台灣CCS封存現況

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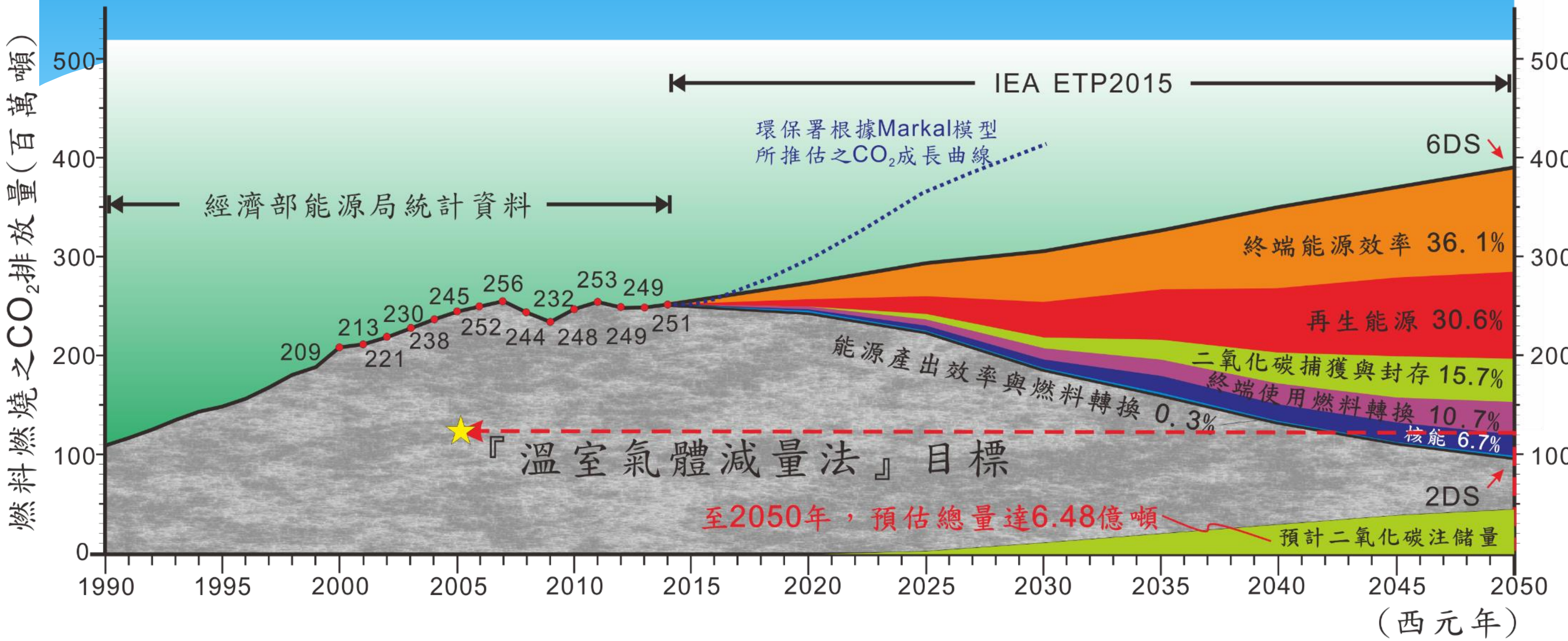
台灣二氧化碳排放歷史與未來趨勢



ETP2015 estimation	2015	2020	2025	2030	2035	2040	2045	2050
End-use fuel and electricity efficiency	54.5%	59.4%	46.7%	41.9%	38.2%	36.5%	35.6%	36.1%
Renewables	23.4%	17.6%	27.5%	29.8%	30.5%	30.7%	31.4%	30.6%
Carbon capture and storage	0.0%	1.3%	5.3%	8.9%	11.8%	13.8%	15.1%	15.7%
End-use fuel switching	9.1%	10.7%	11.0%	10.2%	9.8%	9.6%	10.0%	10.7%
Nuclear	0.0%	4.7%	7.8%	8.1%	8.7%	8.4%	7.5%	6.7%
Power generation efficiency and fuel switching	13.0%	6.3%	1.7%	1.1%	1.0%	0.9%	0.4%	0.3%

台灣二氧化碳主要排放源

Most power plants and industrial parks are located in the western part of Taiwan, where suitable sedimentary basins and rock formations for CO_2 storage are available

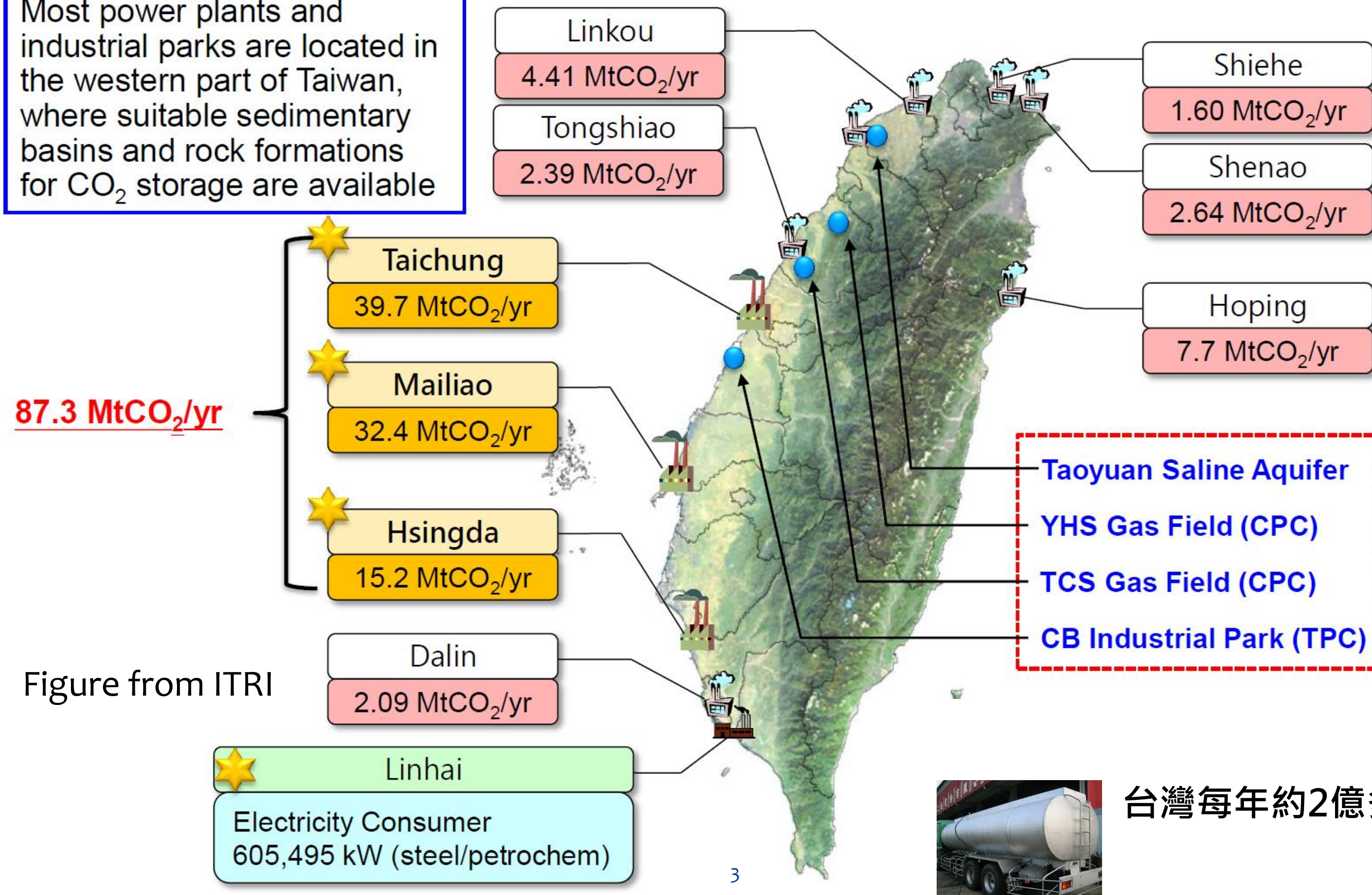
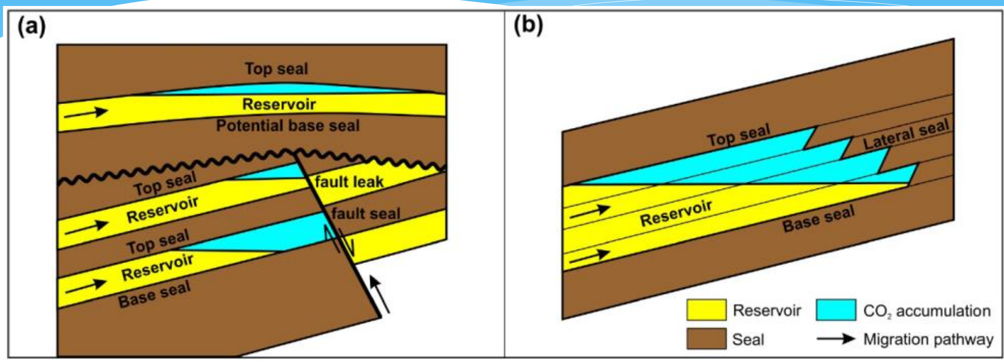


Figure from ITRI

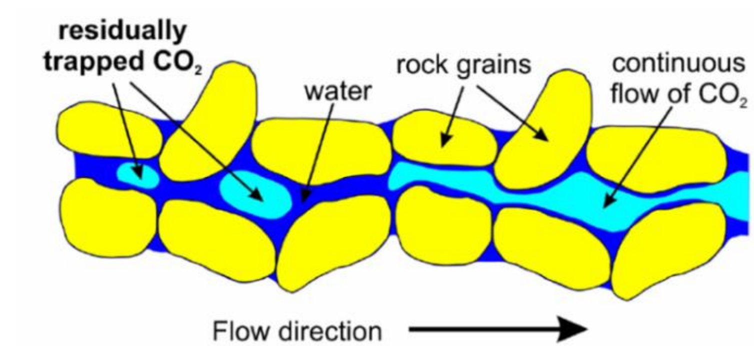
台灣每年約2億多噸

二氧化碳封存機制

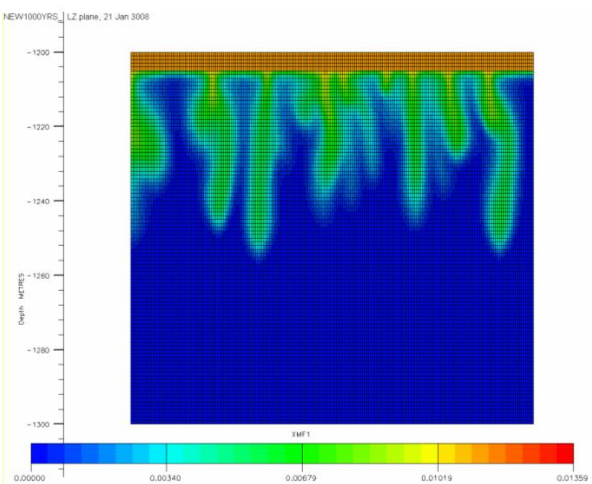
1. 構造或地層封存(鹽水層封存屬於該類型)



2. 殘餘封存



3. 溶解封存



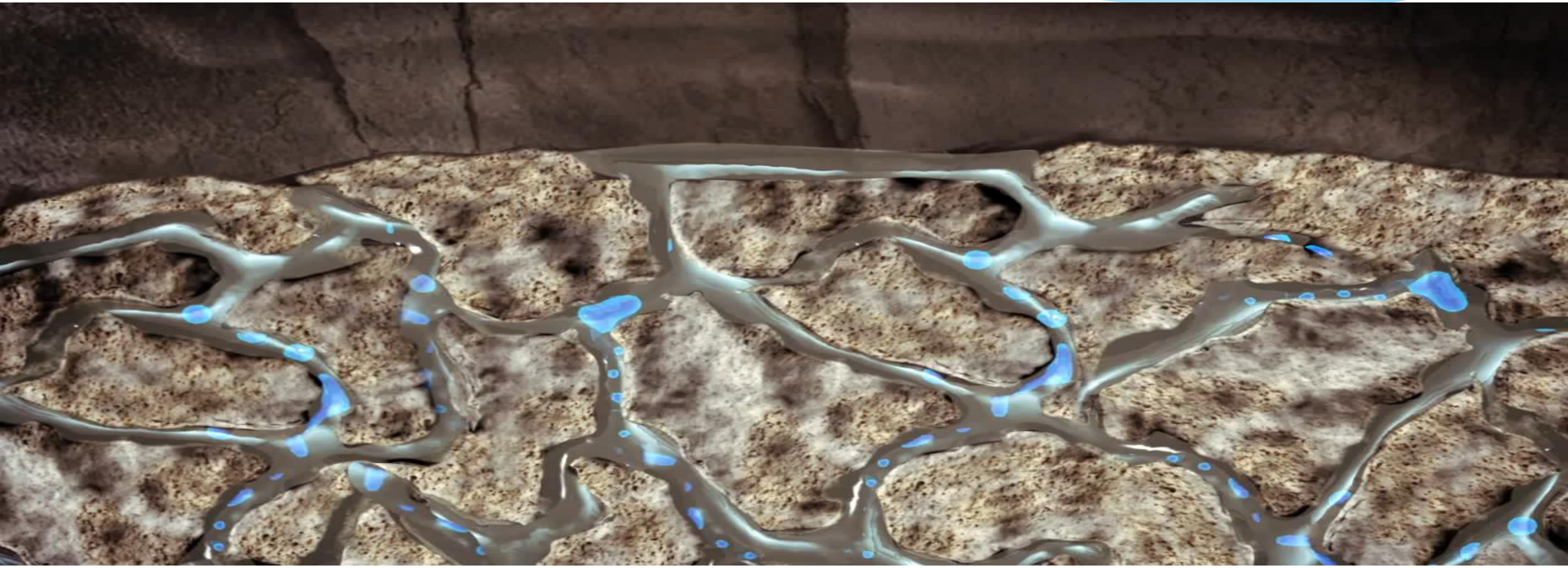
4. 礦化封存

$$M^{2+}_{(aq)} + CO_3^{2-}{}_{(aq)} \Rightarrow MCO_{3(s)} \quad \text{(where M = Ca, Mg, Fe)}$$

CO2CRC (2008)

二氧化碳封存機制

構造封阻作用構造或地層封存- 將二氧化碳限制在蓋岩層下
（鹽水層封存屬於這類型）



(Source: CO_2 Capture Project)

二氧化碳封存機制

殘餘封存

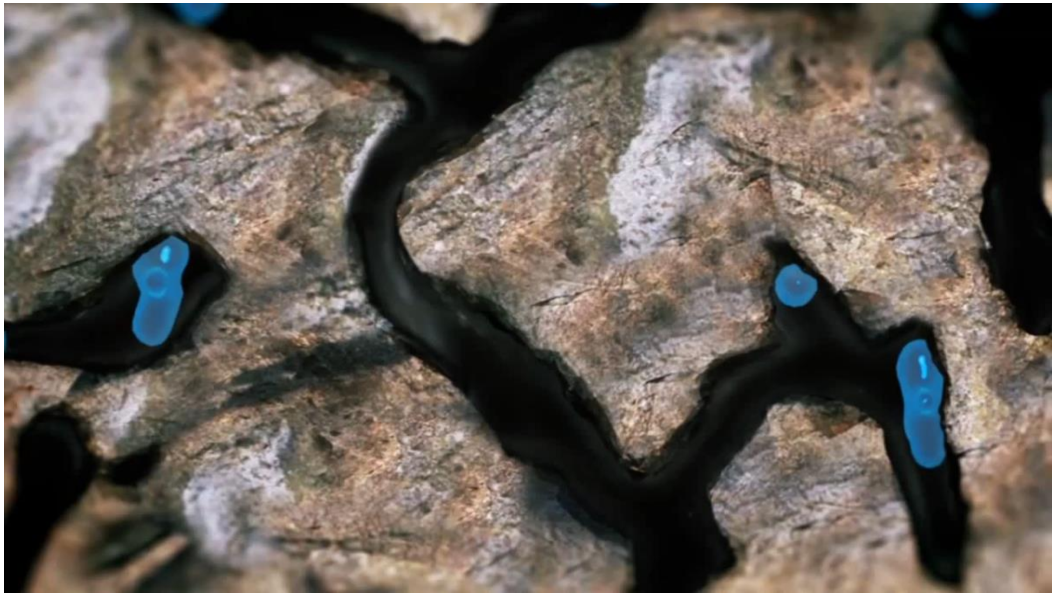
Residual Trapping

CO_2被固定在小孔隙中

(Source: CO_2 Capture Project)

二氧化碳封存機制

溶解封存
Dissolution Trapping



1. 部分被注入的二氧化碳會溶解於原本就存在於孔隙的鹽水中，而此溶解了二氧化碳的鹽水會比未溶解二氧化碳的水重，故會向下沉，進一步將二氧化碳帶往封存層下方移動。
2. 溶解速率取決於二氧化碳與鹽水間接觸程度，可溶解的二氧化碳量有最大濃度的限制。但這樣的溶解作用發生在狹小的孔隙中，所以溶解速度較緩慢。
3. Sleipner 計畫粗估約有15% 的二氧化碳會在注入的10 年後溶解於鹽水中。

(Source: CO_2 Capture Project)

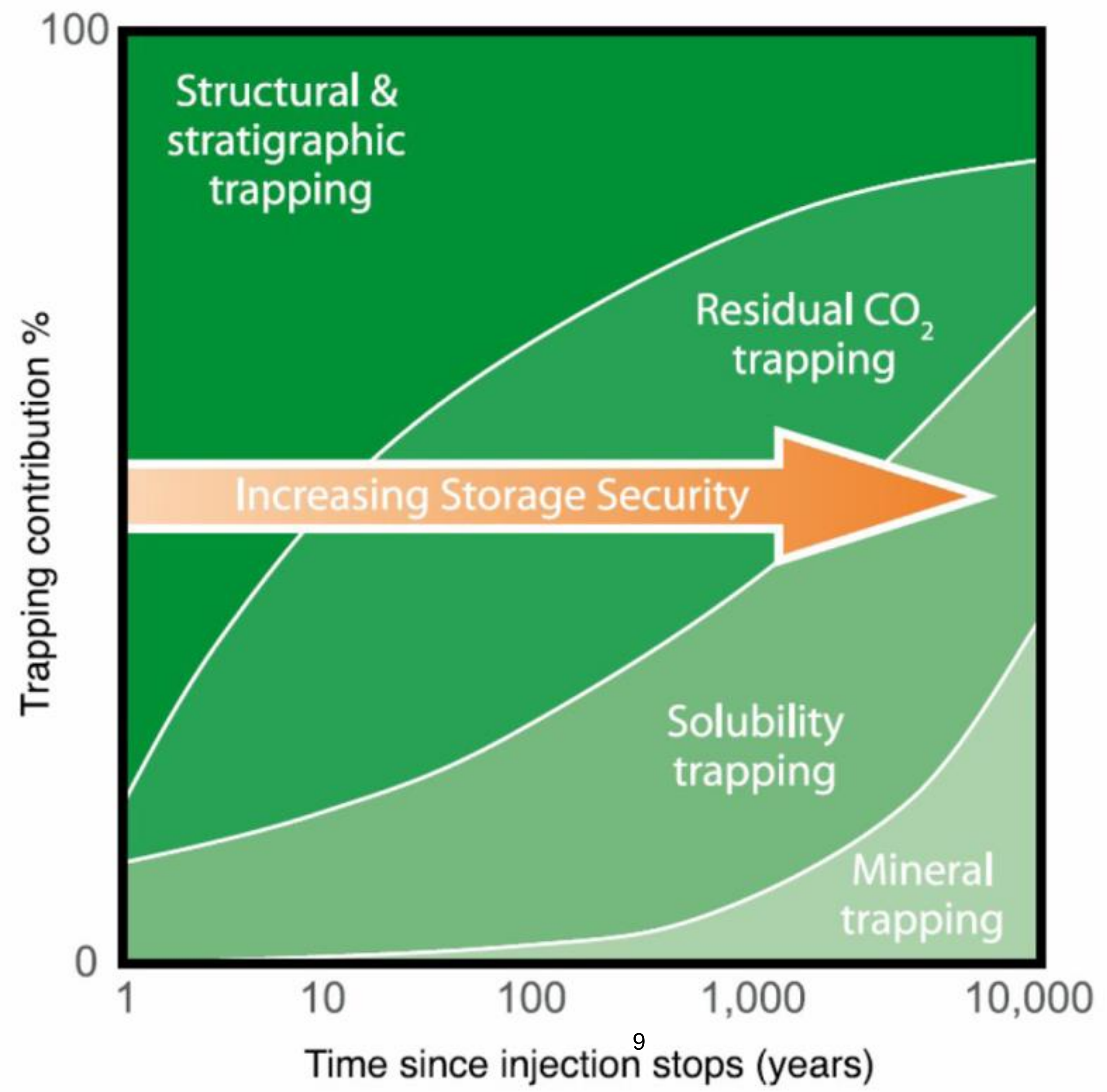
二氧化碳封存機制

礦化封存
Mineral Trapping

1. 二氧化碳可與構成封存層的礦物起交互作用，特別是與鹽水混合的二氧化碳產生的交互作用更大。
2. 根據pH值及封存層礦物組成的不同，某些特定的礦物會溶解，而某些礦物則會沉澱。
3. 根據Sleipner 計畫估計，經過很長的時間後，少部份的二氧化碳會經由礦化封存機制封存在地層中。
4. 一萬年之後，有5%的二氧化碳會礦化，其他95% 則會溶解於封存層中，二氧化碳不會再以原來灌入時的高密度狀態存在。

