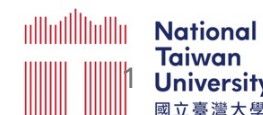
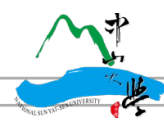
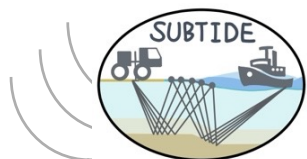
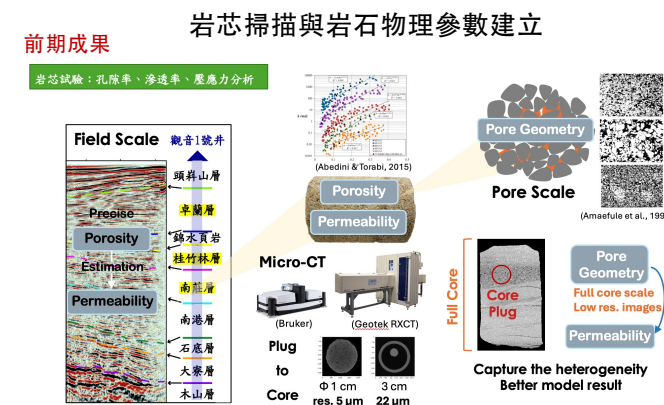
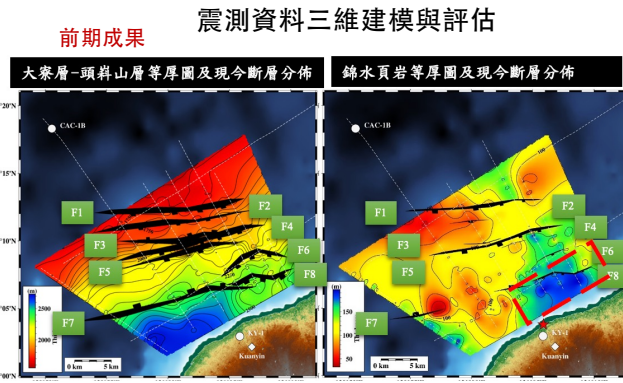
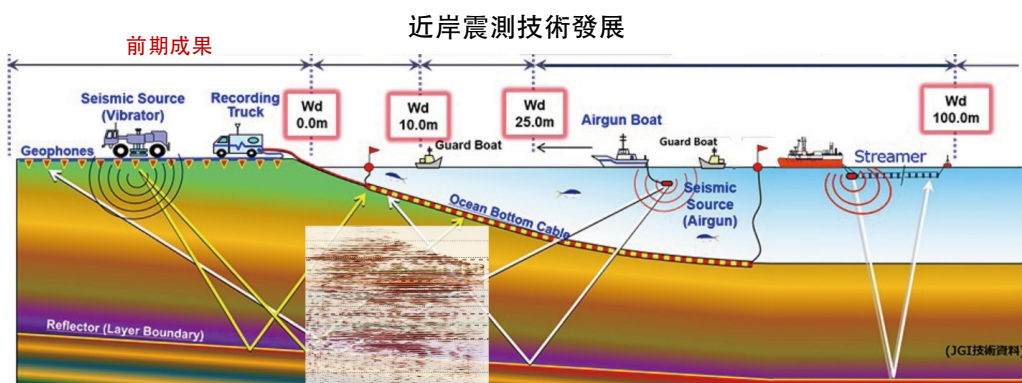
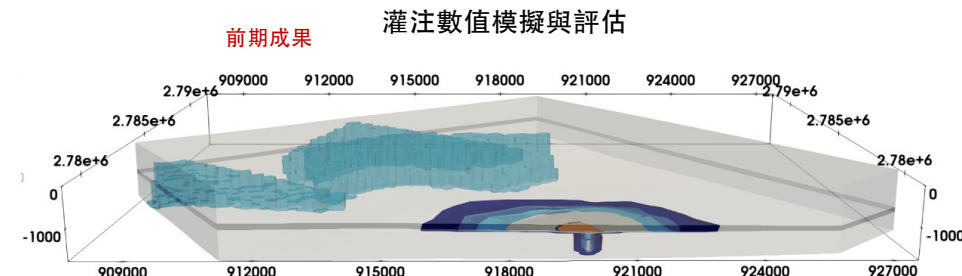


近岸震測探勘技術研發及海域潛力場址評估

郭陳濤、吳逸民、林立虹、郭家瑋、郭婉如
葛宇甯
許鶴瀚、張日新、黃致展、蘇志杰、謝獻祥
林俊宏
林佩瑩
郭俊翔
郭昱廷
盧志恆、張頌平、韓為中
楊汶達
呂政豪
傅慶州

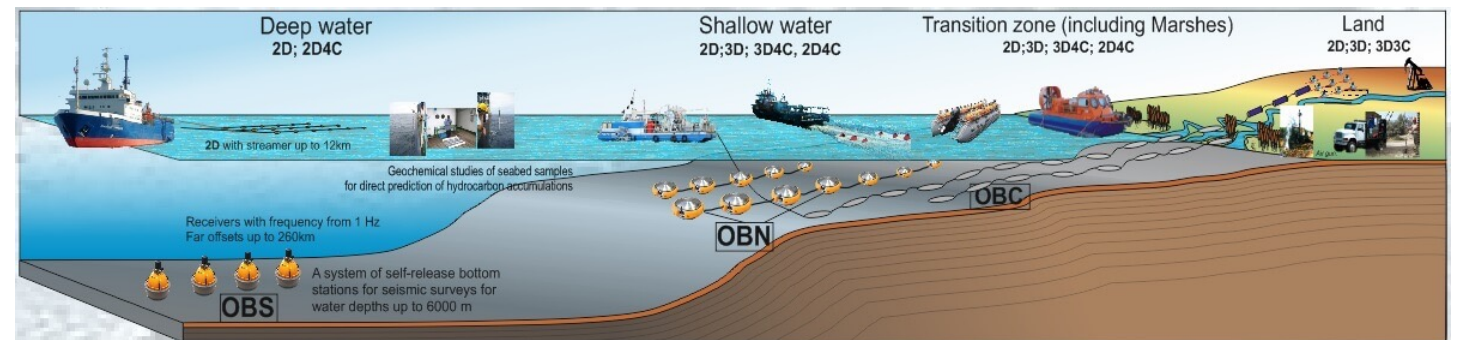
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臺灣大學
中山大學
師範大學
中央大學
中正大學
成功大學
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土木工程學系
海洋研究所、海洋中心
海洋環境與工程學系
地球科學系
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地球與環境科學系
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環境工程學系
觀光休閒系
地球科學所

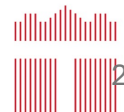
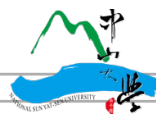
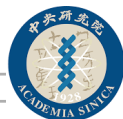
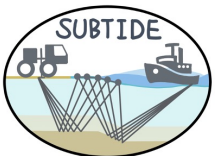


簡報大綱

- Why this project?
 - What is CCS?
 - Where are the potential CCS sites in Taiwan?
- Previous studies in transitional zone (TZ)
- About the experiments
 - What is OBN (Ocean bottom node)?
 - What is mudgun?
- Results and some discussions
- Further applications

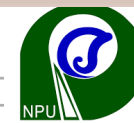
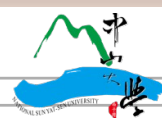
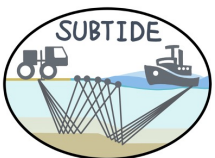
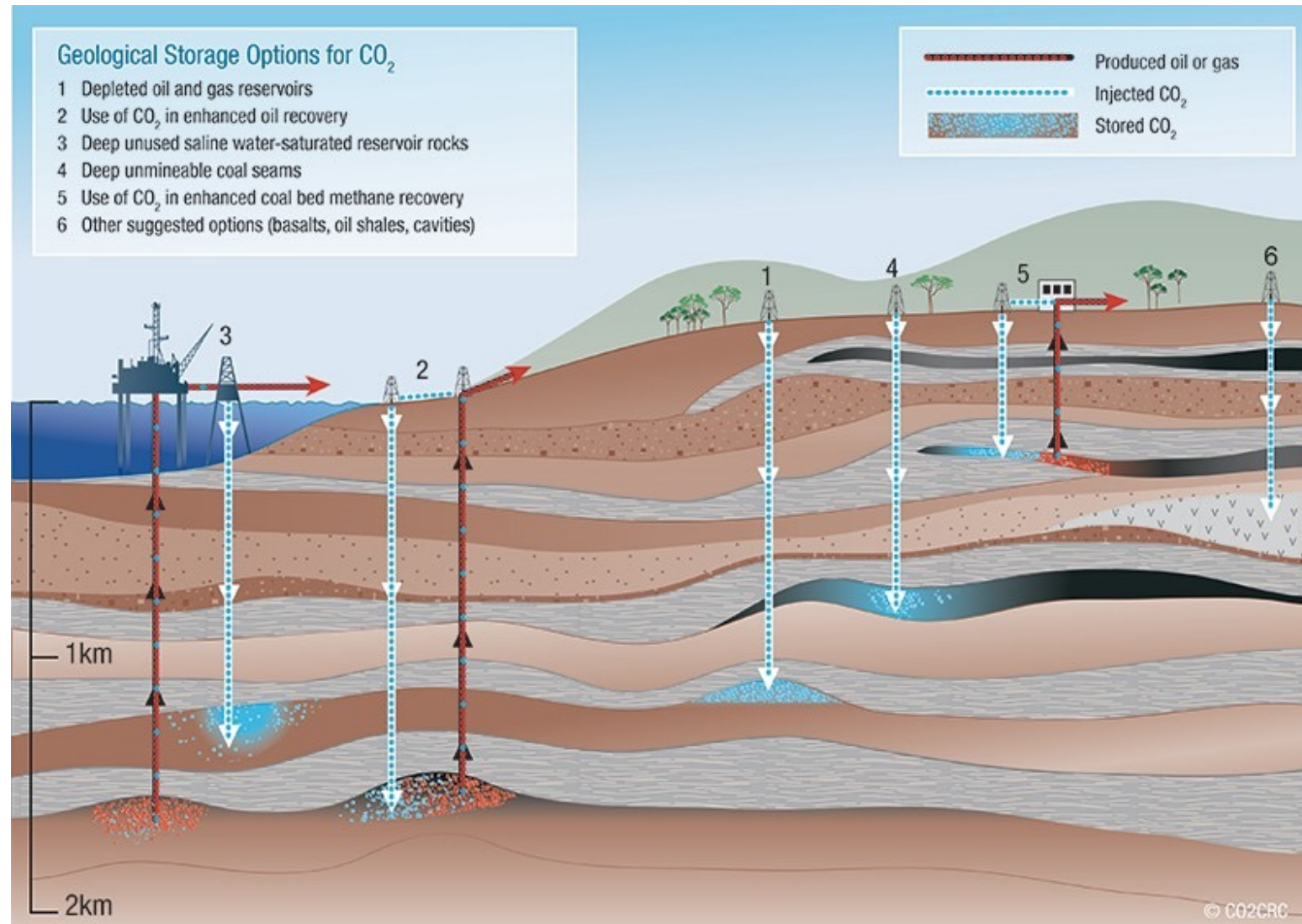


<http://www.marinegeos.com/services/1-seismic-survey>



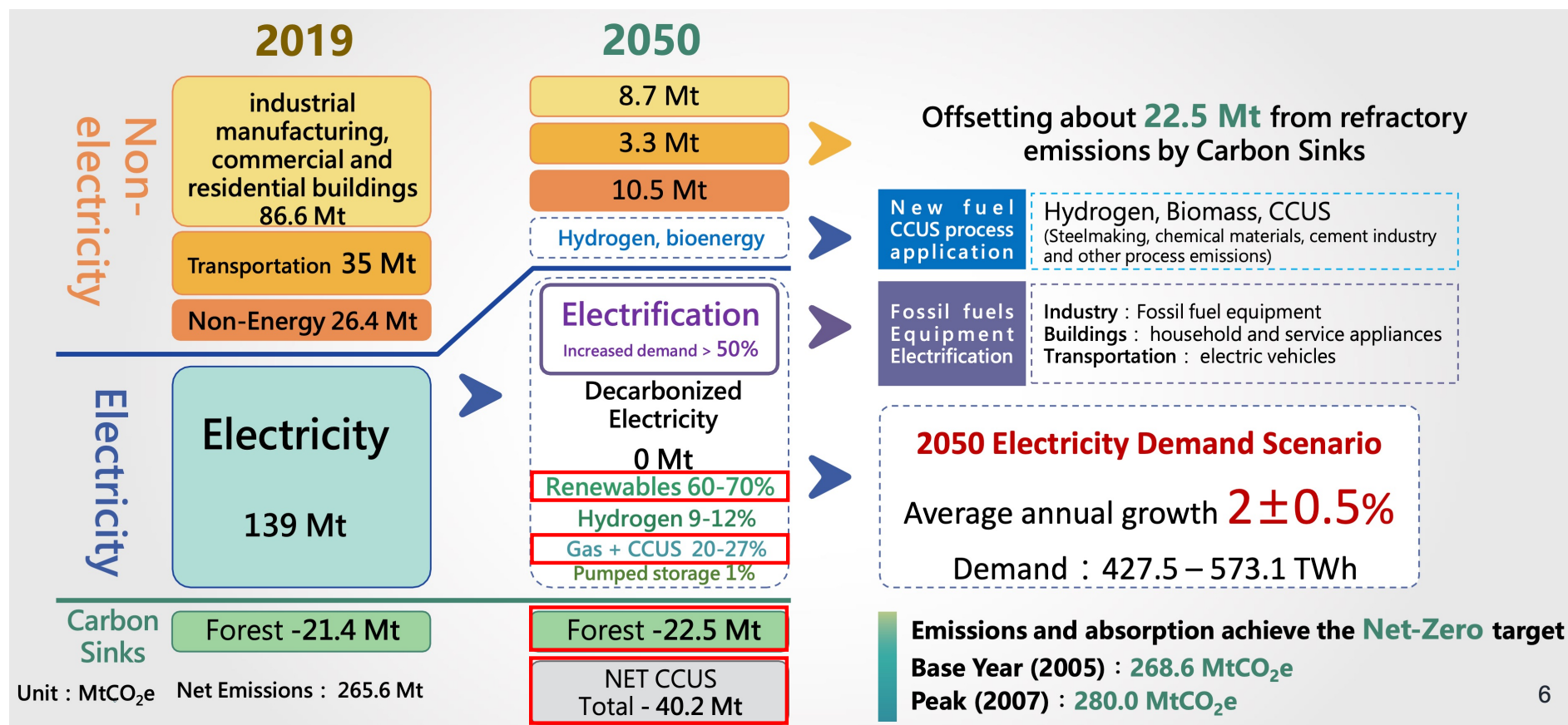
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What is CCS?



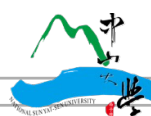
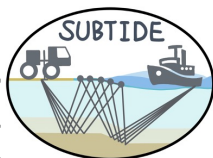
Why CCS?

