreholes

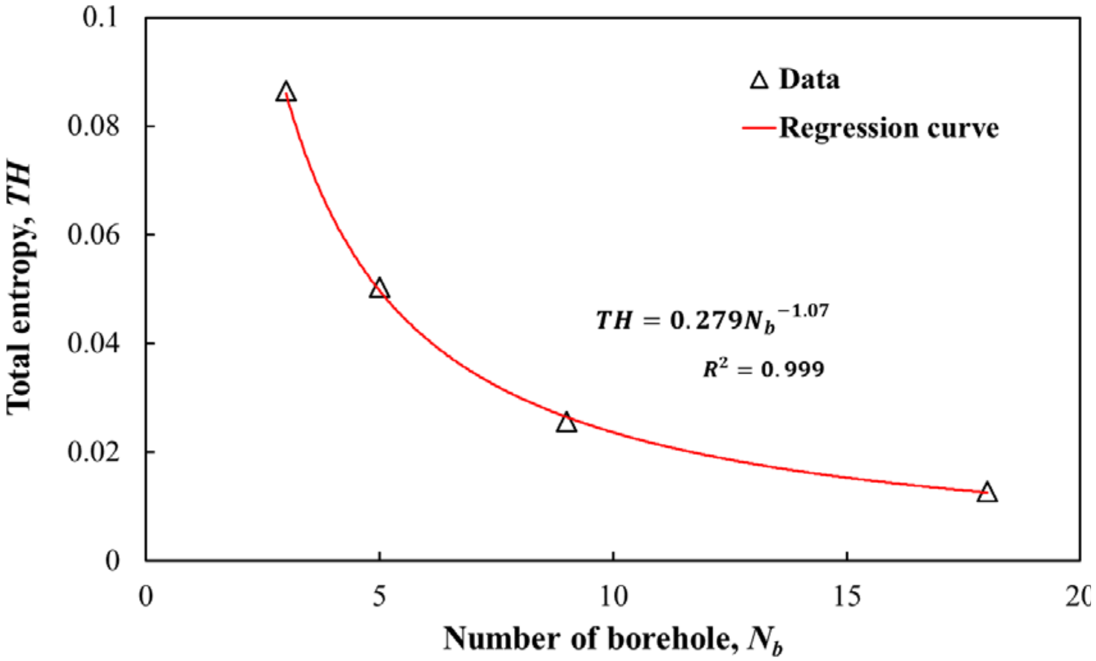


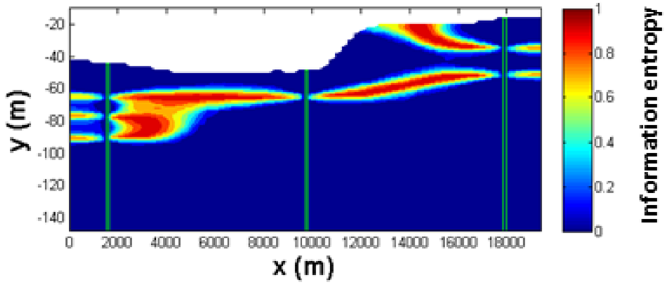
$$H = -\sum_{l \in L} P_l(i) \log P_l(i)$$

H: information entropy increased with increasing uncertainty

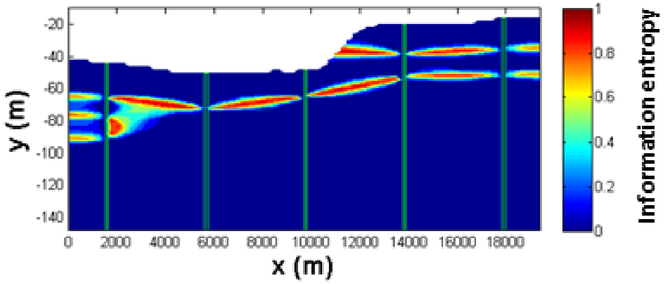
- **Li, Z., Wang, X., Wang, H., and Liang, R.Y. (2016). "Quantifying stratigraphic uncertainties by stochastic simulation techniques based on Markov random field," Engineering Geology, Vol. 201, pp. 106-122.**
- **Gong, W., Tang, H., Wang, H., Wang, X., and Juang, C.H. (2019). "Probabilistic analysis and design of stabilizing piles in slope considering stratigraphic uncertainty," Engineering Geology, Vol. 259, doi: 10.1016/j.enggeo.2019.105162.**

$$TH = -\frac{1}{|S|}\sum_{i \in S}\left[-\sum_{l \in L} P_l(i)\log P_l(i)\right]$$

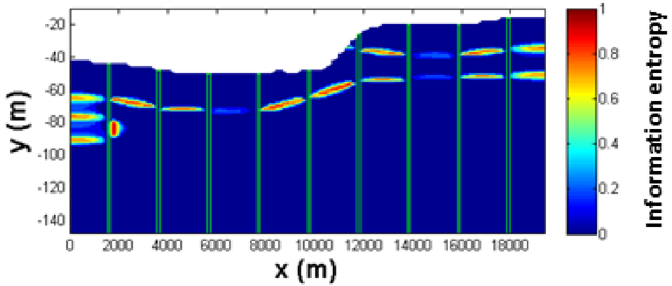




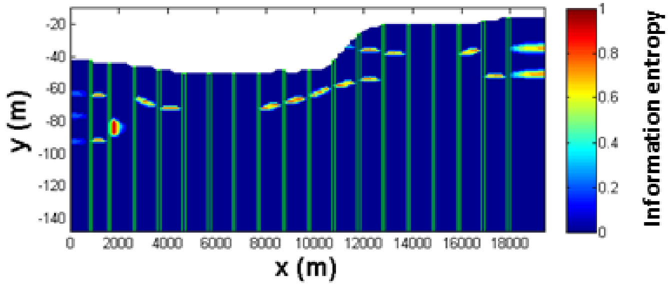
Entropy from 3 boreholes



Entropy from 5 boreholes

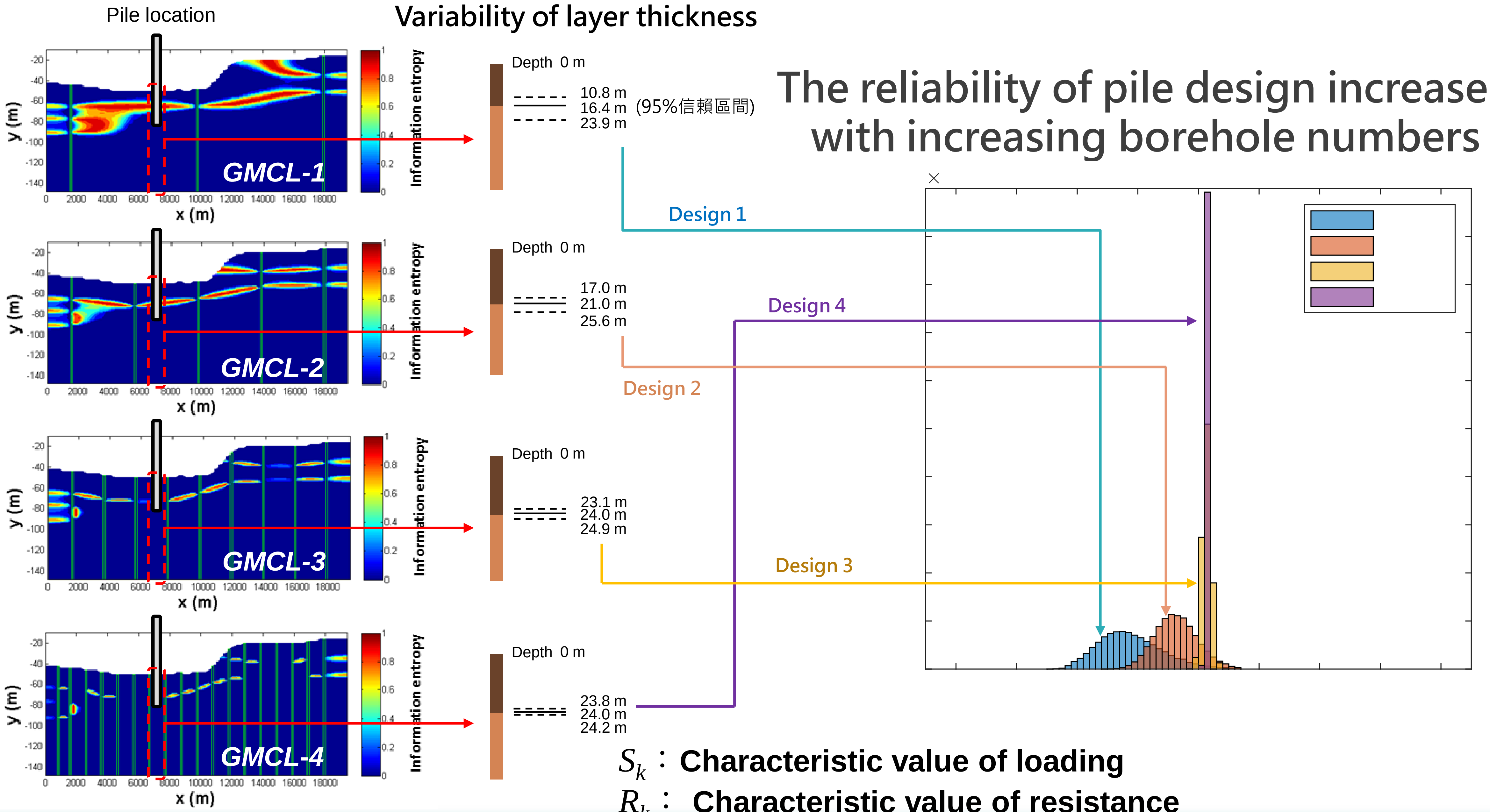


Entropy from 9 boreholes



Entropy from 18 boreholes

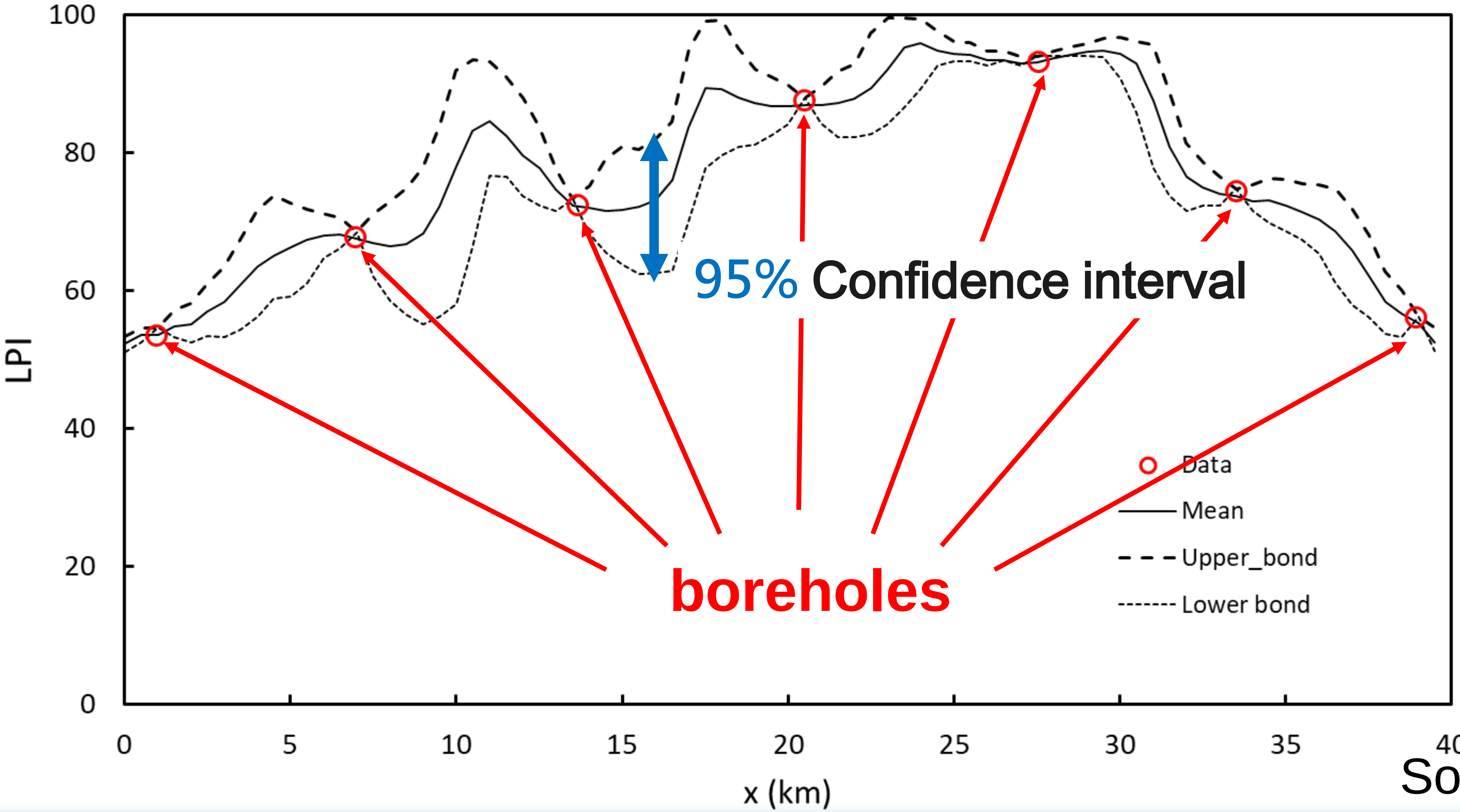
The reliability of pile design increased with increasing borehole numbers



S_k ： **Characteristic value of loading**

R_k ： **Characteristic value of resistance**

Uncertainty of liquefaction potential index (LPI) due to geological model uncertainty



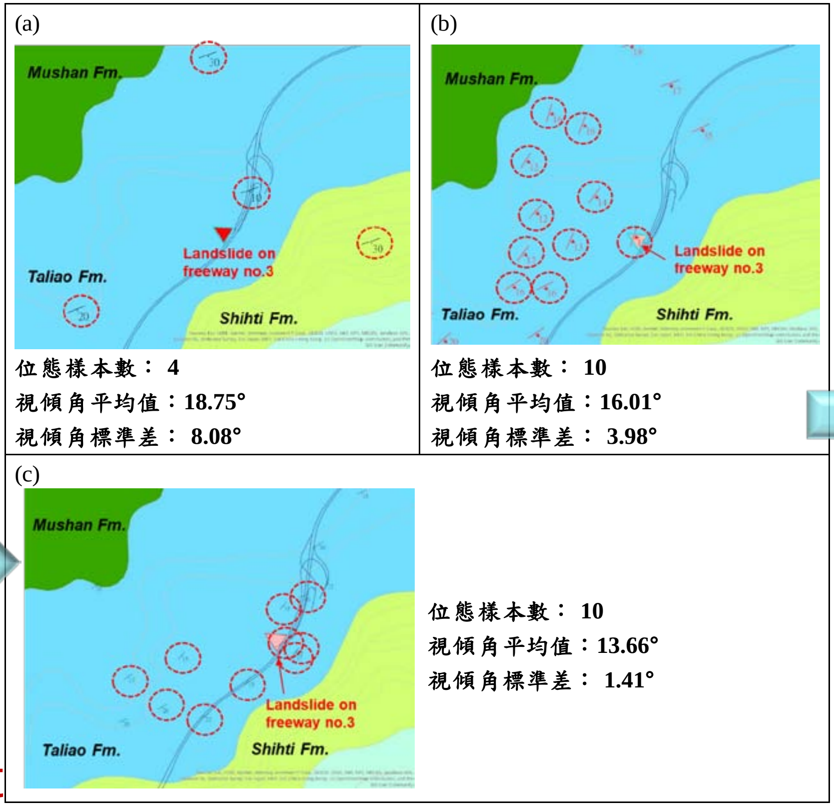
Source: 盧育辰

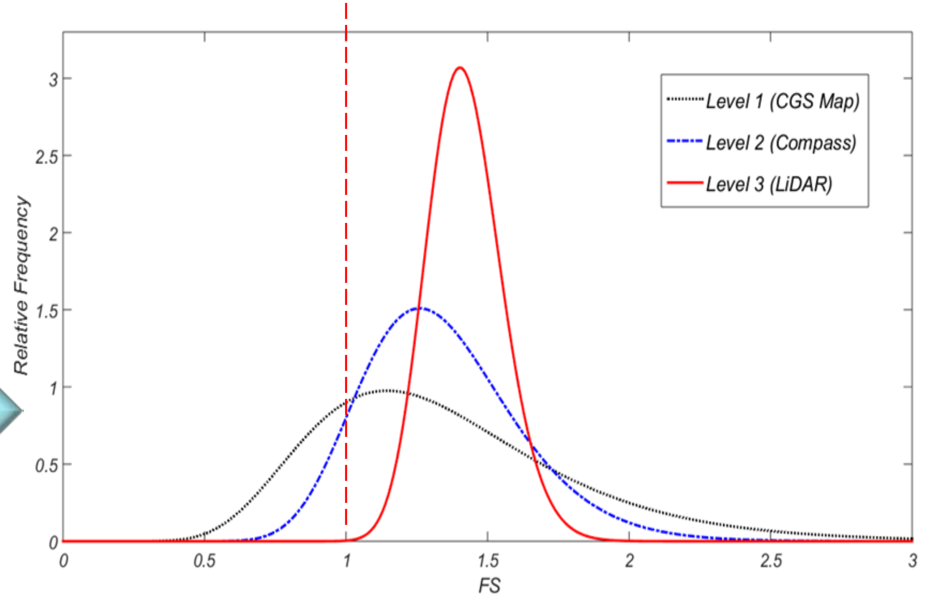
Dip slope failure probability: influence of uncertainty of the orientation of bedding plane

Highway No. 3

Hoek and Bray (1981) limit equilibrium model:

$$FS = \frac{cA + [W\cos(\eta) - U - V\sin(\eta) + T\cos(\theta)]\tan\phi}{W\sin(\eta) + V\cos(\eta) - T\sin(\theta)}$$