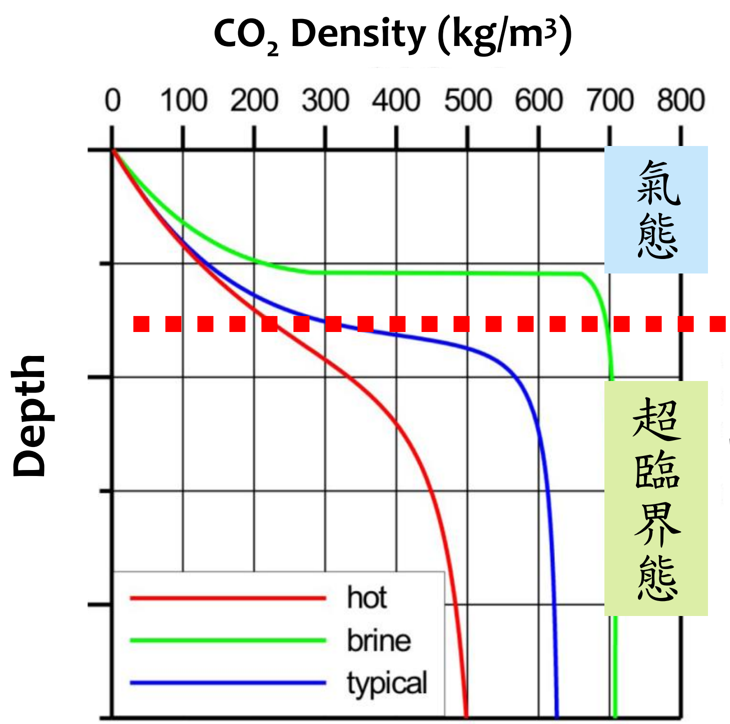
(Source: CO_2 Capture Project)

封存機制貢獻度與安全性時間變化

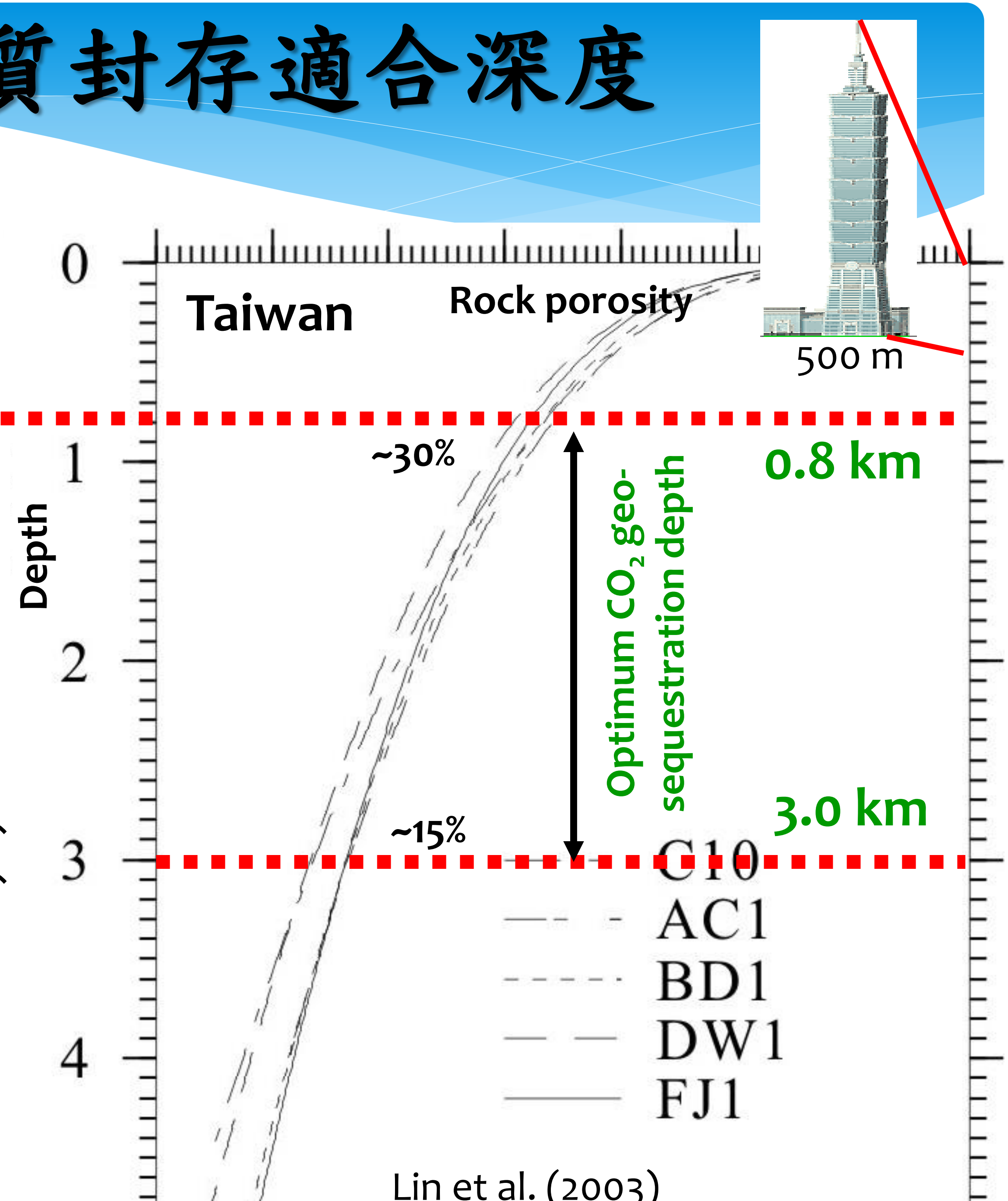


IPCC (2005)

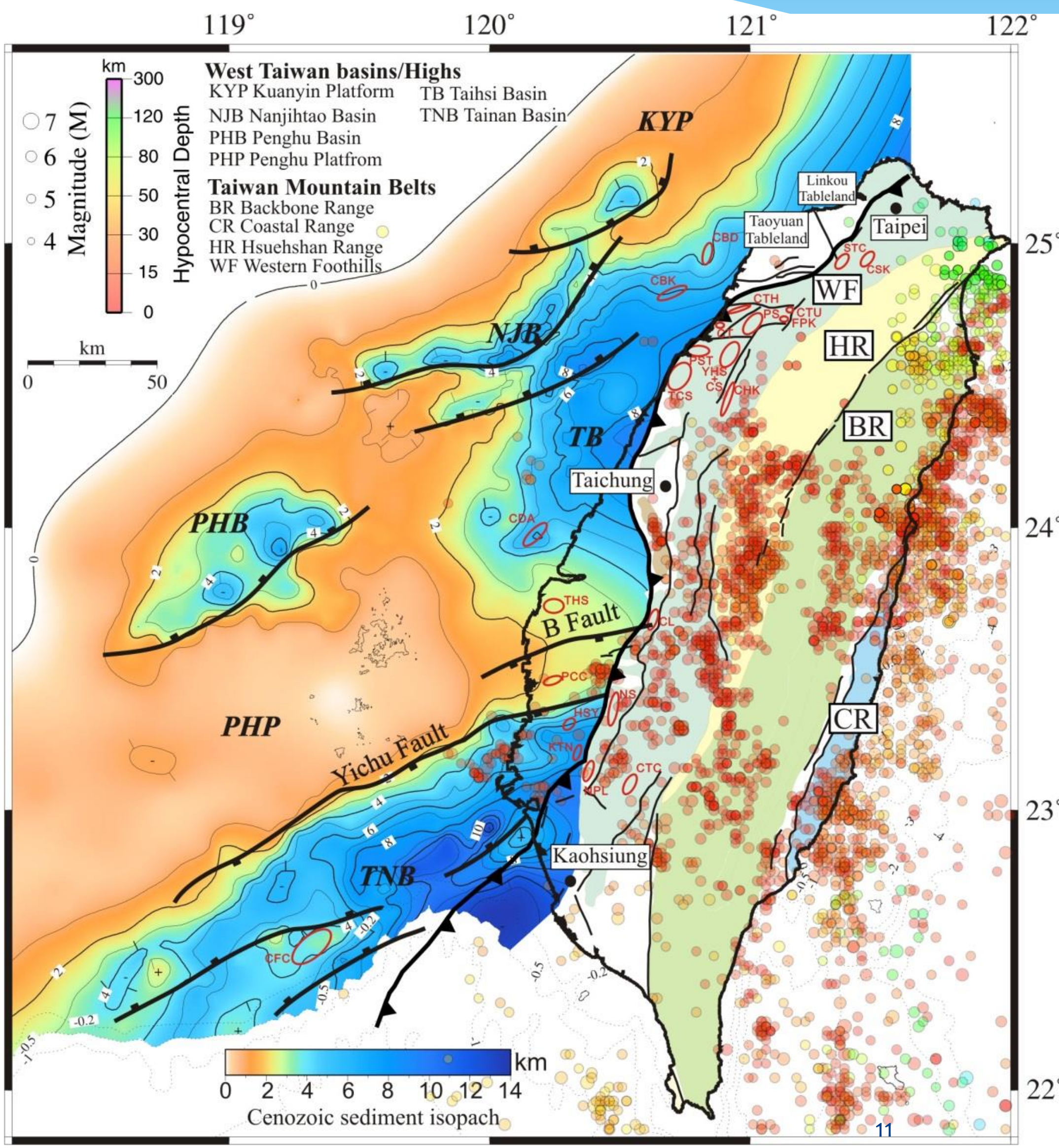
二氧化碳地質封存適合深度



超臨界流體具有低黏度、高密度、高擴散性和低表面張力等介於氣、液相之間的物理性質



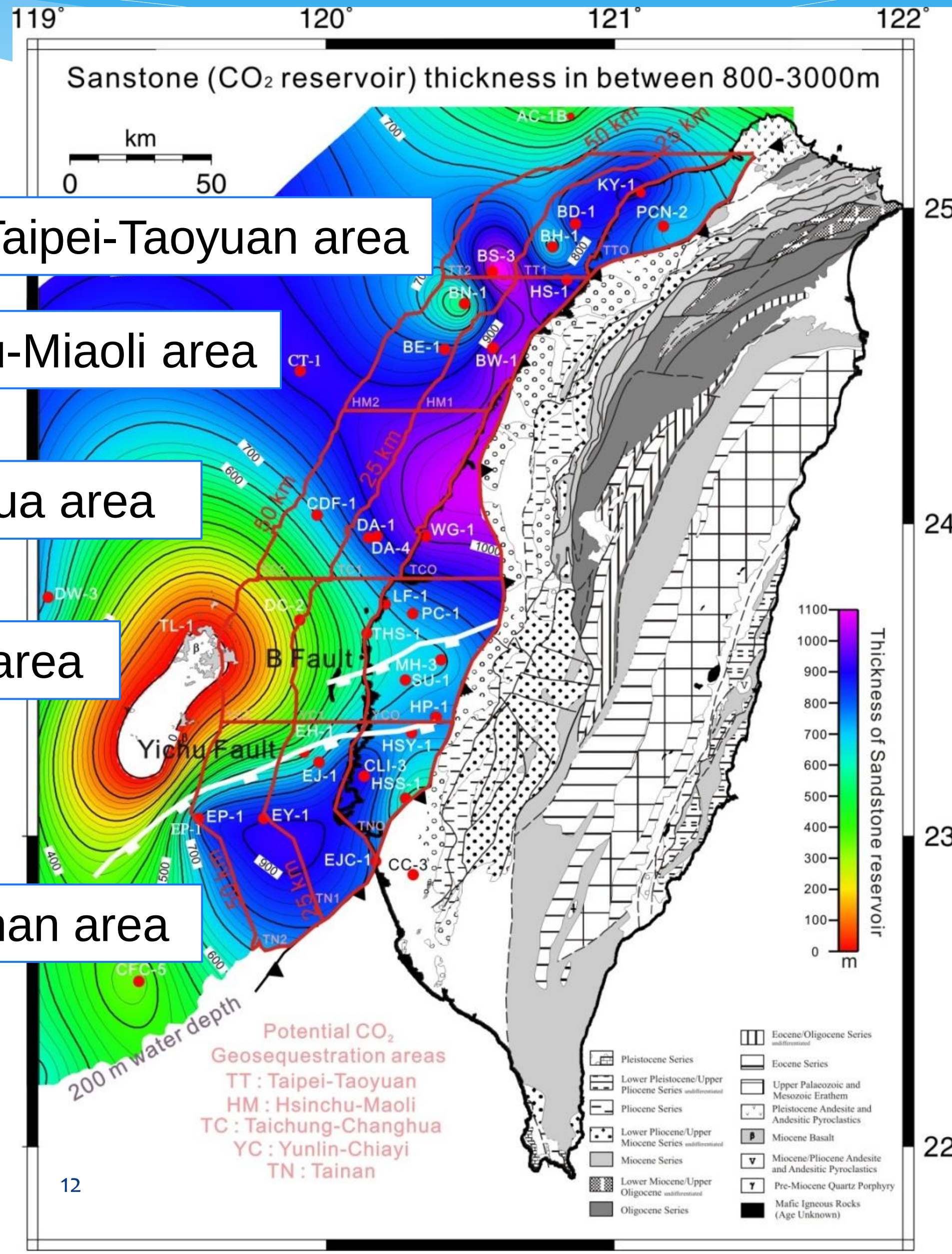
台灣鹽水層封存潛能—新生代沉積物厚度



Sedimentary Rocks

- Up to 8 km thick
- Taiwan Strait (deep saline formation)
- Western Coastal Plain (deep saline formation)
- Western Foothills (depleted gas fields and other structural traps)

台灣鹽水層封存潛能—評估區域劃分



Each area is subdivided into:

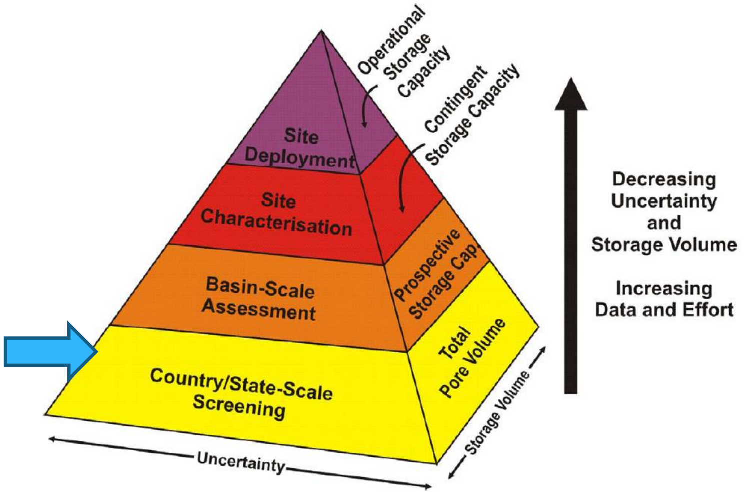
a. **Coastal plain/tableland** area.

b. **Offshore** area within 25 km off the coastline (0-25 k offshore).

c. **Offshore** areas lying in between 25 km to 50 km off the coastline (25-50 k offshore).

台灣鹽水層封存潛能—封存量評估

Areas	Coastal Plain (x100 Mt)	Offshore (coastline to 25 km) (x100 Mt)	Offshore (25-50 km) (x100 Mt)	Total Capacity (x100 Mt)
Taipei-Taoyuan	25	30	33	88
Hsinchu-Miaoli		34	34	68
Taichung-Changhua	37	43	34	114
Yunlin-Chiayi	49	21	10	80
Tainan	27	40	42	109
	138	168	153	459



CO2CRC (2008)

45.9 billion tons (459億噸)

台灣陸域構造封存潛能—封存量評估

構造名稱	面積 (平方公里)	淨厚度 (公尺)	孔隙率 (%)	氣體體積因子	排掃效率	CO^2 飽和度	封存潛能 (億立方公尺)	封存潛能 (億噸)
八德	21.6	120	17.5	178	0.5	0.5	201.63	0.37
平鎮	24	275	22.4	175	0.5	0.5	646.80	1.18
坑子口	6.4	250	15	150	0.5	0.5	90.00	0.16
湖口-楊梅	128	337	15	141	0.5	0.5	2280.82	4.15
竹東	19.2	298	22.5	151	0.5	0.5	485.98	0.88
寶山	44.8	245	23.6	152	0.5	0.5	984.33	1.79
出磺坑	120	255	9.2	162	0.5	0.5	1142.97	2.08
錦水	72	730	15.2	126	0.5	0.5	2516.57	4.58
青草湖-崎頂	96	253	10.3	190	0.5	0.5	1188.29	2.16
鐵砧山	72	255	22.4	171	0.5	0.5	1758.15	3.20
白沙屯	9.6	240	10	177	0.5	0.5	101.95	0.19
永和山	14.4	240	10	162	0.5	0.5	139.97	0.25
八卦山	403	75	19	277	0.5	0.5	3981.70	7.24
牛山	19.2	45	20	95	0.5	0.5	41.04	0.07
總計							15560.20	28.29

呂明達等(2008)

Around 2.8 billion tons (28億噸)

天然氣氣窖注儲歷史

天然氣注儲技術≈二氧化碳封存技術

The 1st project

- The first successful gas storage project was completed in 1915 in Welland County, Ontario.
- The first commercial underground gas storage was build in Buffalo City, New York State, USA in 1916, converting from a depleted reservoir, Zoar. The facility is still in operation.

No. of projects

- Around 600 projects worldwide.