Net-zero pathways for Taiwan



6

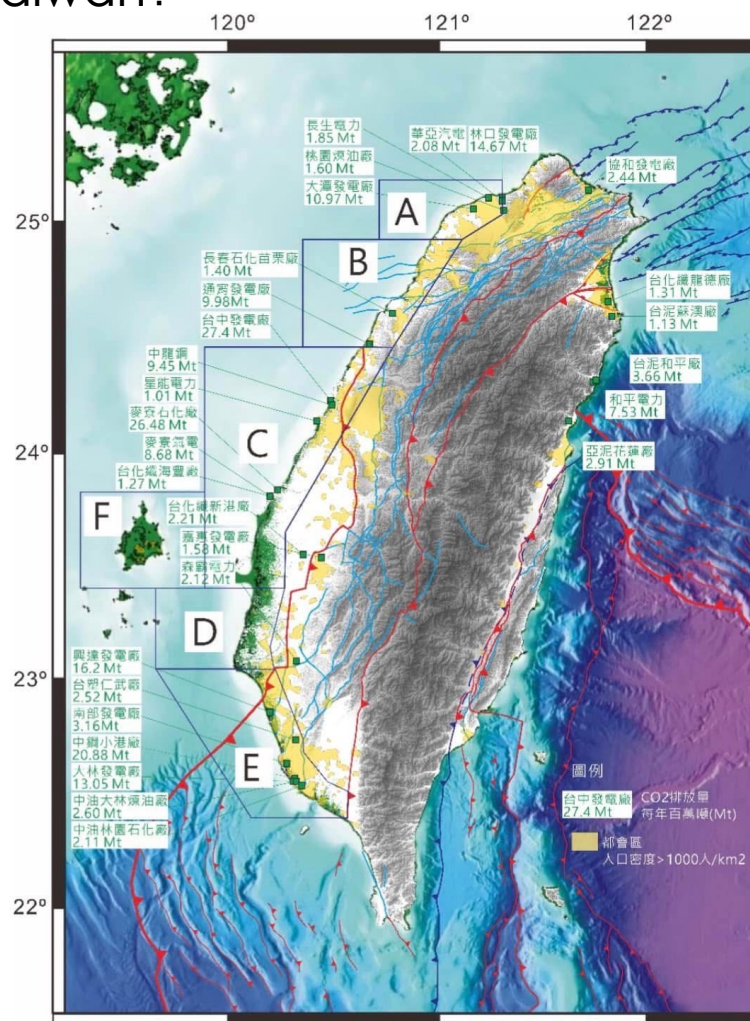
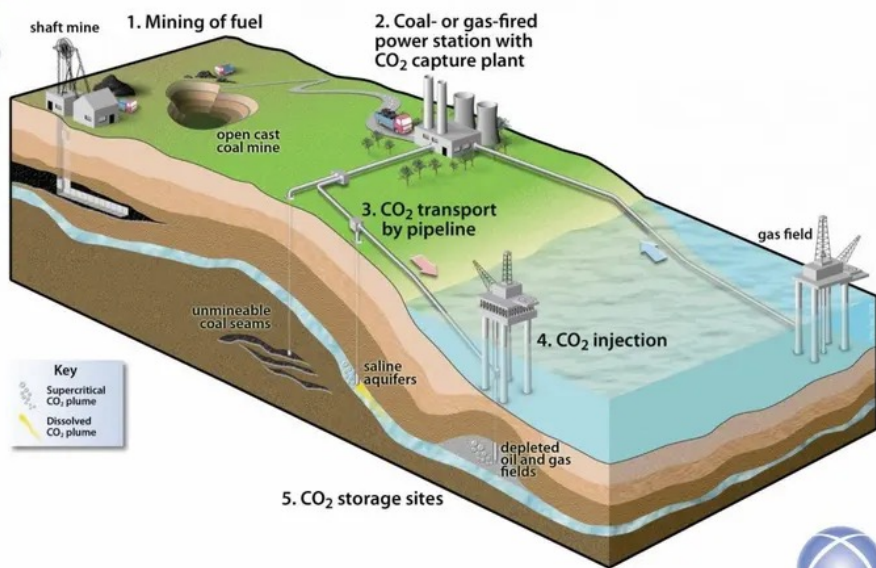
From Taiwan's pathway to net zero emission in 2050



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Where are the potential CCS sites in Taiwan?

www.sccs.org.uk

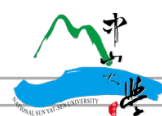
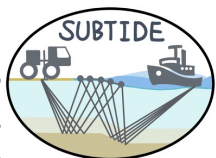


表一 臺灣CO₂封存潛能區的地質風險評估

潛能區	地質構造區	儲積層與蓋層	封存方式	地質風險評估
A區 桃園觀音海岸	臺灣北部張裂帶：正斷層與火山活動	儲積層：關刀山砂岩與上福基砂岩。 蓋層：錦水頁岩。	鹽水層	1. 儲積層與蓋層的位置及厚度明確。 2. 極少地震，無活動斷層。 3. 接近CO ₂ 主要排放源(桃園每年總排放量約31 Mt(百萬噸))。 4. 聚落少人口密度低。
B區 竹苗海岸	西部麓山帶：褶皺-逆衝斷層帶	耗竭油氣田作為儲集層(目前已排除利用油氣田作為儲積層)。	油氣田	1. 地下斷層與裂隙資料不清楚，有CO ₂ 洩漏疑慮。 2. 少有地震，斷層呈現鎖定狀態，具活動斷層與褶皺。 3. 接近CO ₂ 排放源(苗栗每年總排放量約11 Mt)。 4. 聚落少人口密度低。
C區 中彰雲海岸	海岸平原區：前陸盆地	儲積層：卓蘭層(?)。 蓋層未知(依據彰濱一號井)。	鹽水層	1. 位於臺西盆地(涵蓋北港高區)，南北地層的岩性與厚度變化非常大，儲積層與蓋層的位置及厚度有待評估。 2. 少有地震，無活動斷層。 3. 接近CO ₂ 主要排放源(中部地區每年總排放量約74 Mt)。 4. 大肚溪以北聚落多人口密度高，以南聚落少人口密度低。
D區 嘉南海岸	海岸平原區：前陸盆地	以濁水溪以南西部麓山帶地層岩性為研判依據，無適當的儲集層。	鹽水層	1. 濁水溪以南的地層岩性以泥岩為主，是否具有儲集層(高孔隙率的厚層砂岩)有待調查。 2. 地震頻繁，無活動斷層。 3. 聚落少人口密度低。
E區 高屏海岸	西部麓山帶：褶皺-逆衝斷層帶與前陸盆地	以西部麓山帶的地層岩性為研判依據，可能儲集層有烏山層與南勢崙砂岩。	鹽水層	1. 儲積層與蓋層位置及厚度有待調查。 2. 少有地震，斷層呈現鎖定狀態，具活動斷層。 3. 接近CO ₂ 主要排放源(高雄每年總排放量約60 Mt)。 4. 高雄都會區人口密度高，高屏溪以東的聚落少人口密度低。
F區 澎湖群島與海峽底下玄武岩層	前陸盆地	儲積層：中新世玄武岩。 蓋層未知。	玄武岩氣孔與節理	1. 儲積層與蓋層位置及厚度有待評估。 2. 玄武岩的礦化速率有待評估。 3. 無地震，無活動斷層。 4. 遠離CO ₂ 主要排放源。 5. 聚落少人口密度低。

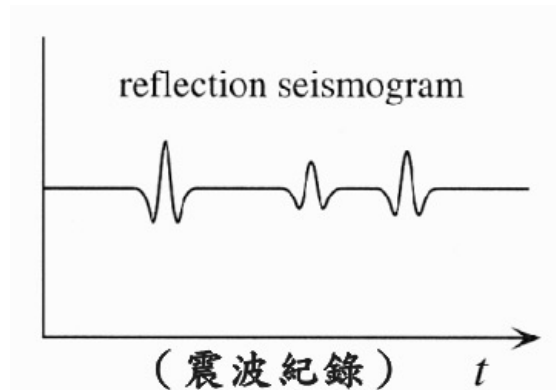
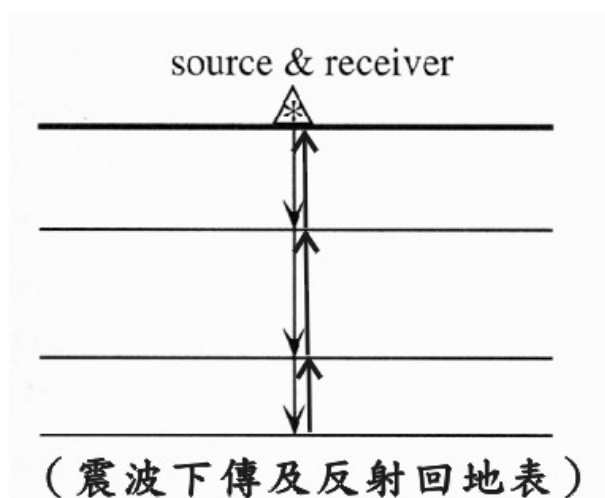
各區尚無法有效評估CO₂封存量，因為儲積層體積、孔隙率、滲透率還沒有取得確切資料。

陳文山, 2025

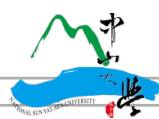
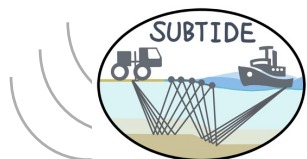
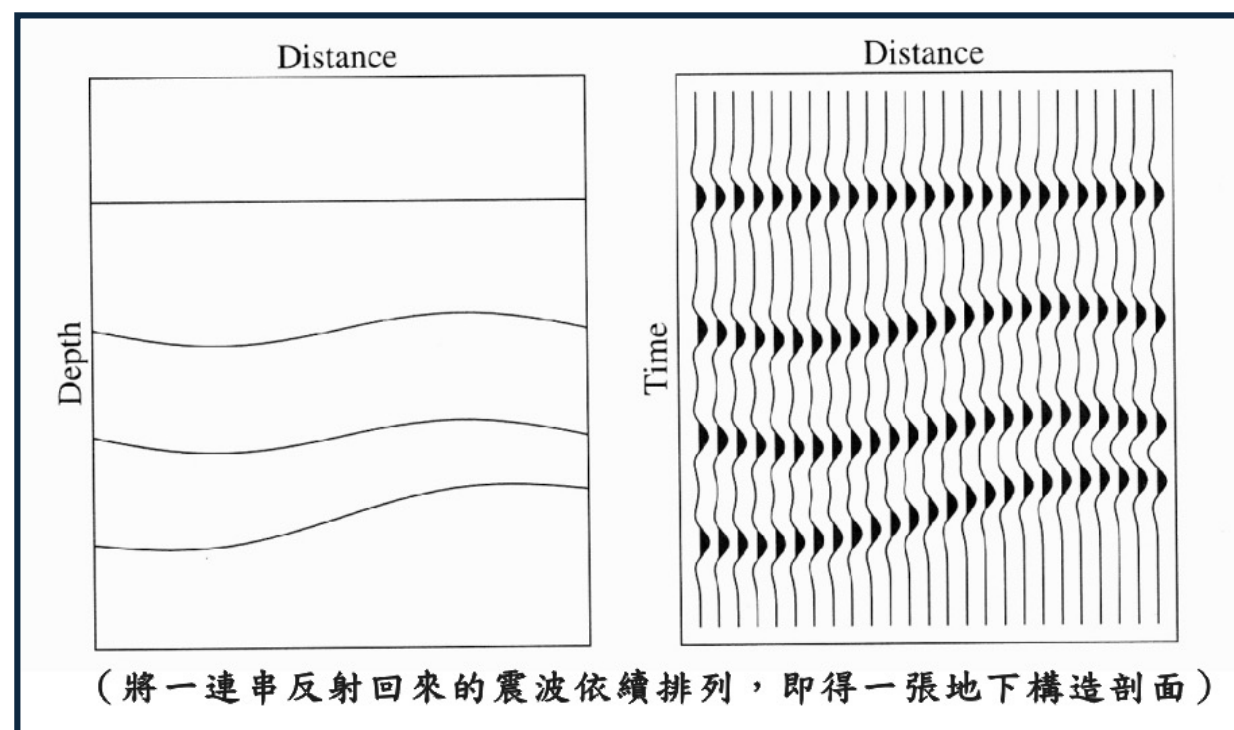


Seismic exploration in Transitional Zone (TZ)

反射震測原理

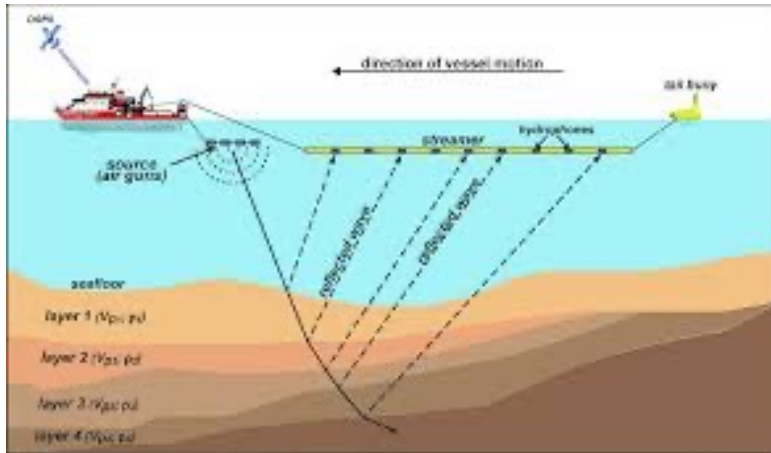


$$\left[\begin{array}{l} \text{Source} * \text{Earth reflectivity} \\ \text{convolve} \end{array} \right] = \text{Seismogram}$$

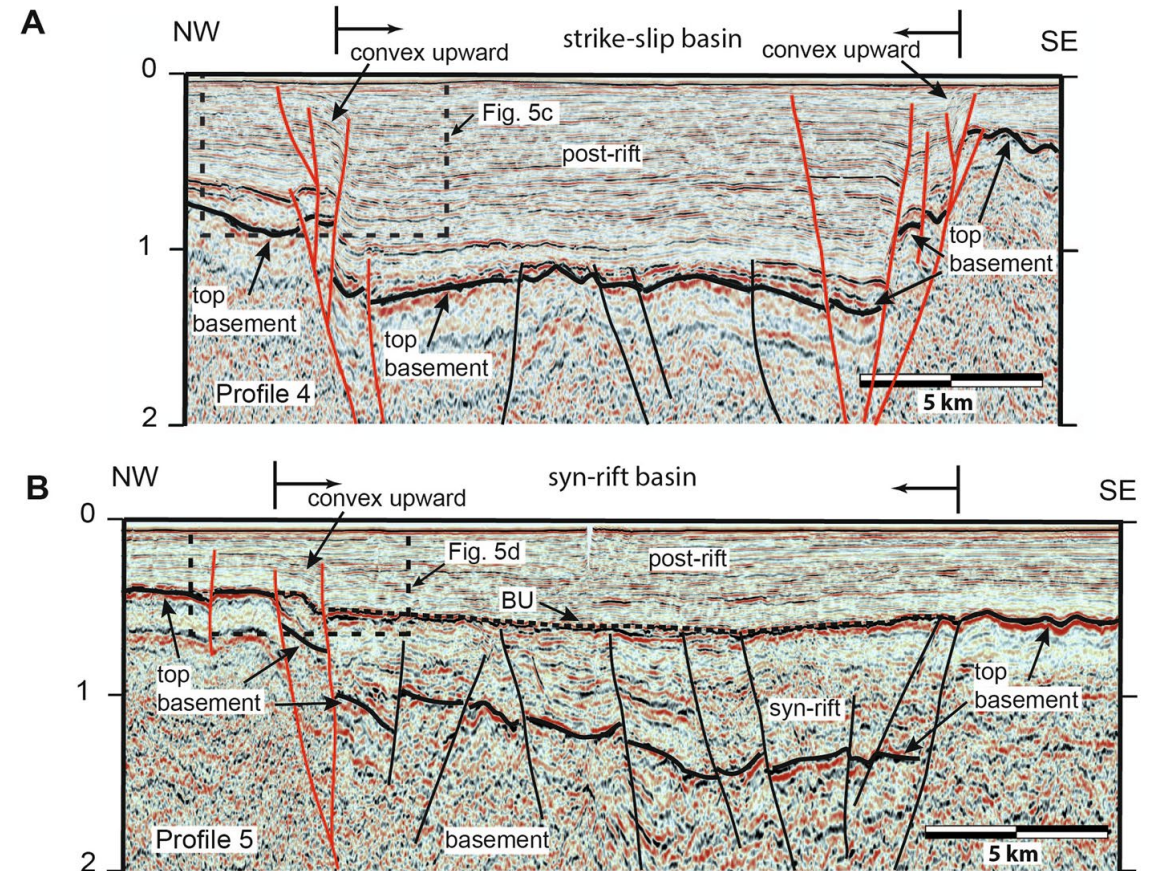
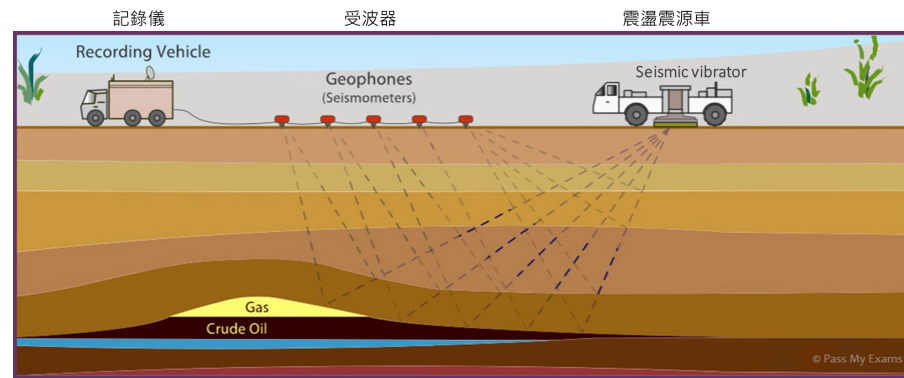