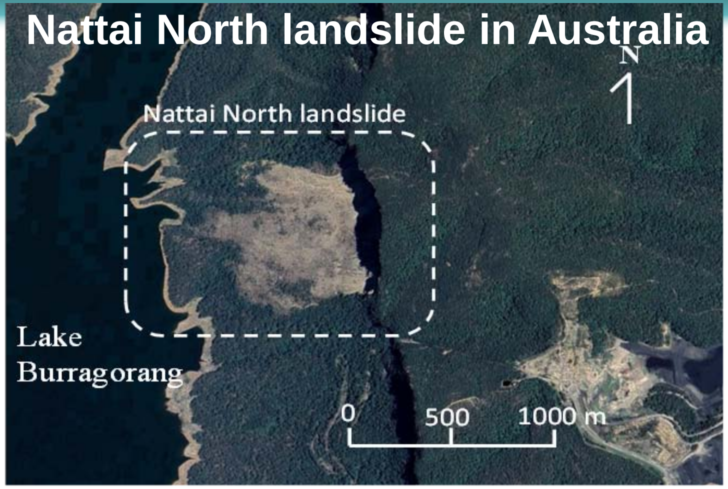


Distribution of factor of safety

Source of orientations：

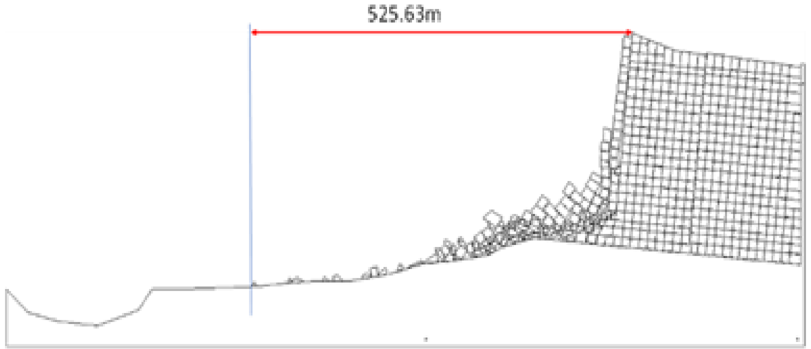
1. CGS Map
2. Compass measurement
3. LiDAR measurement

Source: 葉致翔

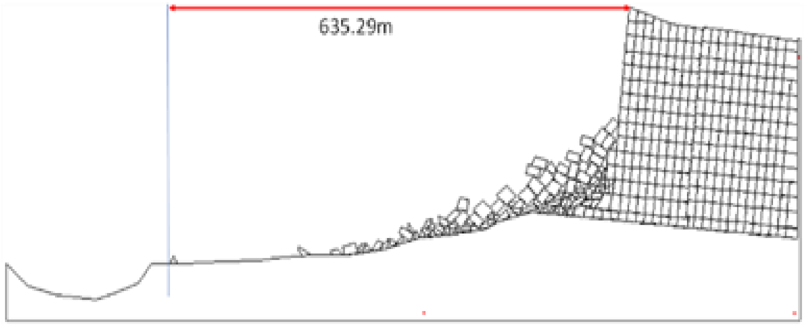


The influence of joint spacing uncertainty of two joint sets on run-out distance

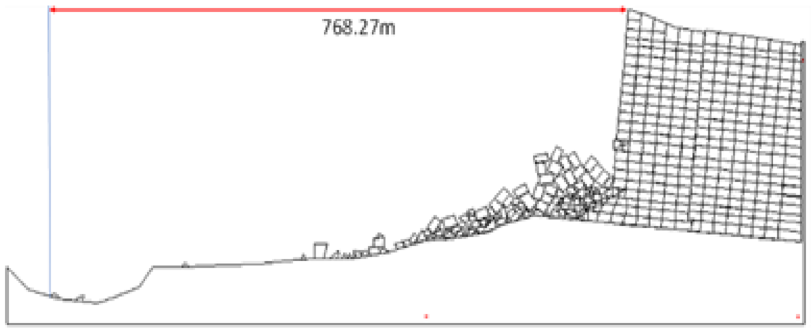
DDA analysis



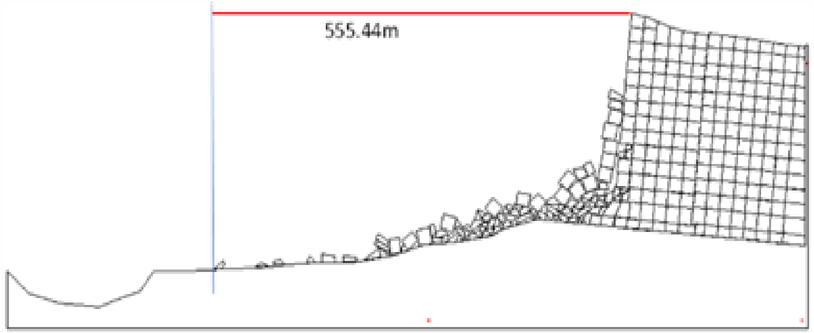
11mx11m



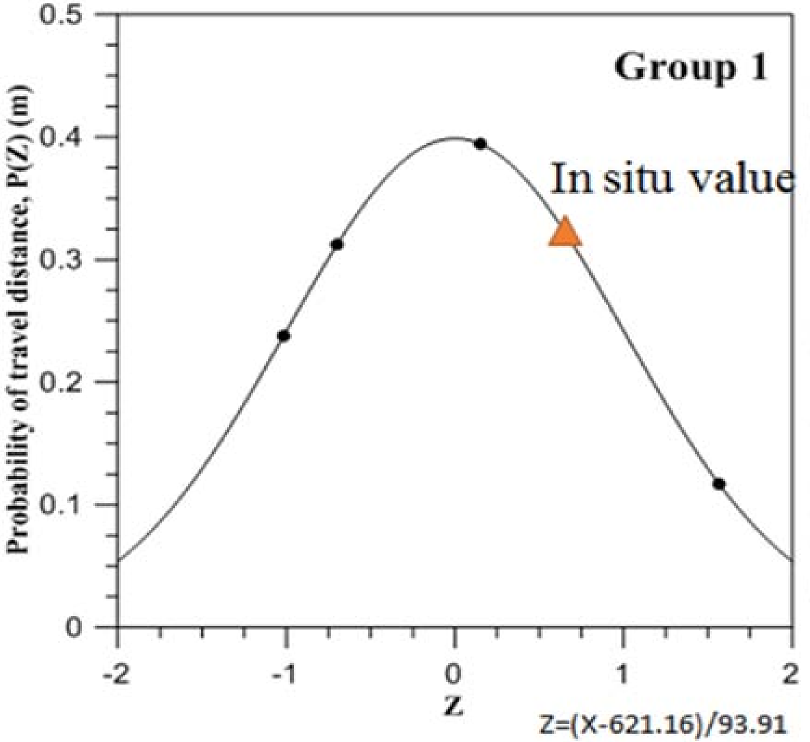
11mx17m



17mx11m



17mx17m

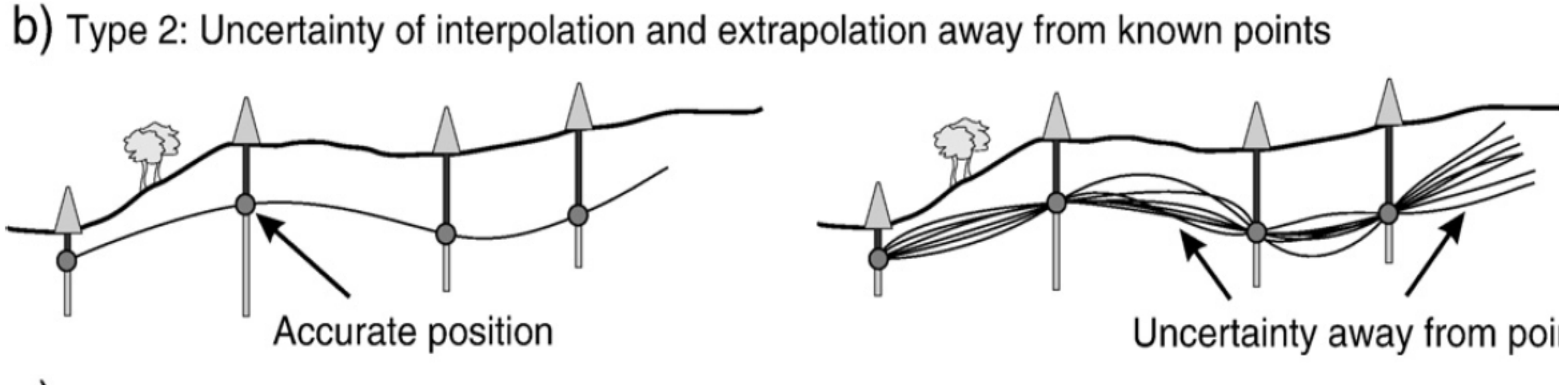


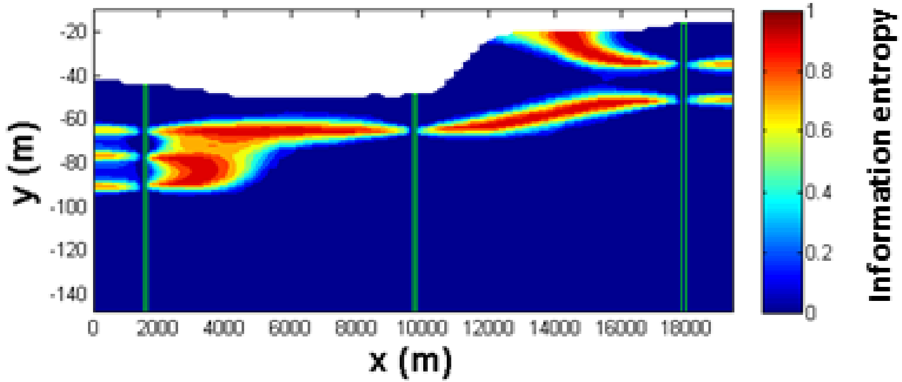
Density function of run-out distance based on point estimation method

Source: 吳建宏

看起來地質模型不確定性量化與傳遞可使用統計方法解決

- **Stochastic modelling is the only way to handle the geological model uncertainty?**





Engineering Geology: Fundamental Input or Random Variable?

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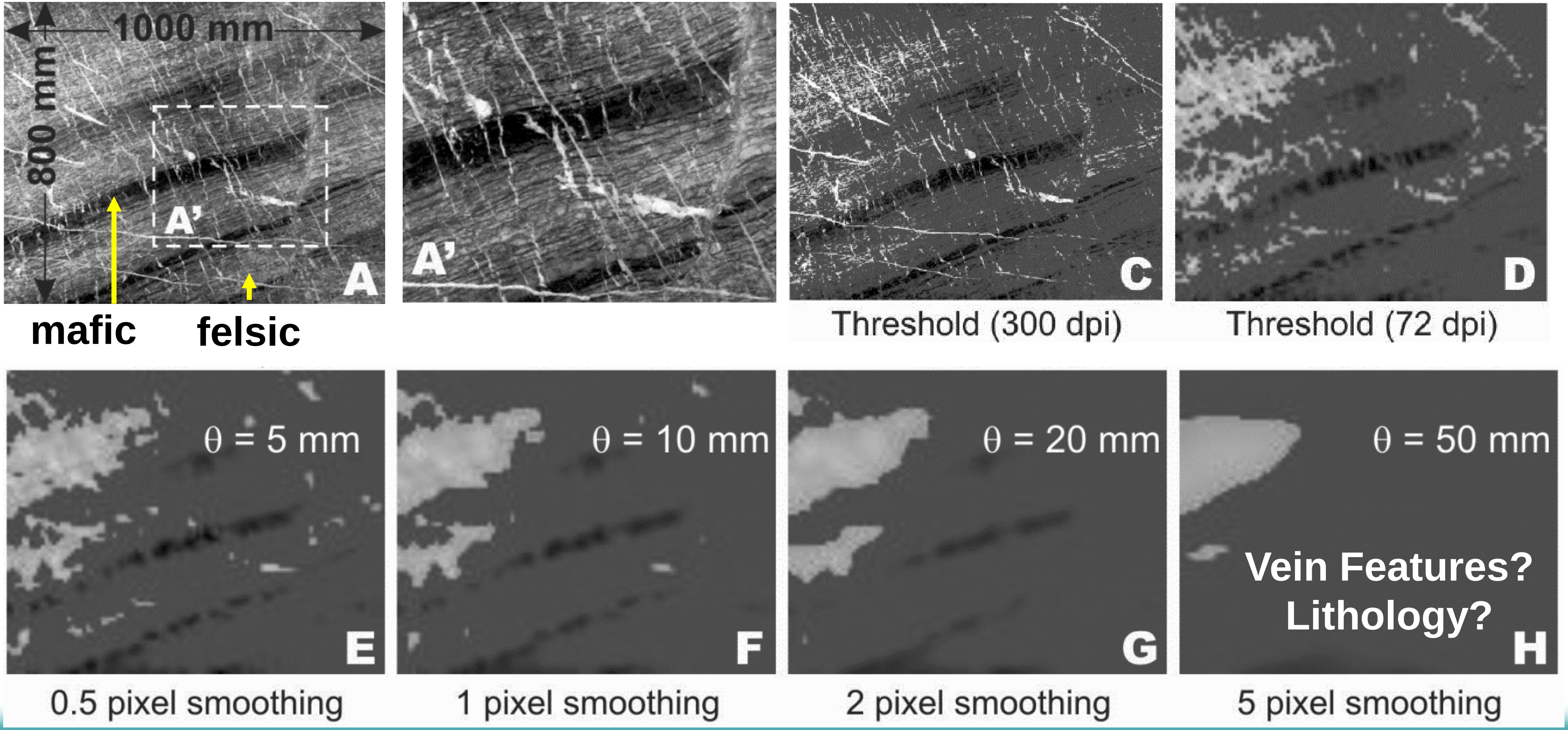
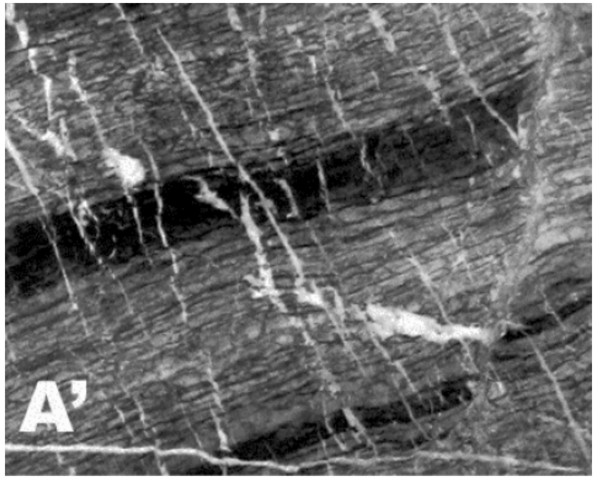
[1]Geotechnical Practice Leader, AMEC, 6001 Rickenbacker Road, Los Angeles, CA 90040; jeff.keaton@amec.com

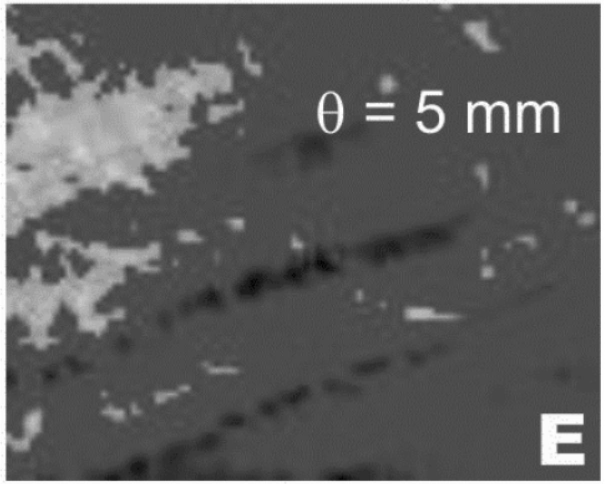
Impact of Gaussian smoothing on geologic details if the geology were considered to be random.



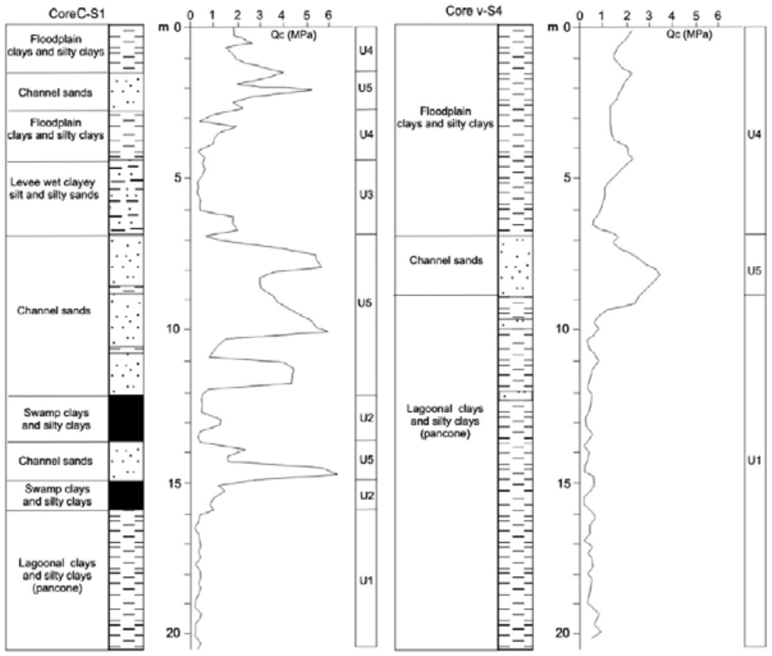
Much relevant **geologic** information is **nonrandom** (e.g., stratigraphy)

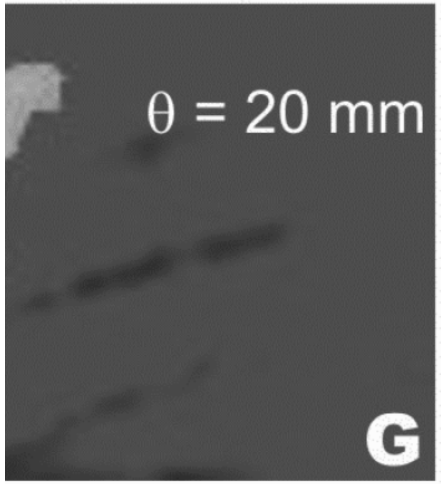


…If geologists do not provide relevant guidance on geologically sensible subdivision of formations, then the engineer will be forced to treat geology as a completely random or unnecessary variable and rely on quantitative field and laboratory test results as a surrogate for geology.