Types of underground storage

- Depleted oil / gas reservoir 450
- Salt cavern/Abandoned mine pit
- Aquifer

145

台灣天然氣氣窖注儲經驗

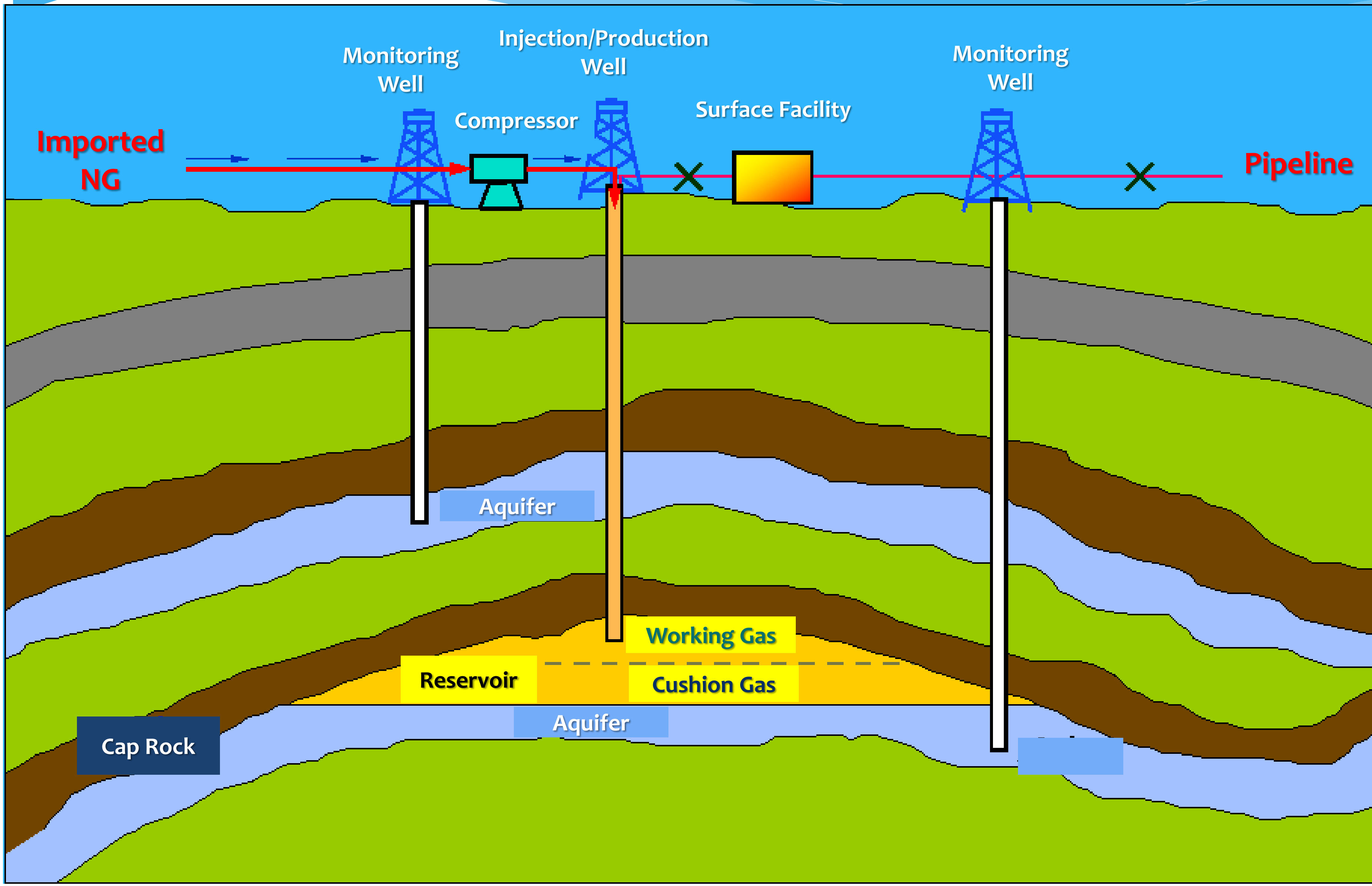
Background

- Since 1990
- Depleted gas reservoir (depth 2,580-2,750 m)
- Supply gas fired power generation
- 9 injection/production wells
  - Max injection rate: 2.6 MMSCM/D
  - Max production rate: 3.9 MMSCM/D

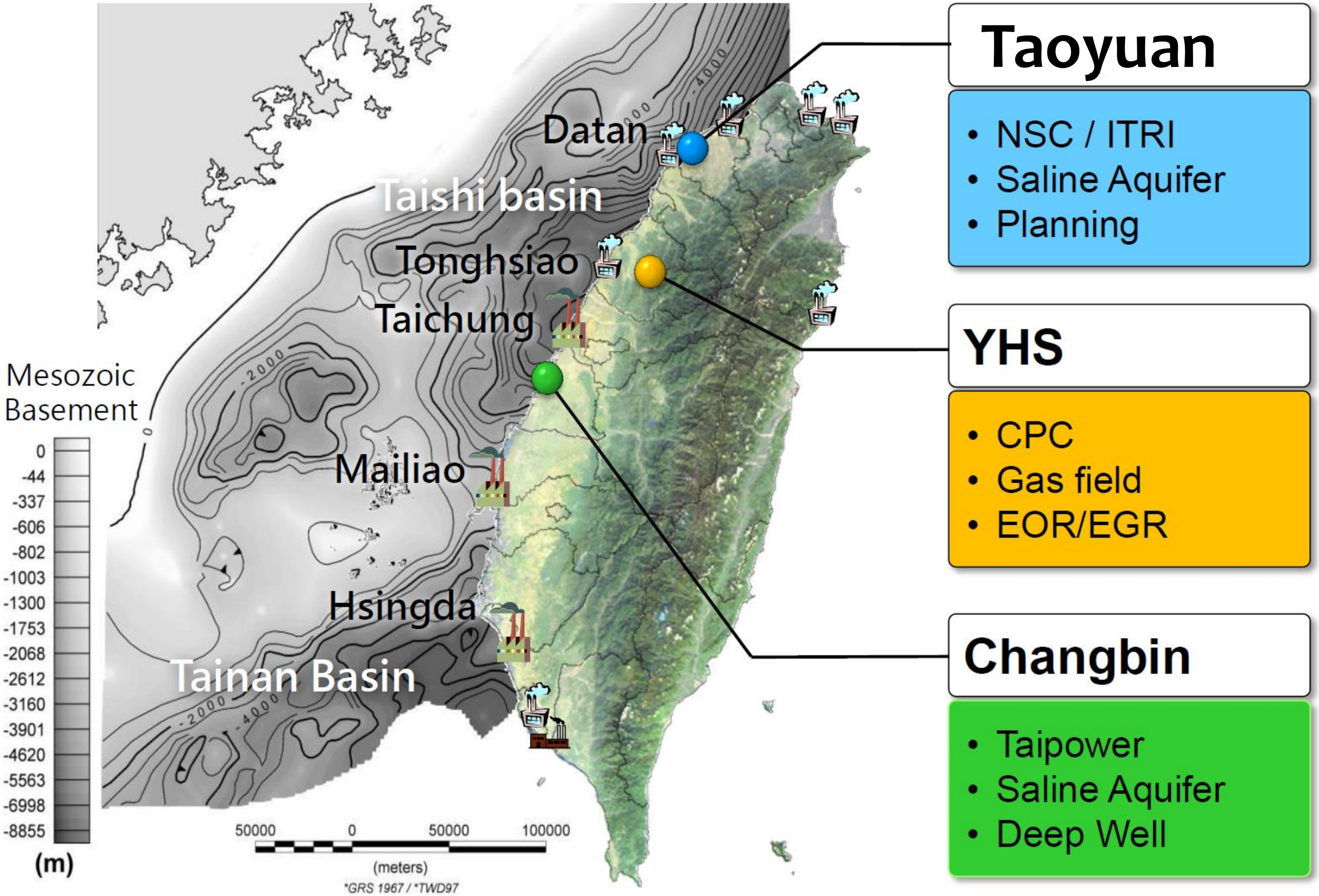
Technology & Experience

- Injection & production
- Pressure & temperature & inventory monitoring
- Modeling & simulation
- Over 20 years operation experience learned by CPC Corporation, Taiwan

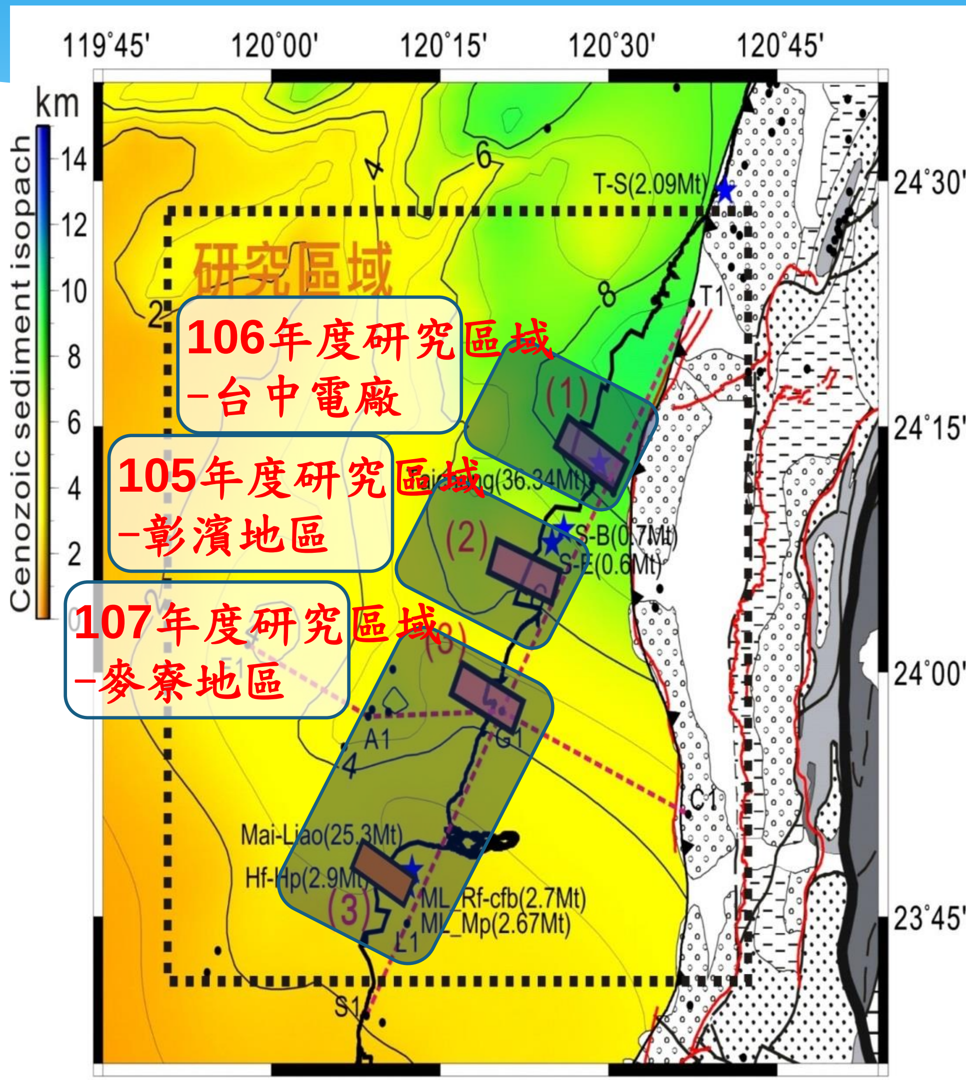
天然氣氣窖工作流程


Monitoring Well
Injection/Production Well
Monitoring Well
Compressor
Surface Facility
Imported NG
Pipeline
Aquifer
Working Gas
Reservoir
Cushion Gas
Aquifer
Cap Rock