Seismic exploration in Transitional Zone (TZ)

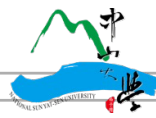
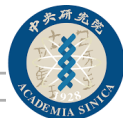
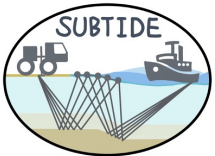
反射震測原理



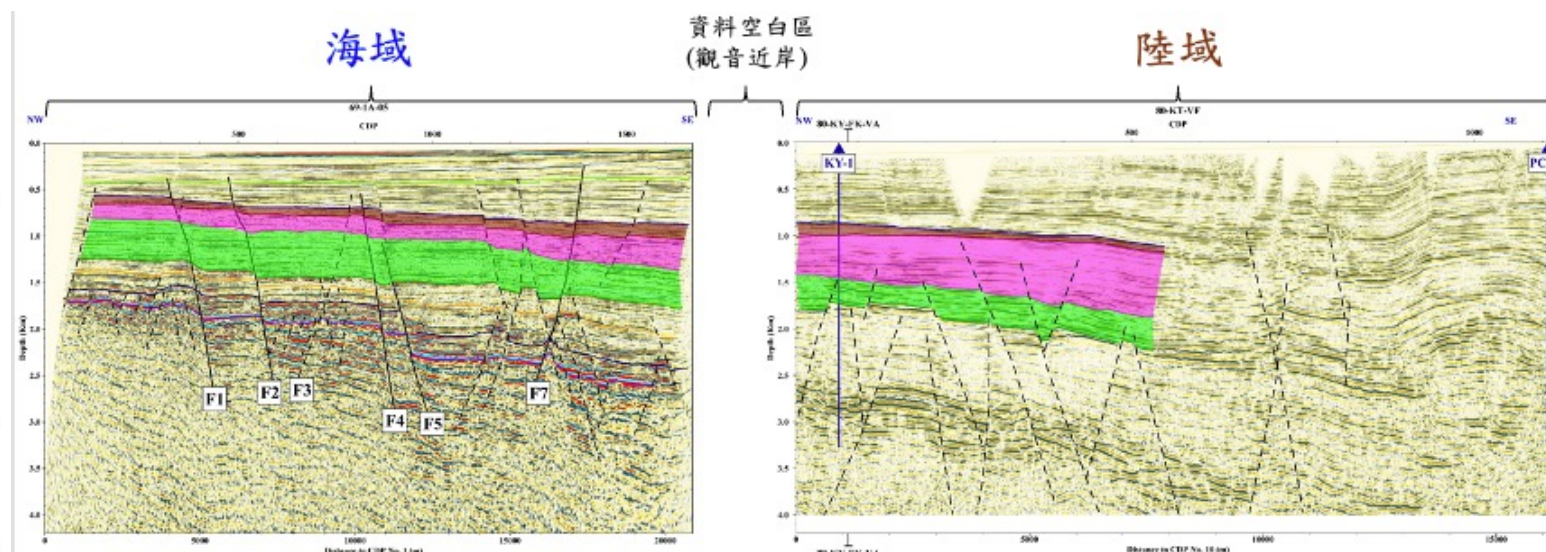
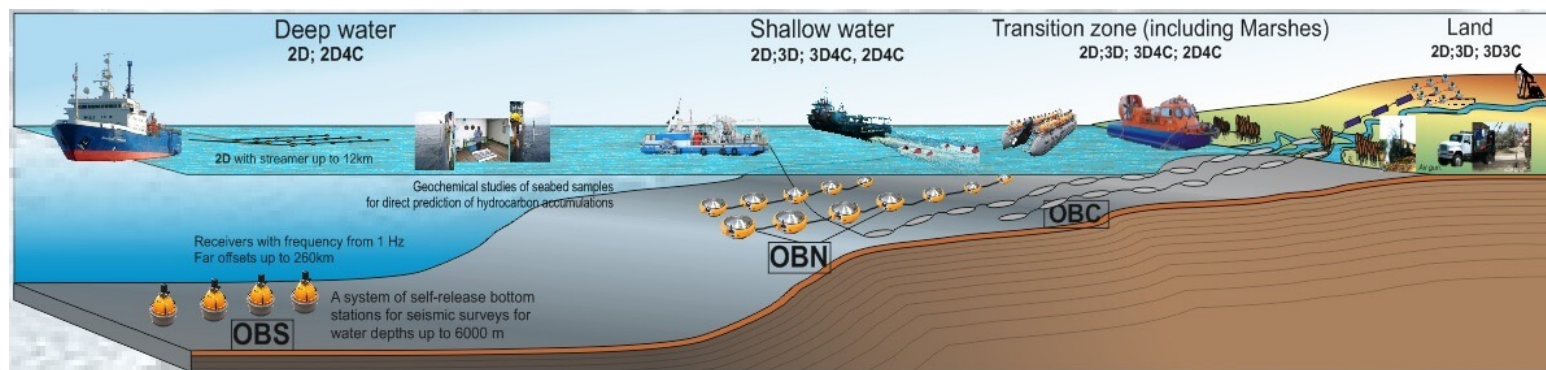
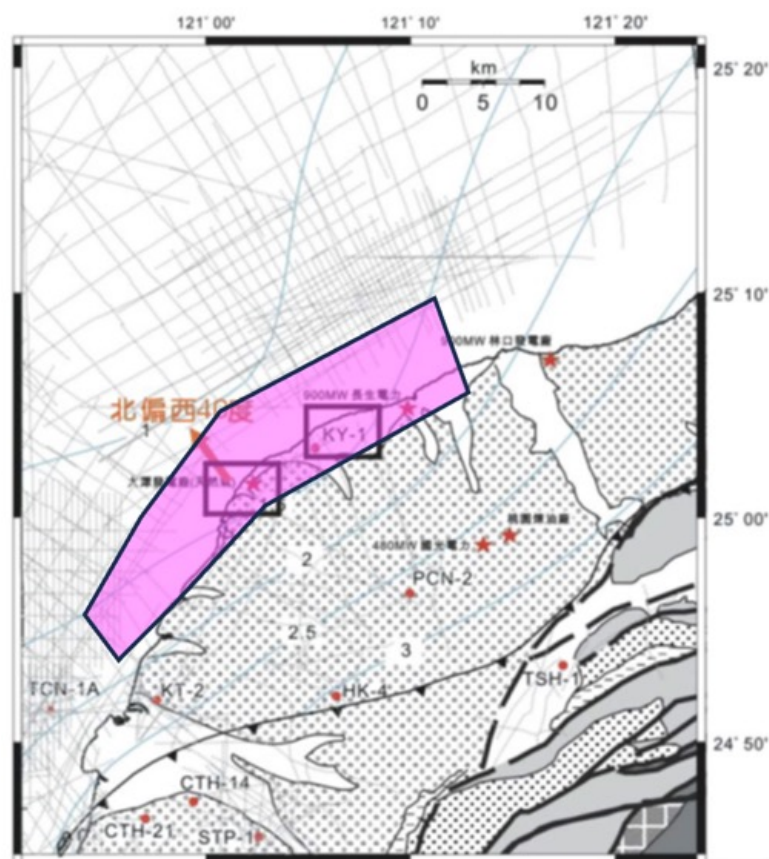
Cameselle et al., 2015



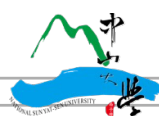
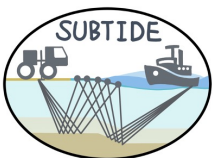
Zhang et al., 2020



Seismic exploration in Transitional Zone (TZ)



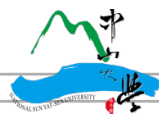
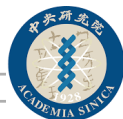
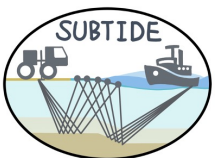
(From CPC)



Seismic exploration in Transitional Zone (TZ)

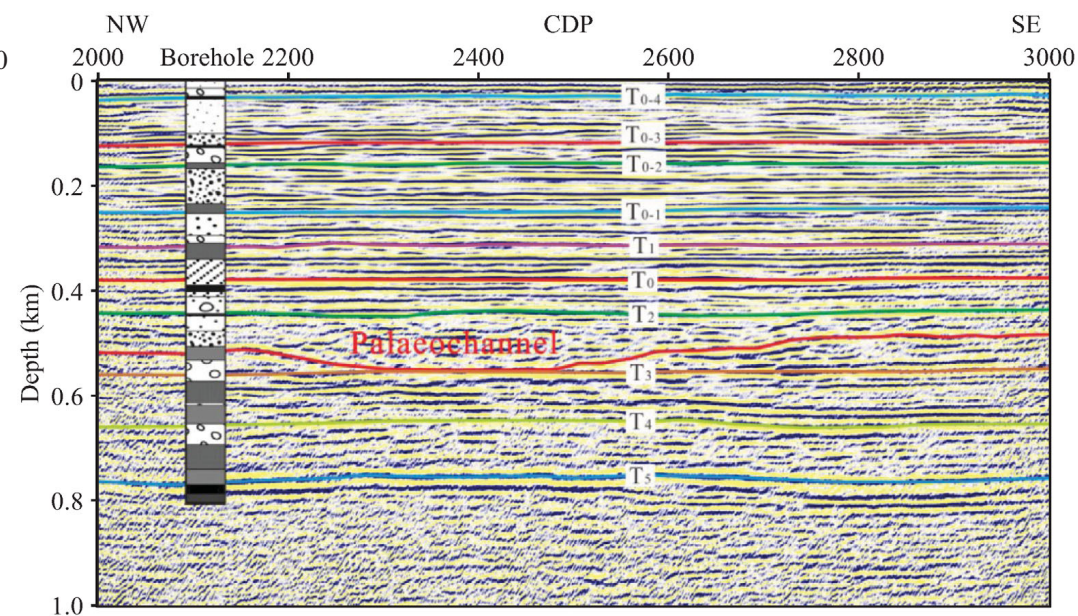
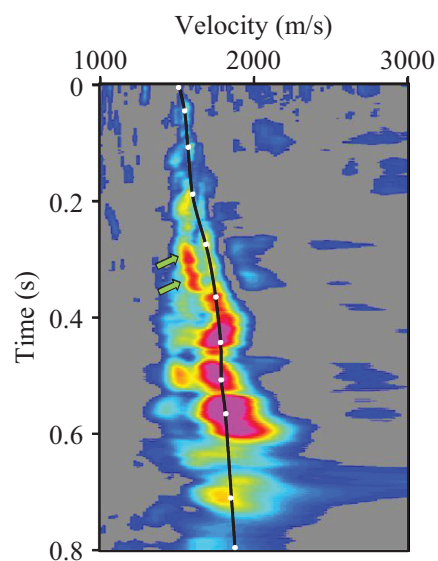
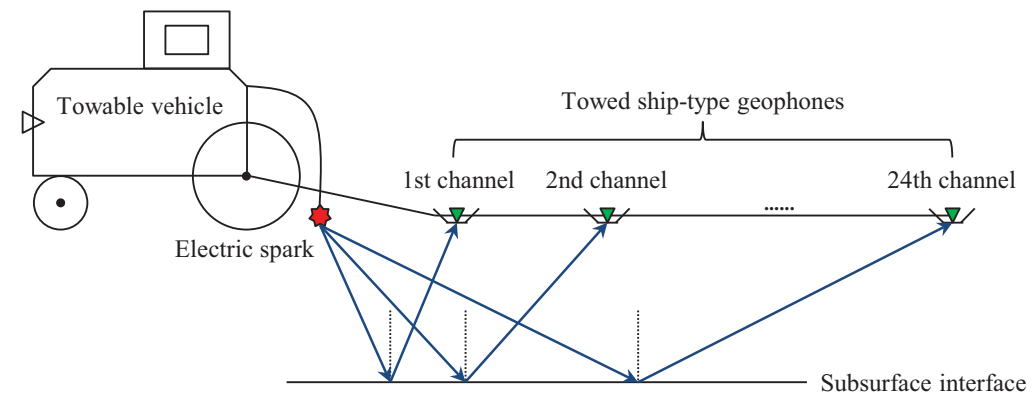
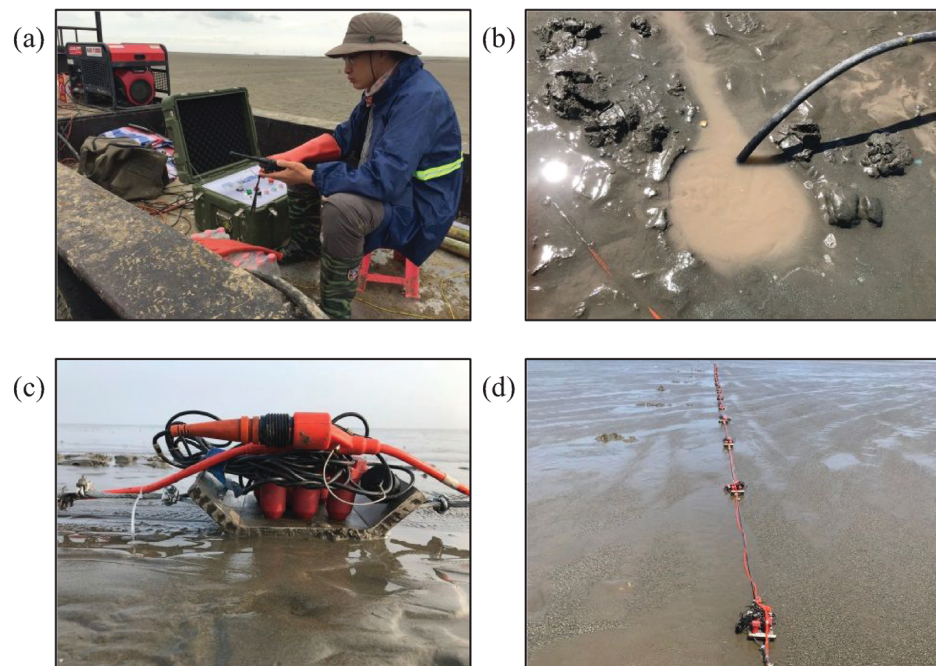
潮間帶環境

風、碎浪、潮汐、風機、地形、沙灘特性

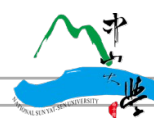
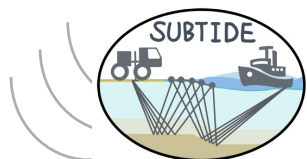


Seismic exploration in Transitional Zone (TZ)