0.5 pixel smoothing





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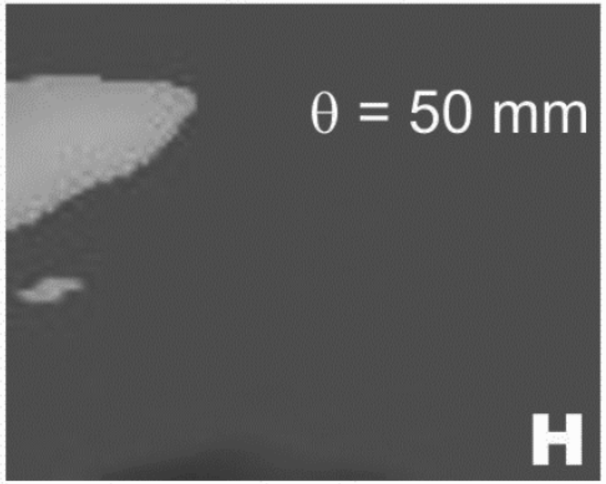
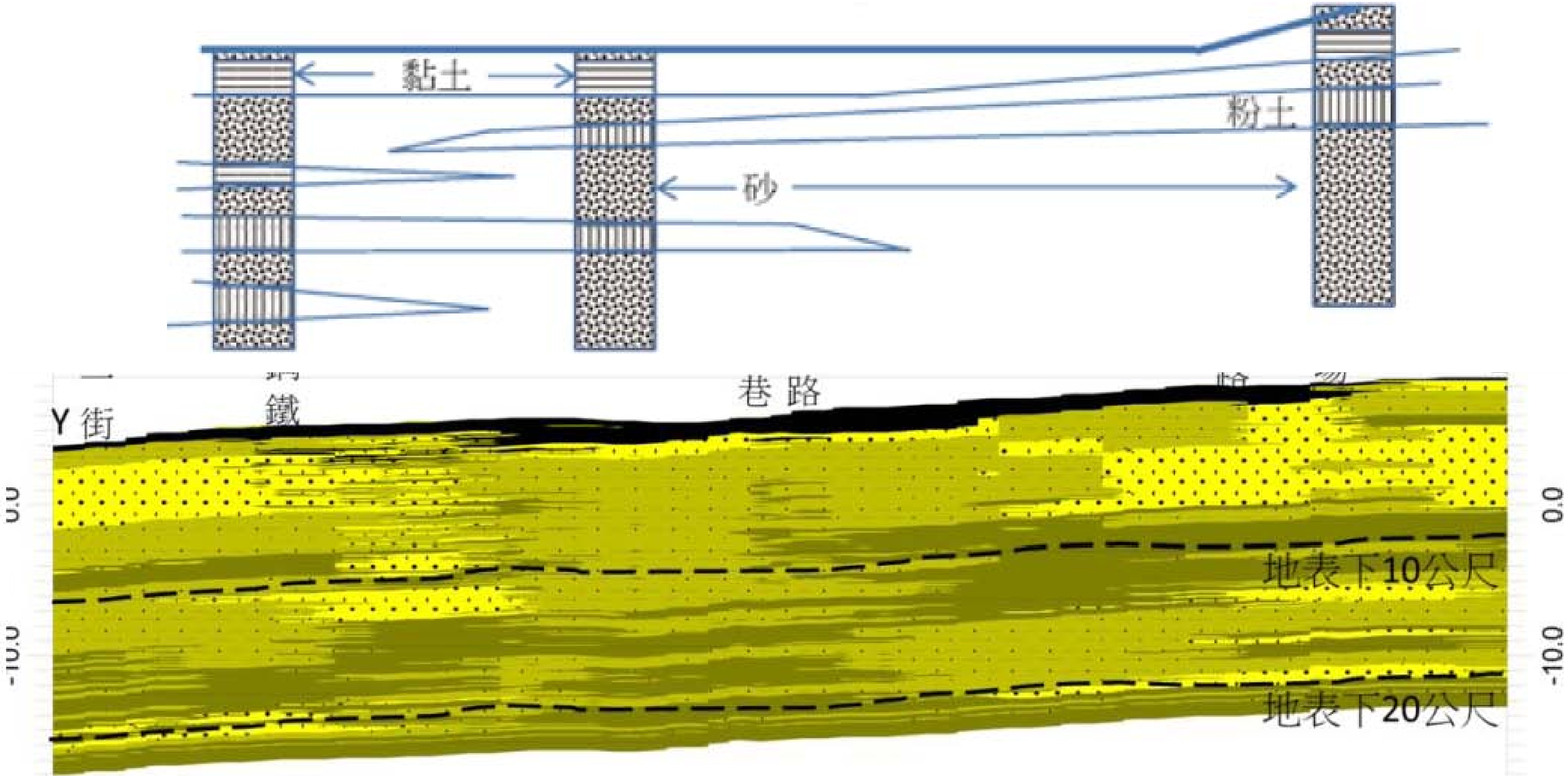


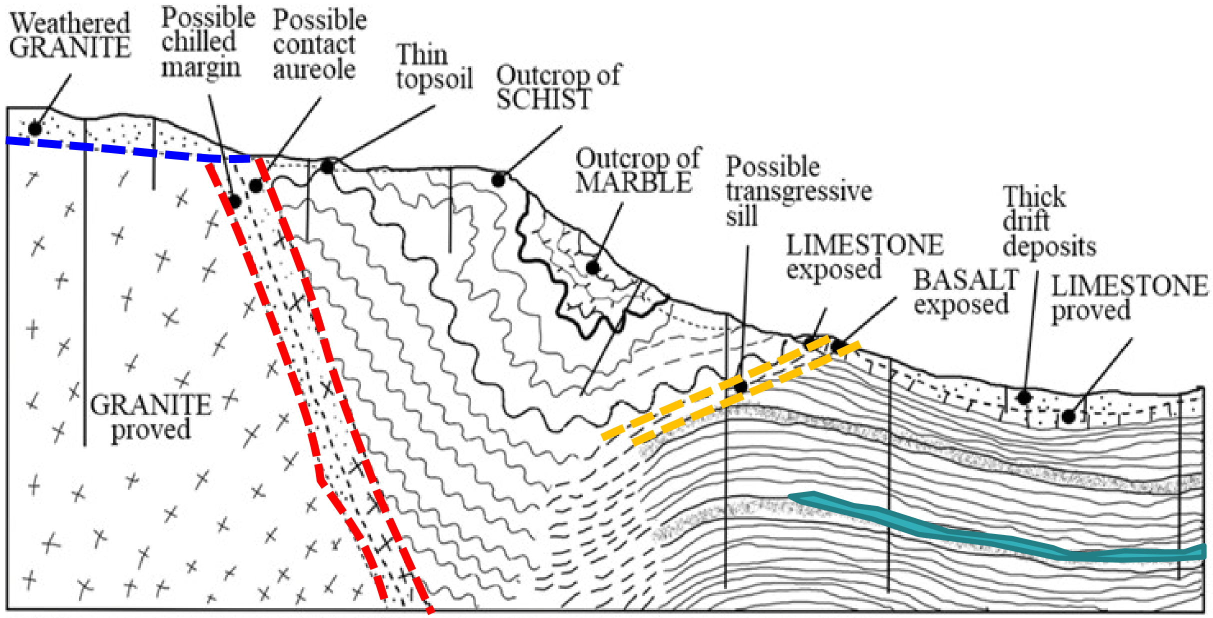
5 pixel smoothing

只看鑽井岩性，未納入地質學知識



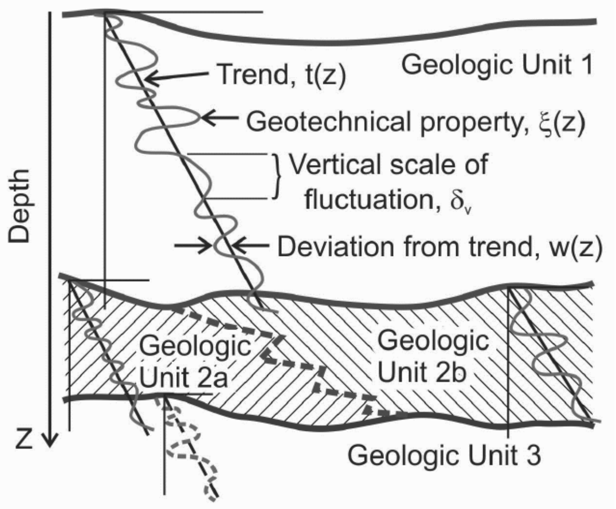
Stochastic modelling using in-situ measured k

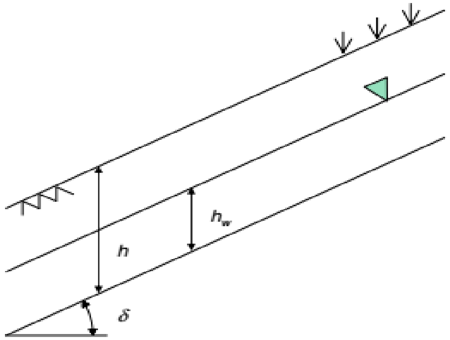
地質學知識對地質模型不確定之影響應被重視

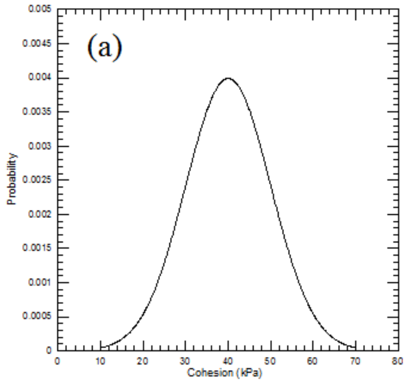


(a) Some potential misinterpretations of geology of (b) from borehole evidence

(after Fookes, 1997)

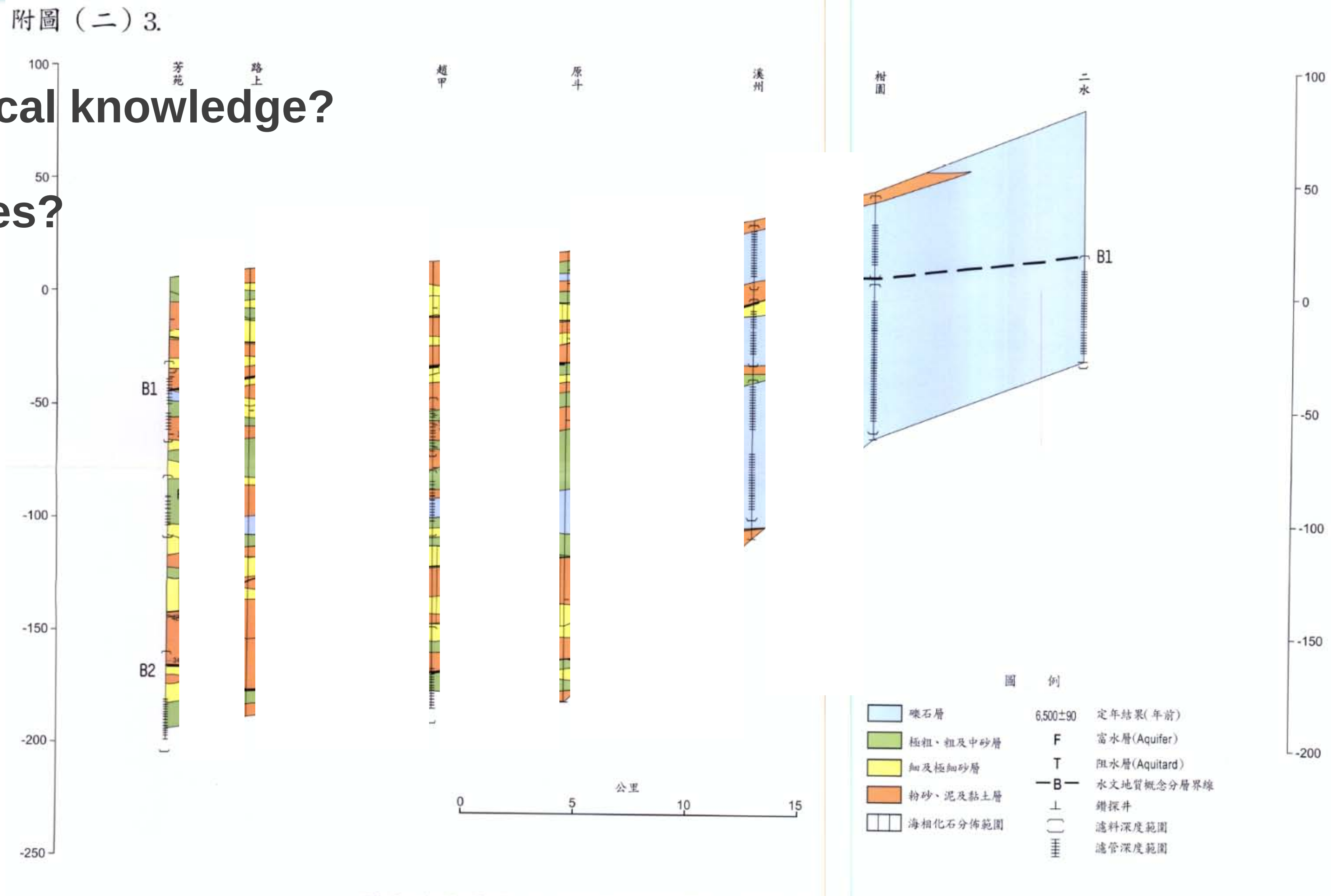






Without Geological knowledge?

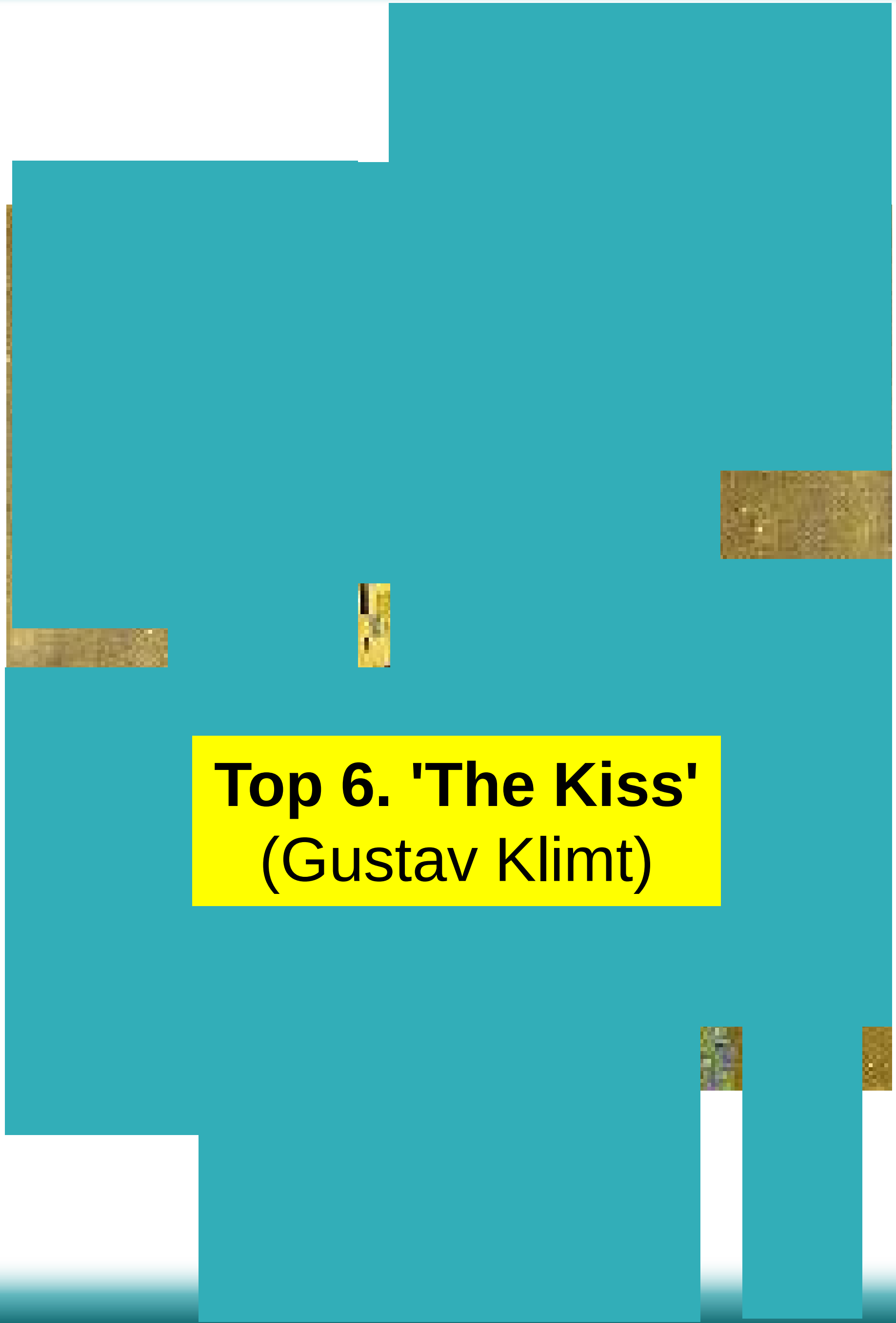
Random Variables?