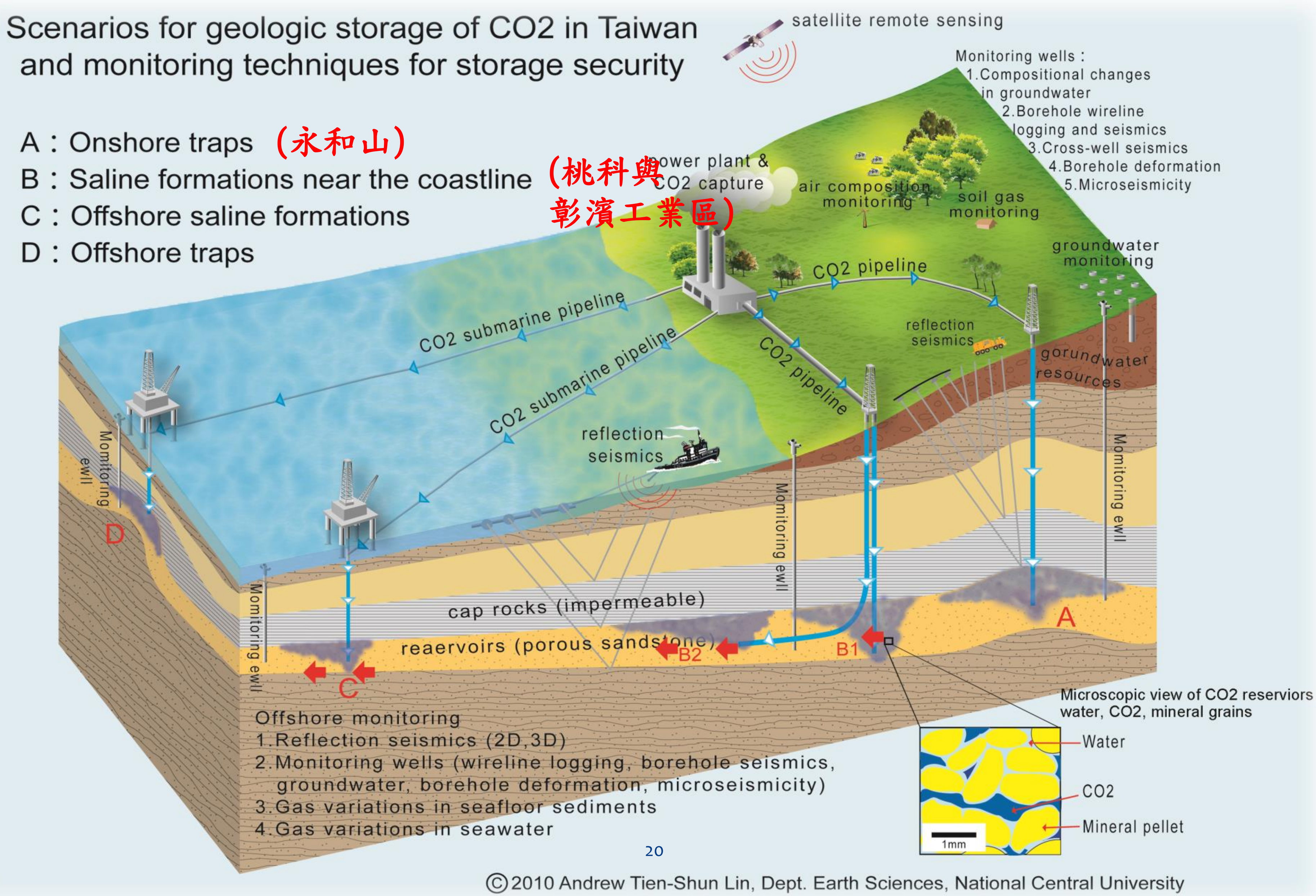
台灣目前二氧化碳封存研究區域



二氧化碳封存研究區域時程規劃

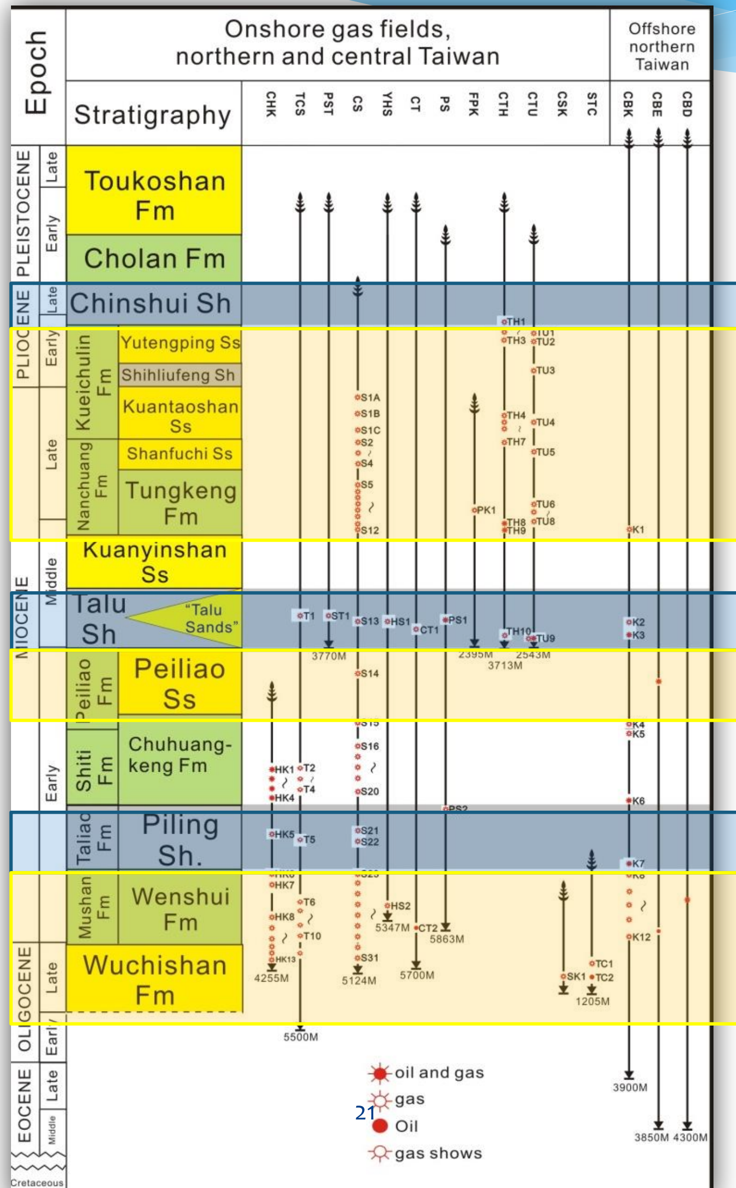


台灣濱海二氧化碳地質封存概念



台灣西部潛在地質封存儲集系統

Three CO_2 Geosequestration Systems



1

2

3

Seal formation

Reservoir formation

Chinshui Shale

Kueichulin & Nanchuang Formations

Talu Shale

Peiliao Formation

Piling Shale

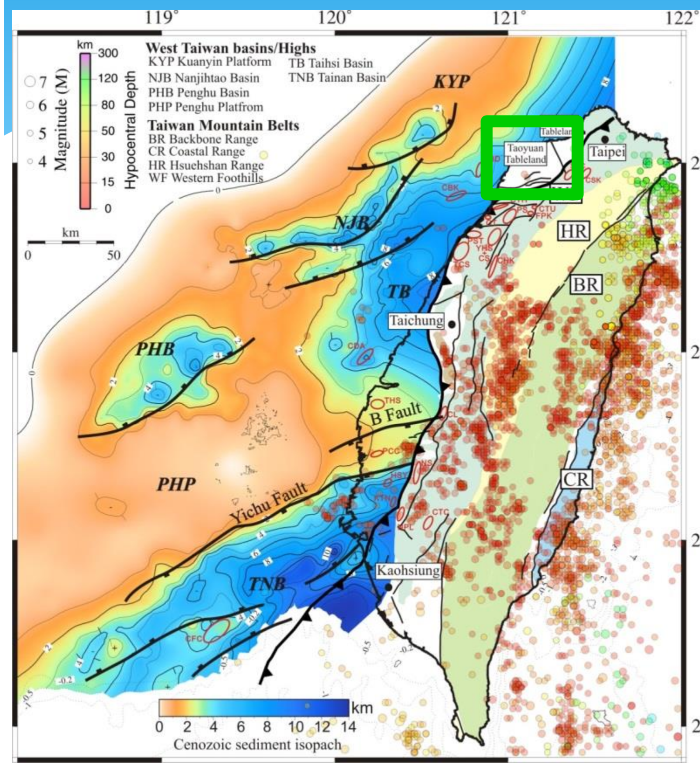
Mushan & Wuchishan Formations

Shales

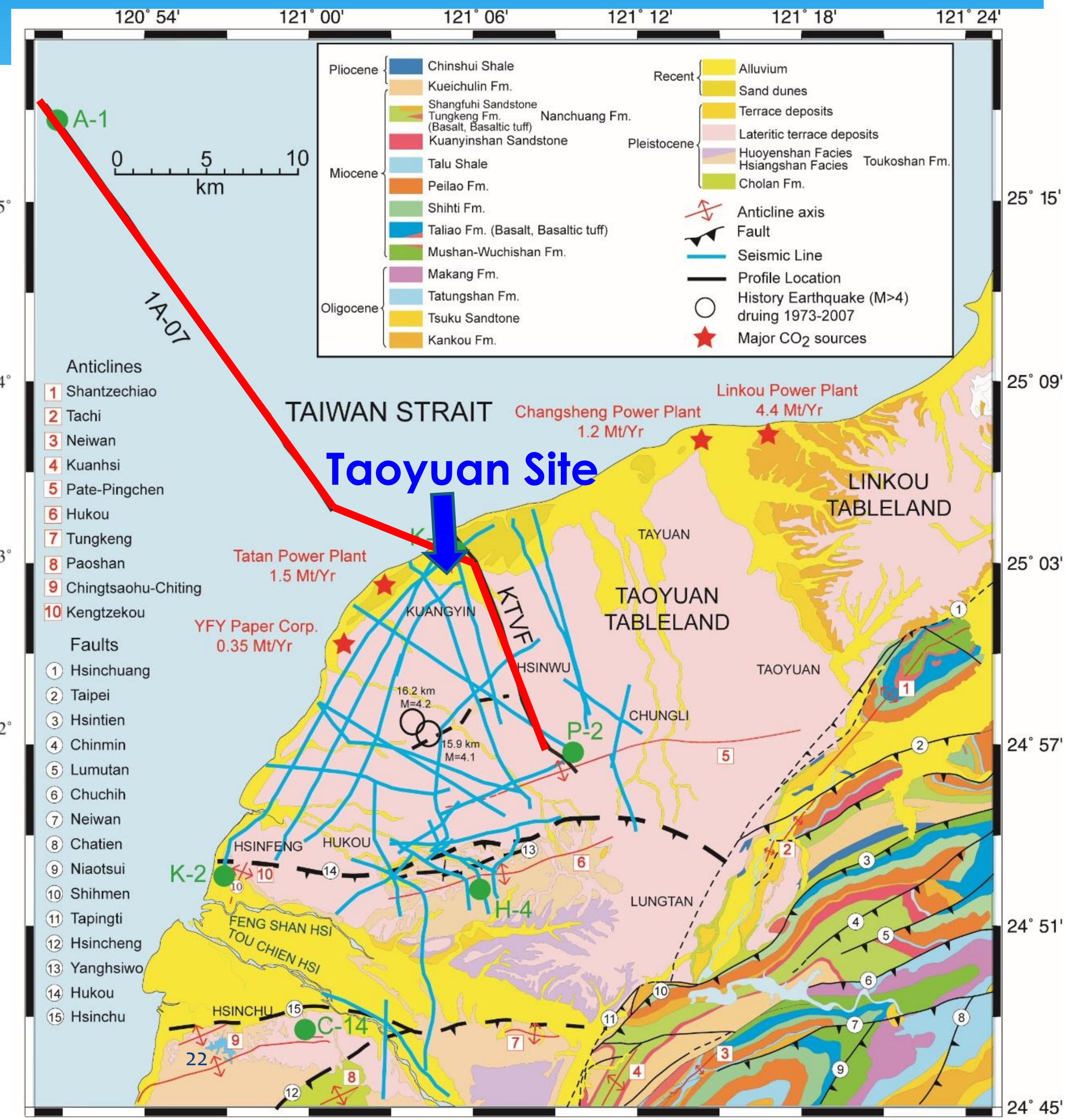
Sandstone/ shale interbeds

Sandstones

桃科園區之區域地質



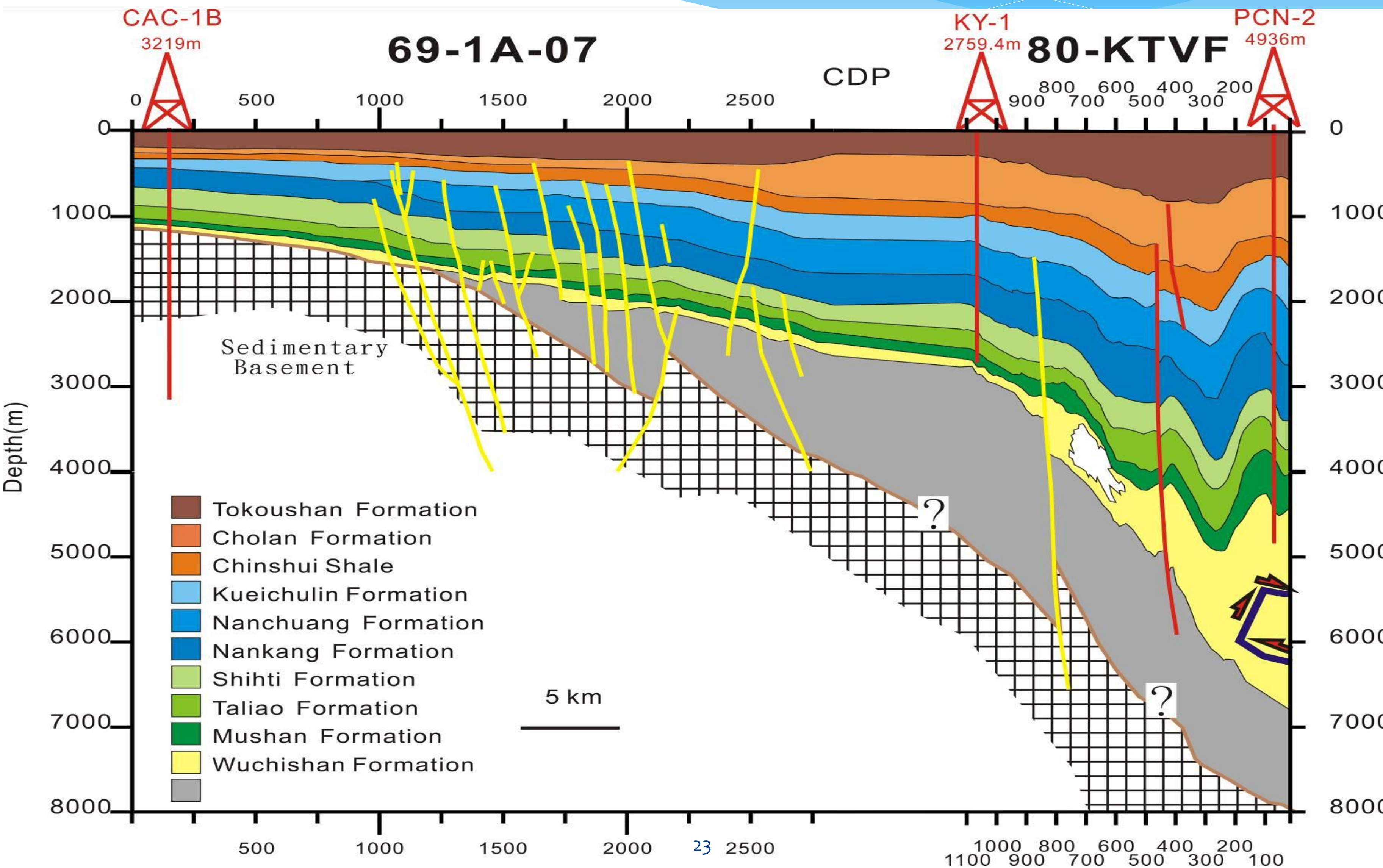
119°
120°
121°
122°
25°
24°
23°
22°
West Taiwan basins/Highs
KYP Kuanyin Platform
TB Taihsi Basin
NJB Nanjihtao Basin
TNB Tainan Basin
PHB Penghu Basin
PHP Penghu Platfrom
Taiwan Mountain Belts
BR Backbone Range
CR Coastal Range
HR Hsuehshan Range
WF Western Foothills
Magnitude (M)
Hypocentral Depth
km
300
120
80
50
30
15
0
7
6
5
4
km
0
50
KYP
NJB
TB
PHB
PHP
TNB
B Fault
Yichu Fault
Taoyuan Tableland
Tableland
Taipei
Taichung
Kaohsiung
HR
BR
CR
km
0 2 4 6 8 10 12 14
Cenozoic sediment isopach



120° 54'
121° 00'
121° 06'
121° 12'
121° 18'
121° 24'
25° 15'
25° 09'
25° 03'
24° 57'
24° 51'
24° 45'
Pliocene
Chinshui Shale
Kueichulin Fm.
Shangfuhi Sandstone
Tungkeng Fm.
(Basalt, Basaltic tuff)
Nanchuang Fm.
Kuanyinshan Sandstone
Miocene
Talu Shale
Peilao Fm.
Shihti Fm.
Taliao Fm. (Basalt, Basaltic tuff)
Mushan-Wuchishan Fm.
Oligocene
Makang Fm.
Tatungshan Fm.
Tsuku Sandtone
Kankou Fm.
Recent
Alluvium
Sand dunes
Terrace deposits
Pleistocene
Lateritic terrace deposits
Huoyenshan Facies
Hsiangshan Facies
Toukoshan Fm.
Cholan Fm.
Anticline axis
Fault
Seismic Line
Profile Location
History Earthquake (M>4)
druing 1973-2007
Major CO2 sources
A-1
1A-07
0 5 10
km
Anticlines
1 Shantzechiao
2 Tachi
3 Neiwan
4 Kuanhsi
5 Pate-Pingchen
6 Hukou
7 Tungkeng
8 Paoshan
9 Chingtsaohu-Chiting
10 Kengtzekou
Faults
1 Hsinchuang
2 Taipei
3 Hsintien
4 Chinmin
5 Lumutan
6 Chuchih
7 Neiwan
8 Chatien
9 Niaotsui
10 Shihmen
11 Tapingti
12 Hsincheng
13 Yanghsiwo
14 Hukou
15 Hsinchu
TAIWAN STRAIT
Changsheng Power Plant
1.2 Mt/Yr
Linkou Power Plant
4.4 Mt/Yr
Taoyuan Site
LINKOU TABLELAND
TAYUAN
Tatan Power Plant
1.5 Mt/Yr
KUANGYIN
KTVF
TAOYUAN TABLELAND
YFY Paper Corp.
0.35 Mt/Yr
HSINWU
TAOYUAN
16.2 km
M=4.2
15.9 km
M=4.1
P-2
CHUNGLI
HSINFENG
HUKOU
K-2
H-4
LUNGTAN
FENG SHAN HSI
TOU CHIEN HSI
HSINCHU
C-14