40,000 J Spark source

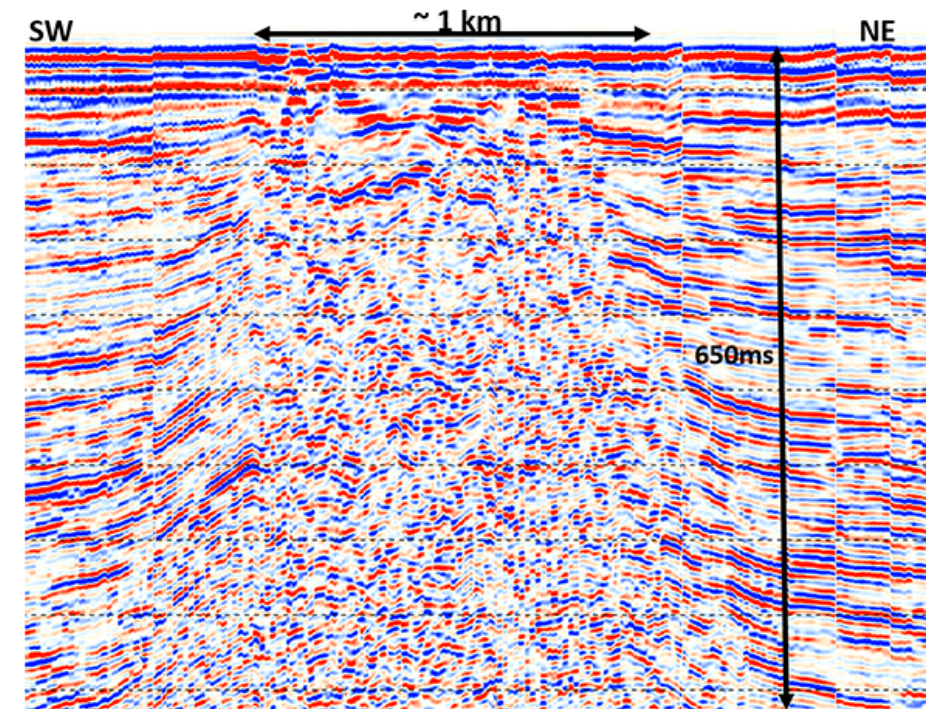
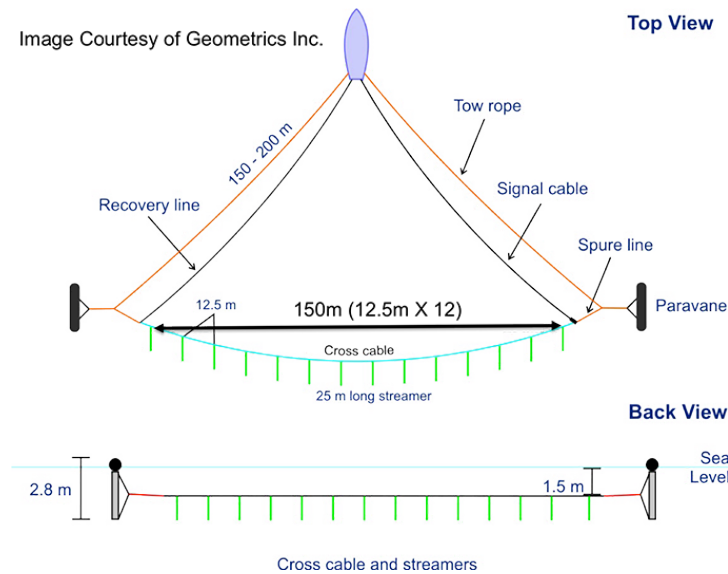
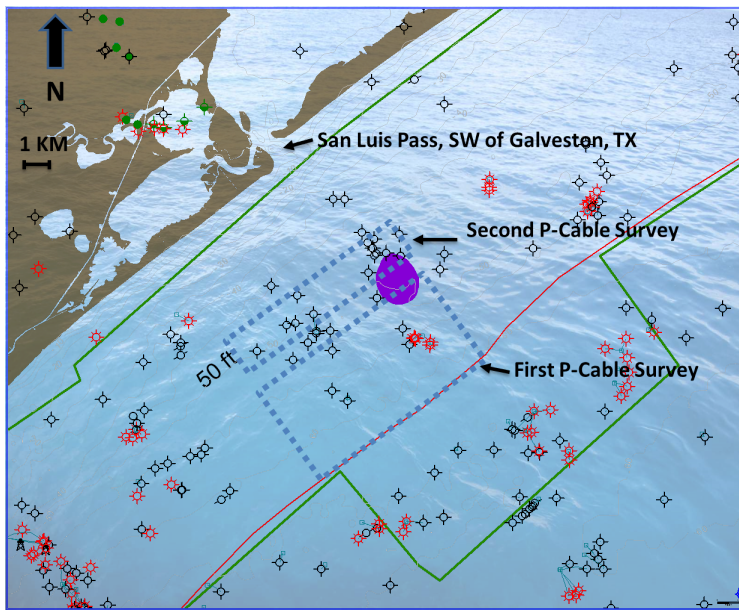


Yue et al., 2020

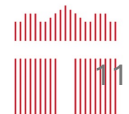
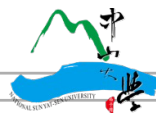
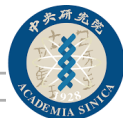
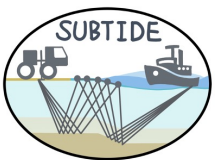


Seismic exploration in Transitional Zone (TZ)

45 in³ GI gun + P-cable



Hess et al., 2014



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Seismic exploration in Transitional Zone (TZ)

Airgun + Vibroseis + Explosive
Nodes + Hydrophone

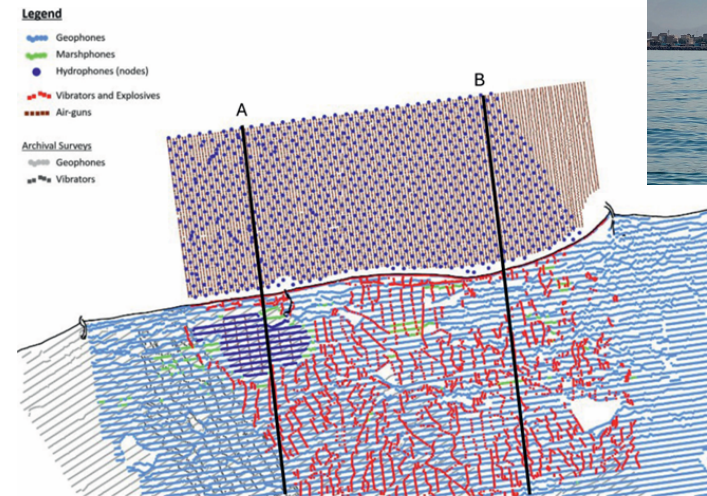
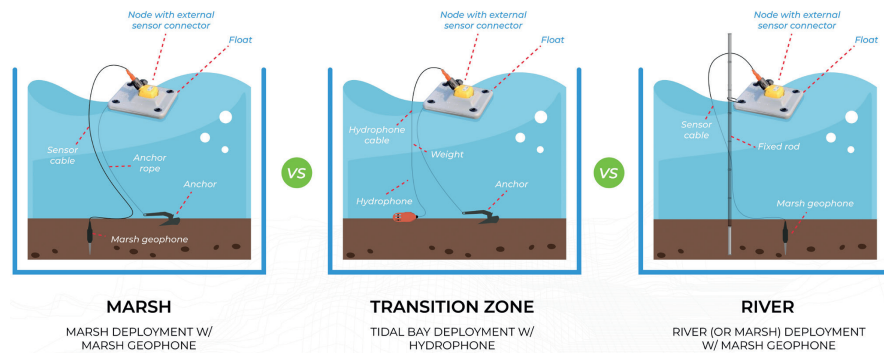
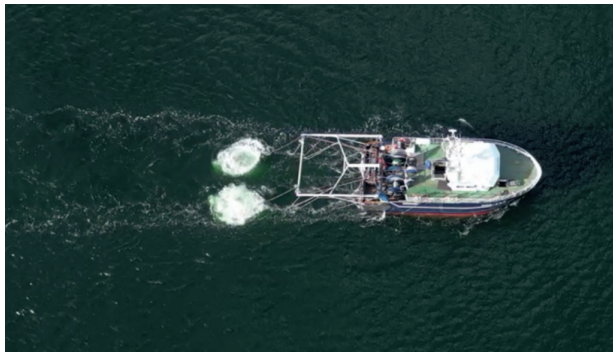


Figure 7 The position of the source and the receiver points on the Bialokury 3D survey. The bold black lines A and B correspond to the seismic sections in Figure 8.

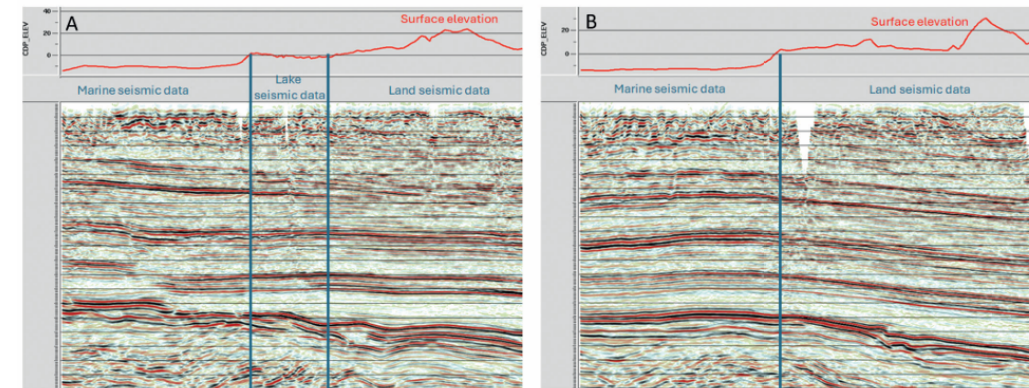
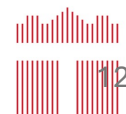
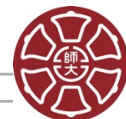
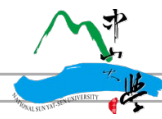
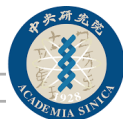
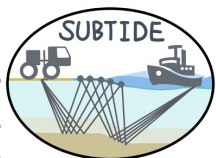


Figure 8 2D seismic sections extracted from the 3D Bialokury data volume across the acquisition area (left – section A, right – section B).

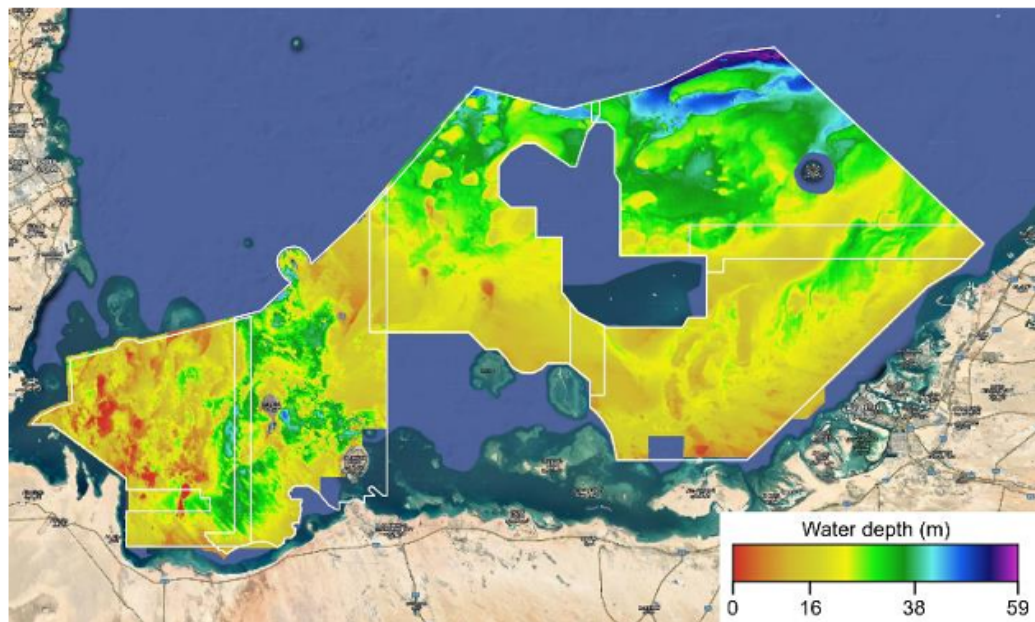
Clark et al., 2025



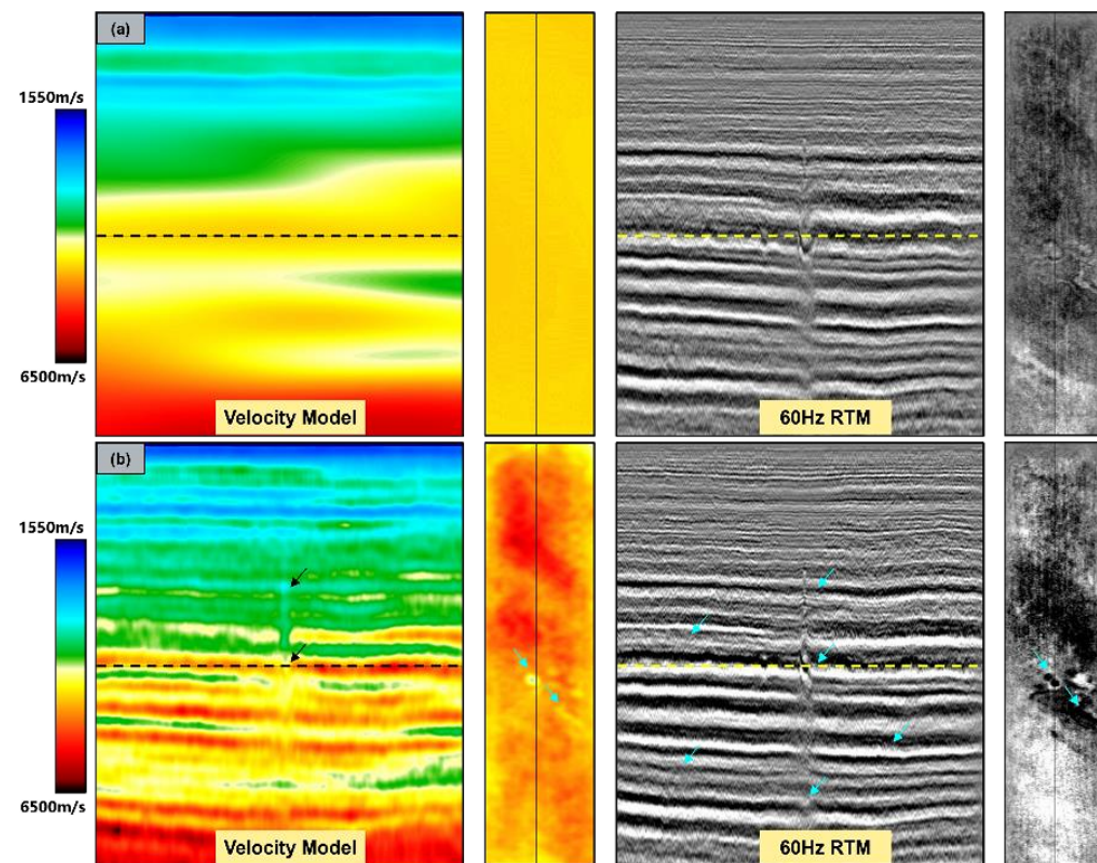
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Seismic exploration in Transitional Zone (TZ)

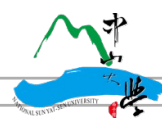
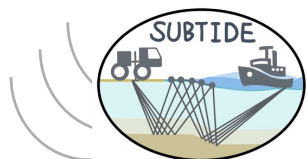
Airgun + Vibroseis
Land Nodes + 4C OBN



Full Waveform Inversion



Damianus et al., 2023



About the experiments

各單位曾多次嘗試，僅獲少數相關資料

過去數十年，臺灣在海域與陸域的震測探勘已相對獲得不少的資訊，然潮間帶由於調查場域環境複雜(潮汐、海浪、離岸流與漂沙等)，造成背景噪訊高與野外施測環境多變，為最困難的調查地區，因此一直為臺灣地下地質空間調查資訊的空白區。此探測技術的研發未來將不僅可應用於**碳封存**，在**地熱探勘**、**風機**、**地下水資源**與**國防**上皆需要此相關技術。