濁水溪沖積扇水文地質剖面圖三（芳苑—二水）

（經濟部中央地質調查所，1999）


Top 1. “Mona Lisa”
(Leonardo da Vinci)


Top 6. 'The Kiss'
(Gustav Klimt)

The geological knowledge can reduce the GM uncertainty

- 開小視窗，無從得知圖案 (調查點密度)
- 若知其為名畫?孟克的畫? (地質學知識)
- 若不確定時讓你開視窗，你要開哪裡? (調查方法與位置)
- 越有經驗的人、越了解一個地區、越適合擔任調查與資料解釋者
- 施工中...視窗大開 (施工中調查)

利用評分系統量化地質模型變異係數

Keaton and Munro (2019)
將區域尺度因子合為一項

地質不確定性評分影響因素		評估準則與評分			
		3分	9分	27分	81分
區域尺度地質複雜程度	原生作用-沉積/置換(火成作用)	條件單純、均質	大致單純、可預測	有些複雜、大致可預測	高度複雜且變異性高
	次生(後成)作用-構造作用與變形	推測無斷層或褶皺	一期地質事件影響、斷層褶皺數量規模有限	兩期地質事件影響、斷層褶皺數量規模有限	多期地質事件影響、有重要斷層或褶皺
	次生(後成)作用-蝕變/溶解	地質條件顯示不太可能發生	地質條件顯示有可能發生	地質條件顯示很有可能發生	已發生/有既存事實
	次生(後成)作用-風化/侵蝕	均勻風化剖面、侵蝕作用輕微	規則之侵蝕剖面、輕度侵蝕作用	不規則之侵蝕剖面、中度侵蝕作用	高度不規則之侵蝕剖面、侵蝕作用顯著，有埋沒谷現象
場址尺度的地質複雜程度		工址地層於垂直及側向延伸均勻	工址地層延伸具規則性	工址地層延伸不具規則性	工址地層延伸具高度不規則性
場址地區/地形特徵		有些許高差、露頭情況良好	有些許高差、露頭情況尚可	地形高差大、露頭情況差	植披密布、非常少或非常糟之露頭
資訊品質		具有各種來源之大量地質調查資料	僅有來自少量來源之有限地質調查資料	僅有初勘資料	僅有蒐集所得地質資料
地質師能力		專業地質師且具有當地地質調查經驗	專業地質師然僅具不同地質條件地區之調查經驗	地質系畢業生或曾受野外地質調查練	未接受過地質教育、或是無野外地質調查訓練資歷
準備地質模型時間		充足時間，地質解釋充分完整	充足時間，地質解釋思考周到	時間不充足，然地質解釋思考周到	時間不充足；地質解釋思考倉促、粗糙

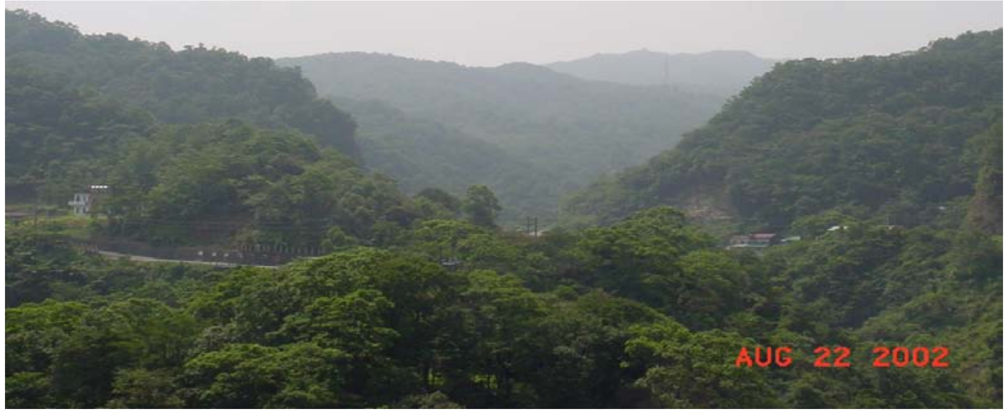
(after Keaton 2013)

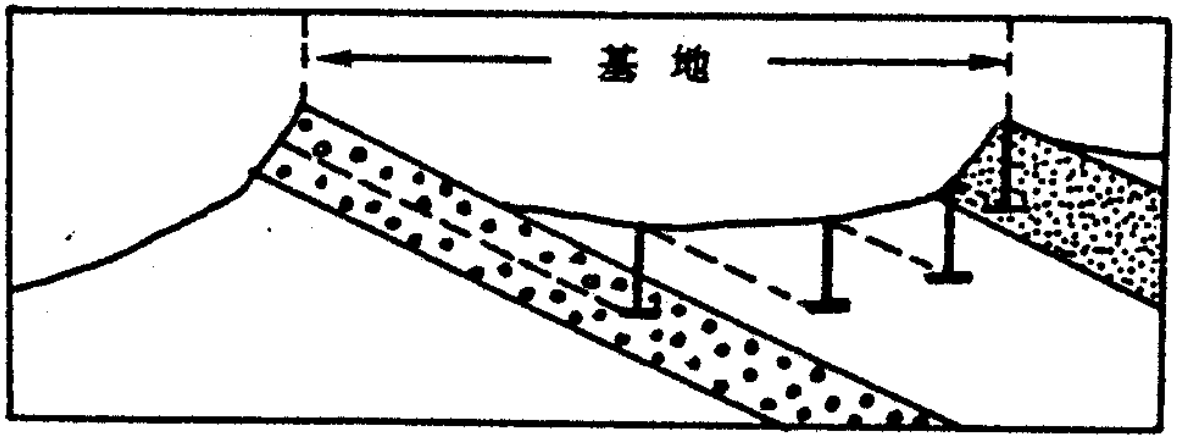
COV= (GMCRS得分) / (GMCRS最高得分)

地質學知識：Exploration Versus Investigation

Exploration Versus Investigation

It is common for engineers and geologists to use the term "exploratory" for geotechnical borings or subsurface investigations. The FHWA guidance (Mayne et al., 2002) uses "subsurface investigation" in its title, but also uses "subsurface exploration" in a first-order heading. "Exploration" refers to the process of searching for the purpose of discovery; the term implies lack of expectation of what might be discovered.





USACE (2001): …subsurface investigations should begin only after a geologic model is constructed. …geotechnical borings should be drilled at locations that are useful for testing and refining the geologic model hypotheses…

R. E. Goodman, 2003, Karl Terzaghi and engineering geology, in Geotechnical Engineering, Ho & Li (eds)

- "In order to get a **maximum of information out of a minimum amount of drilling and digging**" **he wrote in 1928**, "it is first of all necessary to get a **clear conception of the geological history of the dam site**. If this history of a locality is known, a tentative geological profile can be constructed."

'. . . if you do not know what you should be looking for in a site investigation, you are not likely to find much of value'

(Glossop 1968)

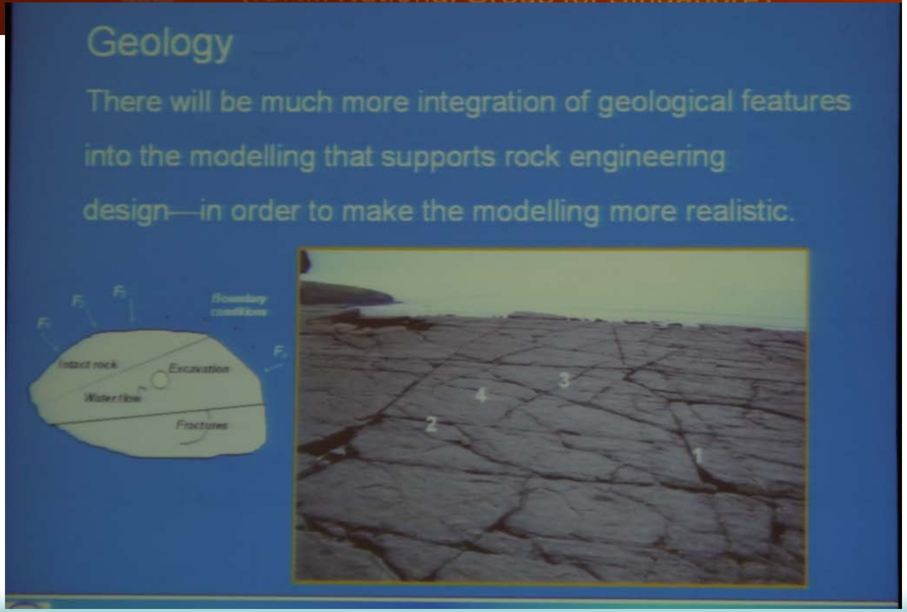
R. E. Goodman, 2003, Karl Terzaghi and engineering geology, in Geotechnical Engineering, Ho & Li (eds)

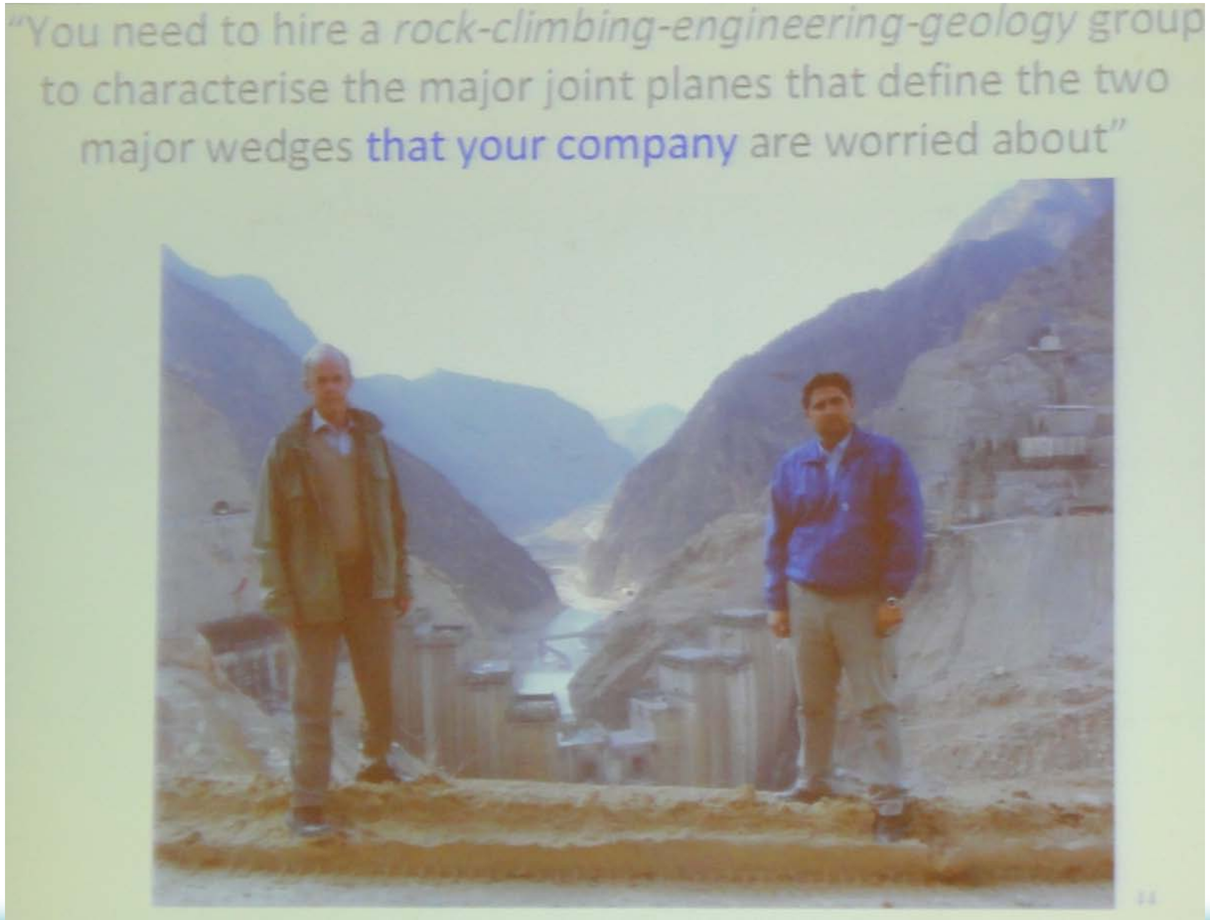
- **…soil mechanics and engineering geology "supplement each other".**
- "In my own practice [which then covered half a century and four continents], I have **never encountered a major engineering problem which could be solved either by geology or by soil mechanics alone**. The solution always required both domains".[4]

[4] **From the opening lecture for Engineering Geology by Karl Terzaghi at Harvard Univ., reprinted by Toshinobu Akagi, in his article " I can hear it now Terzaghi and Peck", Proceedings of the Conference on Developments in Geotechnical Engineering, 27-30 November 2000, Bangkok, Tailand, pp.401-405.**

I always worked with engineering geologists…

J.A. Hudson





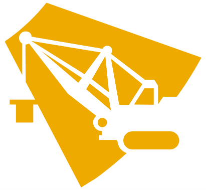
N. R. Barton

Incorporating the geological knowledge into ground model and geotechnical model.

R. E. Goodman, 2003, Karl Terzaghi and engineering geology, in Geotechnical Engineering, Ho & Li (eds)

Terzaghi practiced engineering geology not as a professional geologist but as civil engineer who took his responsibilities seriously and saw geologic investigations and geologic thinking as very necessary steps in achieving *wise engineering solutions*.

Engineering Geologist



Civil Engineer

R. E. Goodman, 2003, Karl Terzaghi and engineering geology, in Geotechnical Engineering, Ho & Li (eds)

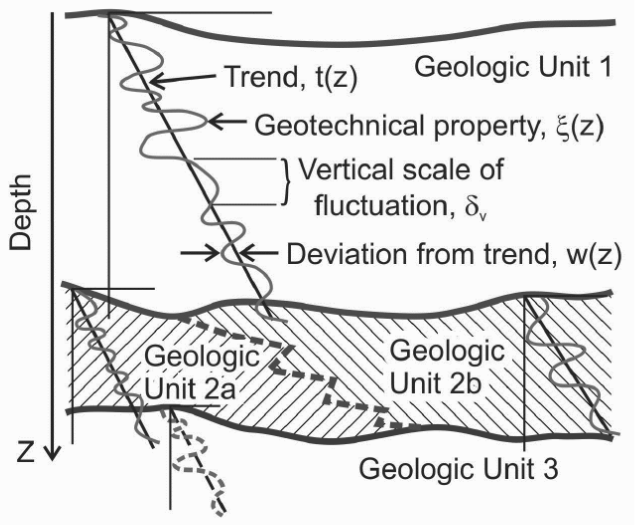
- He warned that **unforeseen structural, morphological**, or **hydrological details** might otherwise **endanger a design**.
- A fine observer of nature, he tried to understand the geology of his sites and became an artist in **adjusting his design to geological realities and uncertainties**.

After almost one century…

How Do Engineers Use Geologic Maps? --- **Keaton (2013)**

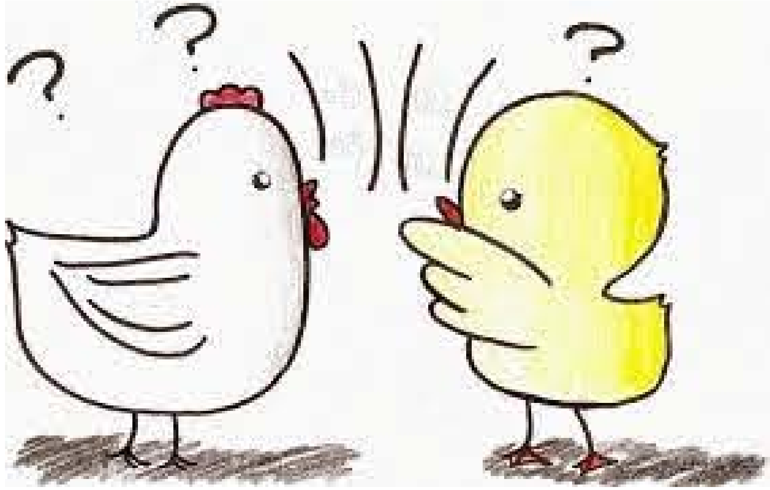
Traditional geologic maps tend to be used by engineers in one of three ways:

1. Geologic boundaries **are accepted as deterministic** truth**; geologic units guide geotechnical characterization based on subsurface data and laboratory test results.**
2. **The overall range of geologic conditions on a site is estimated and somehow applied to a site as a** single random variable with design **dominated by quantitative** geotechnical data**.**
3. The geology is ignored**** and quantitative subsurface geotechnical data are used as a surrogate for stratigraphy. (*The geology is neatly tucked away in an appendix to document that it was done, in the event that a reviewer asks about it.)**



為什麼會這樣?

- 溝通不良??!!

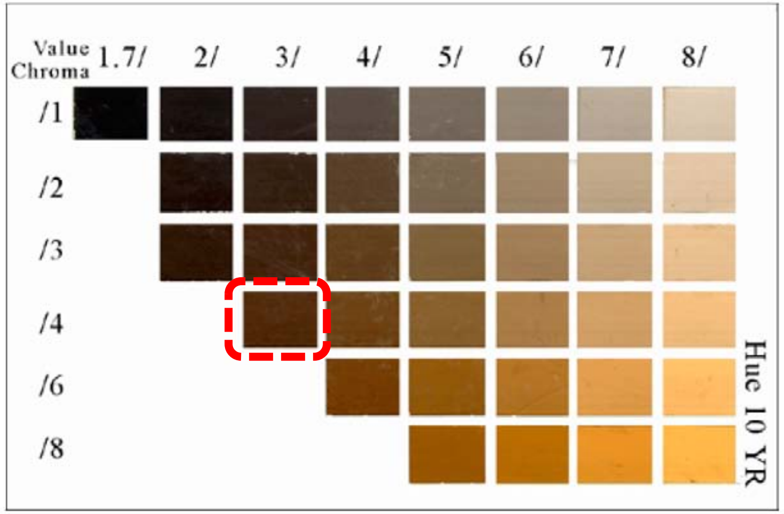


https://memes.tw/image/1172

Engineer and geologist on their way to a field site. The engineer is frustrated at not being able to get a straight answer from the geologist. The engineer driving the car sees an isolated, brown cow is standing. The engineer realizes that this setting provides an opportunity to ask the geologist a question so simple that the geologist might give a straight answer.

- **Engineer: ."I am going to ask you a simple question about that cow in the pasture ahead.."**
- **Geologist: ."Okay.."**
- **Engineer: ."What color is that cow?."**
- **Geologist: ."The color of that cow looks like 10YR 3/4.."**
- **Engineer: ."What?!."**

Standard soil Color Charts



Communications between Geologists and Engineers!

Engineering Geology: Fundamental Input or Random Variable?

Jeffrey R. Keaton[1], P.E., P.G., F.ASCE

…Geologists and engineers view the world in complementary but different ways. Science seeks to explain all observed details, whereas engineering seeks to design with specific objectives and multiple constraints. …

Table 1. Selected contrasting elements of science and engineering.