Taoyuan Site

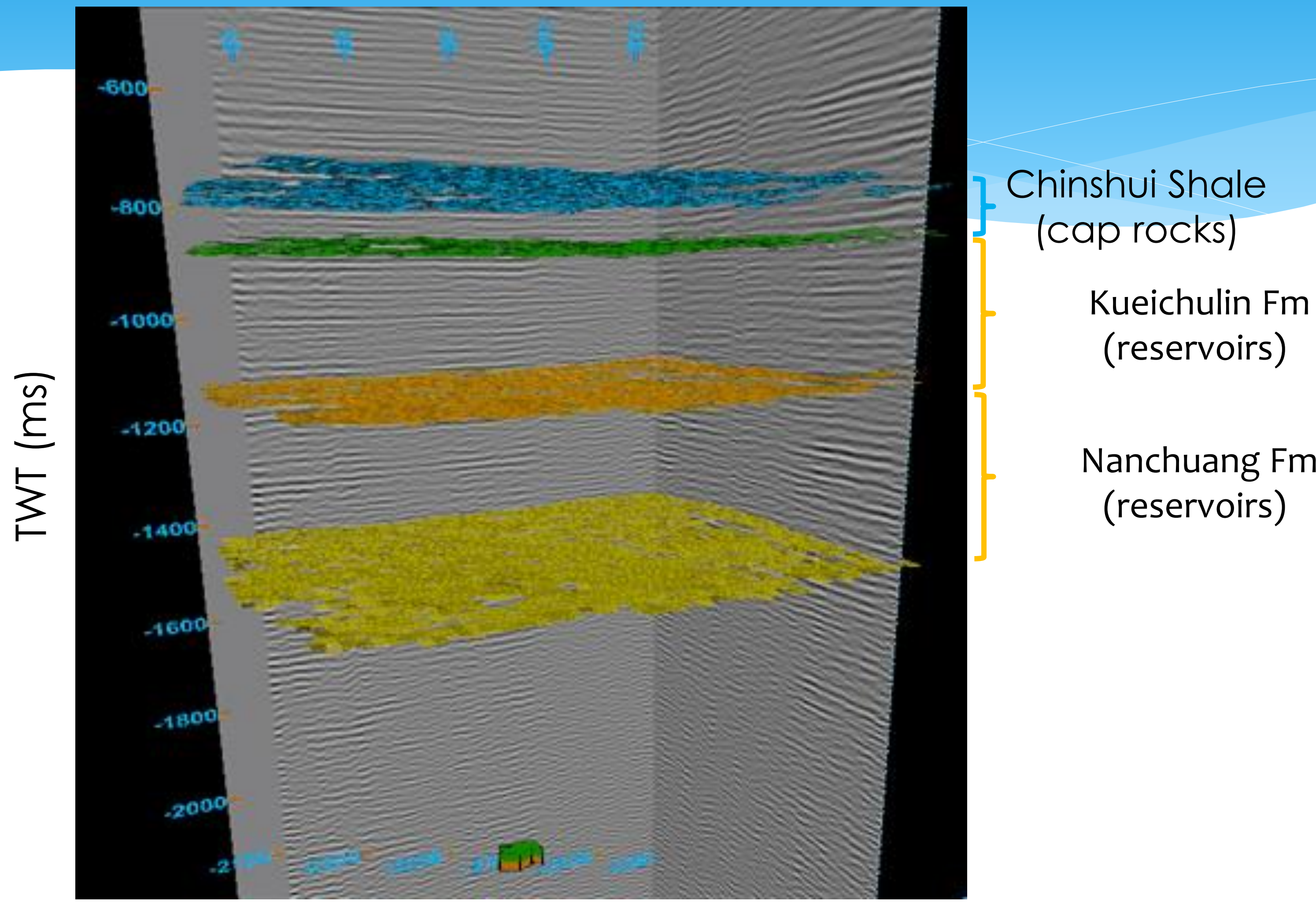
W Offshore Onshore E



Taiwan Carbon Storage Project– Taoyuan (TCSP-T): Under planning

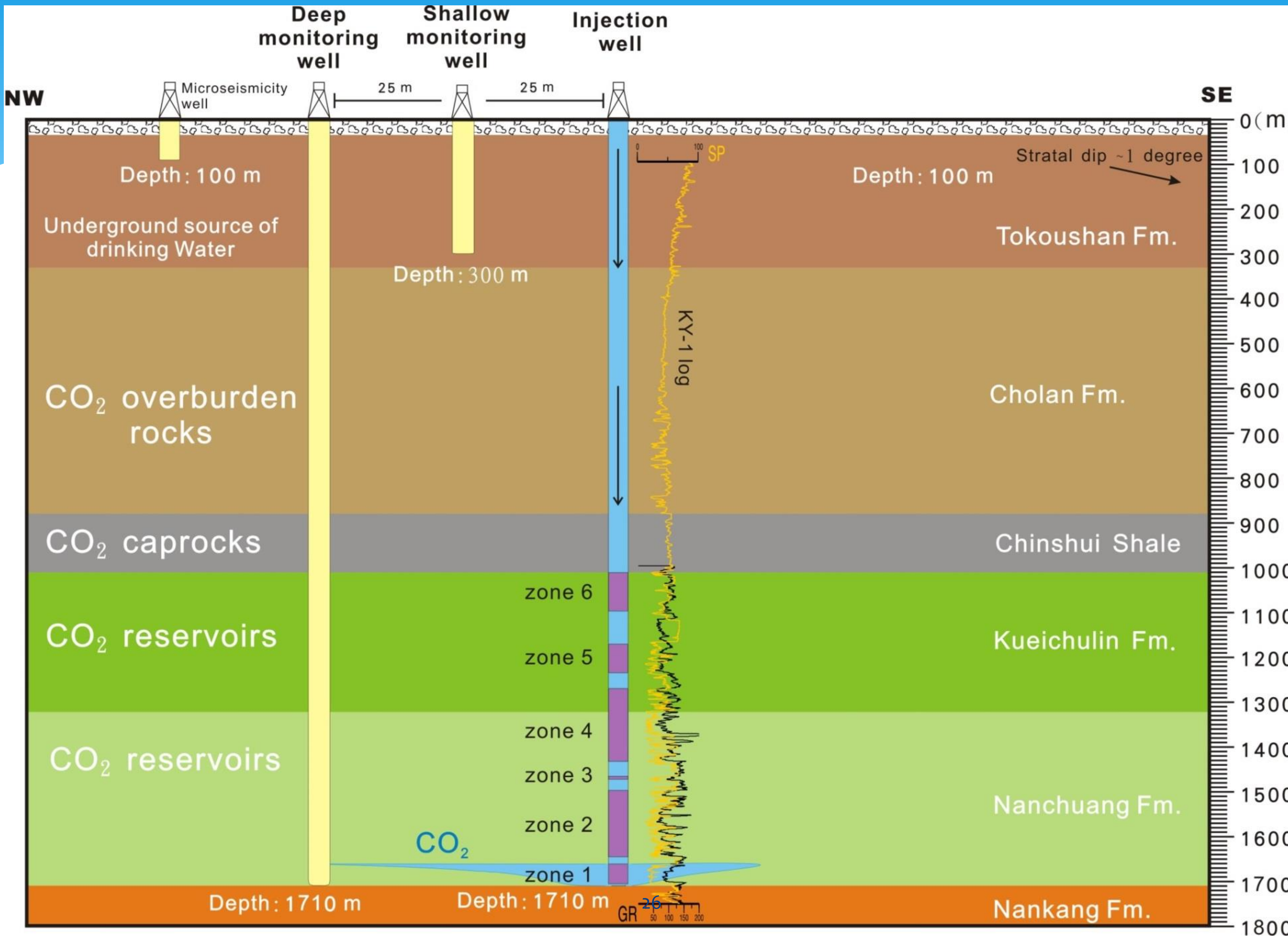
桃科園區三維震測施測範圍

桃科園區三維震測剖面

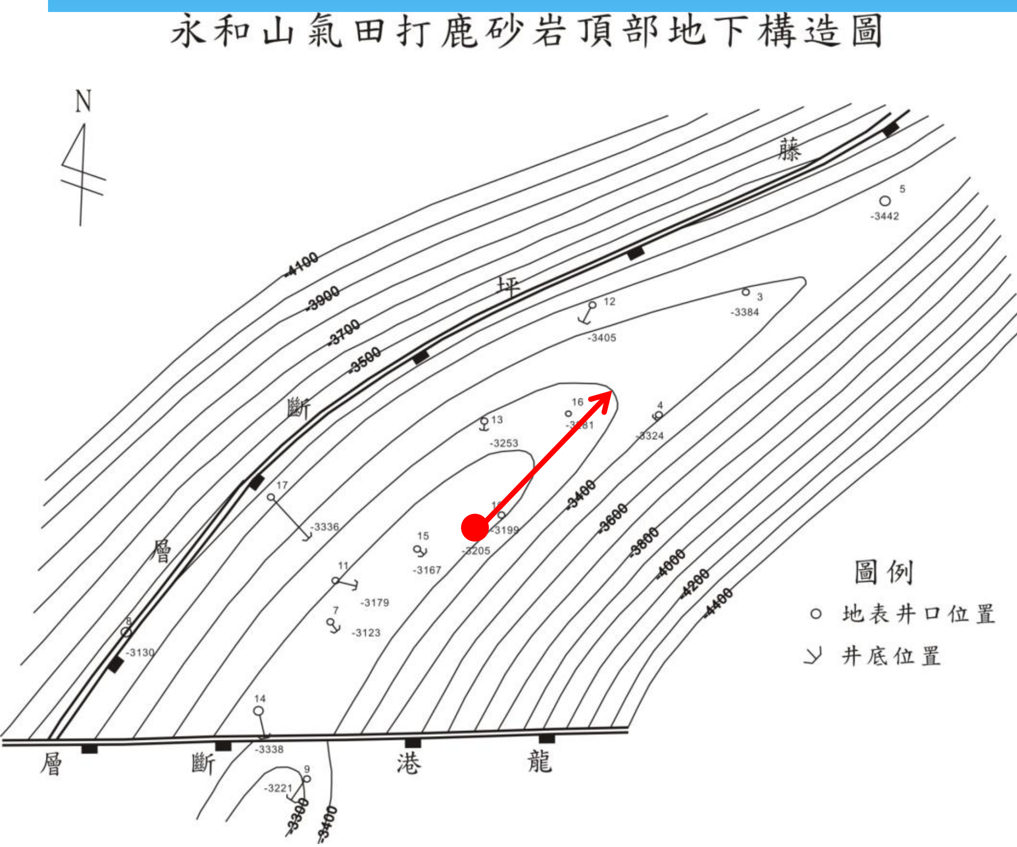


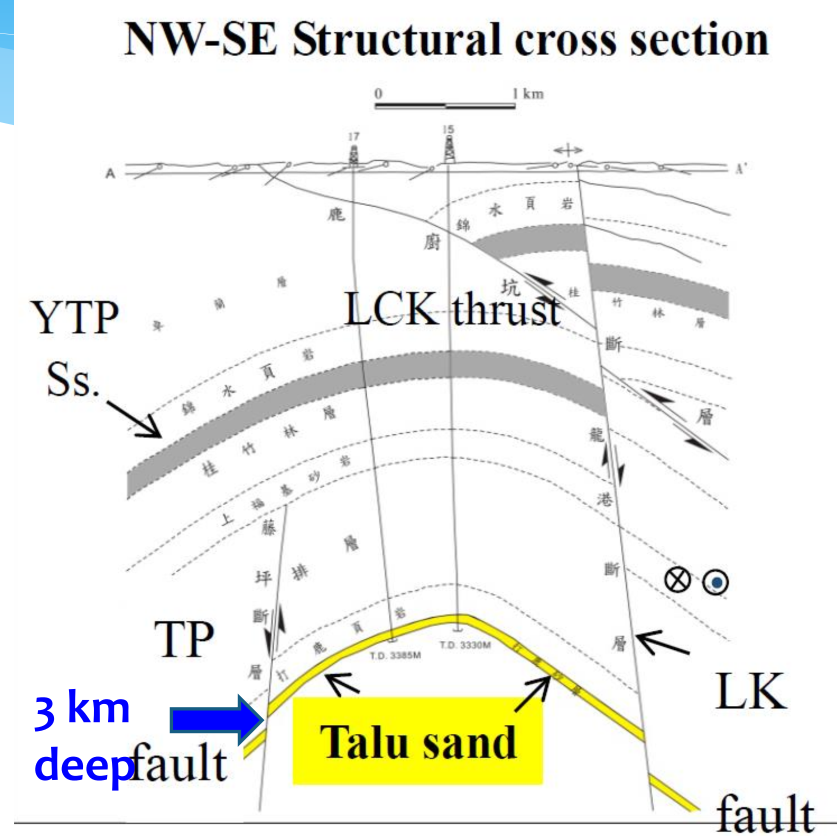
Data collected by Prof. C.-Y. Wang

桃科園區測站之井位規劃



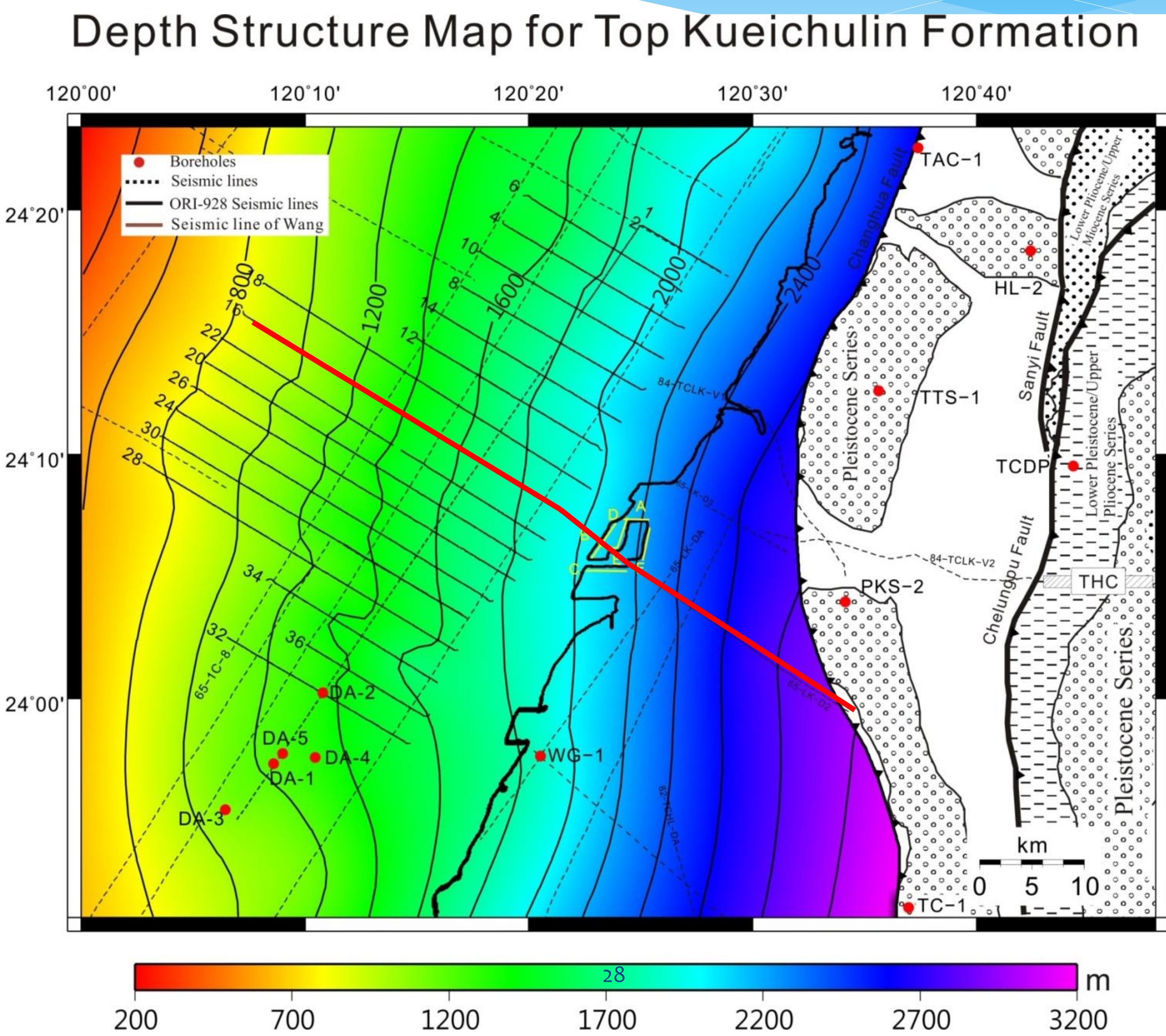
Taiwan Carbon Storage Project – Miaoli (YHS depleted gas field)





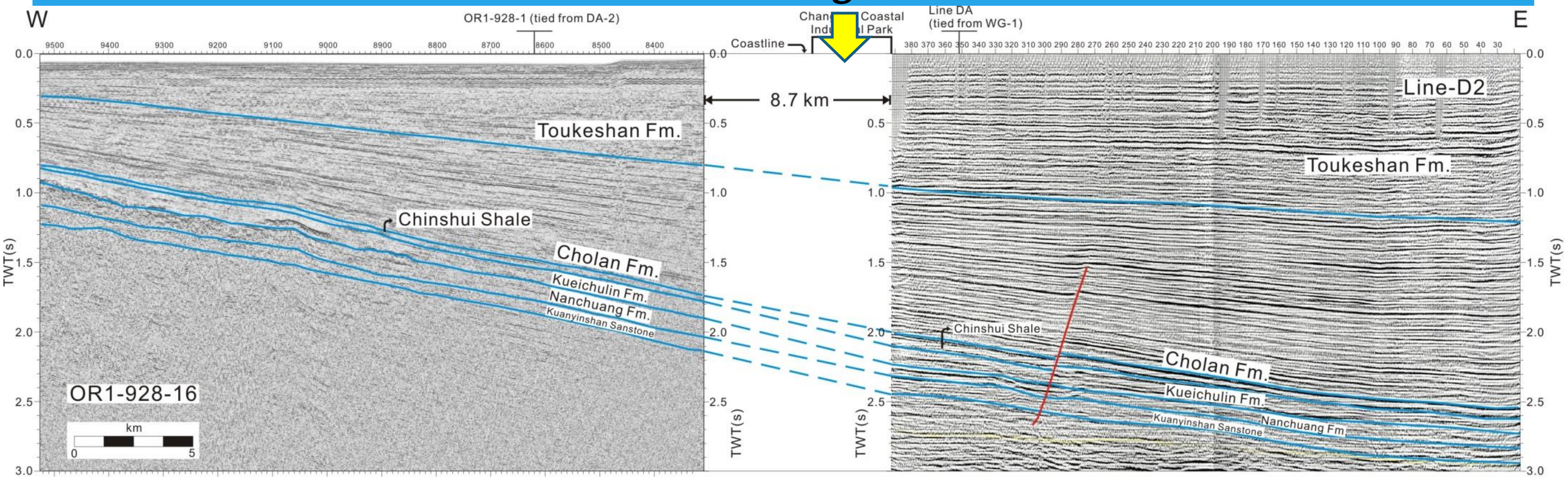
This project has been suspended since early 2015 due to protests from local residents.

Taiwan Carbon Storage Project – Changhua (Changbin Industrial Park)

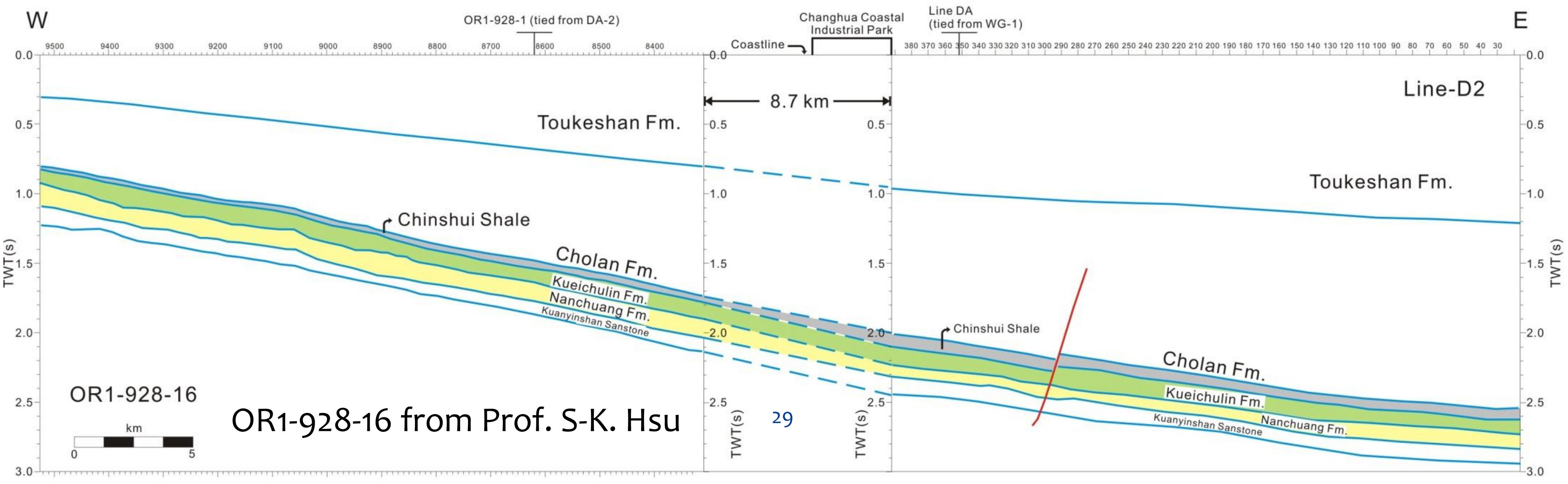


彰濱工業區震測調查

Changhua Site



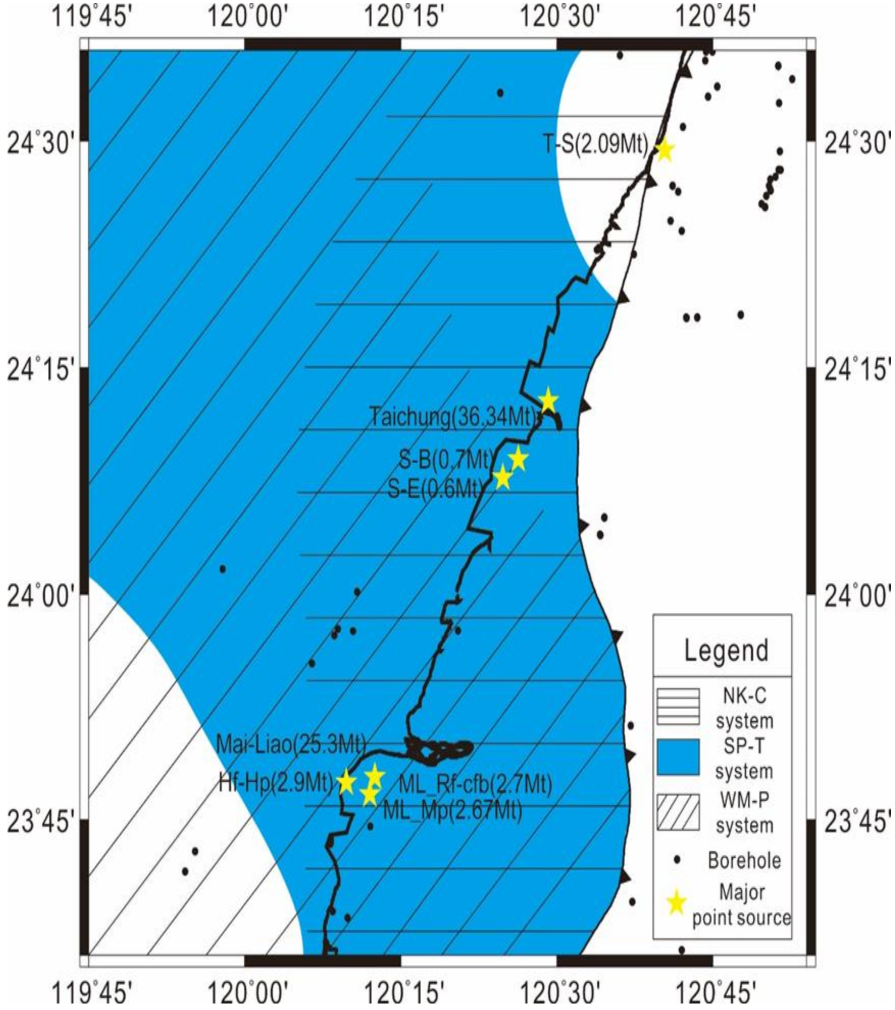
One well has been drilled and this project has been suspended.

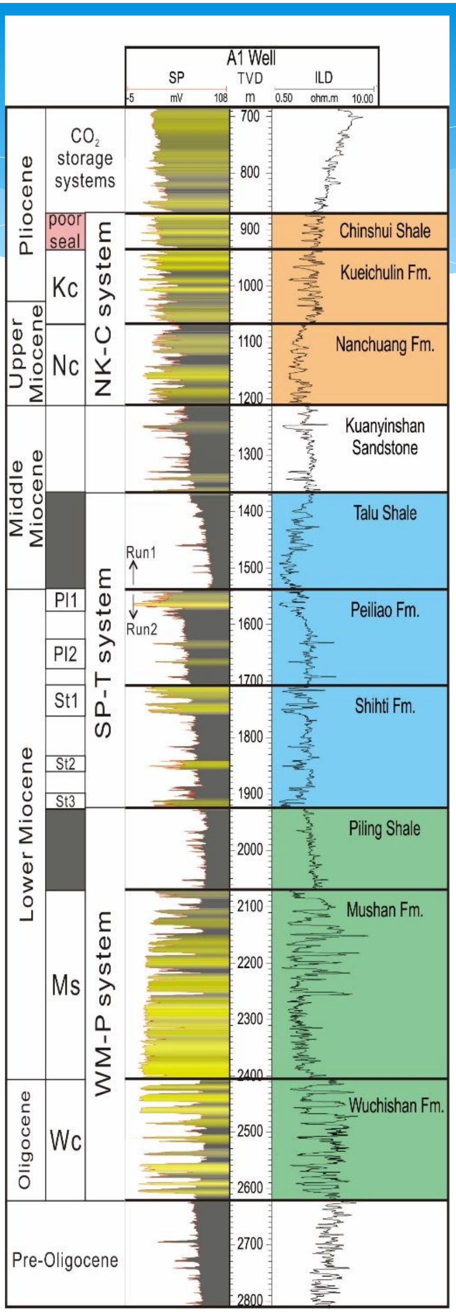


OR1-928-16 from Prof. S-K. Hsu

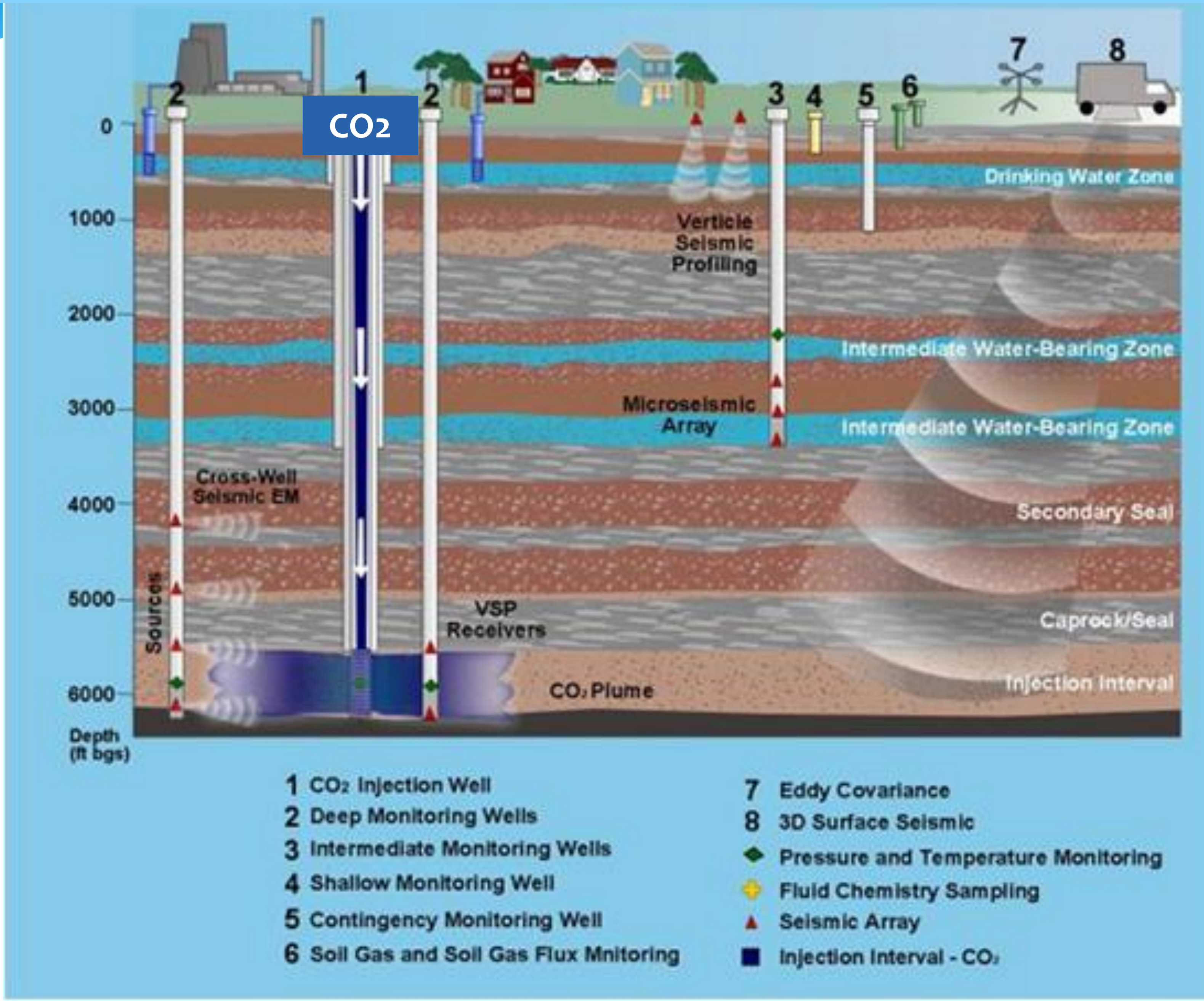
下部卓蘭系統(R1, 待取得彰濱井電測資料後，
並與周遭鑽井資料比對後再決定其封存可行性)

南莊桂竹林-錦水系統 (NK-C System, R2)
石底北寮-打鹿系統(SP-T System, R3)
五指山木山-碧靈系統(WM-P System, R4)





二氧化碳注儲後之監測方法



Atmospheric Monitoring Techniques

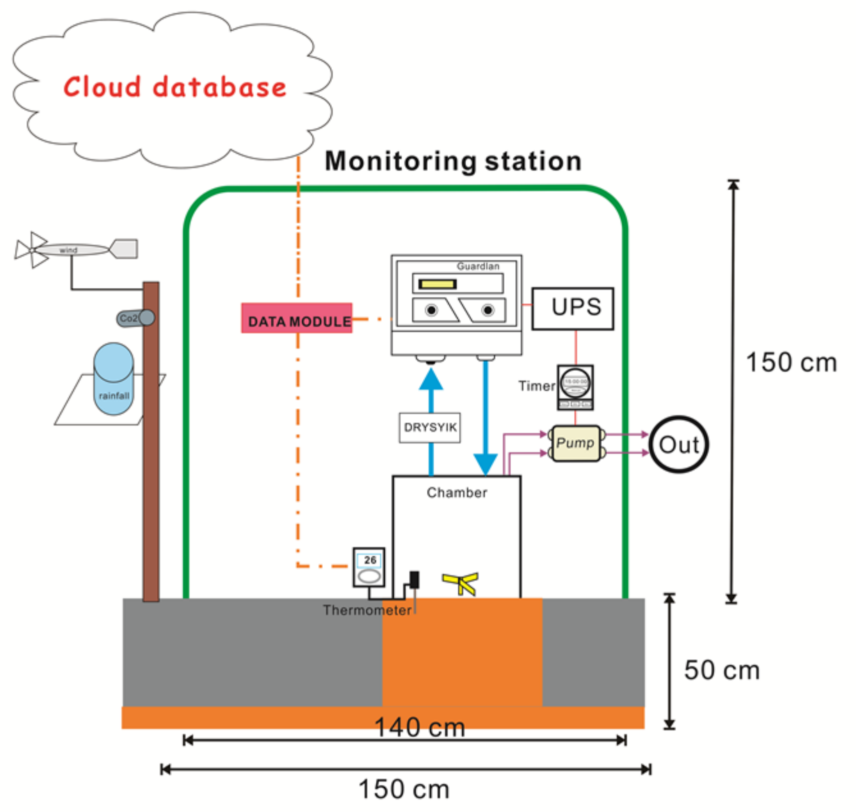
Approach	Techniques	Measured Parameters	Applications
Eddy Covariance	EC flux towers	CO_2 flux	Characterize net CO_2 flux. Detect and quantify CO_2 release to atmosphere should it occur.
CO_2 Detectors - IRGA	CRDS, NDIR-based CO_2 sensor	CO_2 concentration	Temporally characterize CO_2 concentrations within 3 m of land surface.

