

For the summer school “China-Australia Geological storage of CO₂”

Geophysical and engineering methods for offshore CO₂ storage

(海上CO₂封存的地球物理与工程方法)

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- Many of the methods were introduced in this popular scientific book.
- (本报告中许多图片来自我们新出版的科普书籍《中国海洋油气产业》)



主编介绍：
孙珍，女，1971年生，博士，中国科学院南海海洋研究所研究员。曾先后毕业于南京大学和中国地质大学（武汉）。现在主要从事海洋地质与油气研究工作。代表性论文为《南海岩石圈破裂方式与扩张过程的三维物理模拟》。



副主编介绍：
张举梅，女，1983年生，博士，中国科学院南海海洋研究所助理研究员，毕业于中国地质大学（武汉），主要从事海洋地质研究工作。目前研究方向为含油气盆地构造—沉积分析。



How to do with CO₂?

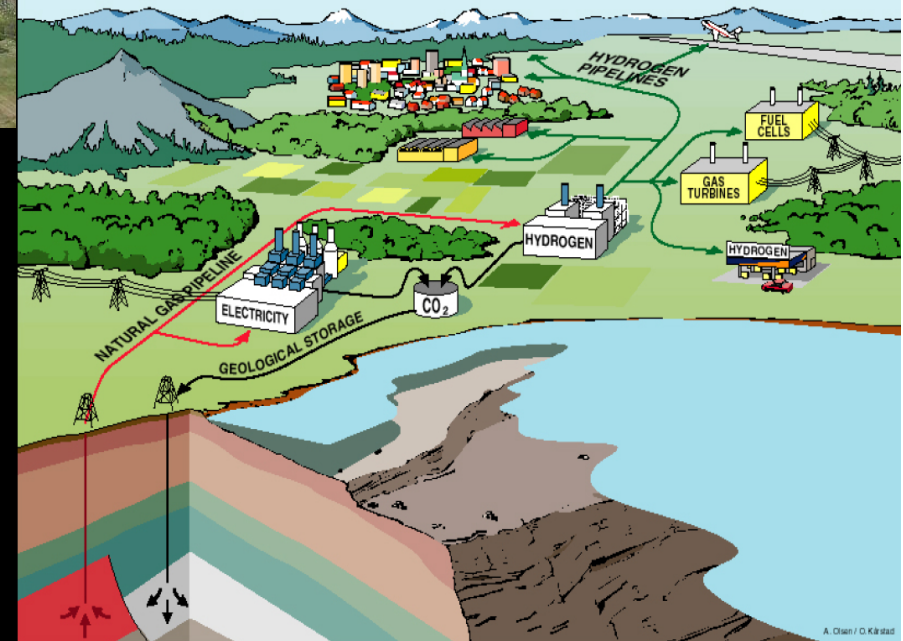
Greenhouse
Gas

- Find a place, bury it.