Geological Science	Engineering Design
Qualitative, observational	Quantitative, data-driven
Largely interpretive	Focused on specific design objectives
Site viewed as part of geologic region	Site viewed as discrete location
Seeks to explain geologic details	Focused on multiple project constraints
Seeks to predict distribution of formations	Seeks to satisfy specific design requirements

地質資訊之轉譯

- Terzaghi (1929) realized how important it was to .“start with a clear conception of the physical factors which are likely to endanger.” a project and then .“translate the terms of the geologist into terms of physics.”. The results of these two elements, conception and translation, essentially comprise a Geologic Model and perhaps a Ground Model, also. The .“practical conclusions.” that must be drawn can be associated with the Geotechnical Model.
- 地質學家需要清楚**概念化**所有可能**危及工程計畫之物理因子**，然後**將地質術語轉譯為物理術語**。概念化和轉譯這兩個要素對建立**地質模型與地面模型**均相當重要，調查所得最後之結論必須**與大地工程模型相關聯**。

地質知識需要轉譯為工程規設所需資訊

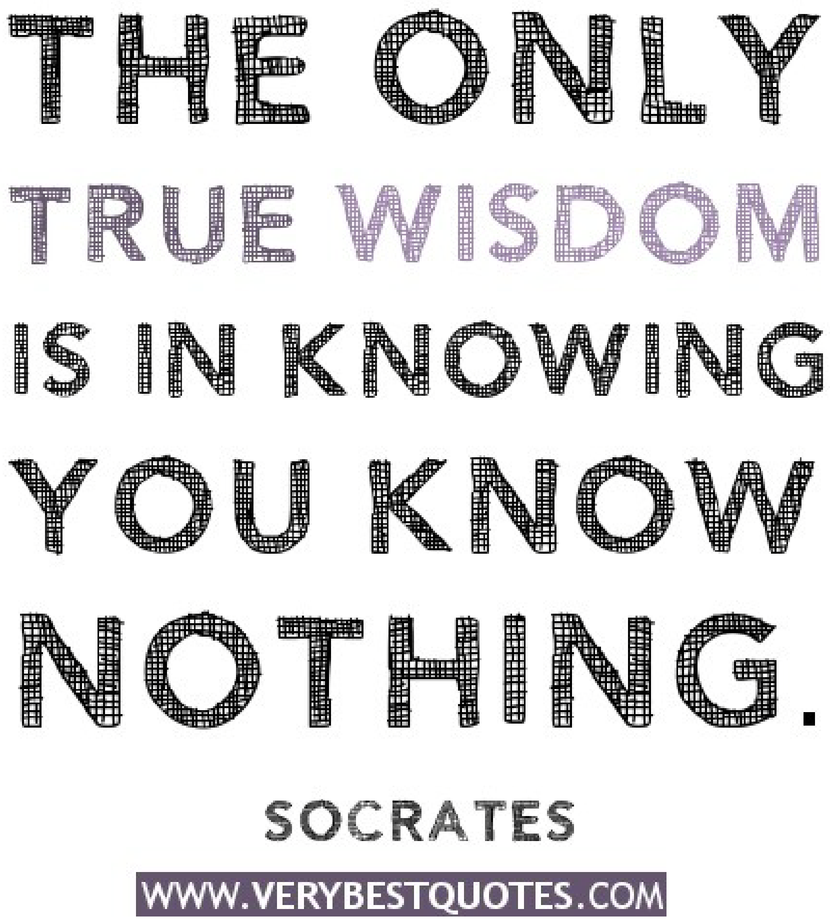
- Varnes (1974, p. 42) recognized that .“As computer technology becomes increasingly employed in geologic science and operated by specialized personnel, we may find that if the practicing field professional fails to define both his [or her] words and the concepts they represent, then they may, through necessity, be defined by people whose principal business is the processing of data..” Similarly, engineering geologists must transform geologic maps to quantify uncertainty and variability or risk being marginalized by computer scientists and statisticians who will translate the geology using random field theory without knowledge of geologic principles.
- **隨著電腦在地質科學的應用越來越廣泛，並由資訊專業人員進行操作，我們可能會發現，如果地質專業人士無法清晰的定義地質專業術語與地質概念，這些地質資訊將被資料分析者定義。同樣的道理，工程地質學家必須量化地質圖之不確定性和變異性，否則，地質圖所呈現之資訊將被資訊處理專業人員或統計學家使用隨機場理論進行風險量化，而不含任何地質原理。**

Conclusions

Lumb (1972 quoted in Kulhawy, 2010) stated:

"Ignorance of soil behaviour is always regrettable but not necessarily reprehensible, provided that ignorance is recognised and advice sought where necessary, but ignorance of being ignorant can no longer be condoned."

The same can be said for ignorance of engineering geology.



地質師的角色–

和使用者(工程師)溝通地質模型不確定性

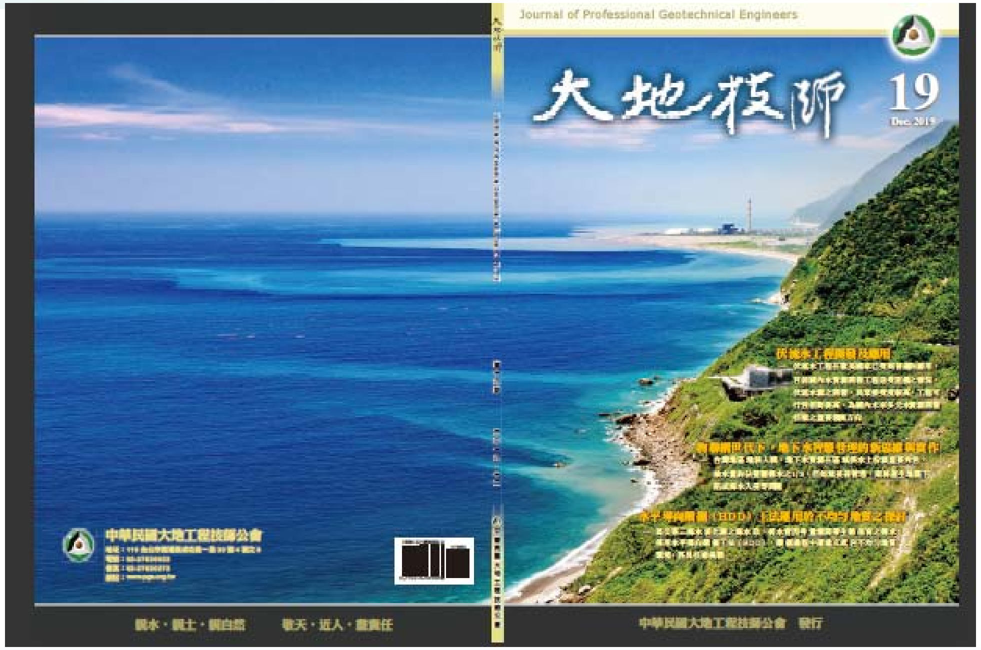
- 地質(模型)重要的特徵是**不確定性 (uncertainty)**
- 地質師在傳遞資訊給工程師時，必須把地質模型的不確定性一併交待，使工程師得以做出恰當的工程判斷與設計(以**風險為基準**的決策)

工程漫談

知之為知之，不知為不知，是知也：淺談地質模型不確定性

董家鈞 國立中央大學應用地質研究所 / 教授

子曰：「由！誨女知之乎？知之為知之，不知為不知，是知也」(為政第二)。



九、結論與建議

1. 地質模型不確定性為地質與工程溝通重要工具。地質師應盡可能質化或量化地質模型之不確定性種類、發生原因以及不確定性程度，工程師則需嘗試質化或量化上述不確定性對土木工程規劃、設計、施工、營運之影響，特別是對工程預算編列與工期掌握之影響。這樣的觀念若能轉化為具強制性之規範，方能減少工程失效之發生機率，降低人民之生命財產損失之風險，並對臺灣社會、經濟、環境發揮正面之影響力。而不是每每於產生重大災害後將責任推給台灣地質複雜，並不斷口號式的強調「地質很重要」。

USGS 地質圖之圖例

USGS
science for a changing world

fgdc
Federal Geographic Data Committee

FGDC Digital Cartographic Standard for Geologic Map Symbolization (PostScript Implementation)

Prepared in cooperation with the Geologic Data Subcommittee of the Federal Geographic Data Committee

科學信心 Science Confidence
(**特性**Identity 與**存在性** Existence)

均**有把握**
(certain)

任一有**懷疑**
(May be questionable)

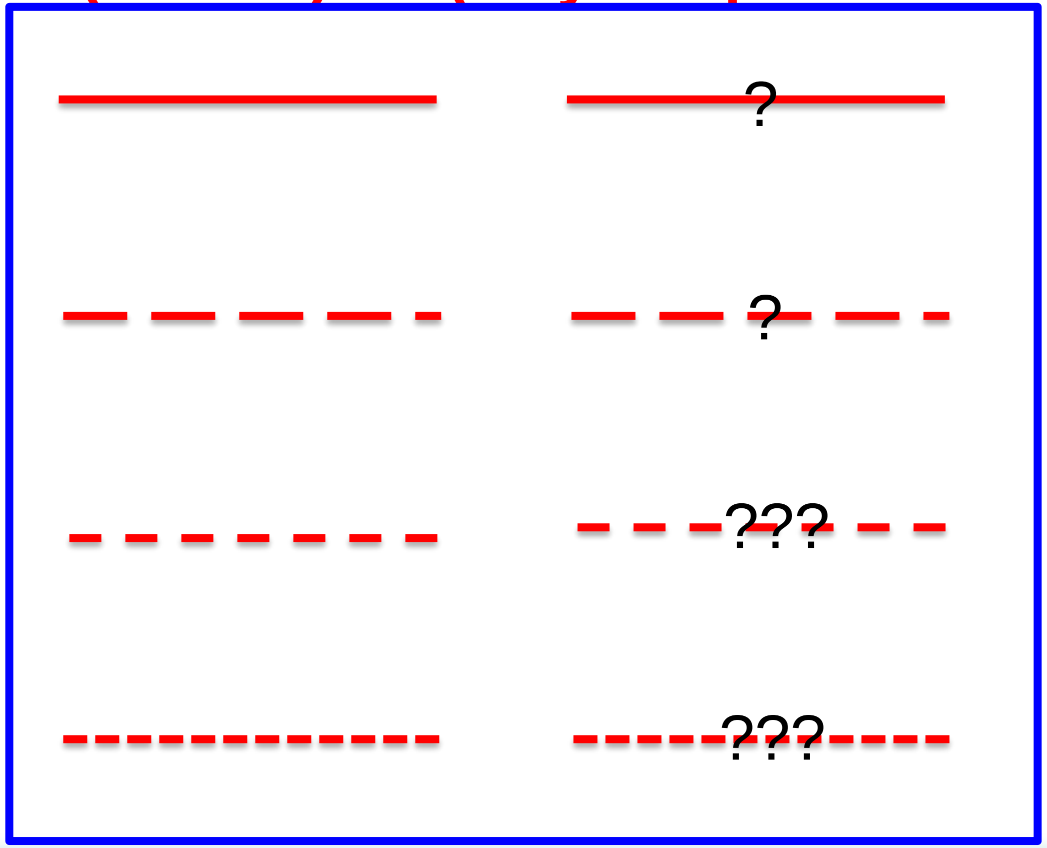
位置
(Location)

準確
(Accurate)

概略性
(Approximate)

推論的
(Inferred)

隱蔽
(Concealed)



有多少把握?

Are you sure?

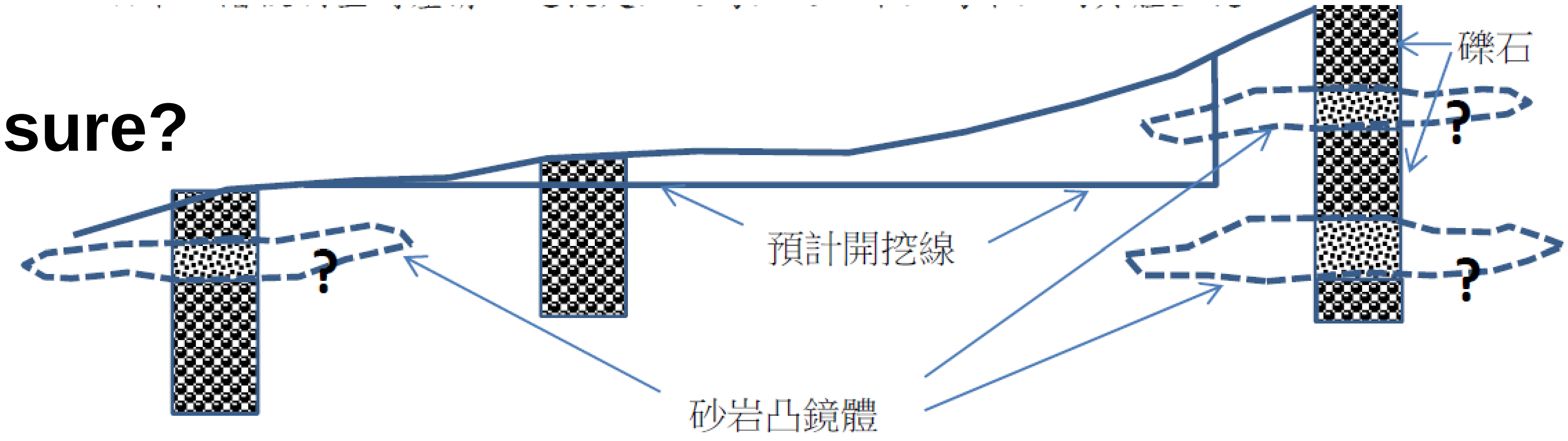
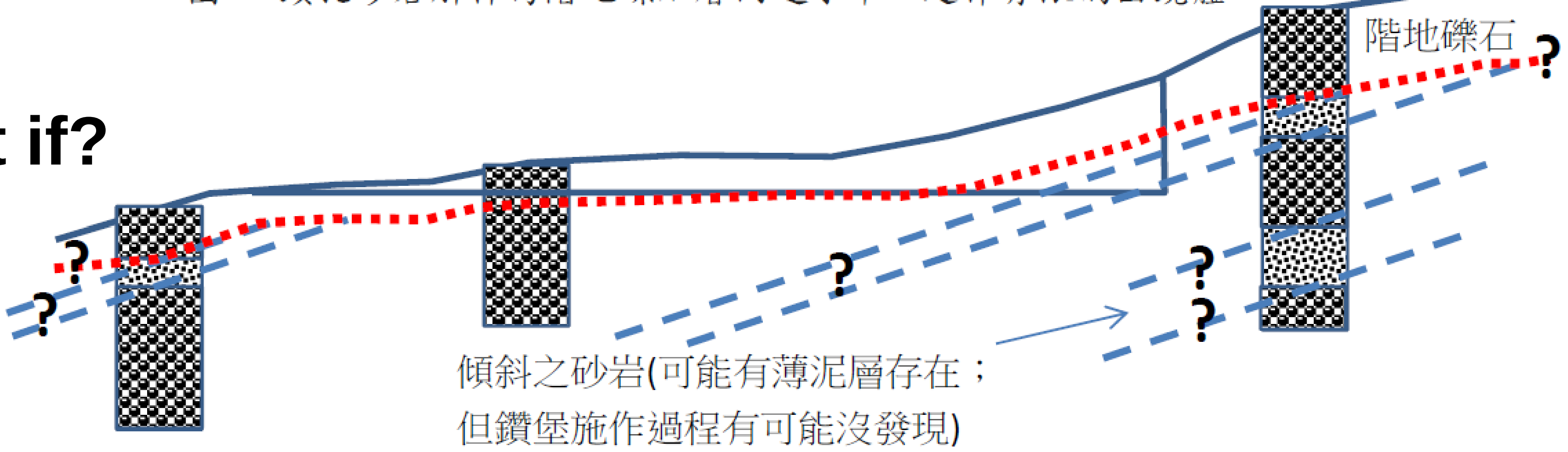


圖4a 鑽孔砂岩解釋為階地礫石層內近水平、延伸有限的凸鏡體

What if?



地質很重要!!

工程師與地質師之間

1. 建立共同語言，以及

2. 促進雙方之了解

非常關鍵

應設法強化雙方之交流與溝通

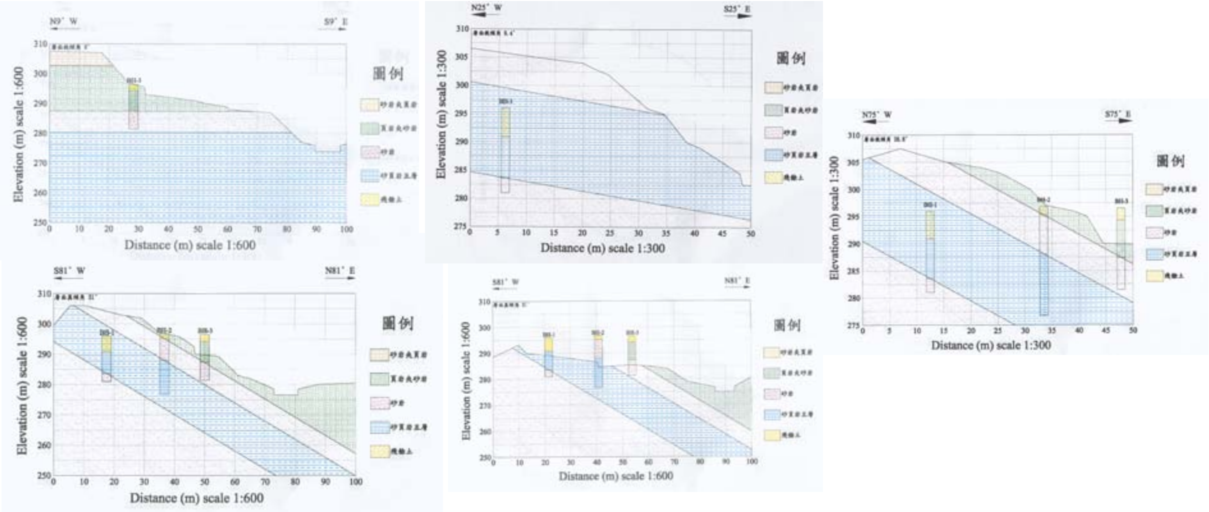
不要怪別人不重視地質、要問自己為了證明地質很重要，做了多少的努力?

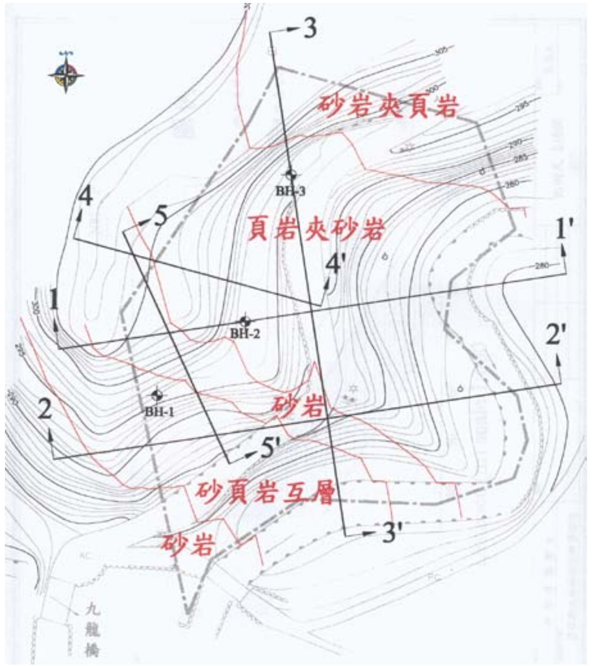
謝謝您的聆聽!