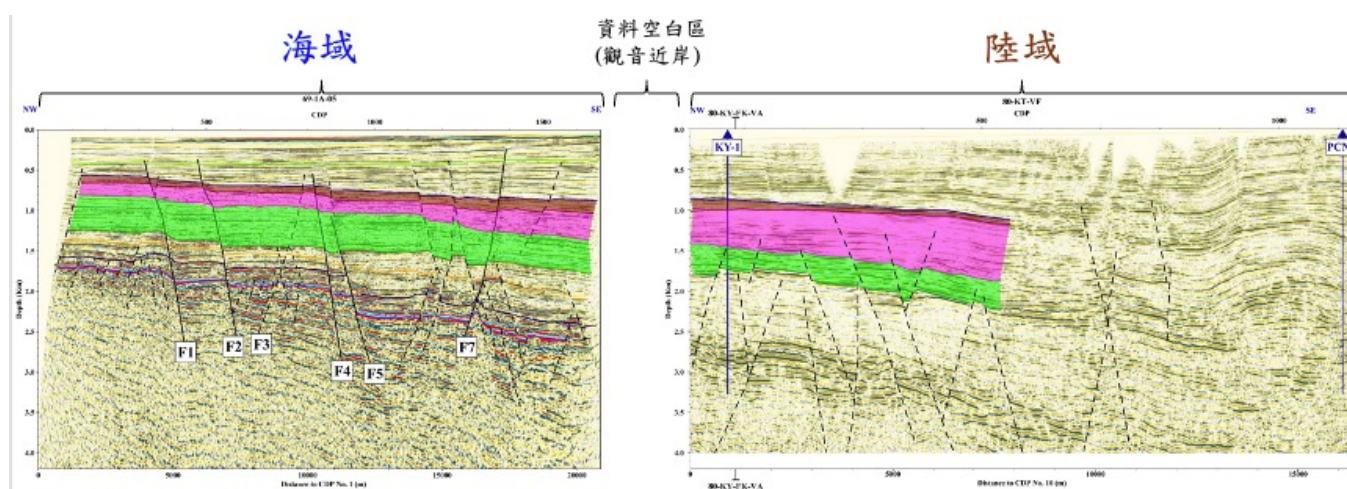
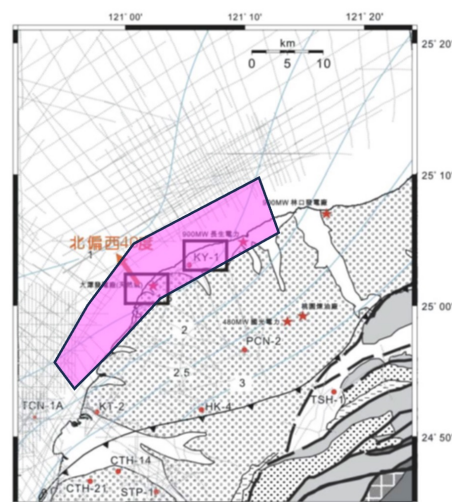
無近岸震測資料

無儀器

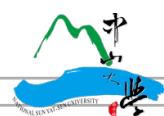
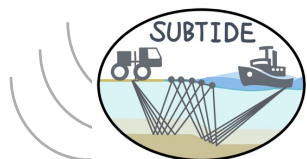
無海陸整合震測人員

無海陸資料整合與處理經驗

無野外工作規劃經驗



資料來源：中油
資料解釋：許鶴瀚實驗室



About the experiments

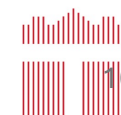
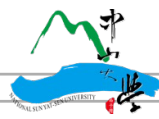
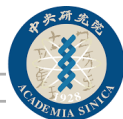
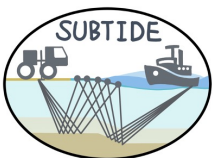
欲解決之問題？？

人員

儀器

野外規劃

資料分析



About the experiments

台大 郭陳濤



陸域震測

中山 林俊宏



潮間帶震測

台大 許鶴瀚

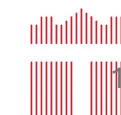
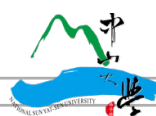
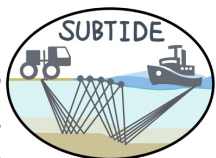
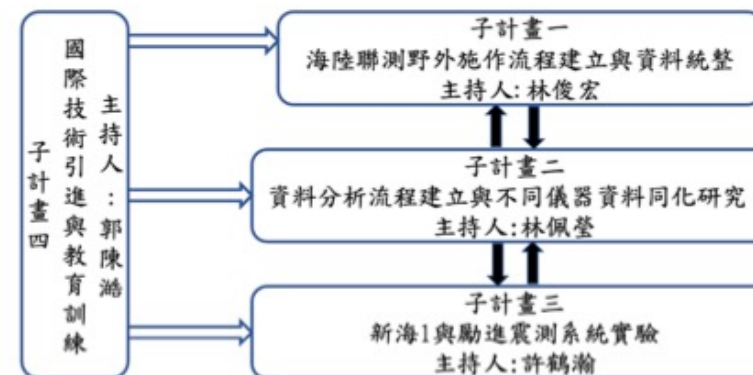
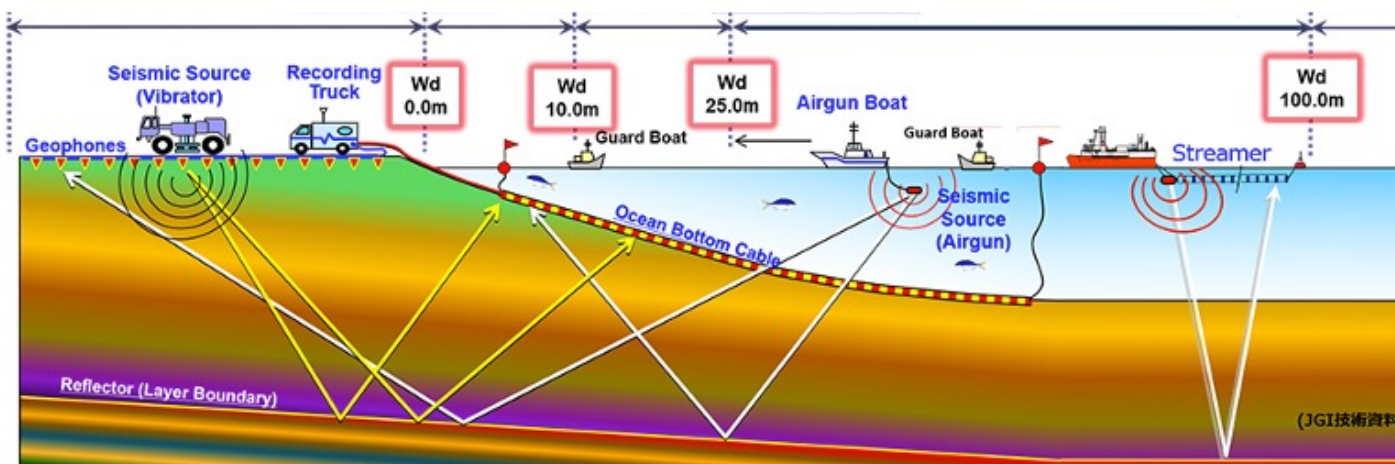


海域震測

師大 林佩瑩



資料統合



About the experiments

人員



About the experiments

設備盤點

	聲 源	接 收 端
陸域	震盪車	Smartsolo1C & 3C
潮間帶	自然訊號 泥槍	• 商用海底感測器(OBN) • 自製海底感測器(OBN)
海域	自然訊號 空氣槍陣列	Streamer

★ Challenges ★

➤ 不同震源與儀器資料

- 解析力
- 格式統合

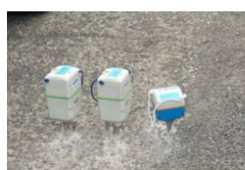
➤ 儀器測試

- 聲源強度
- 自製OBN檢驗



最大作用力 26,000磅力

1C & 3C



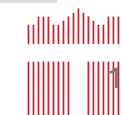
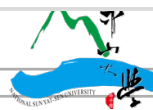
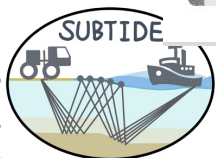
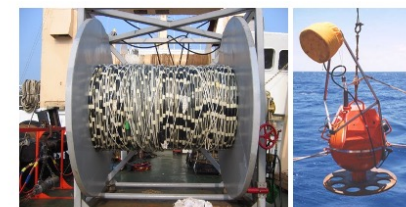
現有聲源能量：12s/25 m; 1,000 in³
20s/50 m; 2,000 in³

Streamer：
規劃長度：240 頻道 (間距12.5公尺)
設備長度：480 頻道 (間距12.5公尺)



現有聲源能量：10s/25 m; 1,500 in³
20s/50 m; 3,000 in³

Streamer：
16 X 4 (2/3D) (間距3.125公尺)
12/24 頻道(間距6.25公尺)
120 頻道 (間距12.5公尺)

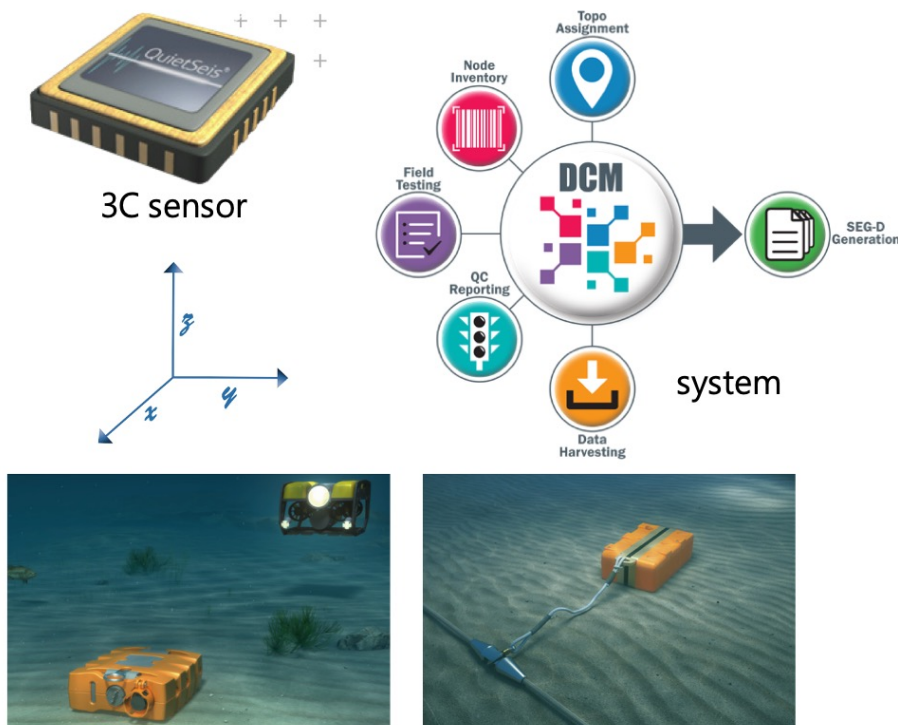


About the experiments

What is OBN (Ocean bottom node)?

商用OBN:

- 成熟商用感測器
- 系統化



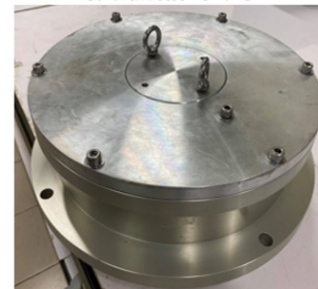
自製OBN (中山大學 林俊宏團隊):

- 可加裝不同感測元件
- 依潮間帶狀況不同可以調整固定方式
- 監測做先前準備

4.5Hz 3C geophone



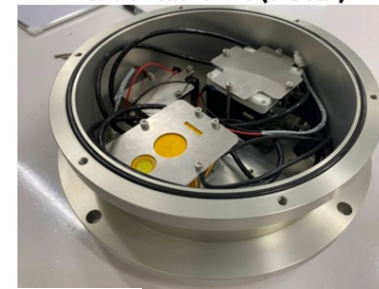
接收器單元



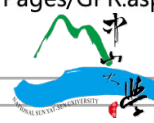
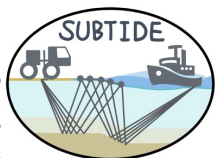
德國DiGOS Data-Cubes seismic recorder



接收器單元(內部)



<https://www.sercel.com/products/Pages/GPR.aspx>



About the experiments

What is OBN (Ocean bottom node)?

Why 4C
and OBN?

- 直接部署在海床上的地震儀
 - 直接接收地層傳送上來的震波，不必通過水層
- 好處
 - 可接收Swave，做出S波剖面
 - 相較於Streamer可以放置在更安靜的海床上
 - 分散式的地震儀可以更好的設計出施測幾何
 - 有效收所有震波（P，S）利於後續Full Waveform Inversion

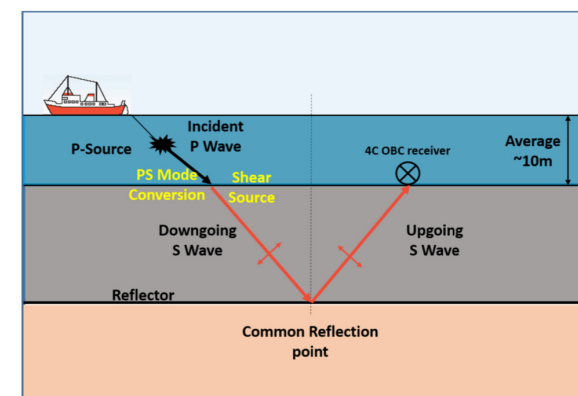


Figure IV-1: Illustrating PSS mode conversion at the sea bottom.

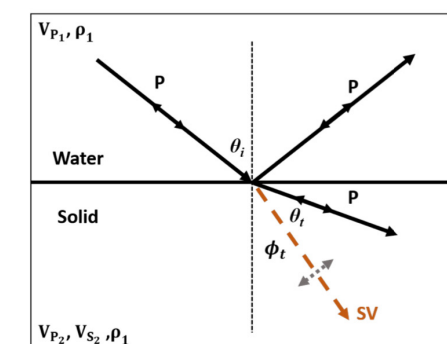
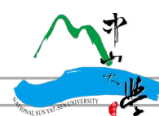
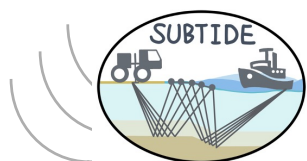


Figure IV-2: Sketch of the energy partitioning at a water-bottom interface.

68

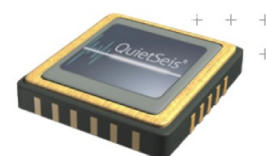


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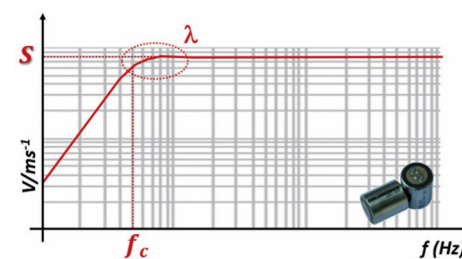
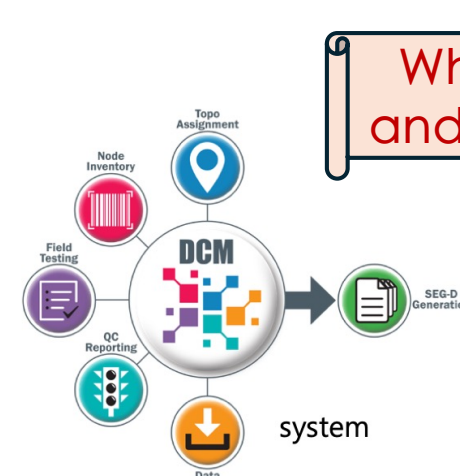
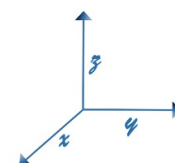
About the experiments

What is OBN (Ocean bottom node)?