Near-Surface Monitoring Techniques

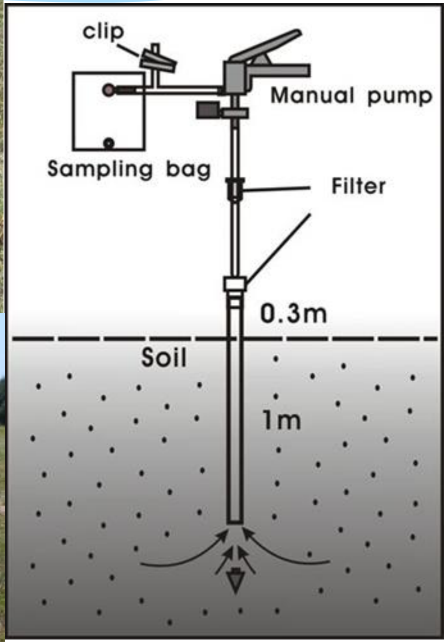
Approach	Techniques	Measured Parameters	Applications
Surface Displacement Monitoring	InSAR/PSInSAR, GPS, Tiltmeter	Ground deformation	Detect surface deformation if any due to CO_2 injection.
Geochemical Monitoring in the Soil and Vadose Zone	Flux accumulation chambers, Soil-gas tracer sampling, soil-carbon analysis	Soil CO_2 flux	Detect, locate and quantify CO_2 release should it occur.
Geochemical Monitoring of shallow groundwater	Shallow-groundwater sampling, geochemical analysis	Chemical and isotopic compositions of groundwater	Characterization of shallow groundwater, CO_2 release detection
High Resolution Earth Electrical Resistivity	Electrical resistivity imaging (ERI)	Electrical resistivity of shallow geological materials	Characterize shallow subsurface geology (< 40 m) and detect potential CO_2 or brine impacts.

Near-Surface Monitoring Techniques

Soil-gas monitoring station



Soil gas sampling

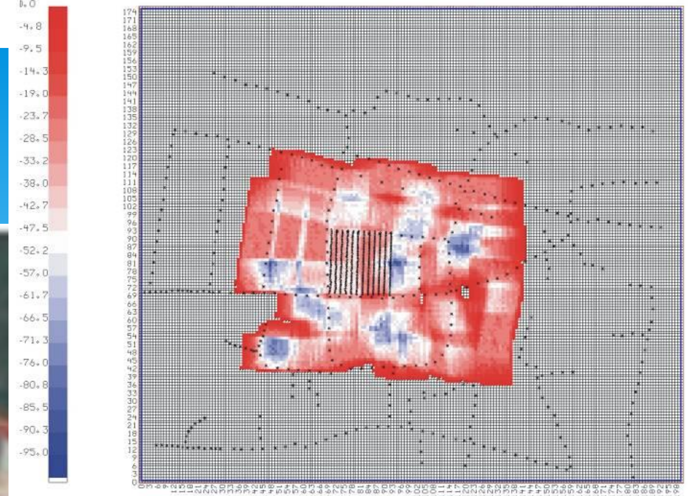


From Prof. Tsanyao Yang (NTU)

Subsurface Monitoring Techniques

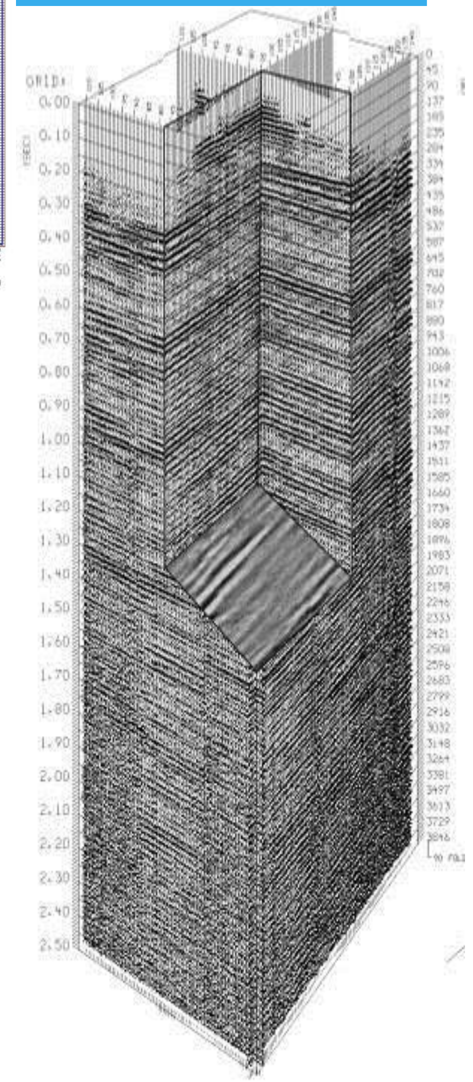
Approach	Techniques	Measured Parameters	Applications
Well Logging Tools (open and cased holes)	Traditional standard logging, density, neutron porosity logs, pulsed neutron tools (PNT), magnetic resonance	Petrophysical properties of rocks and fluids (including injected CO_2)	To characterize rocks and fluids and condition of wellbore. CO_2 saturation
Downhole Monitoring Tools	Downhole/wellhead pressure, temperature gauges, flow meters, oxygen-activation logs, radioactive tracer surveys, corrosion monitoring, borehole seismometers	Formation and annulus pressure and temperature, micro-seismicity	Control formation pressure below fracture gradient, monitor wellbore and injection tubing conditions, detect migration of CO_2 near injection well. Monitor well integrity and rock fracturing during injection
Seismic Methods	Time-lapse surface seismic (2D or 3D), Borehole seismic (vertical seismic profile, VSP), Crosswell seismic tomography	P- and S-wave velocity, reflection horizons, seismic amplitude, attenuation	Geological characterization of the sites. Tracking distribution and migration of injected CO_2.
Electrical Techniques	Crosswell electrical resistivity tomography (ERT), surface-downhole ERT	Resistivity of the rocks between boreholes	Tracking distribution and migration of injected CO_2. Estimating CO_2 saturation
Subsurface Fluid Sampling and Tracer Analysis	Wireline-based samplers, U-tube sampling, ChemWish sampling	Chemical compositions of fluids including tracers	Fluid compositions before and after CO_2 injection. CO_2 saturation. Monitor for CO_2 leakage.

Surround shooting



Folding number

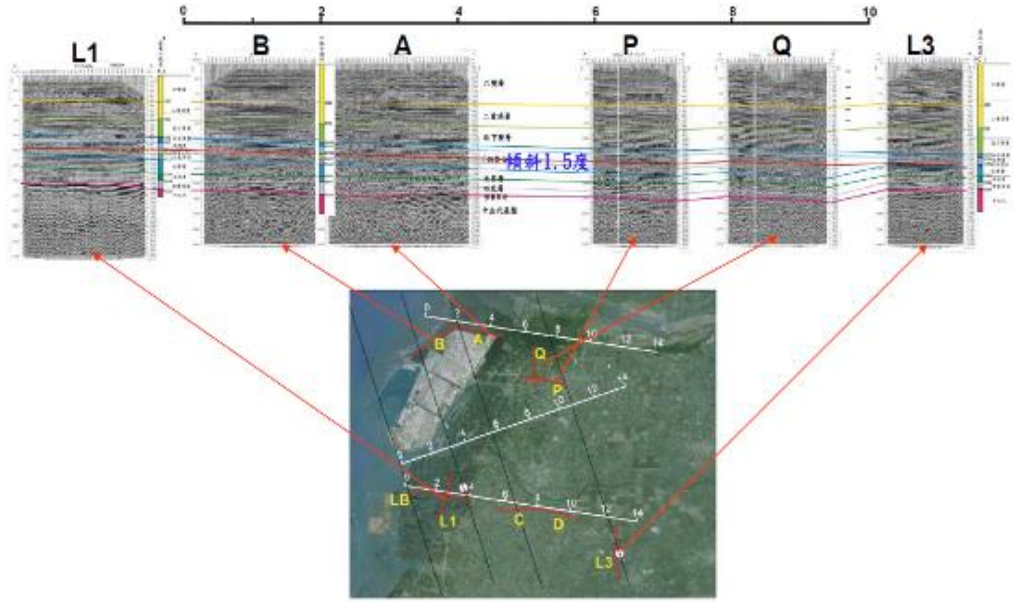
Reflection Seismics

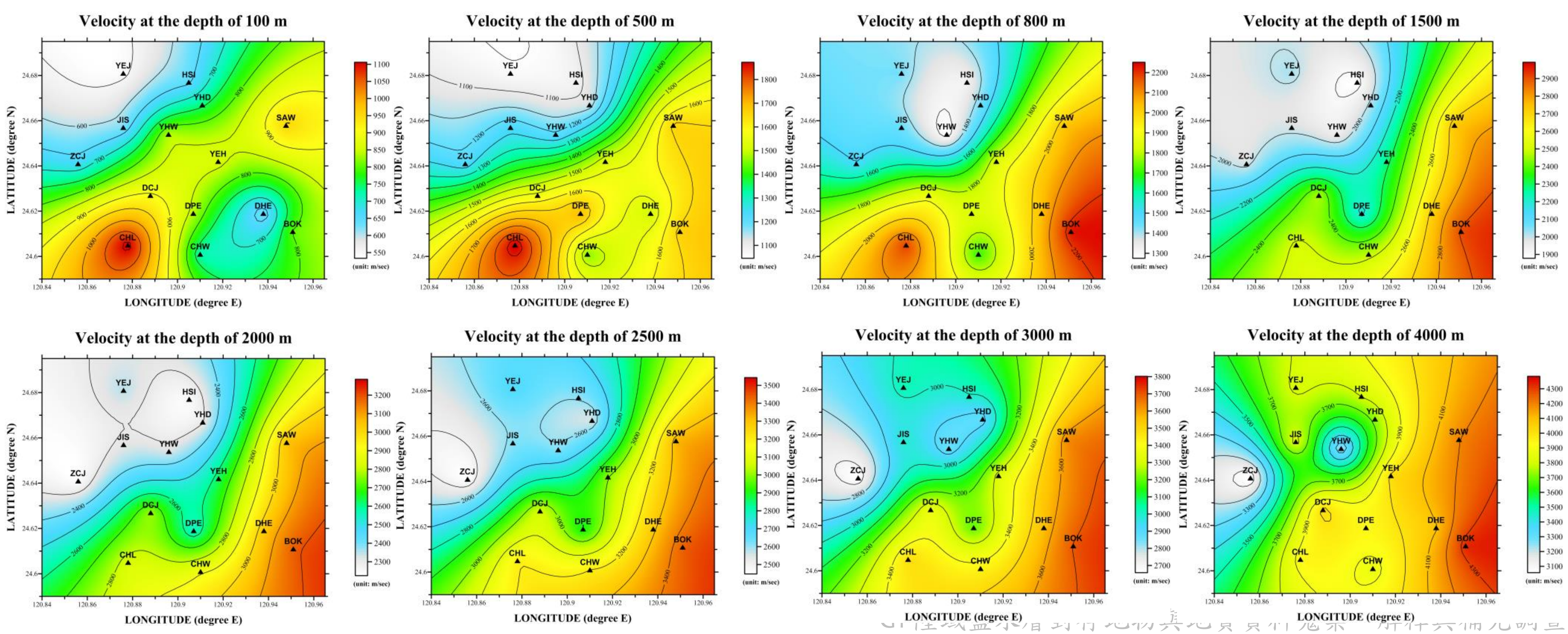


Slide provided by Prof. C.Y. Wang (NCU)

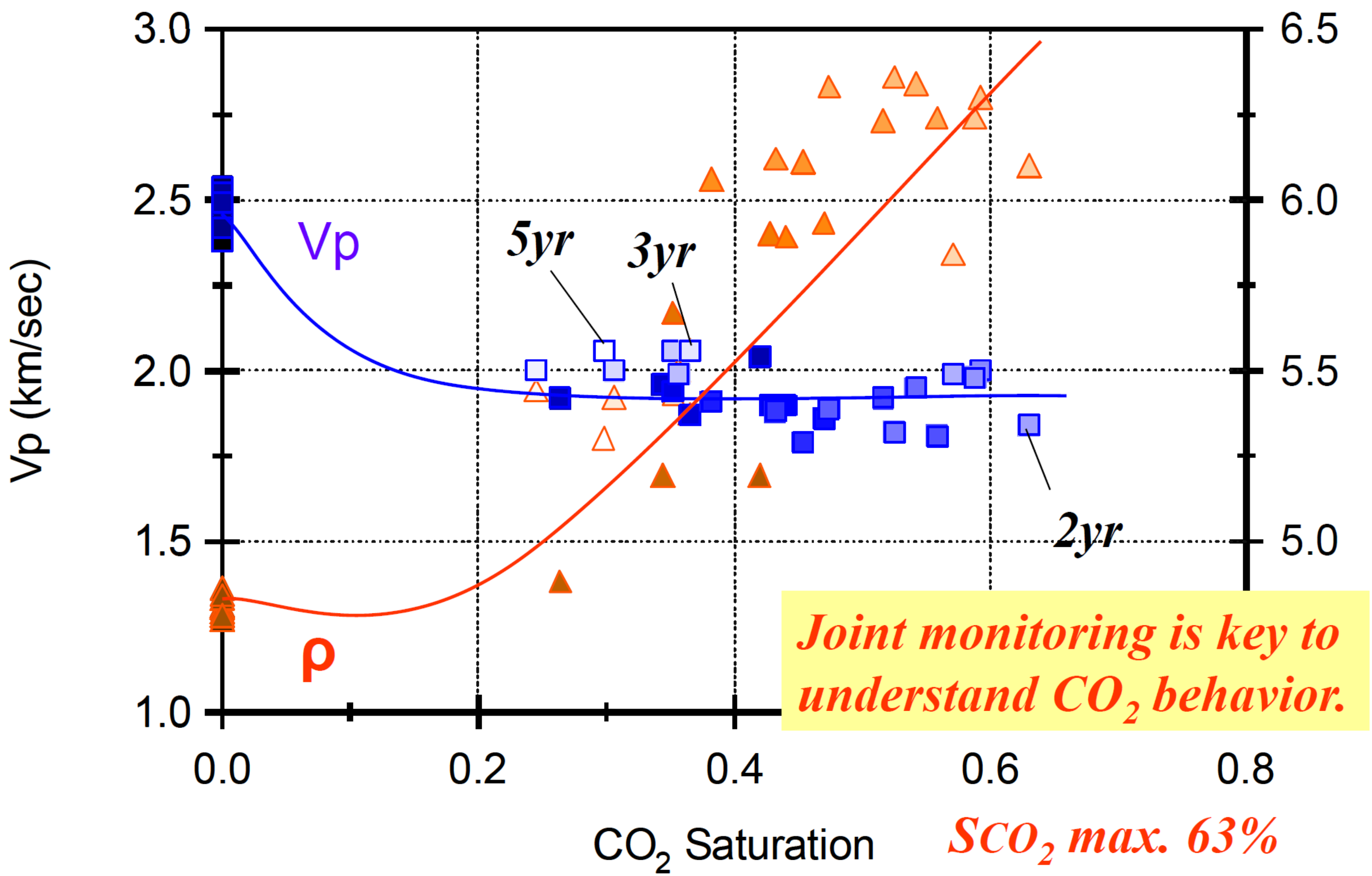
Monitoring Projects in Taiwan

1.Seismicity
2.Microseismicity
3.Wellhead/Bottom Pressure
4.Soil gas
5.Atmospheric Concentration
6.Well logs
7.Satellite Images
8.Groundwater concentration





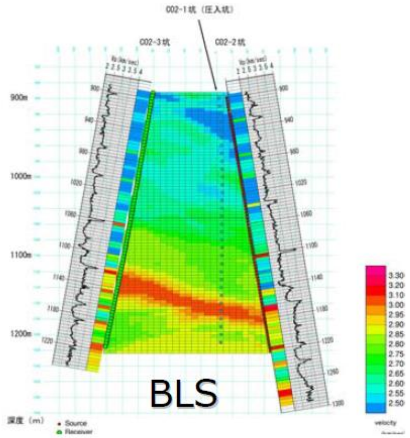
Variations of P-wave Velocity and Resistivity vs CO_2 Saturation: Nagaoka Example

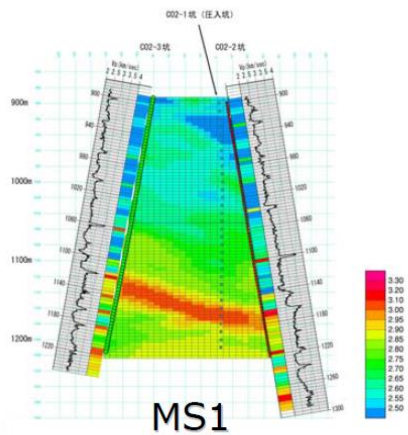


Slide provided by Dr. Ziqiu Xue (RITE)