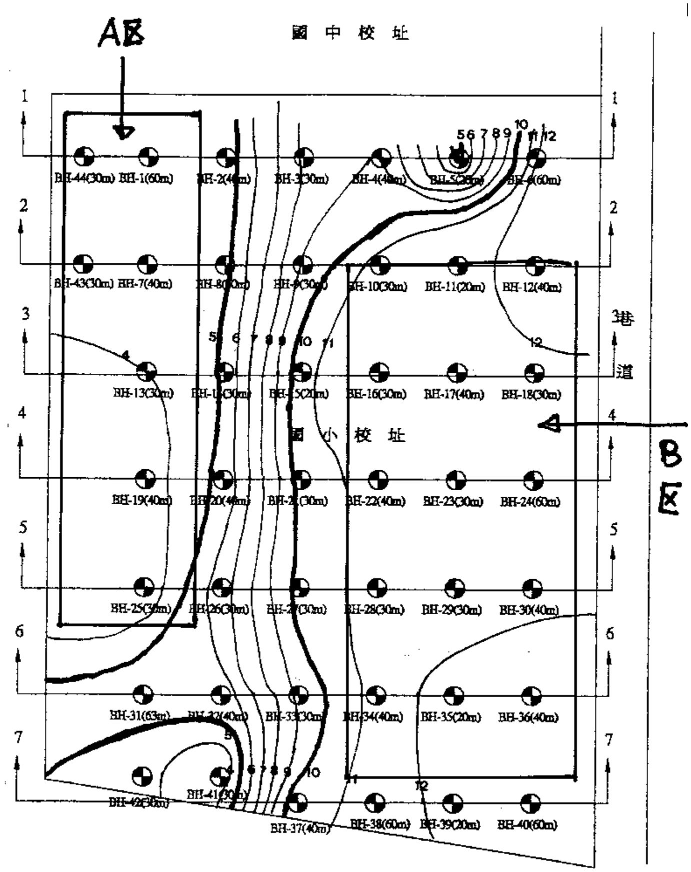
同場加映

三維工程地質模型的重要性

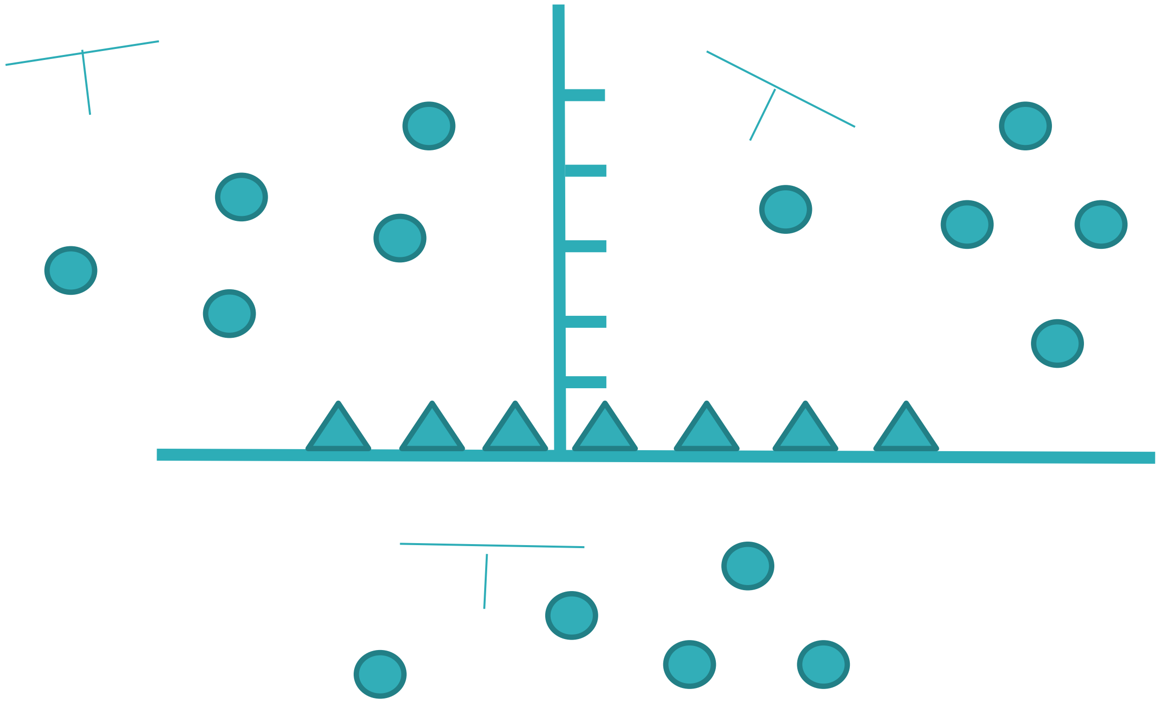
- 鑽孔平行主要構造線、一個基地至少四個剖面
- 填土、崩積層等高線
- 所有整地剖面均需附地質資料
- 三維地質模型!!





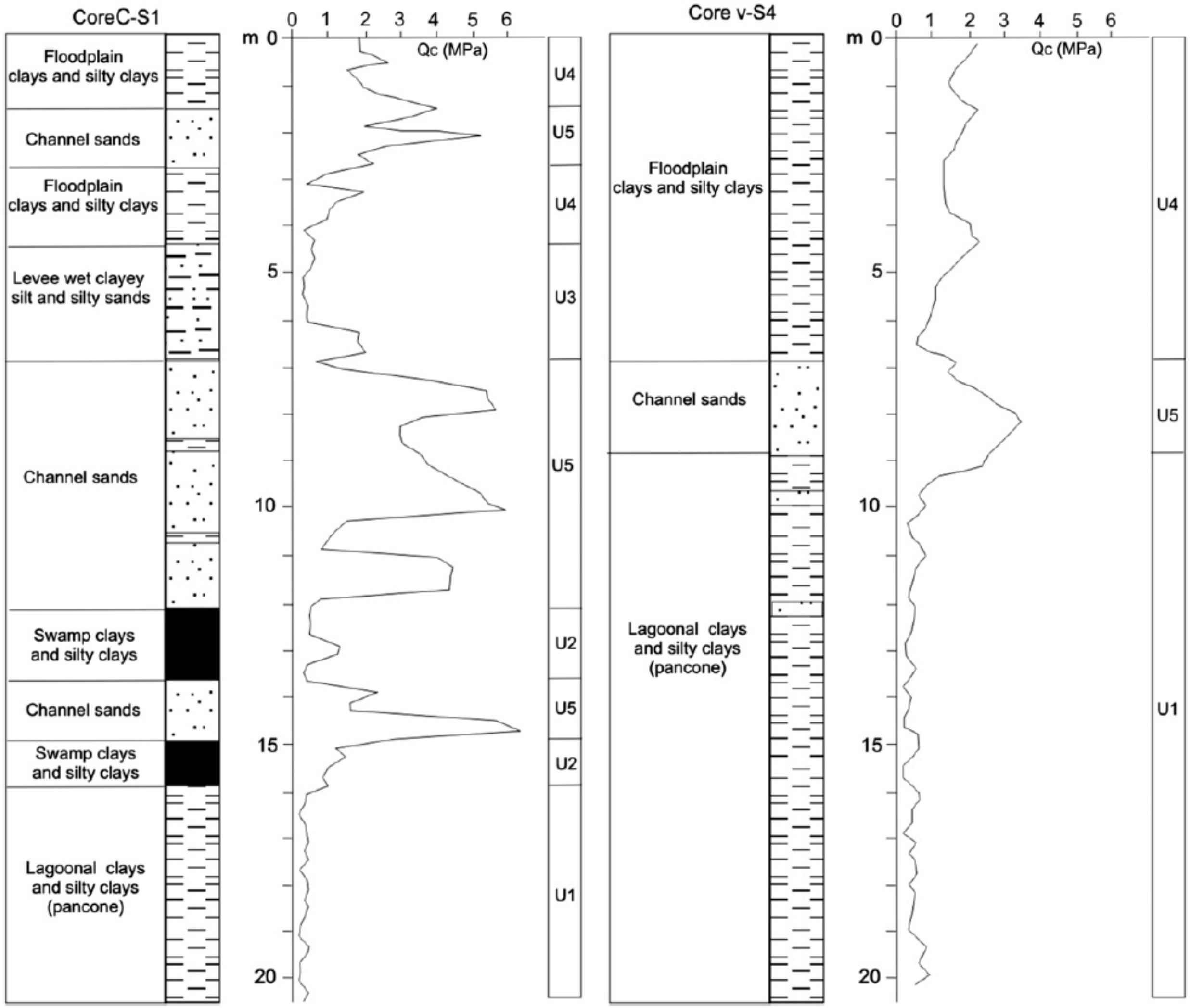


如何建立三維工程地質模型?



岩心判釋與紀錄標準化?

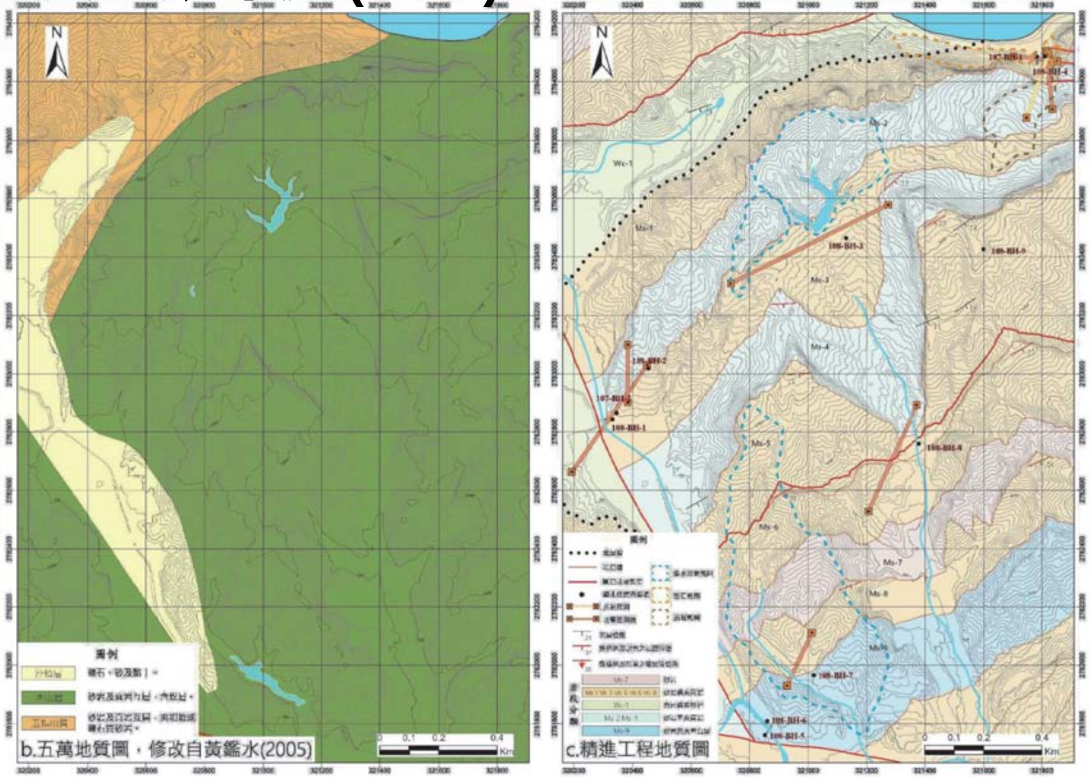
分階段調查
不同人判釋分層
結果有顯著差異



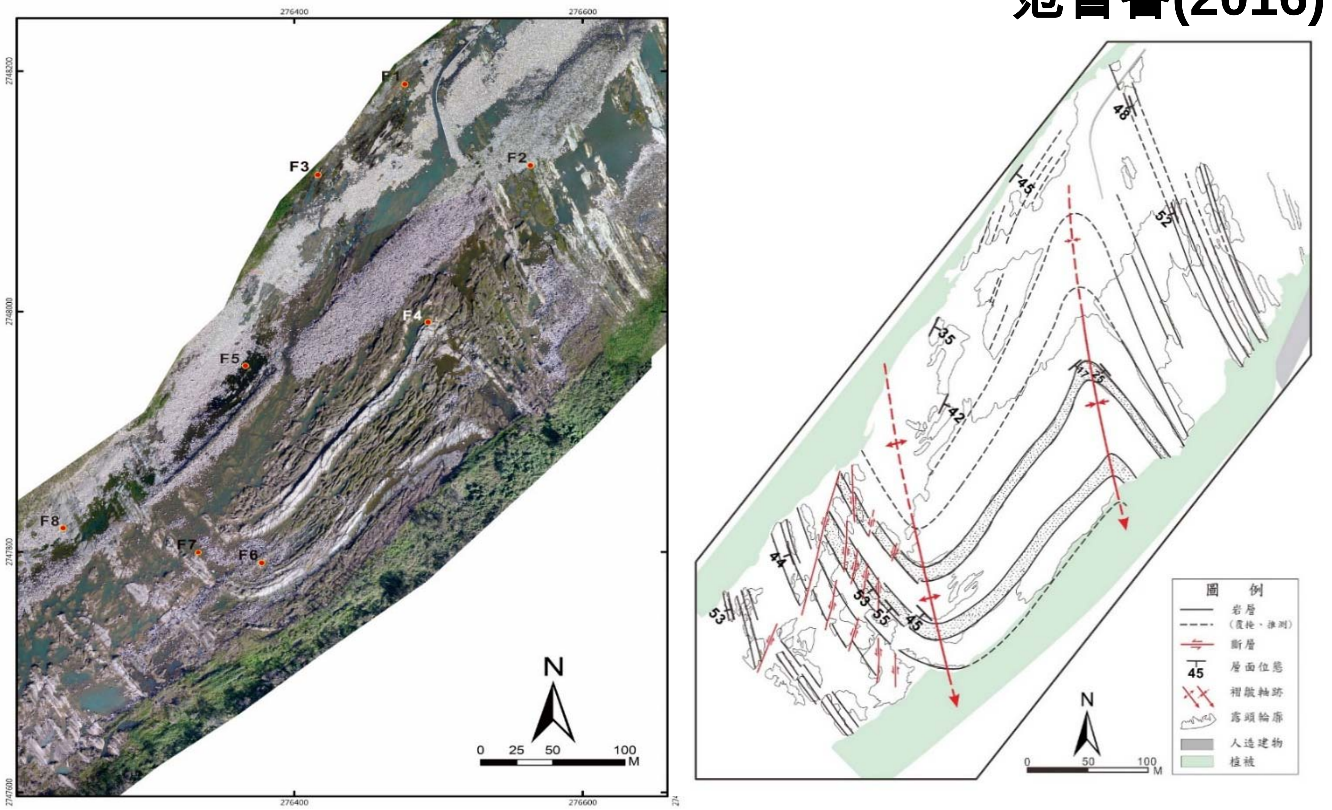
如何降低地質模型不確定性?

- 新科技、新技術(LiDAR、UAV、孔內攝影...)

邱家宏、李彪 (2020)



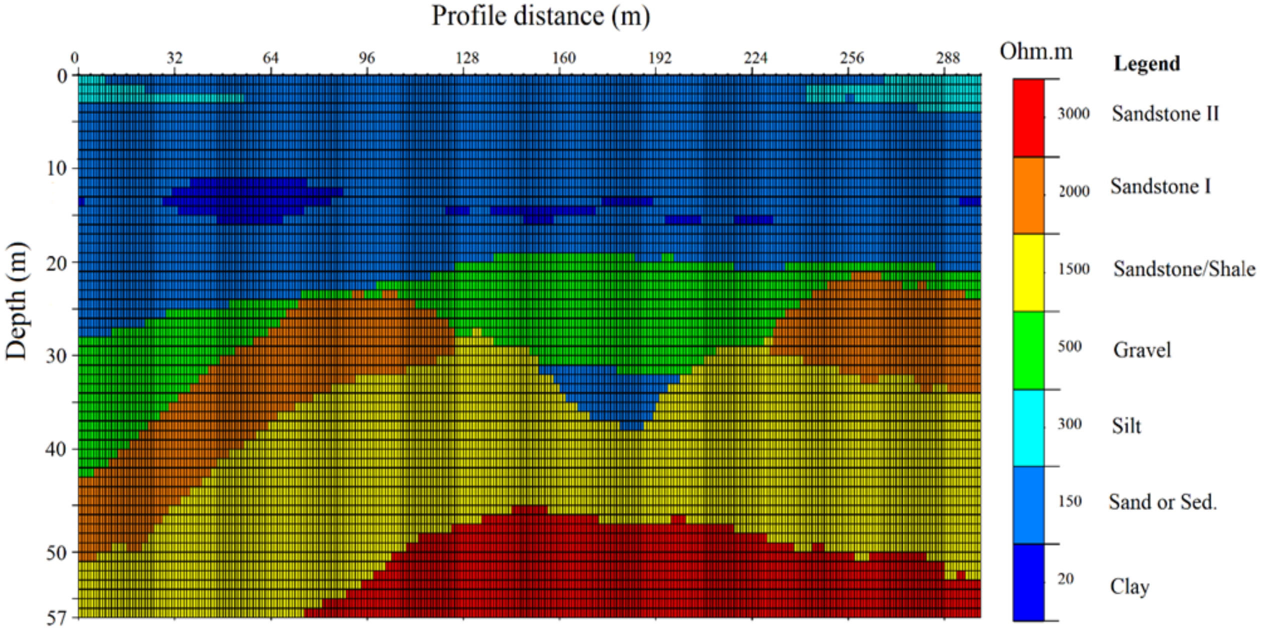
范書睿(2016)



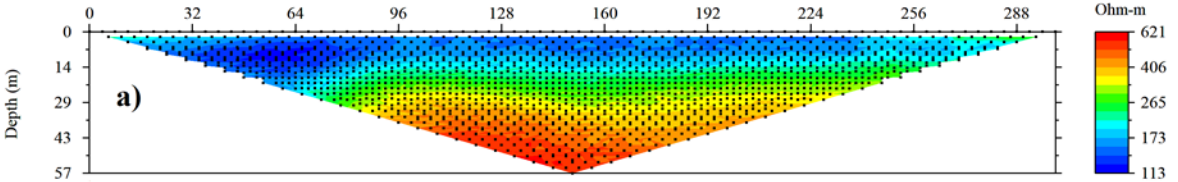
- 地球物理探測技術

先驗知識之重要性(Data driven + Geo-model driven)

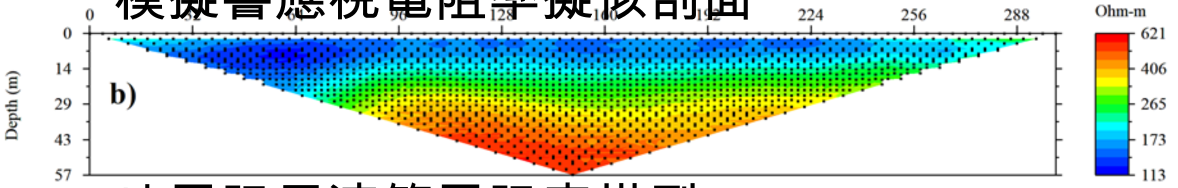
向斜? 若知道有背斜?
低阻是水?若知道有黏土?