- 理論寬頻
- 不存在自然頻率所造成的頻率失真與相位差
- 接受到更能反映地下構造的波形
- 低頻訊號的保留有利於後續的全波形反演



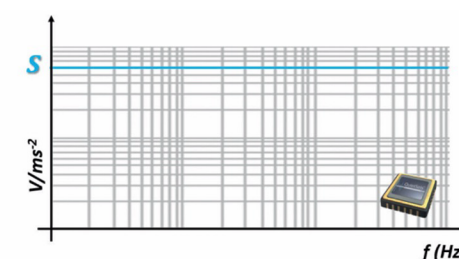
3C sensor



	Geophone
Sensitivity S_{nom}	80 V/m/s ($\pm 5\%$)
Natural frequency f_{nom}	5 Hz ($\pm 7.5\%$)
Damping λ_{nom}	0.6 ($\pm 7.5\%$)

$$R(f) \sim S_{nom} \cdot LC(f; f_c, \lambda_{nom}) \cdot v(f)$$

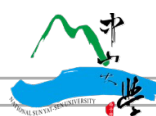
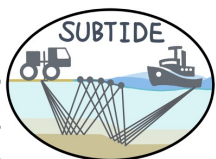
↑
Data Jitter



	MEMS
Sensitivity S	452 mV/m/s² ($\pm 0.25\%$)

$$R(f) = S \cdot a(f)$$

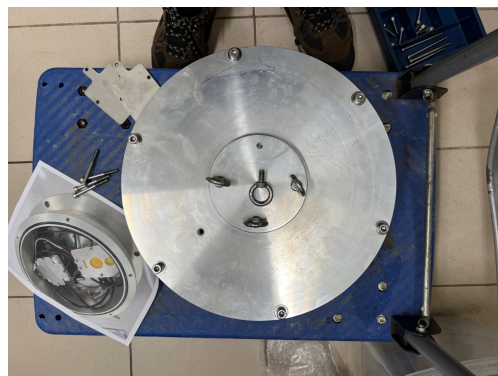
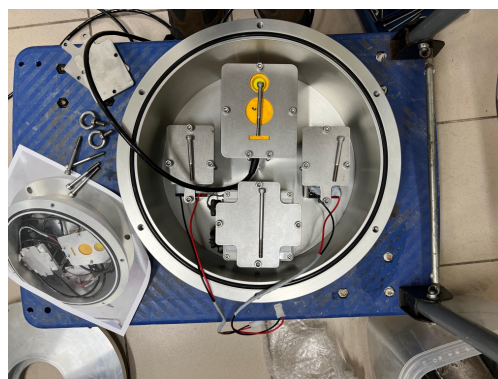
↑
No Data Jitter



About the experiments

What is OBN (Ocean bottom node)?

自製儀器OBN (中山大學林俊宏教授)



電源供應
(12V, 1.2Ah鉛電池)



傾斜記錄系統

無

振動訊號記錄器(商購)



電源供應
(12V鋰電池)



傾斜記錄系統



振動訊號記錄器(自行開發)

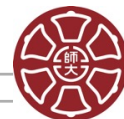
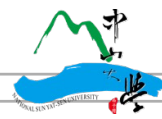
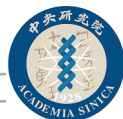
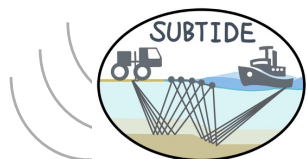


- 體積縮小，蓄電量增加，運行時間增加
- 室內測試 OK
- 陸域現地測試 OK
- 海域現地測試 OK

- 可校正OBN傾斜度
- 室內測試 OK
- 陸域現地測試 OK
- 尚未與震動量測整合

- 擷取頻率提升至800Hz
- 成本降低
- 室內測試 OK
- 改採網路校時

圖 4 自製 OBN 性能提升研發前後比較與測試狀況



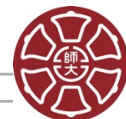
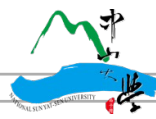
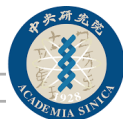
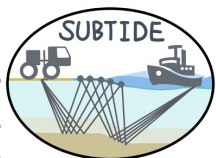
About the experiments What is OBN (Ocean bottom node)?

2024/03/18

80顆商用地震感測器(GPR)以及相關設備抵台



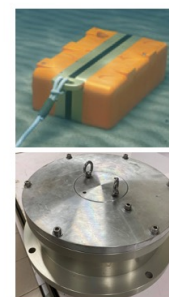
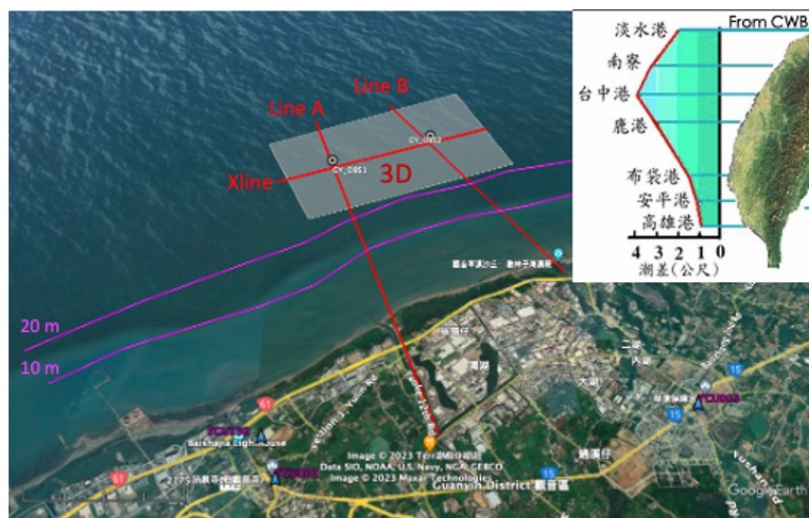
註：由於此設備在國際上仍為新產品，
許多資料處理程式並未完備，團隊已解決資料處理問題



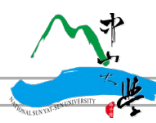
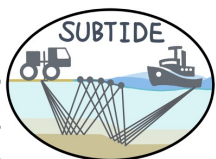
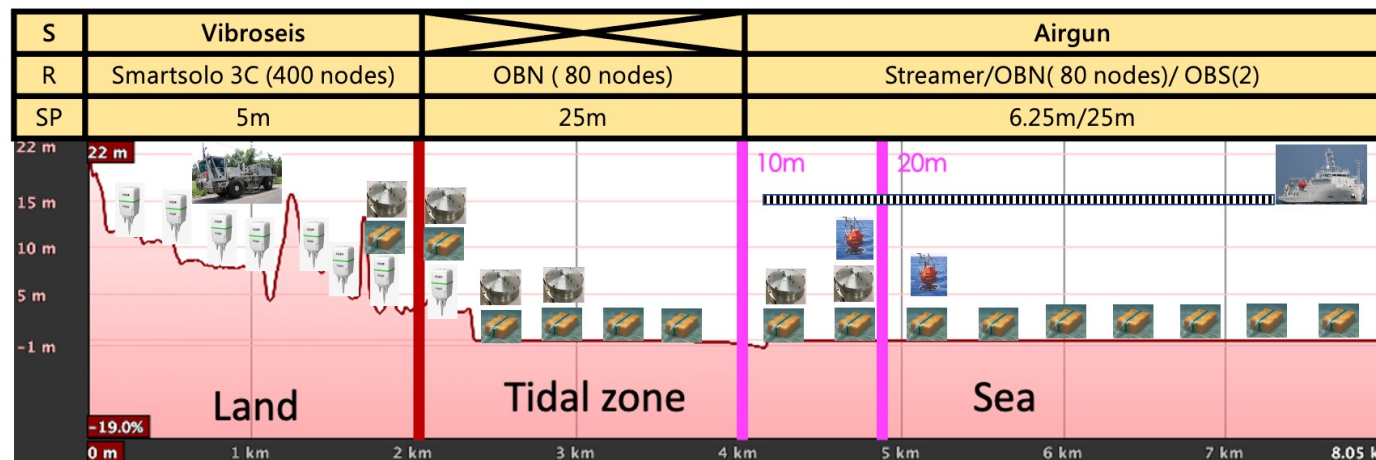
About the experiments



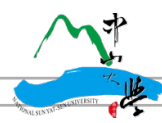
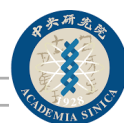
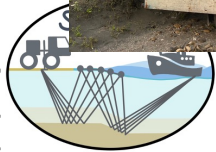
Major test Line (Line A) (First year)



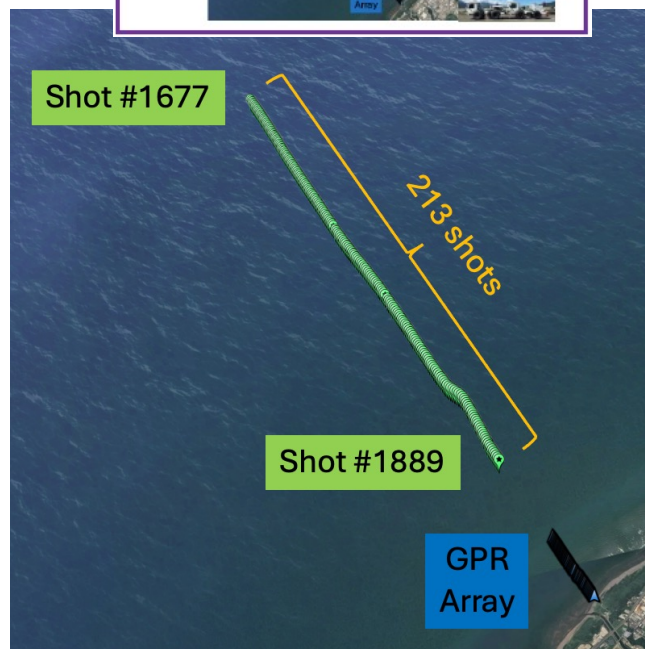
施測儀器佈設規劃



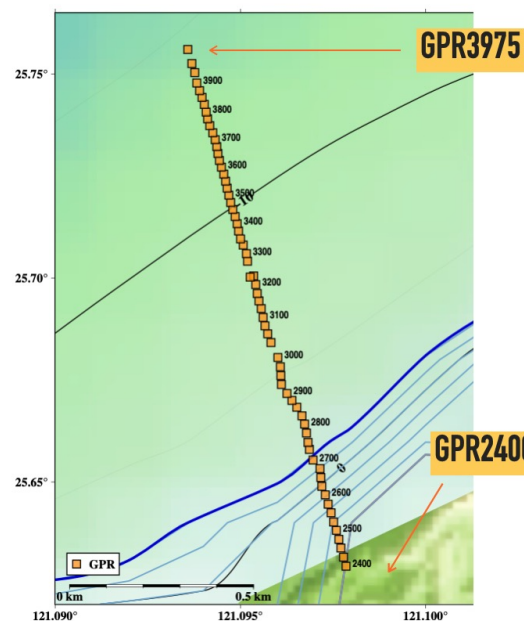
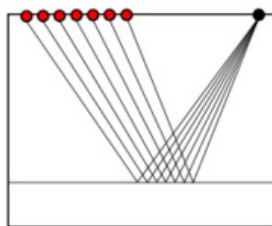
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國立臺灣大學



Results and some discussions



Common receiver



GPR紀錄勵進空氣槍情況： 水平分量反射訊號

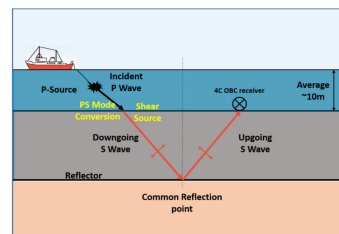


Figure IV-1: Illustrating PSS mode conversion at the sea bottom.

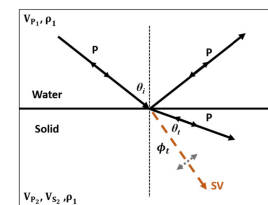
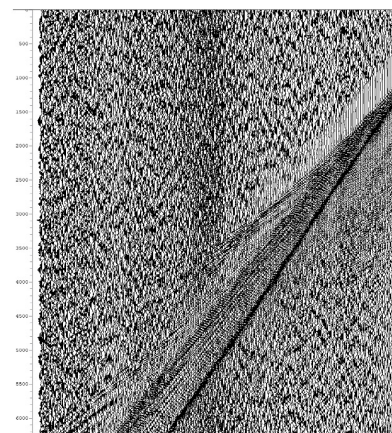
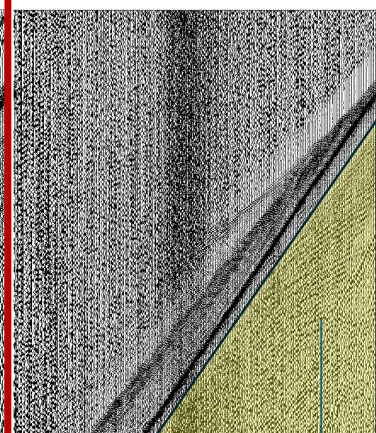


Figure IV-2: Sketch of the energy partitioning at a water-bottom interface.

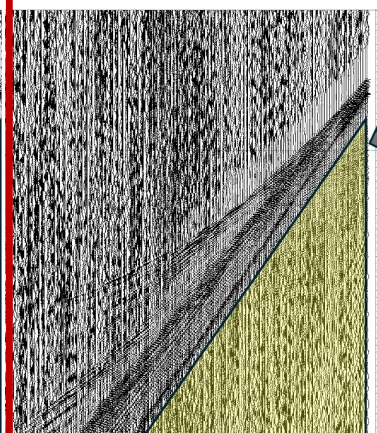
Channel #1
Vertical component



Channel #2
Horizontal component



Channel #4
Hydrophone

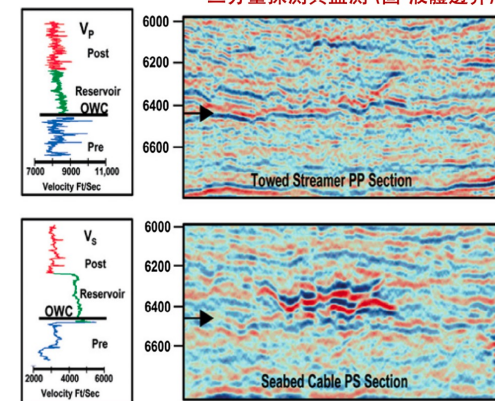


Reflections

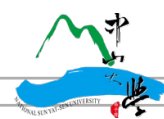
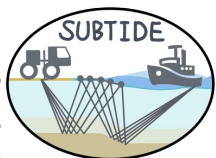
S wave Reflections?

Why 4C?