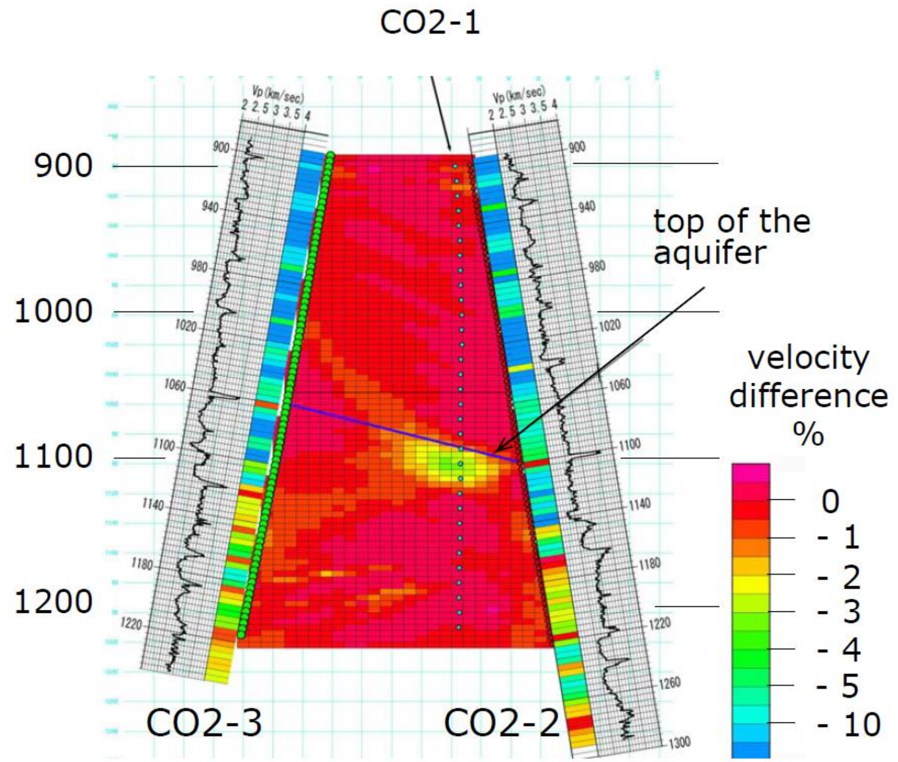
Crosswell Seismic Tomography: Example from Nagaoka Site, Japan

Velocity Difference Tomogram (BLS / MS1)





MS1
3,200 t -CO_2



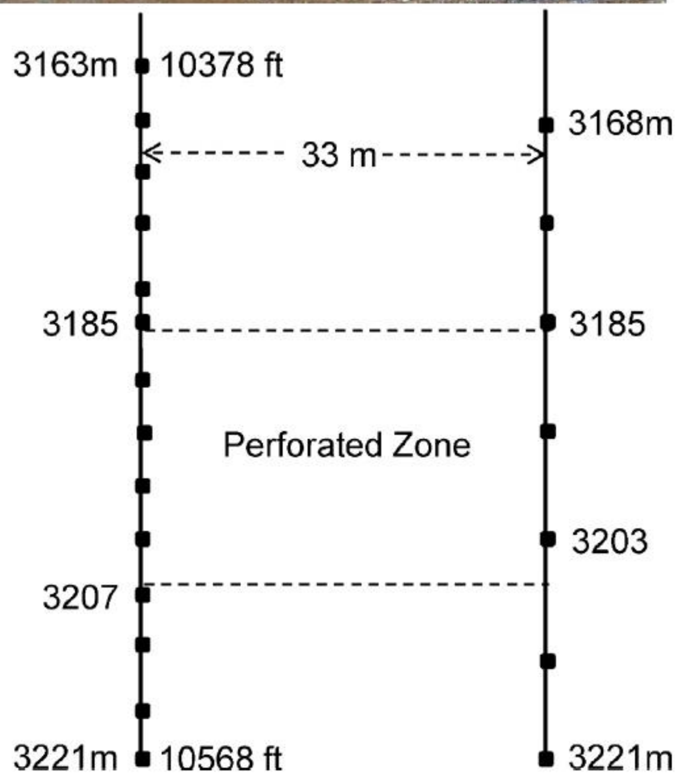
max. velocity reduction = 3.0%

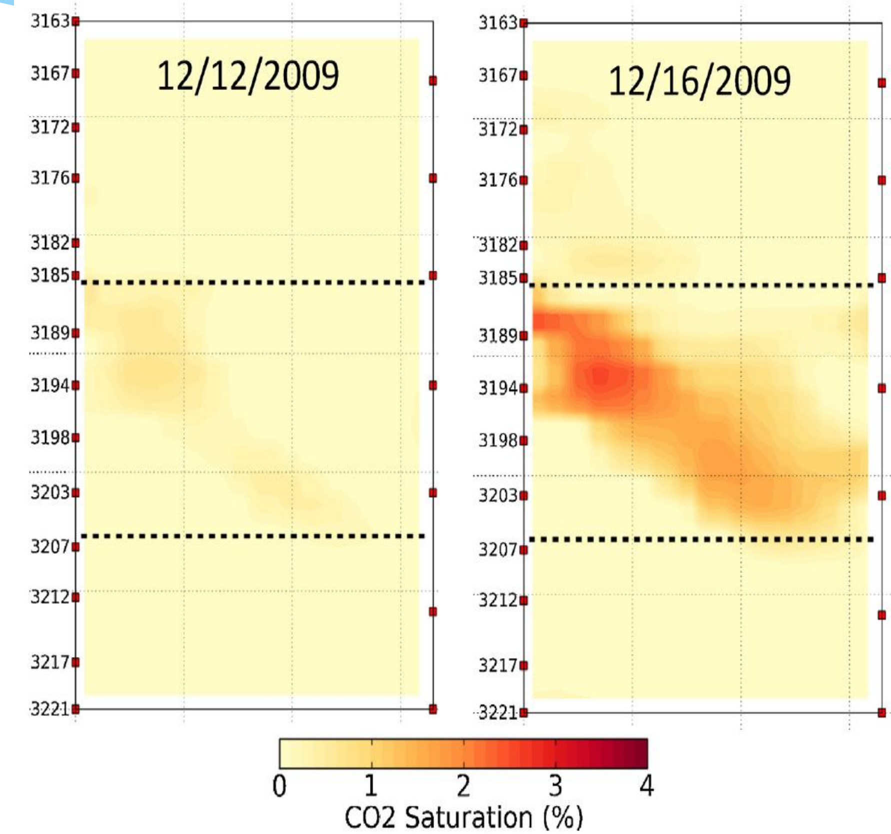
Velocity difference = $(V_{MS1} - V_{BLS}) / V_{BLS}$

Crosshole Electrical Resistance Tomography (ERT)

Cranfield, Mississippi

12/1/2009 injection 1 M tons CO_2

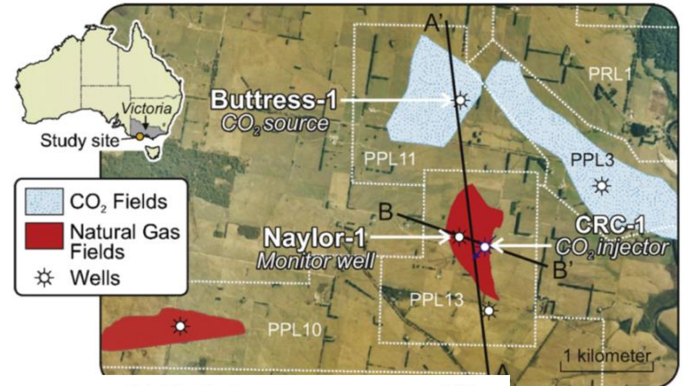


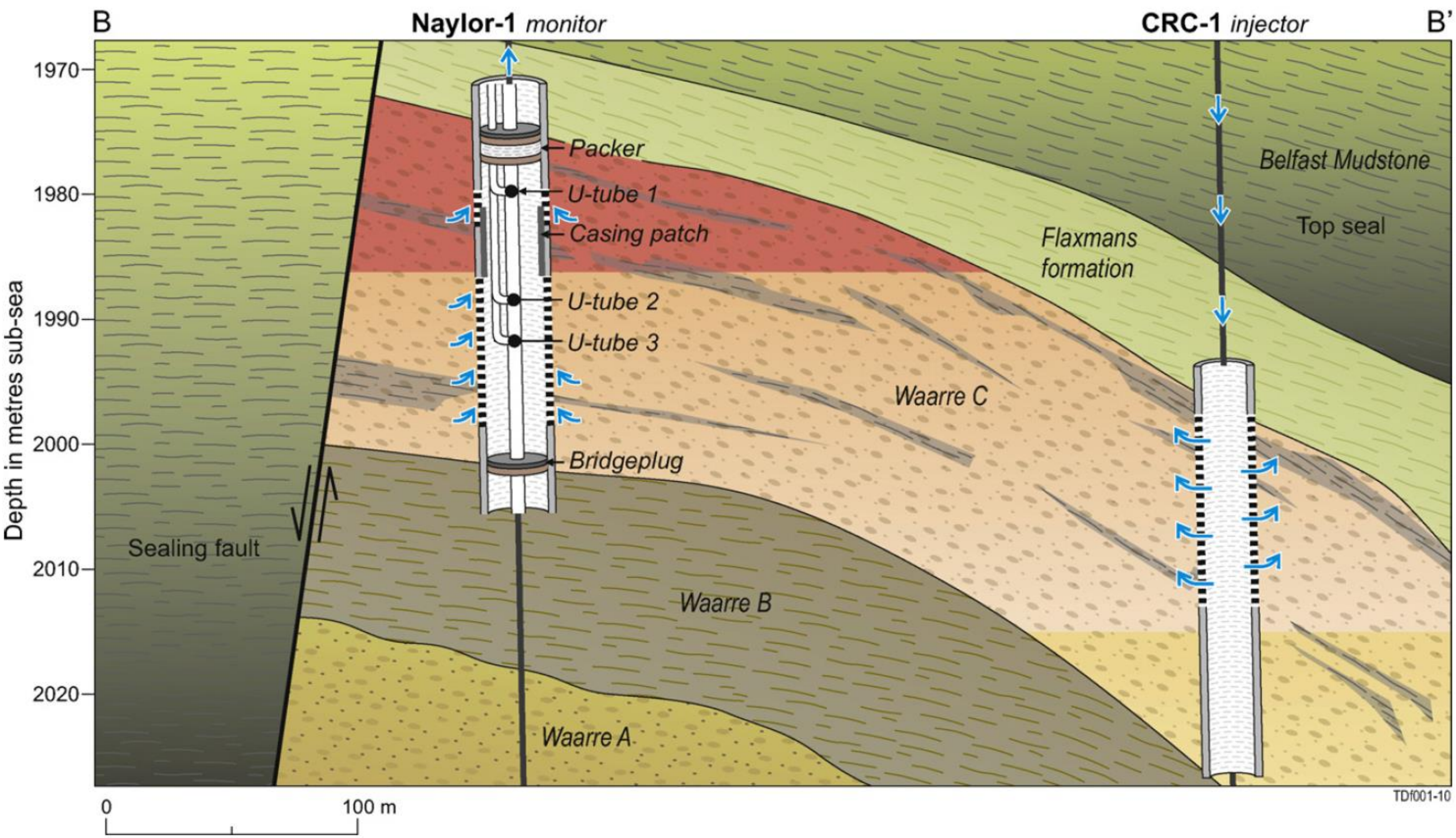


F-1 injection, F-2 and F-3 monitoring

U-tube fluid sampling at Australian Otway Site

CO2CRC Otway Project

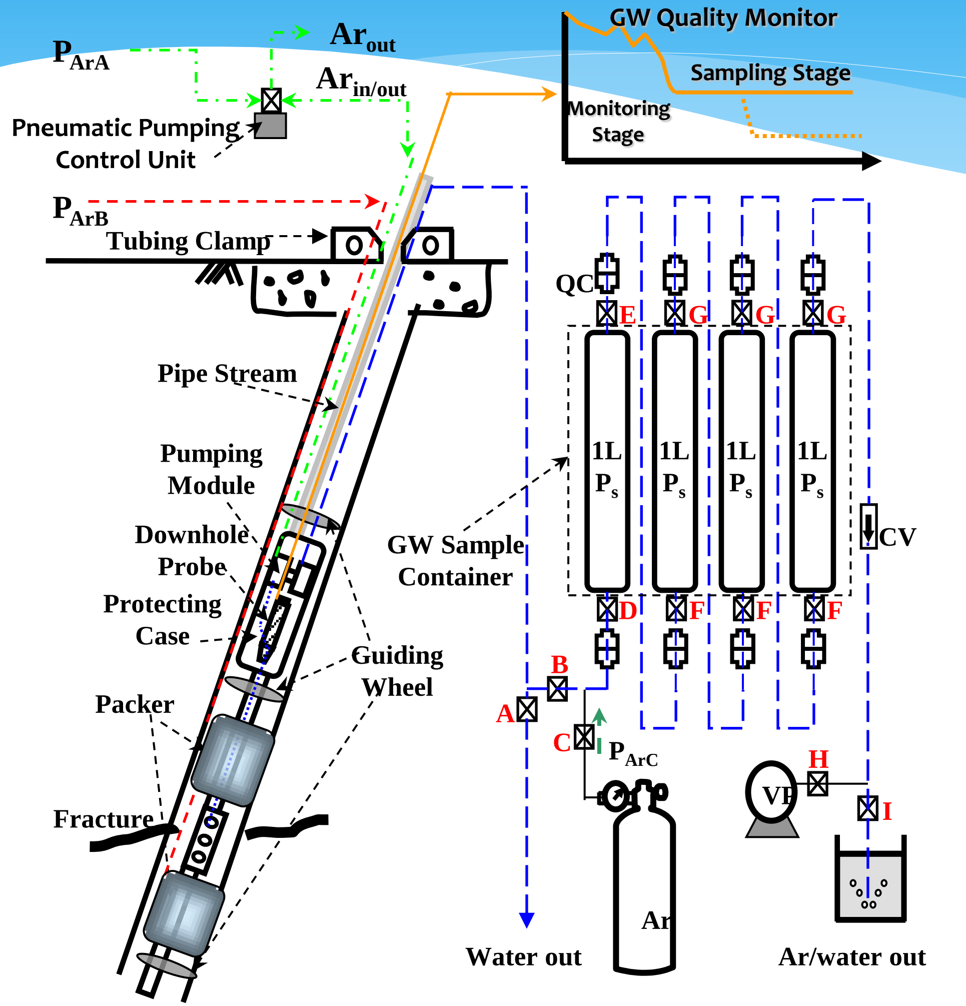




Underschnultz et al. (2011) IJGGC

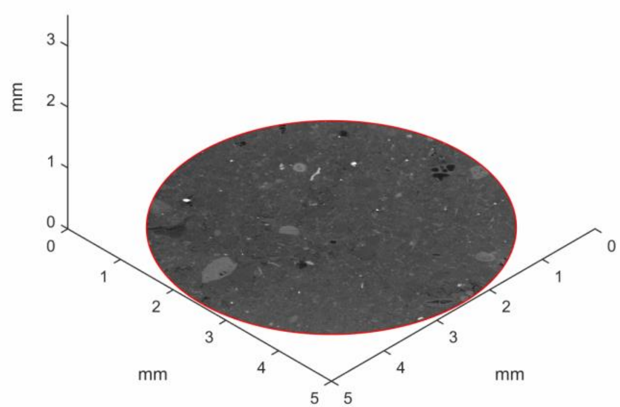
ChemWish- Subsurface fluid sampler developed by ITRI

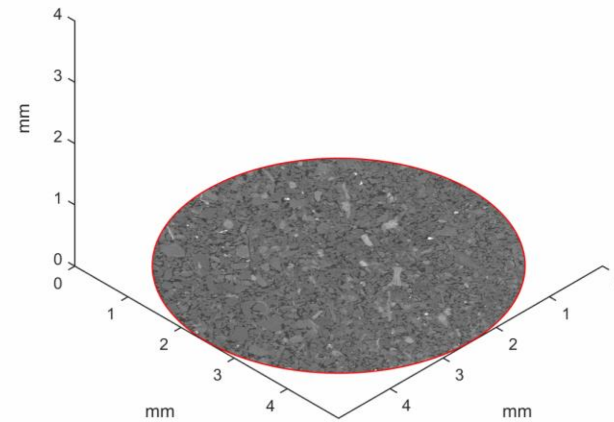
(**C**hemical and **H**ydraulic **E**xploration **M**arlinespike for ground **W**ater **I**solated in a bore**H**ole)

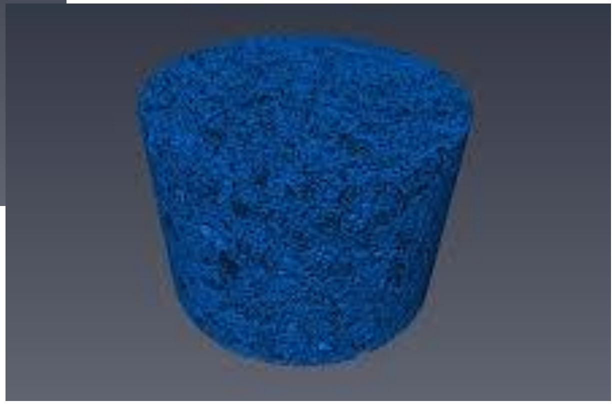


地質材料物化特性試驗與分析

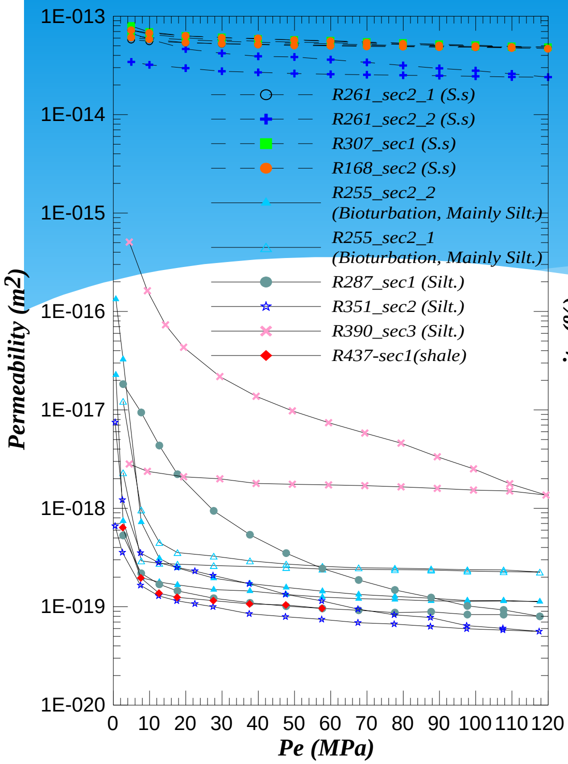
1.分析試體深度
2448.28 m
2.試體大小
1x1x1 cm^3
3.CT掃描範圍
直徑0.2 cm
高 0.2 cm
圓柱體
4.CT解析度
2 um
5.CT影像原始檔
15 GB