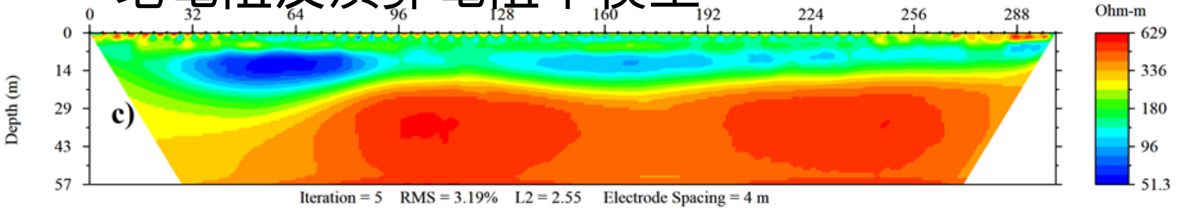
量測的電阻率擬似剖面

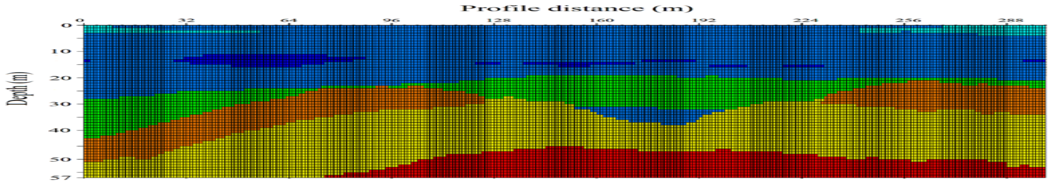


模擬響應視電阻率擬似剖面

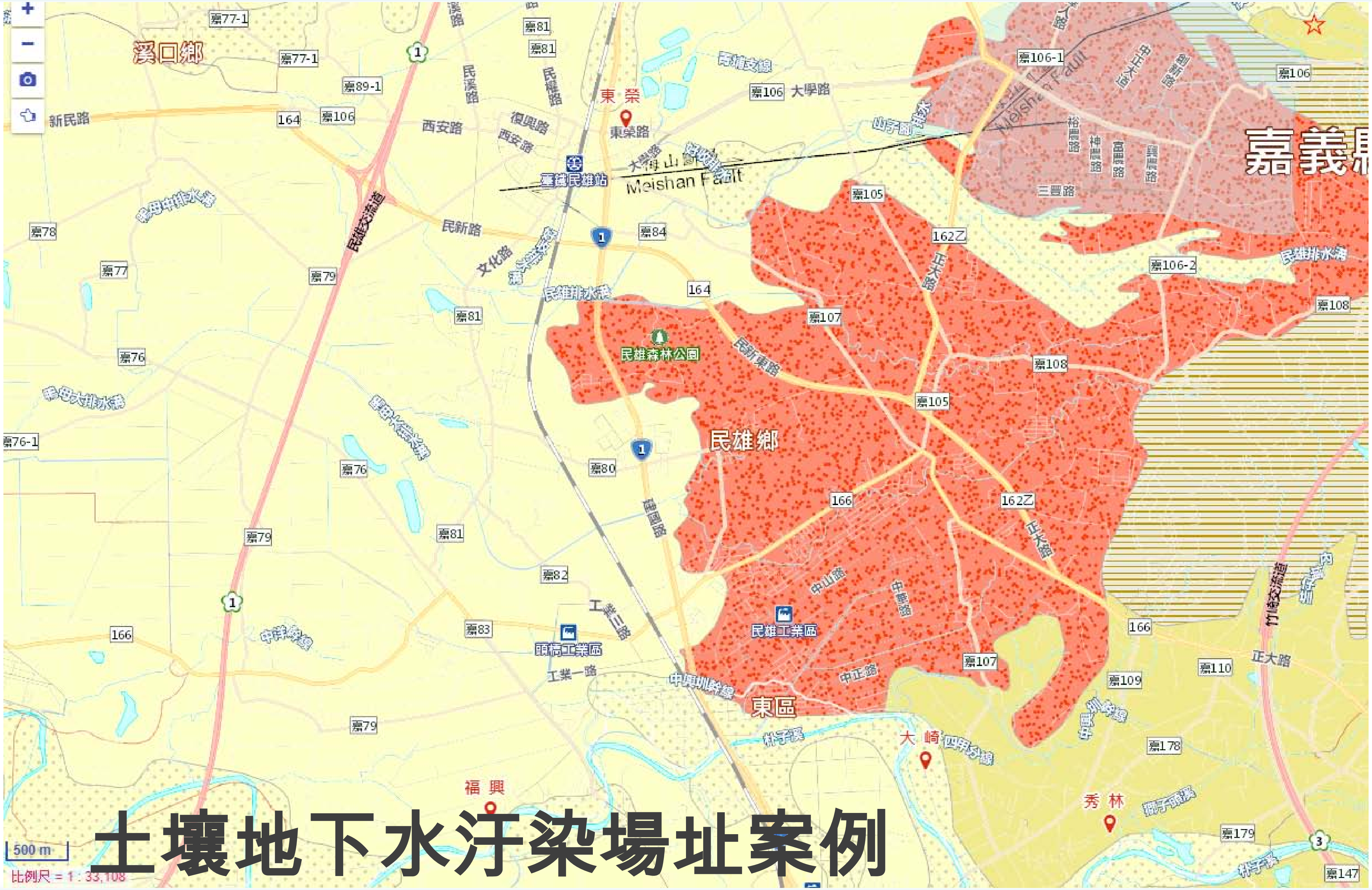


地電阻反演算電阻率模型



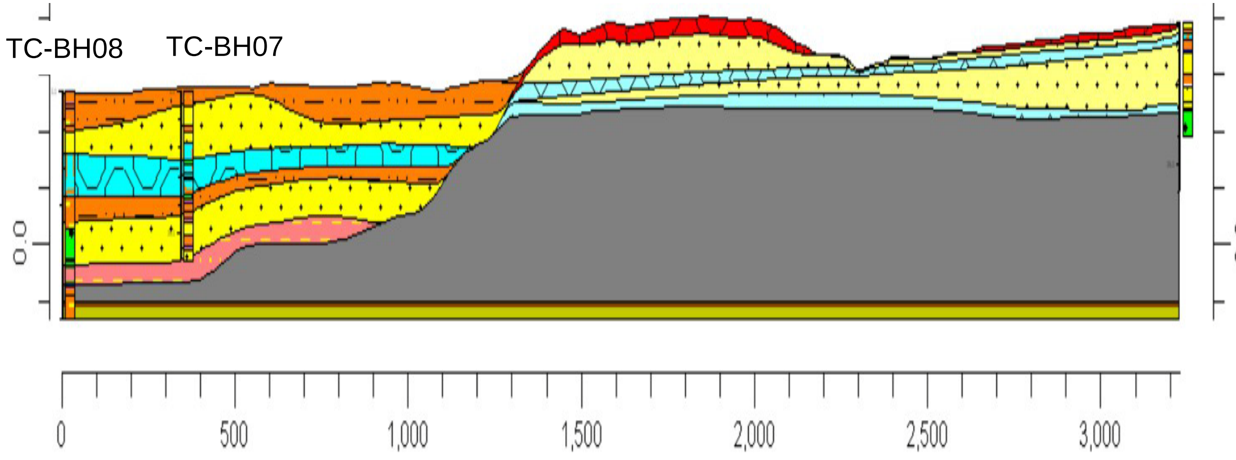


地球物理探測成果之不確定性如何量化?

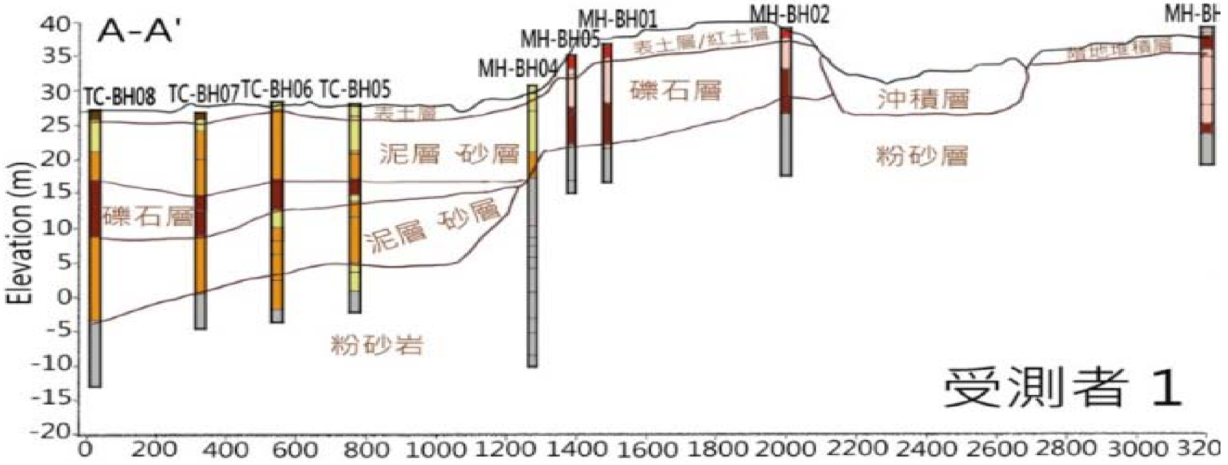


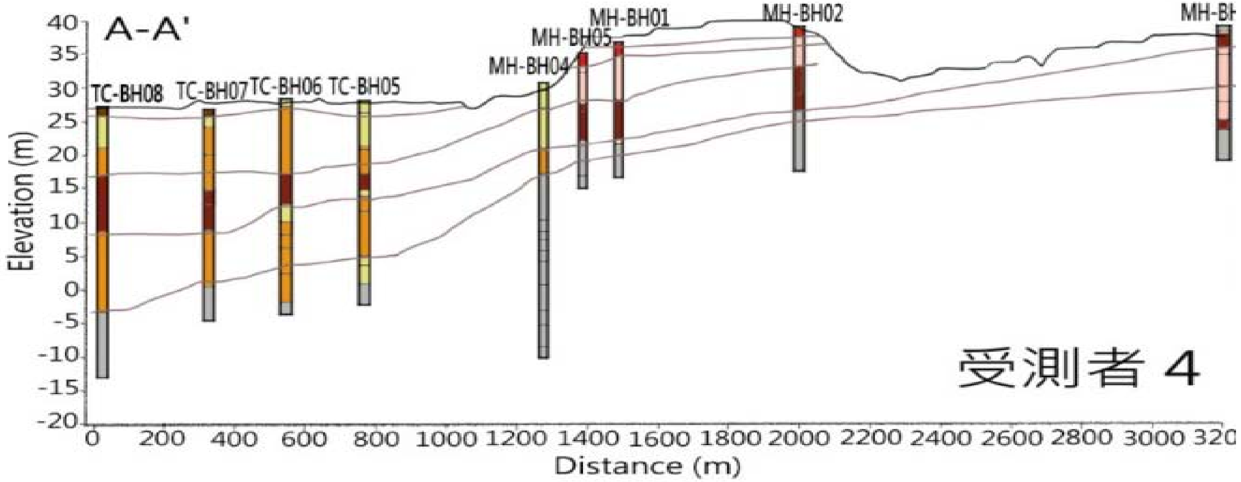
土壤地下水汙染場址案例

Geological interpretations by different geologists

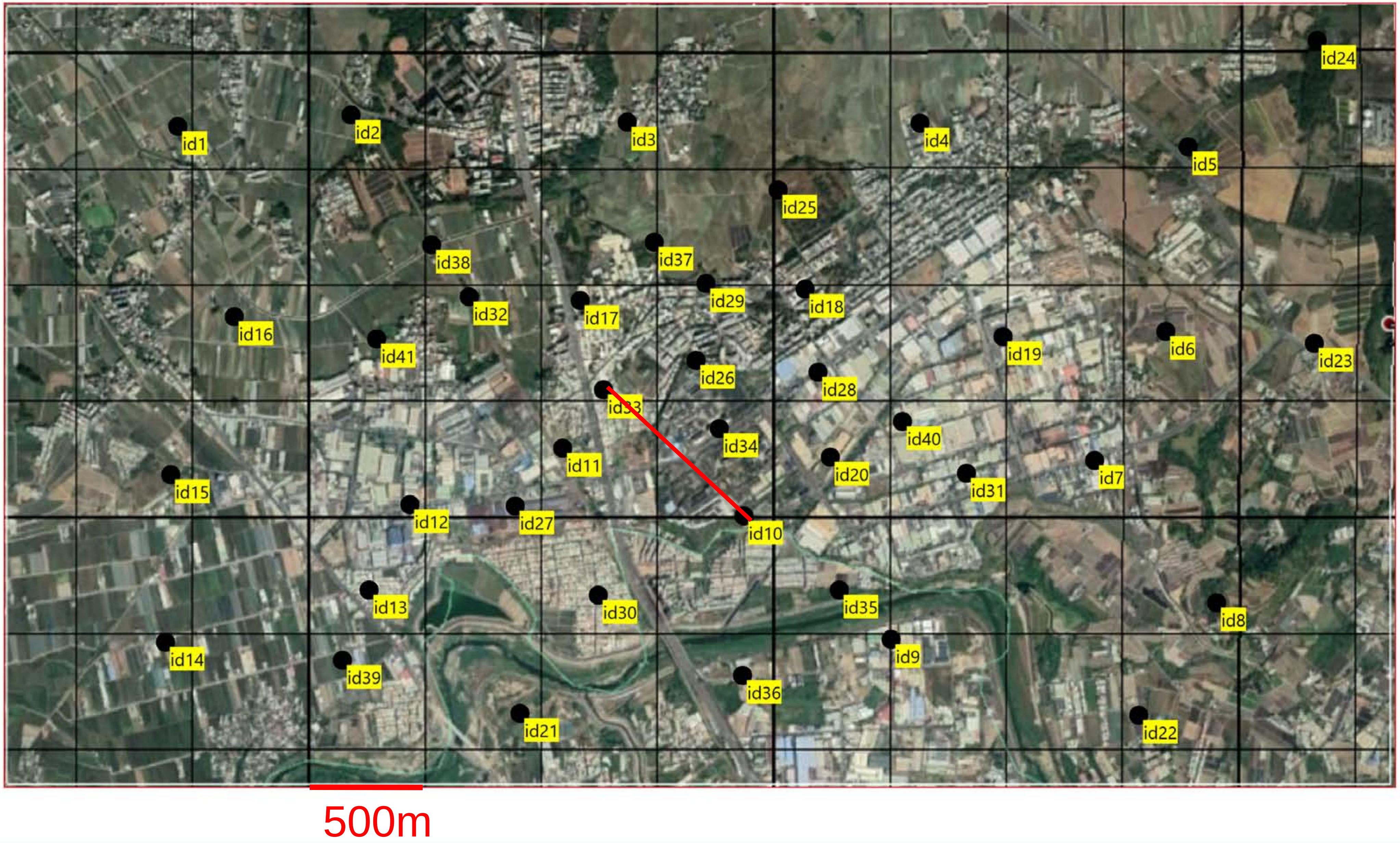


Synthetic geological model





Same geological logging, different geological profile interpreted!!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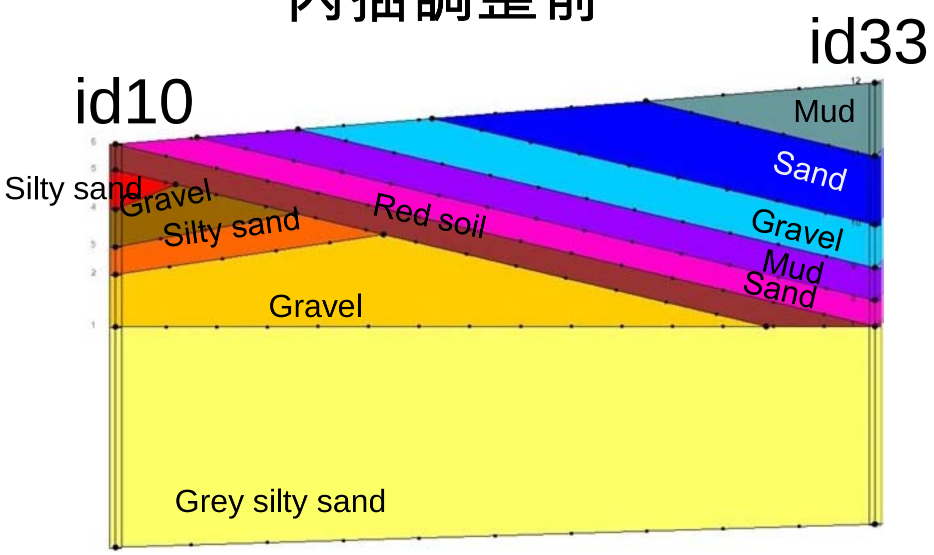
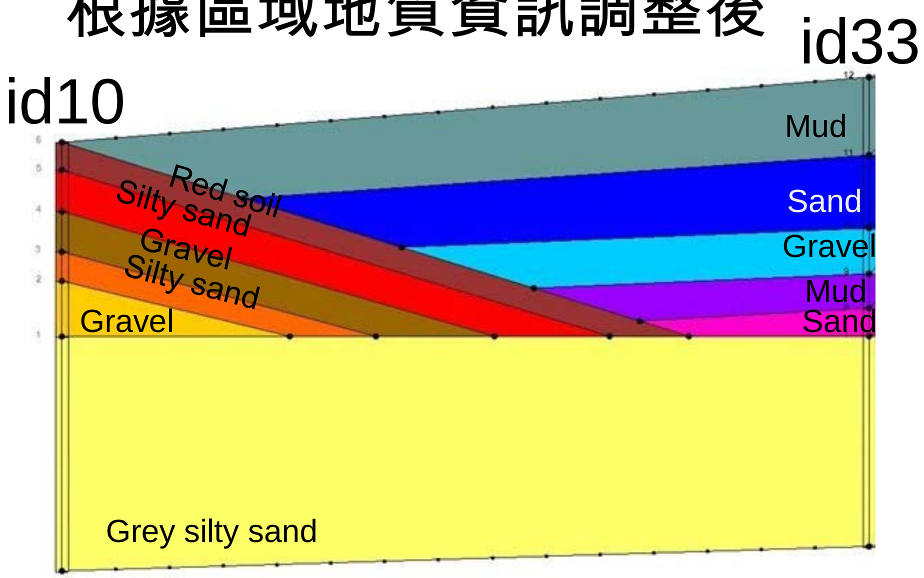
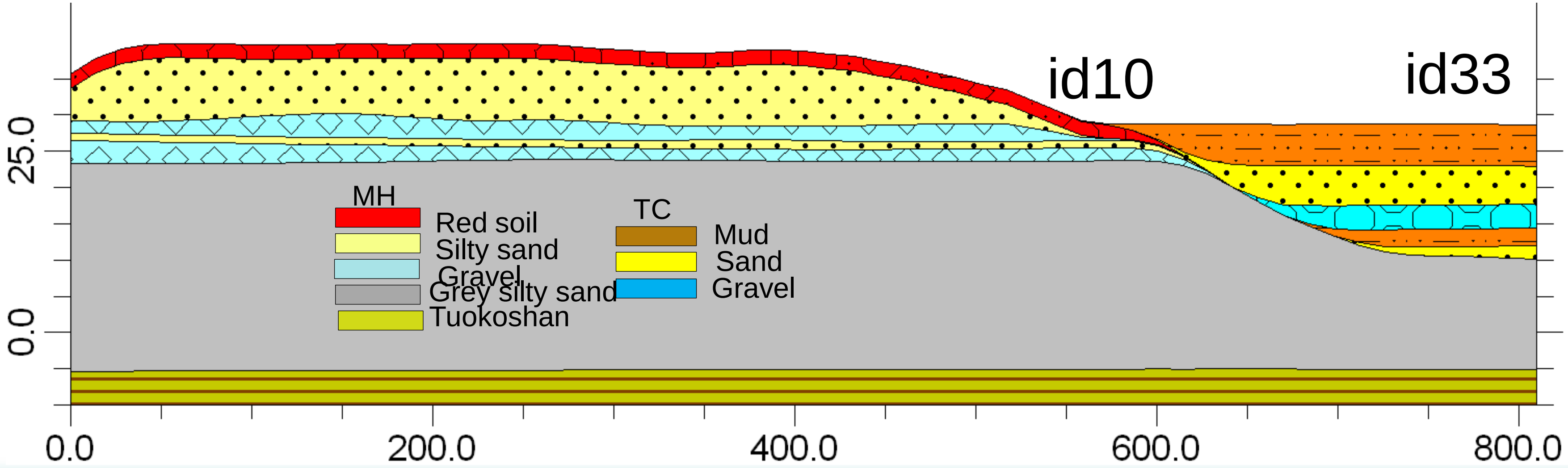
軟體內插三維地質模型

內插調整前



根據區域地質資訊調整後





Engineering Geology: Fundamental Input or Random Variable?