三分量探測與監測 (固-液體邊界)



Farfour and Yoon, 2015



Taiwan University
國立臺灣大學

Results and some discussions

3975



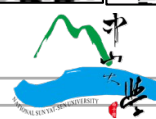
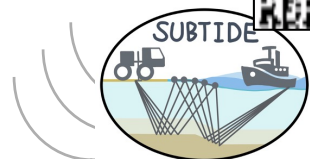
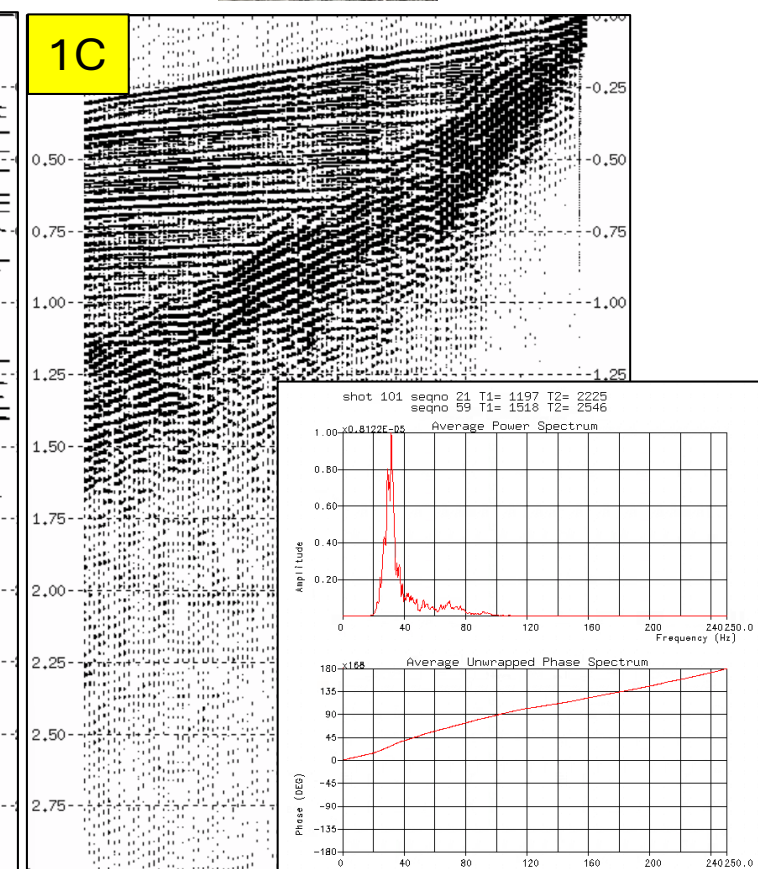
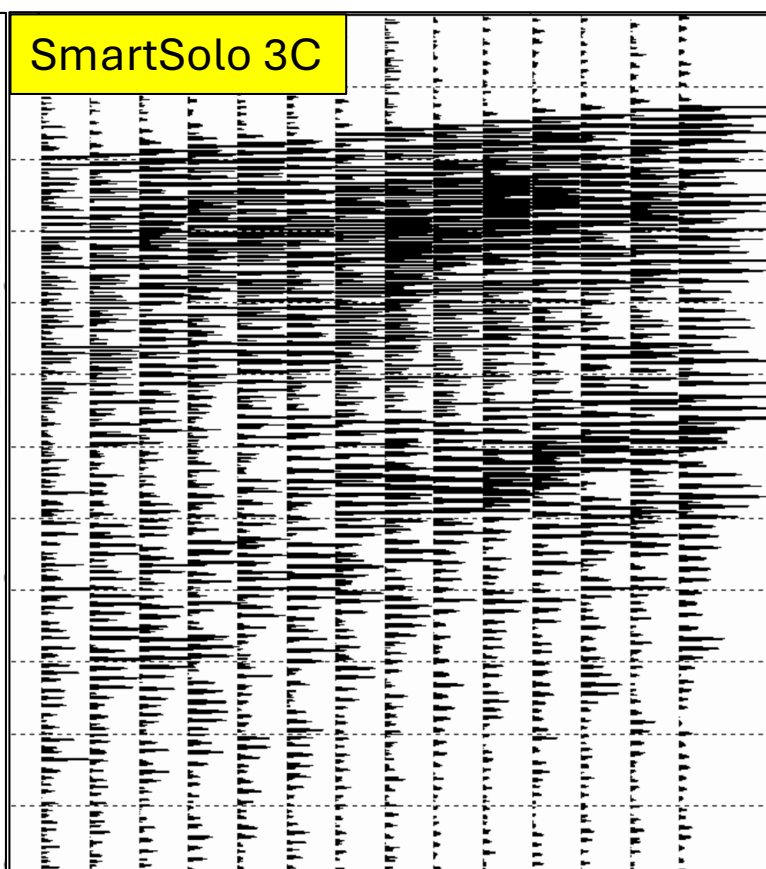
2400



2050



1550

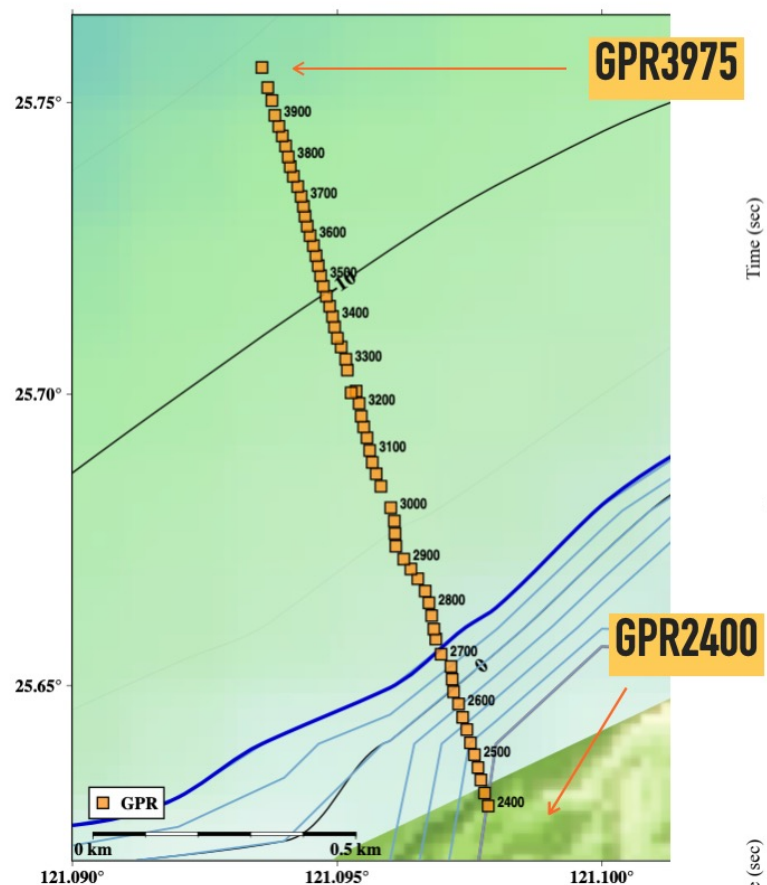


Results and some discussions

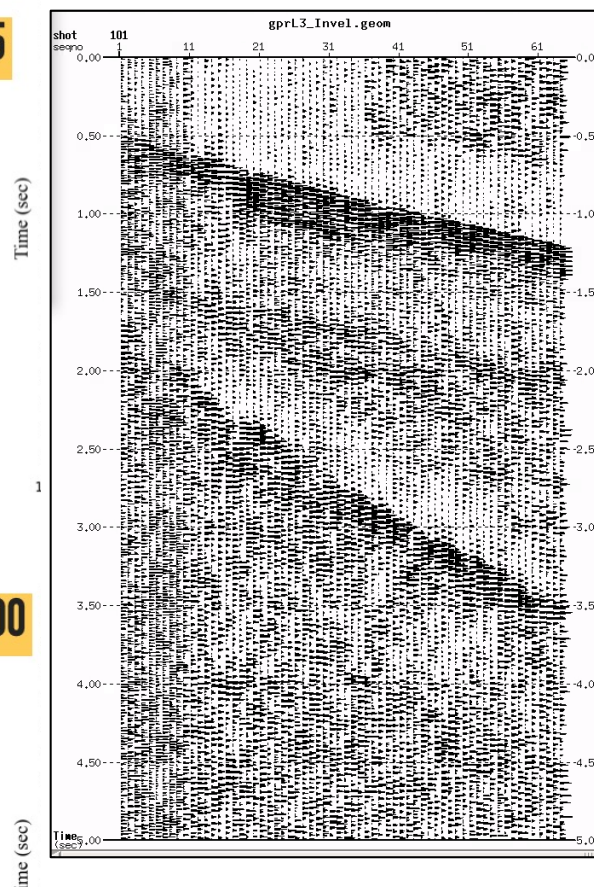
GPR紀錄震盪車震源情況：
水平分量反射訊號

64顆G P R 水平分量紀錄 (P轉S波)

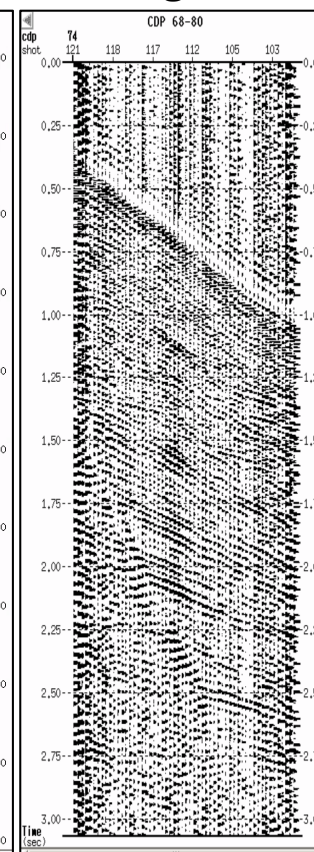
Why 4C?



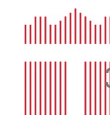
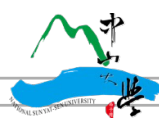
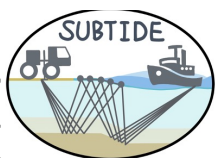
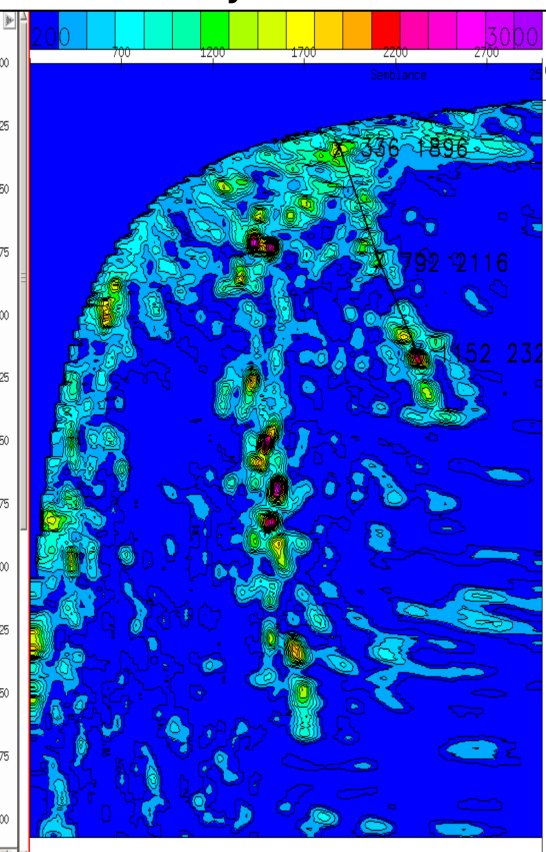
Receiver gather



CMP gather

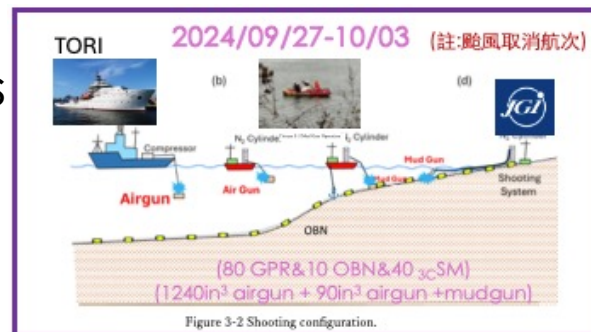


Velocity semblance



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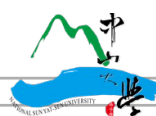
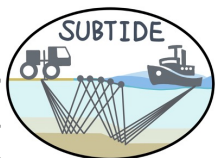
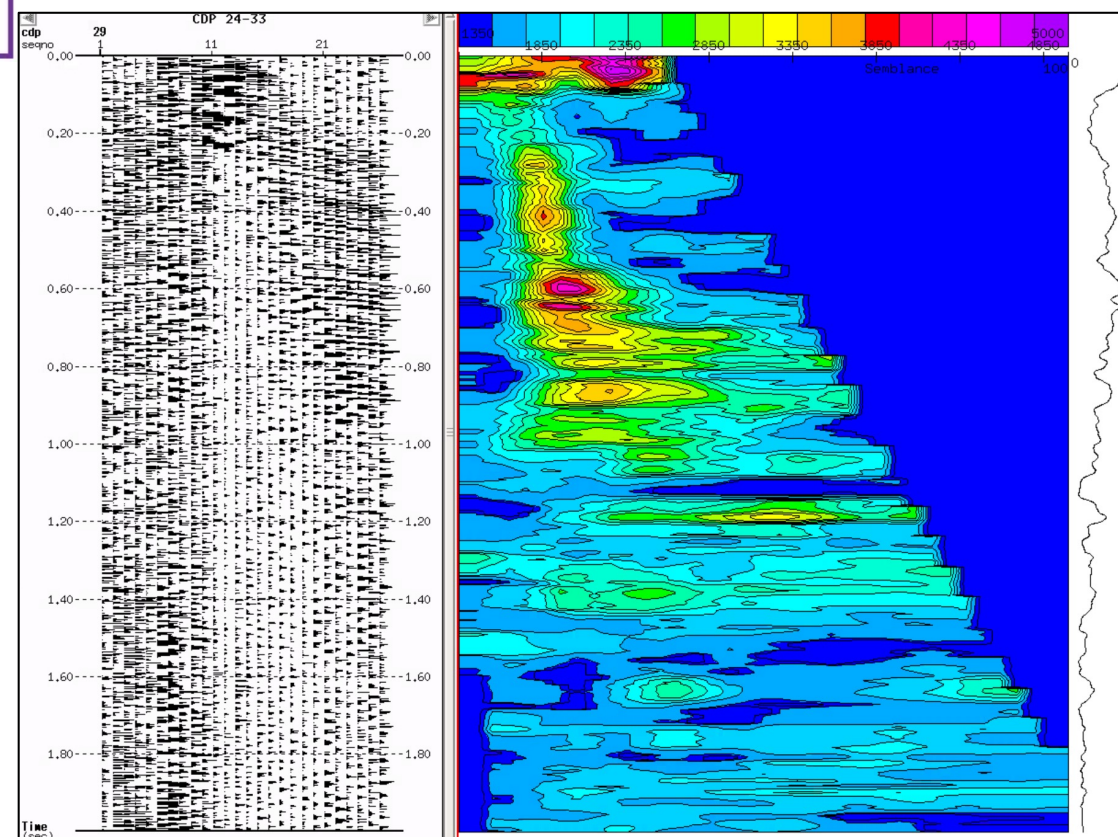
Results and some discussions



泥槍(40 in³ Mudgun)

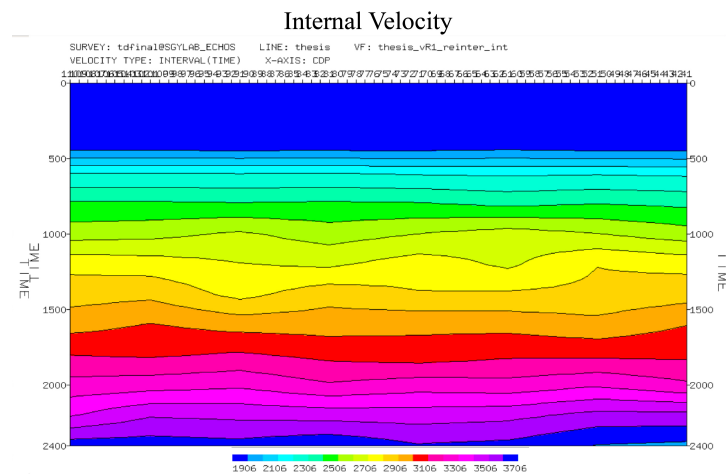
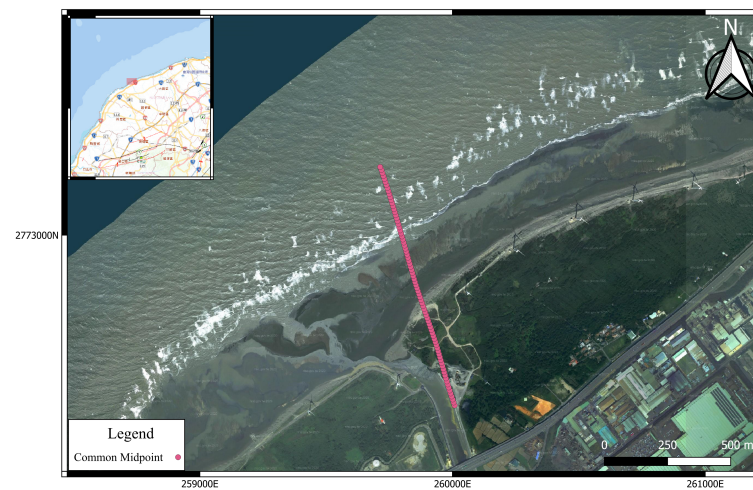
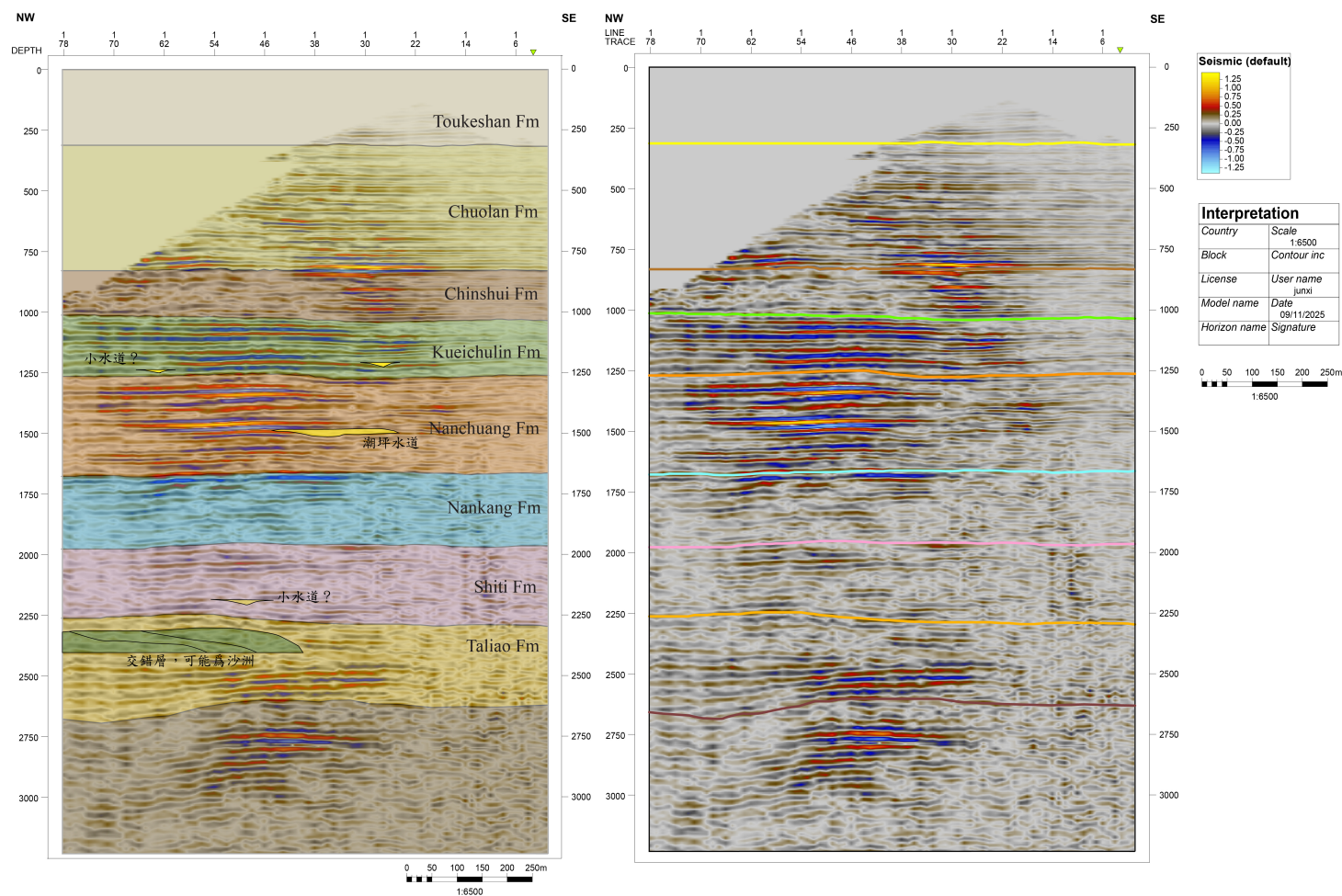
CMP gather