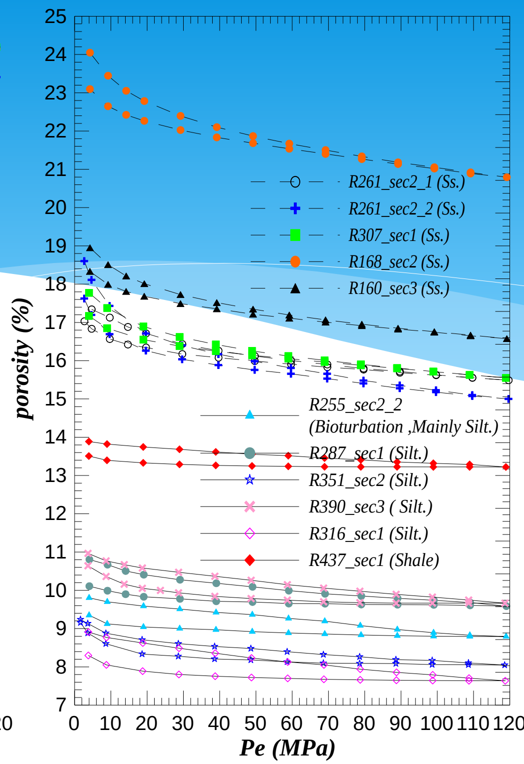


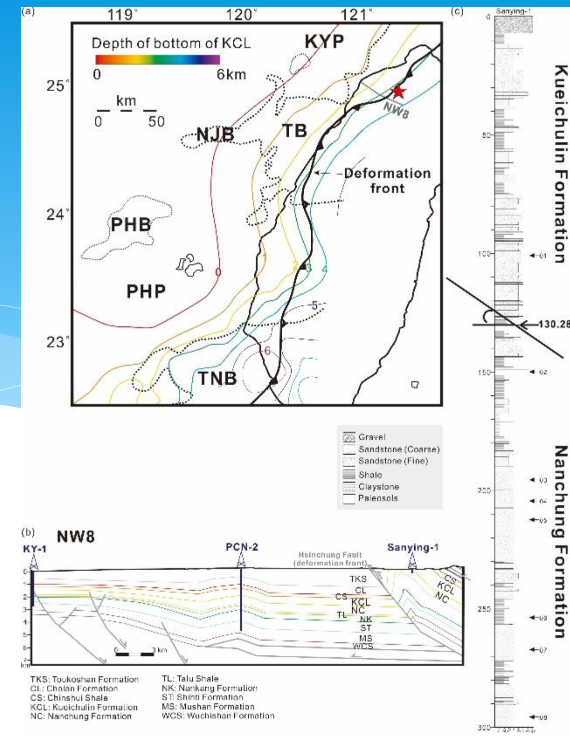


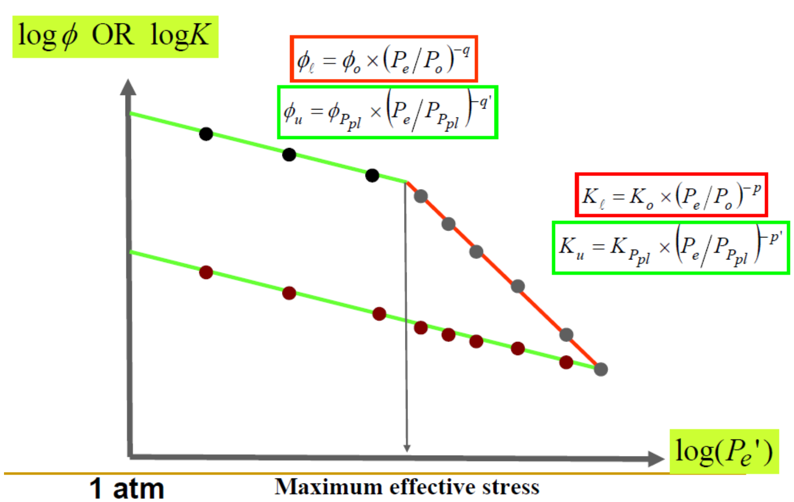


Stress history dependent Permeability and Porosity



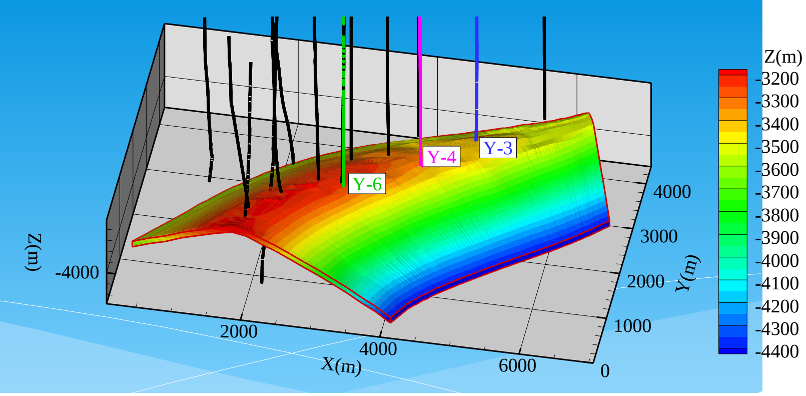


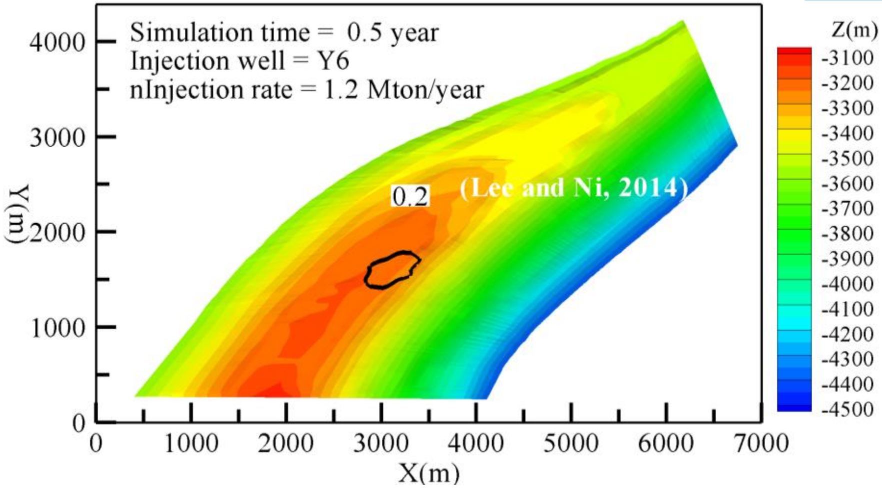


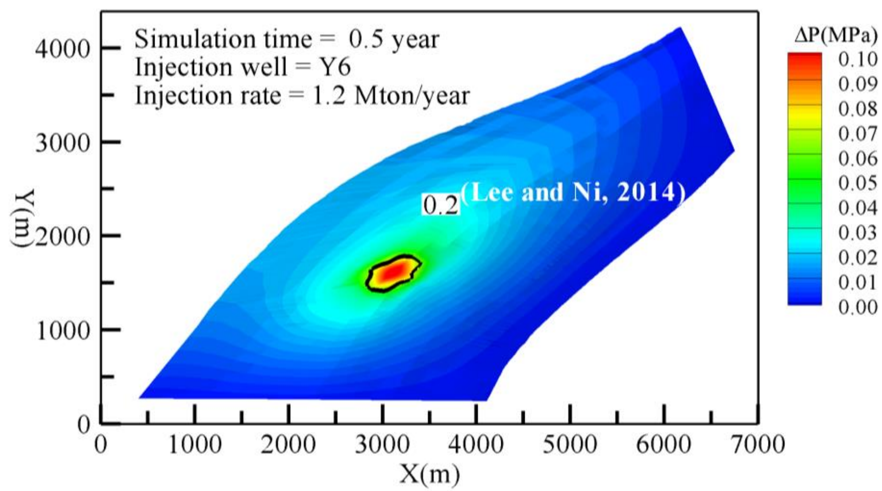


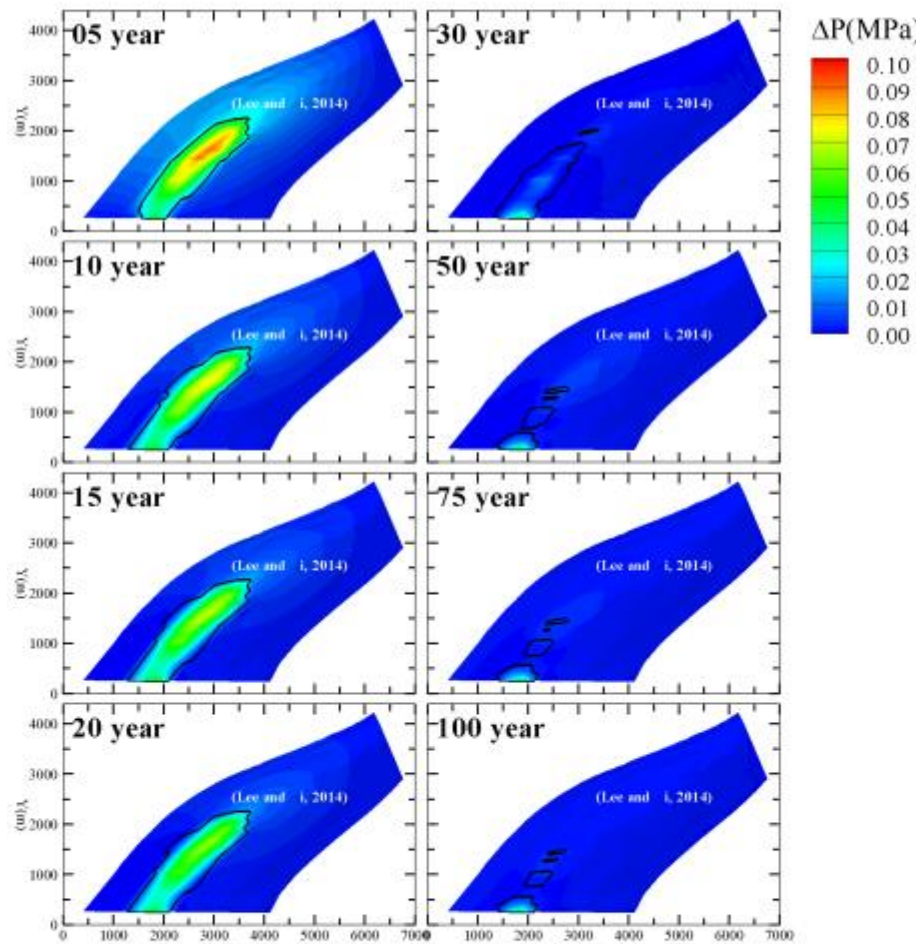
區域尺度二氧化碳地質封存模擬

斷層(Low permeability)



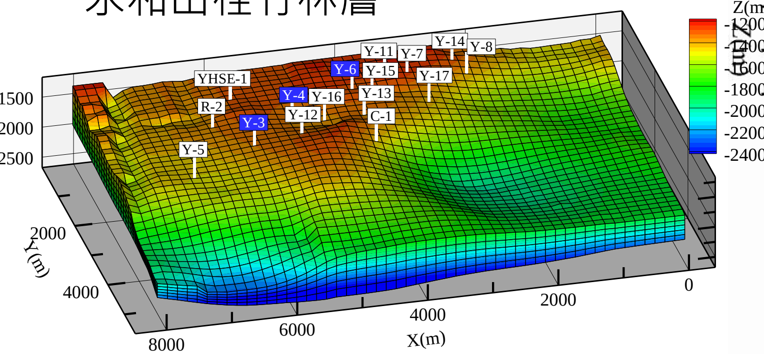


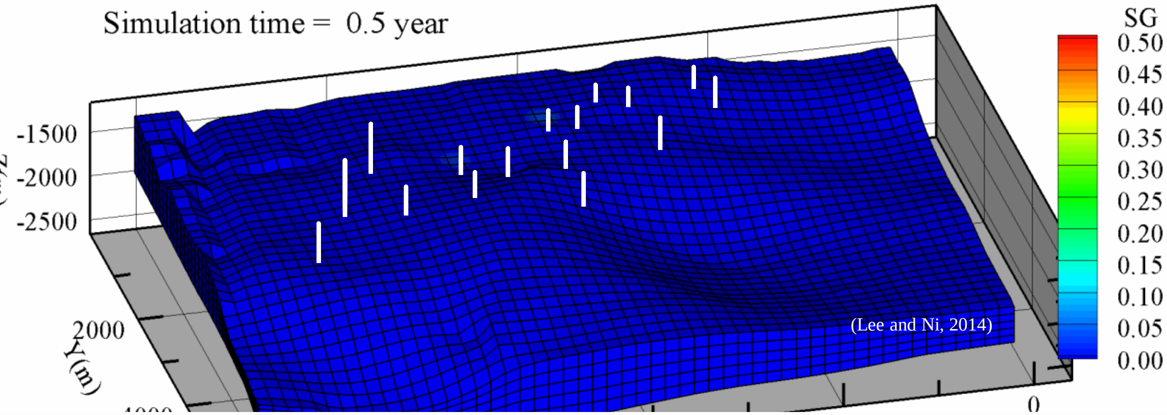


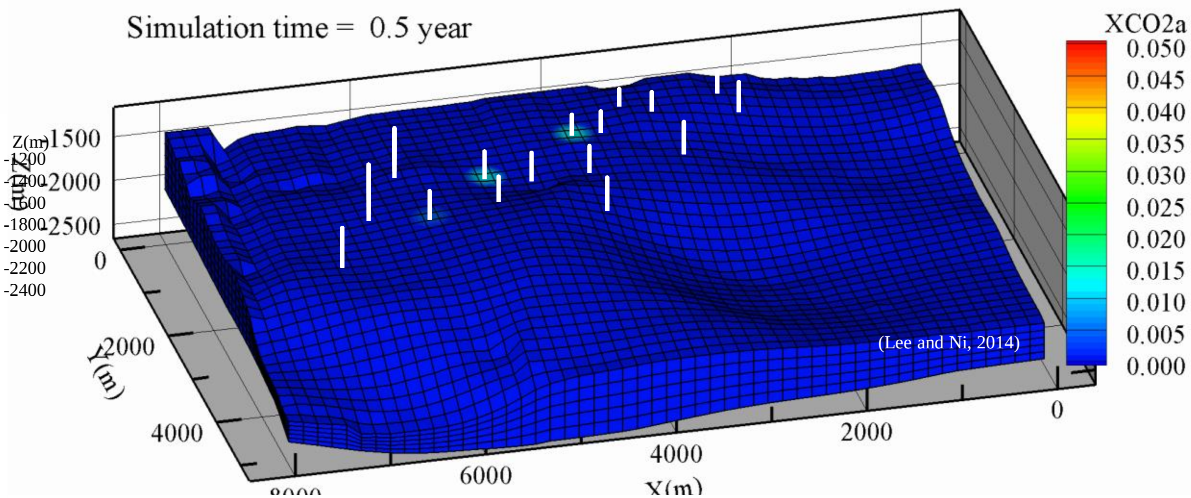


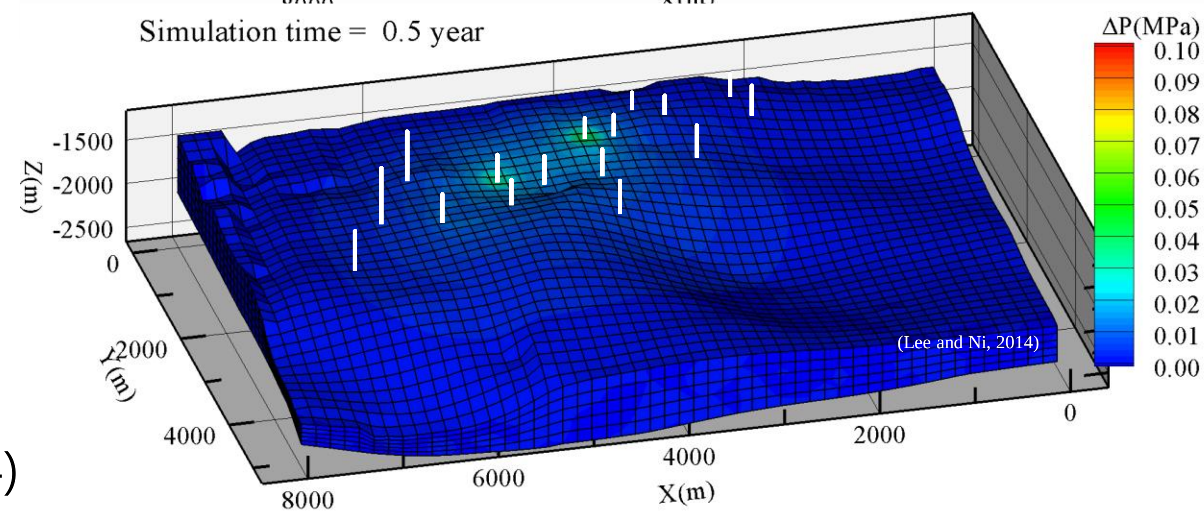
區域尺度二氧化碳地質封存模擬

永和山桂竹林層







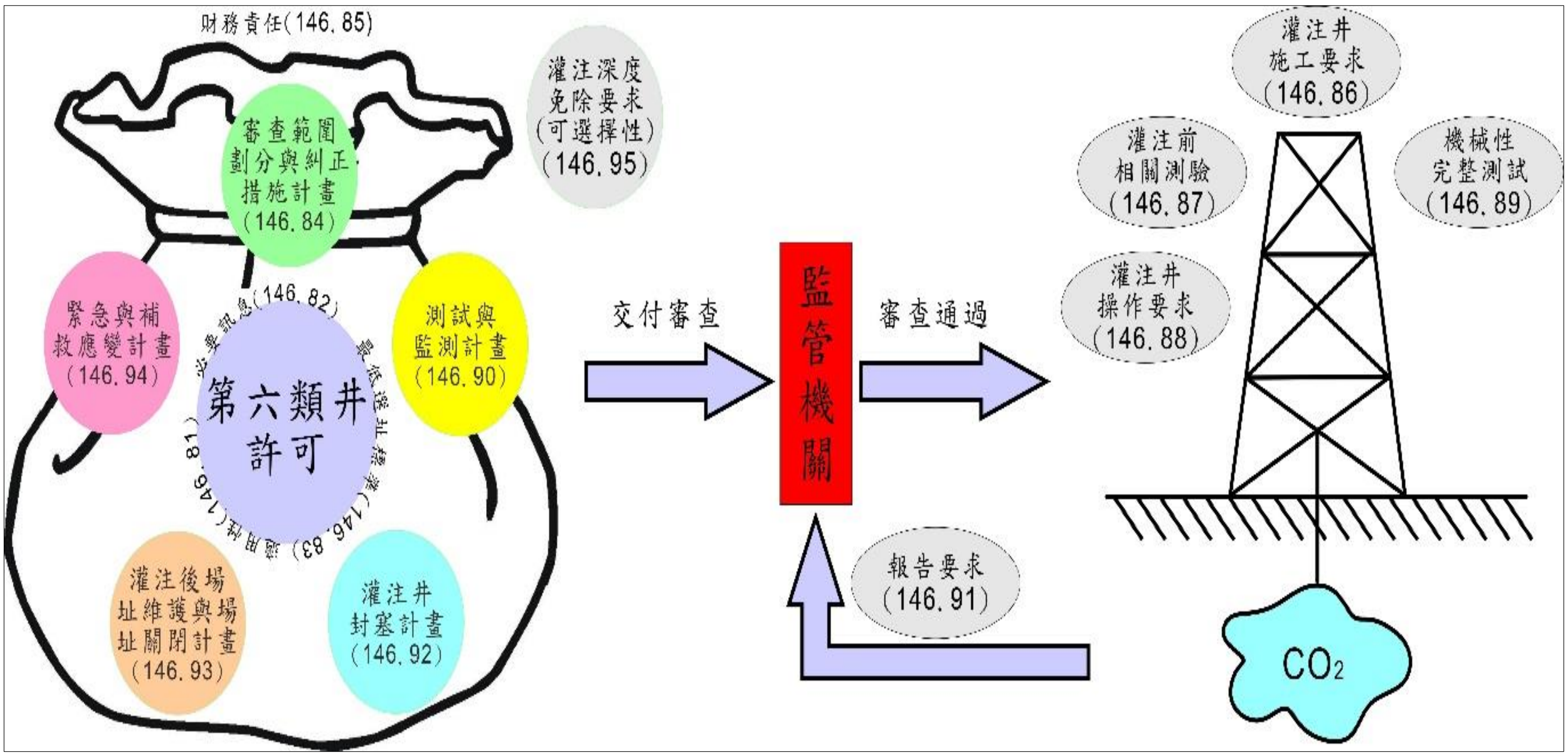


Three injection wells (Y3, Y4 ,Y6)
Injection rate = 3.6 Mton/year
Injection time = 20 years

臨界孔隙液壓差 = 3.04 MPa
(林器暉，2014)

建立試驗場址標準規範之框架

- 歐盟之2009/31/EC指令-明訂排除10萬公噸以下之注儲井
- **<u>美國UIC-第六類井之法規</u>**-屬於聯邦層級法規，在架構上較為完善
- 二氧化碳封存之國際規範ISO/TC265-仍未完成與公布，預備提升至國際標準草案
- 加拿大標準協會Z741-12號規範-目前僅是建議性質，並未法規化



結論

1. **Taiwan has an excellent geological condition for CO_2 geosequestration and a huge capacity for CO_2 storage of around 48.7 billion tons (first-order estimate) for both onshore and offshore areas.**

2. **Pilot test sites for different storage scenarios (i.e. depleted gas fields and deep saline formations) need to be implemented ASAP.**

3. **Various monitoring technologies that tailored to Taiwan's geological conditions should be developed, verified and benchmarked based on pilot tests.**