Jeffrey R. Keaton[1], P.E., P.G., F.ASCE

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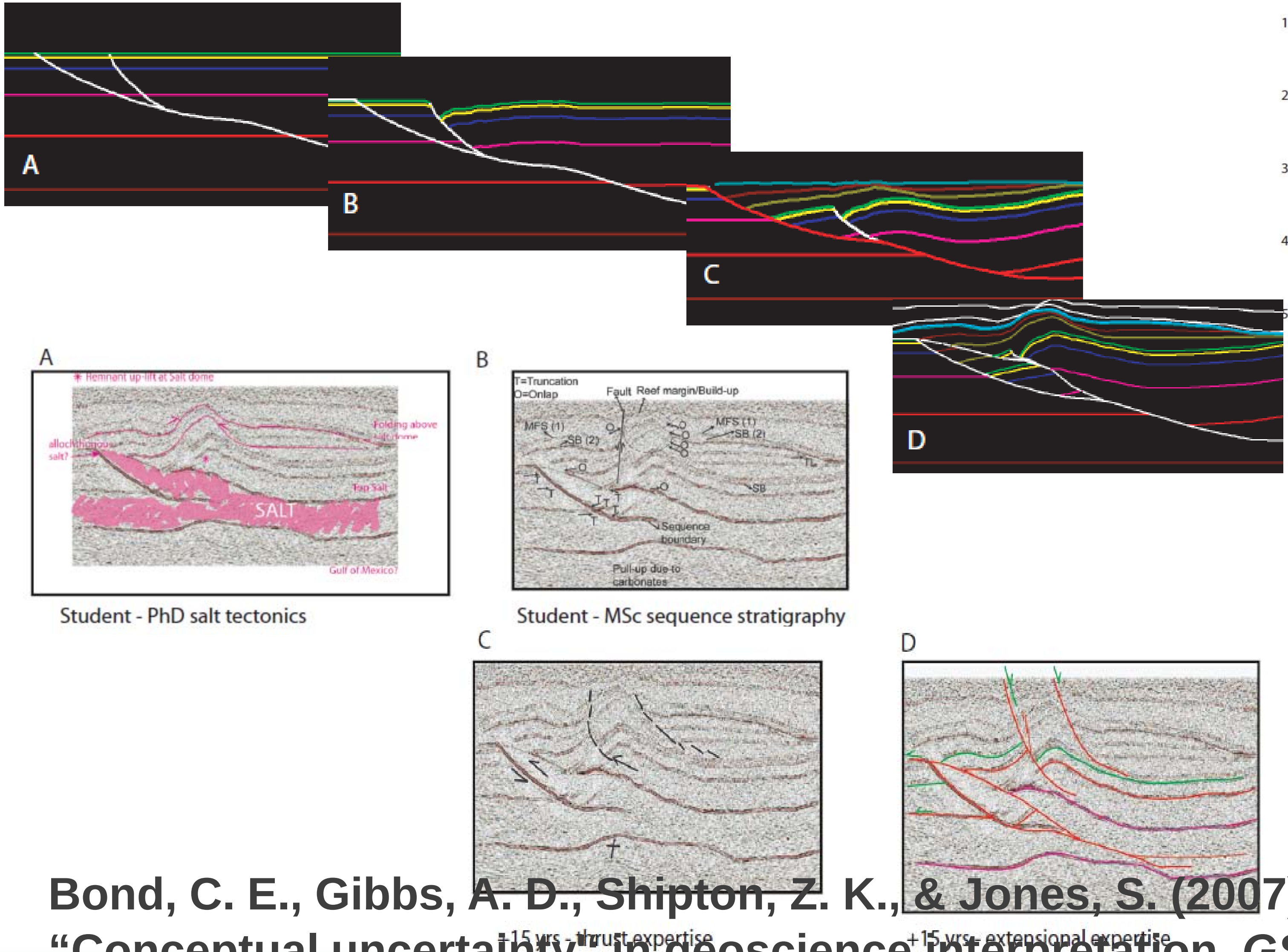
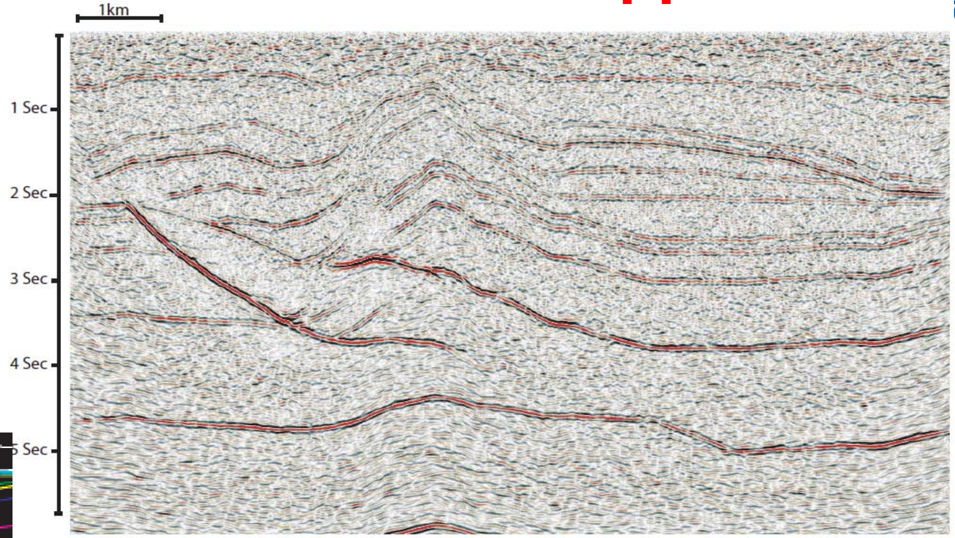
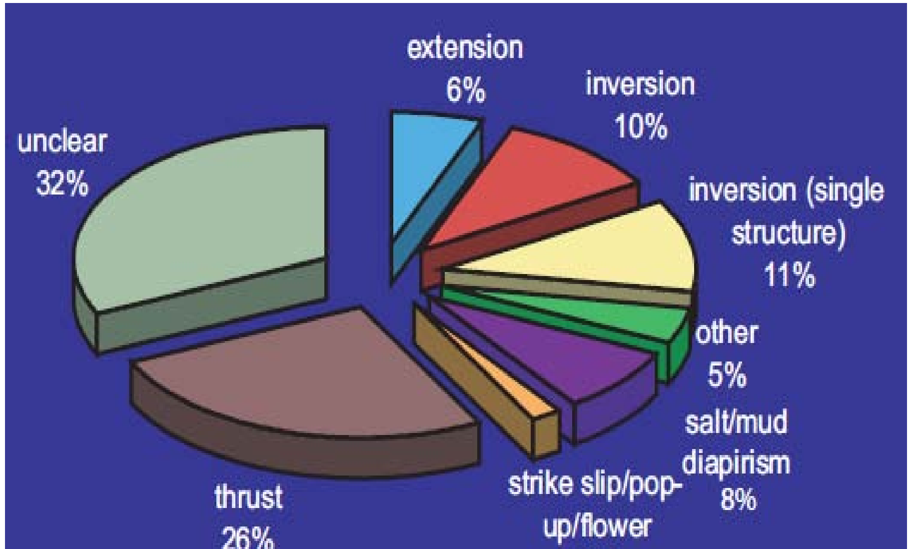
ABSTRACT: Geologists and engineers view the world in complementary but different ways. Science seeks to explain all observed details, whereas engineering seeks to design with specific objectives and multiple constraints. National guidance in the United States calls for geotechnical site investigations to be performed by geotechnical engineers and engineering geologists. Site characterization should start with Geologic Models which form the basis for Ground Models (Geologic Models with engineering parameters) and Geotechnical Models (Ground Models with predicted performance based on design parameters). If the Geologic Model is wrong, then neither the Ground Model nor the Geotechnical Model can be correct. Fundamental geologic variability makes some details unforeseeable. Insufficient geotechnical investigations, faulty interpretations, or failure to portray results understandably contribute to inappropriate designs or failures. If the geologist does not interpret the geology and explain it clearly, then the engineer will be forced to interpret it or ignore it. Incomplete or inaccurate geotechnical site characterization can lead to selection of incorrect models, geotechnical properties, and design values. Furthermore, project managers responsible only for design and construction may view geologic site characterization as extra cost if benefits result in improved life-cycle reliability or reduced maintenance costs but do not improve design or construction.

GM Uncertainty

Data Driven Approach







What do you think this is?

Bond, C. E., Gibbs, A. D., Shipton, Z. K., & Jones, S. (2007). "Conceptual uncertainty" in geoscience interpretation. *GSA today*, *17*(11), 4.

Seeing is believing?

https://youtu.be/_x1sme-jM-U

Geological model uncertainty

Geology for Engineers: the Geological Model, Prediction and Performance

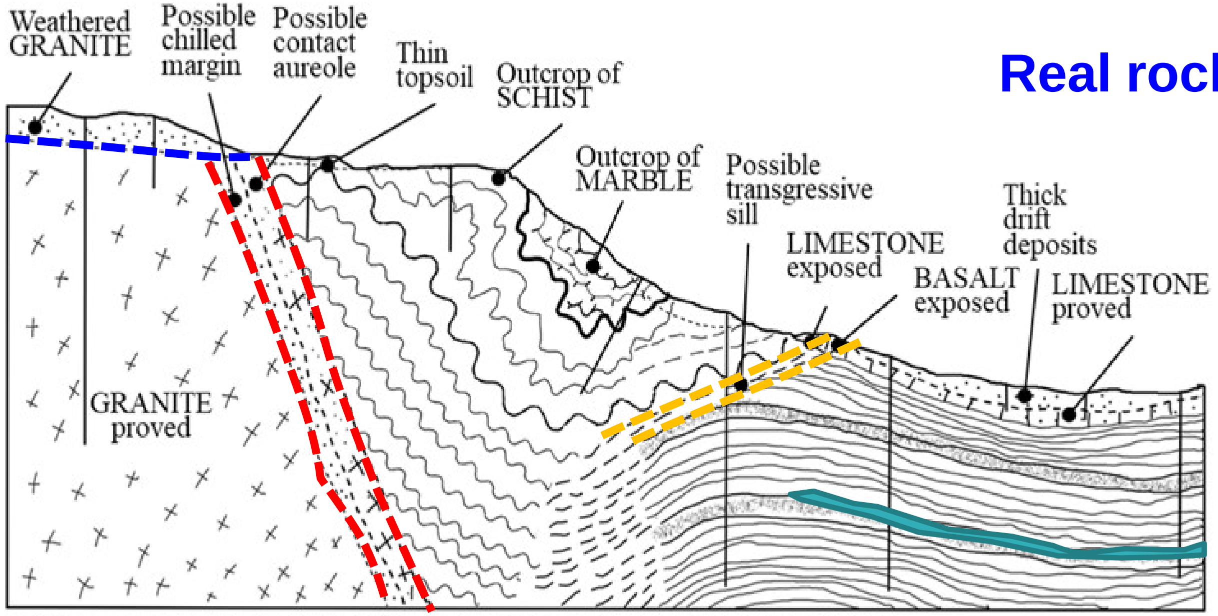
P. G. Fookes

'. . . if you do not know what you should be looking for in a site investigation, you are not likely to find much of value'

(Glossop 1968)

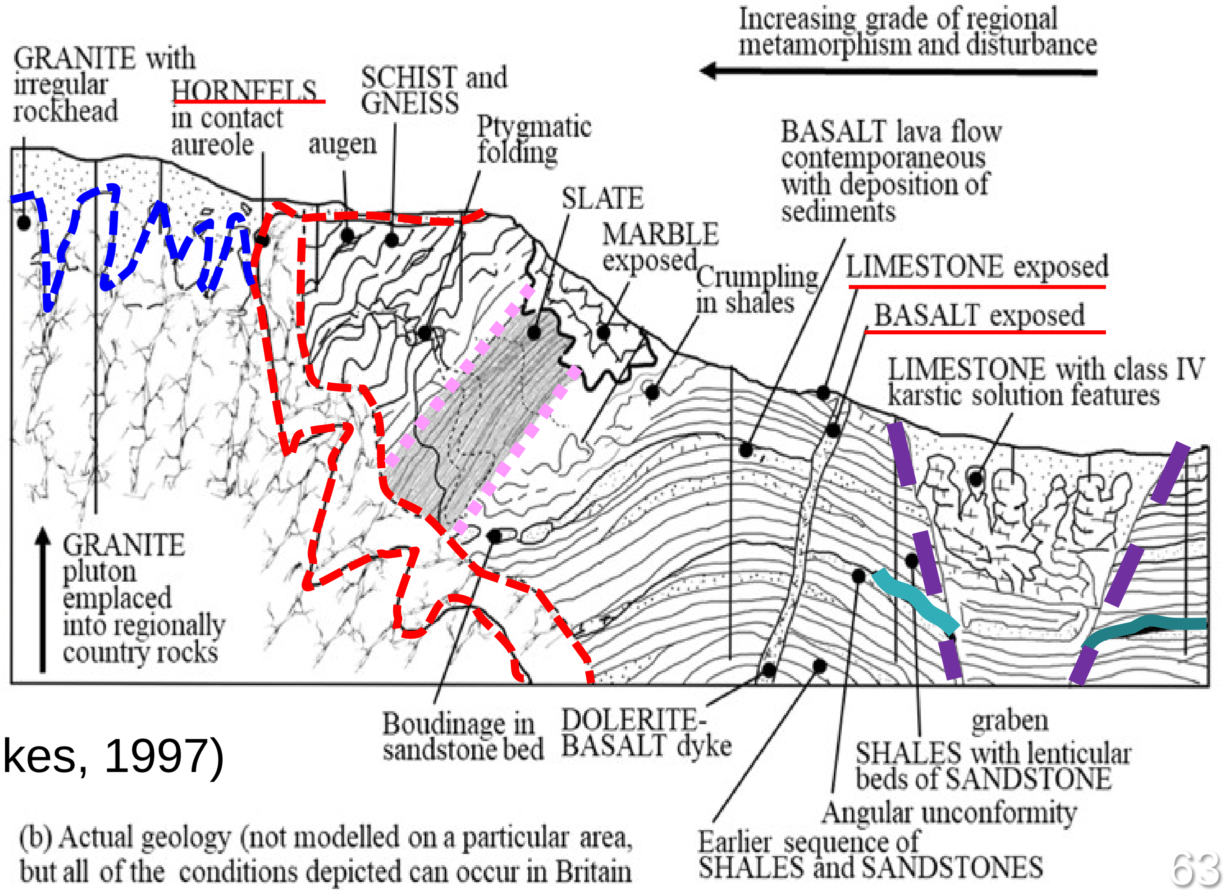
First Glossop lecture

School rocks from limited information



(a) Some potential misinterpretations of geology of (b) from borehole evidence

Real rocks



(b) Actual geology (not modelled on a particular area, but all of the conditions depicted can occur in Britain

(after Fookes, 1997)

Geo-model Driven Approach

Richard P. Feynman: "...Scientific knowledge is a body of statements of varying degrees of certainty — some most unsure, some nearly sure, but none absolutely certain. ..."

"The scientist has a lot of experience with ignorance and doubt and uncertainty, and this experience is of very great importance, I think. When a scientist doesn't know the answer to a problem, he is ignorant. When he has a hunch as to what the result is, he is uncertain. And when he is pretty damn sure of what the result is going to be, he is still in some doubt. We have found it of paramount importance that in order to progress, we must recognize our ignorance and leave room for doubt. Scientific knowledge is a body of statements of varying degrees of certainty — some most unsure, some nearly sure, but none absolutely certain. Now, we scientists are used to this, and we take it for granted that it is perfectly consistent to be unsure, that it is possible to live and not know. But I don't know whether everyone realizes this is true. Our freedom to doubt was born out of a struggle against authority in the early days of science. It was a very deep and strong struggle: permit us to question — to doubt — to not be sure. I think that it is important that we do not forget this struggle and thus perhaps lose what we have gained."

― **Richard P. Feynman**

https://www.goodreads.com/quotes/899021-the-scientist-has-a-lot-of-experience-with-ignorance-and