速度分析

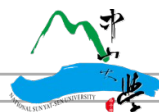
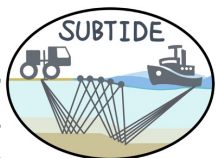


Results and some discussions

解析深度超過3.5公里

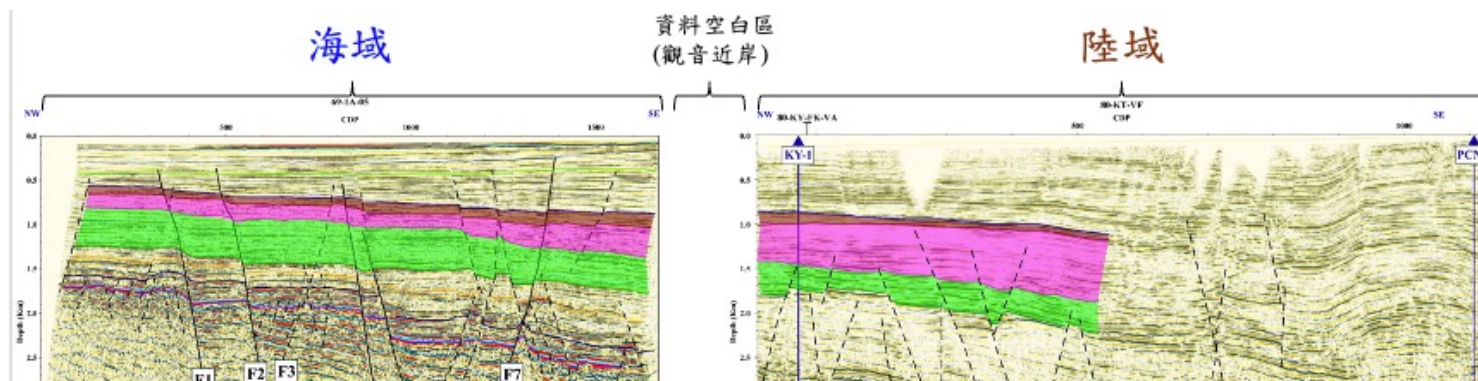


(范峻翔, 2025)



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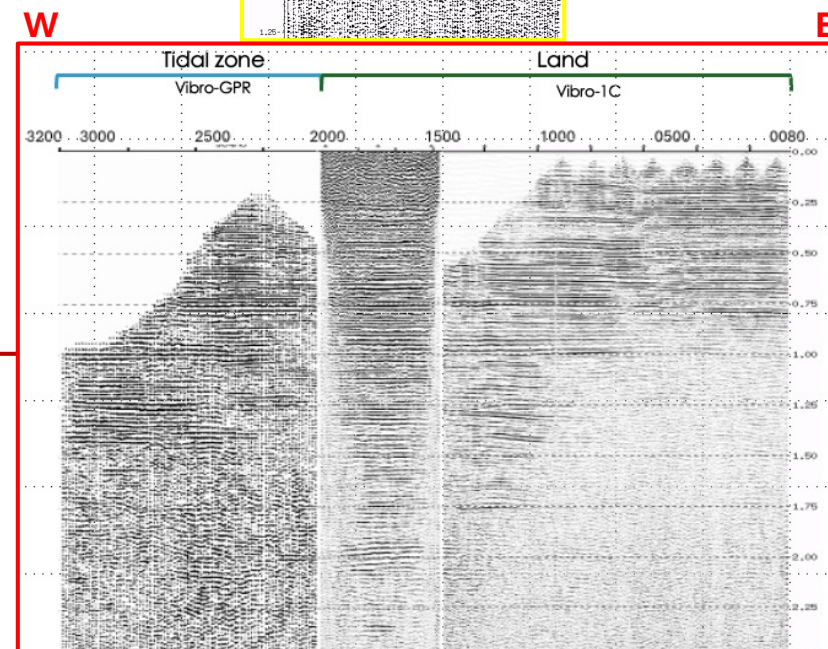
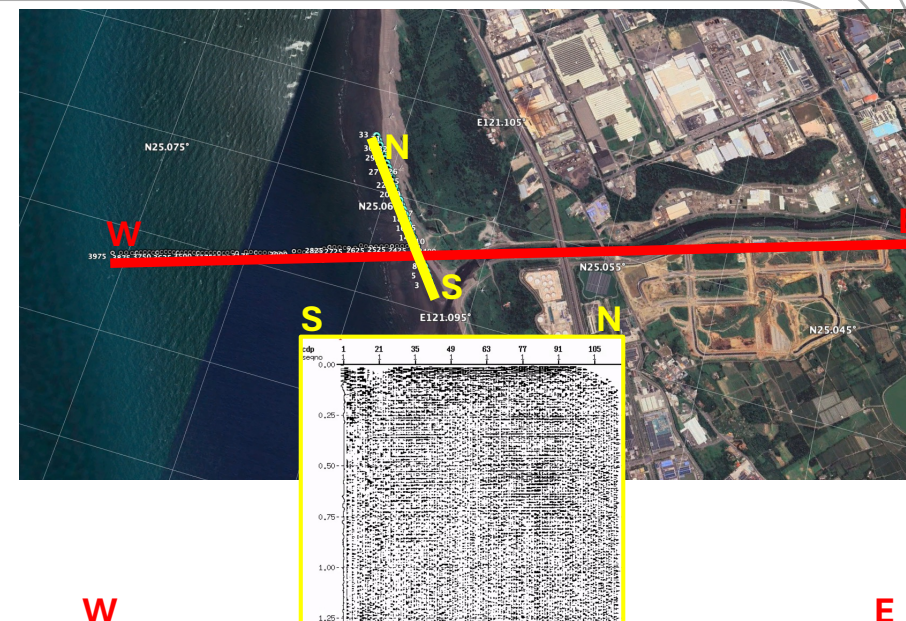
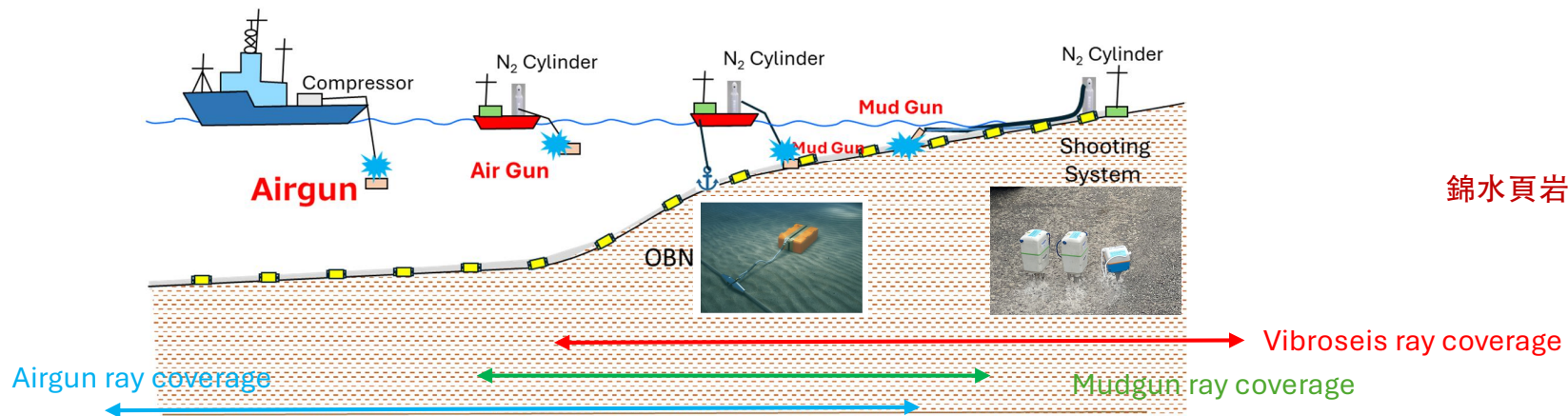
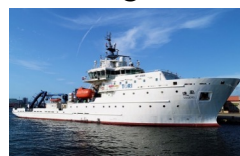
Results and some discussions



Airgun

Mudgun

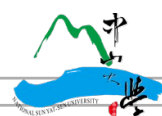
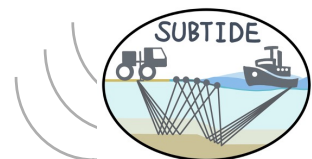
Vibroiseis



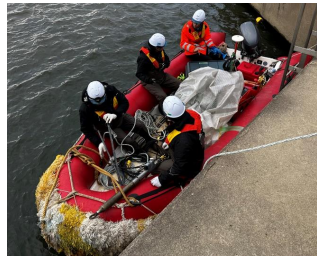
錦水頁岩

Vibroseis ray coverage

Mudgun ray coverage



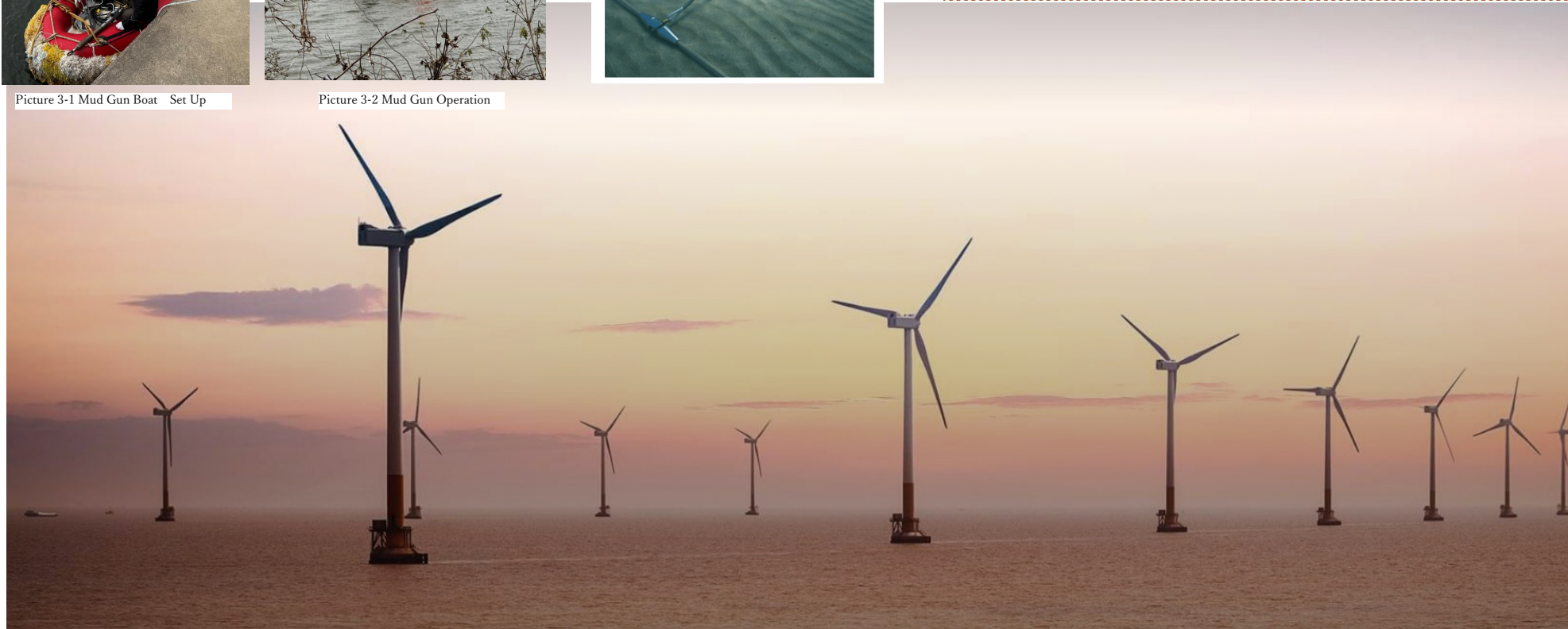
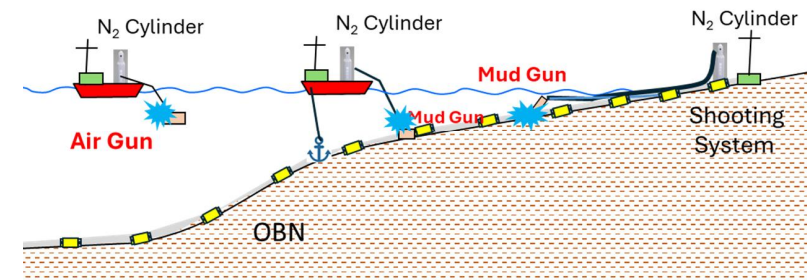
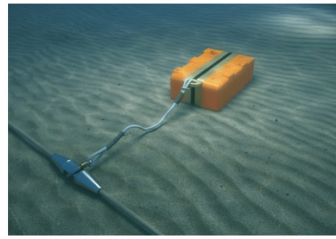
Further applications



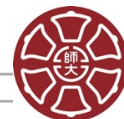
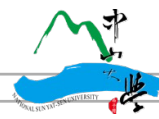
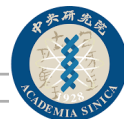
Picture 3-1 Mud Gun Boat Set Up



Picture 3-2 Mud Gun Operation



<https://cleanpower.org/facts/offshore-wind/>



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謝謝聆聽，敬請指教！