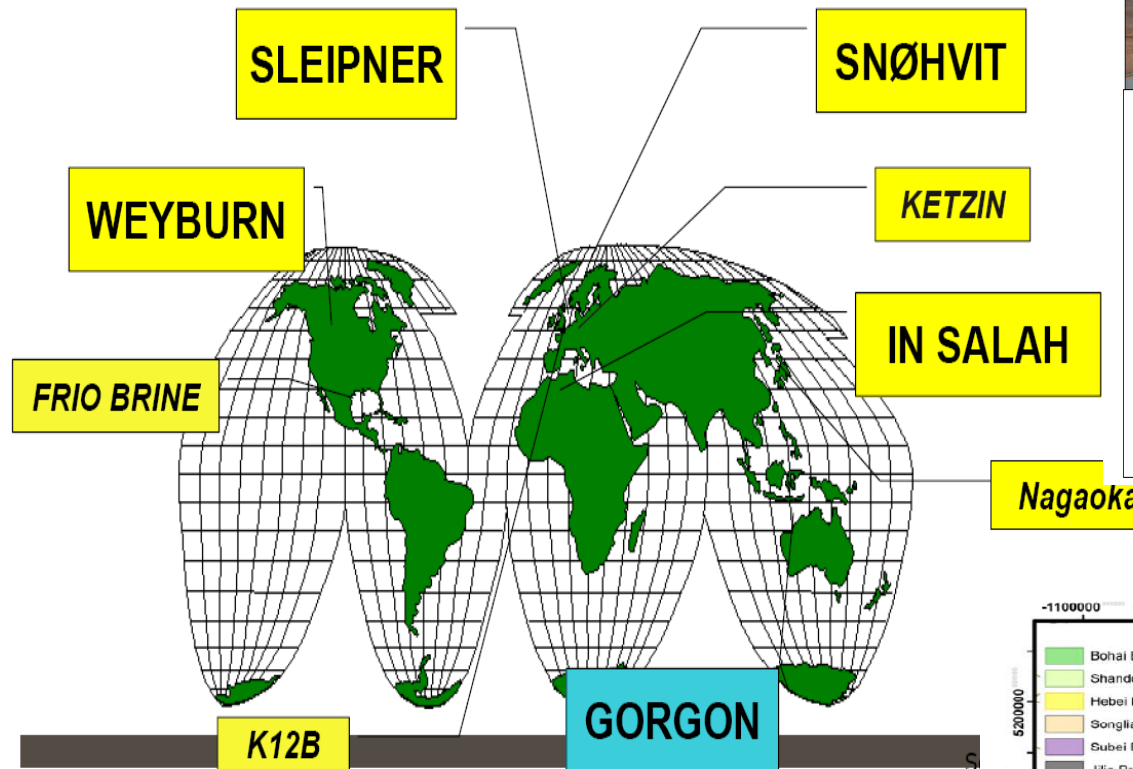


Tore A Torp, Dr.ing., 2009

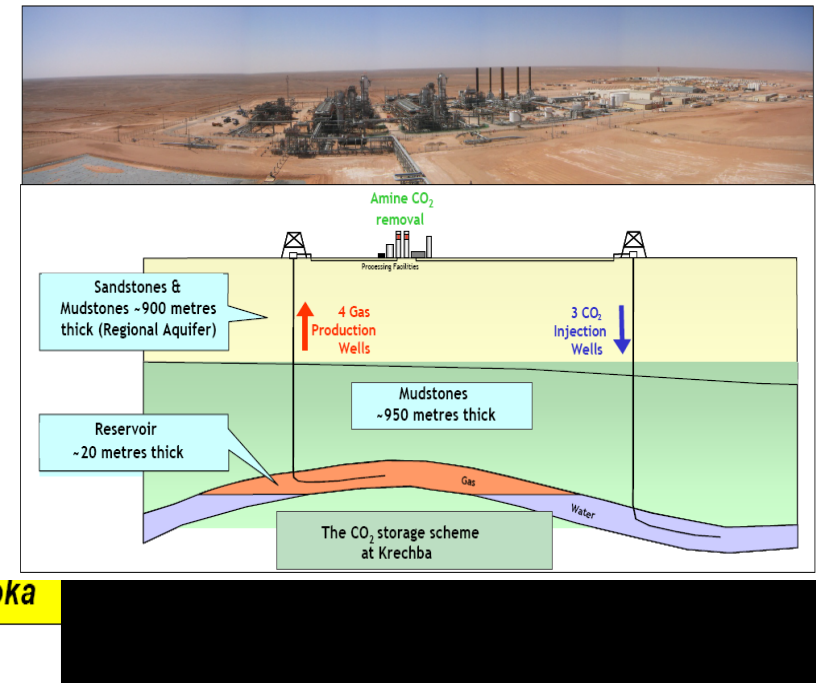
DECARBONISATION OF FOSSIL FUELS TO ELECTRICITY AND HYDROGEN



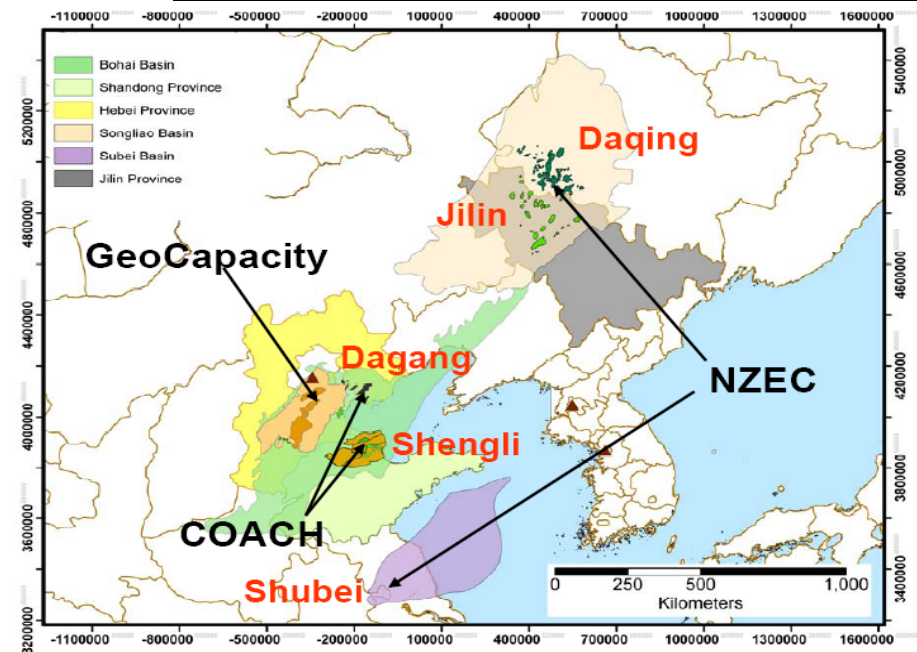
Demonstrate CO₂ Storage around the Globe



In Salah – Algeria



Nagaoka

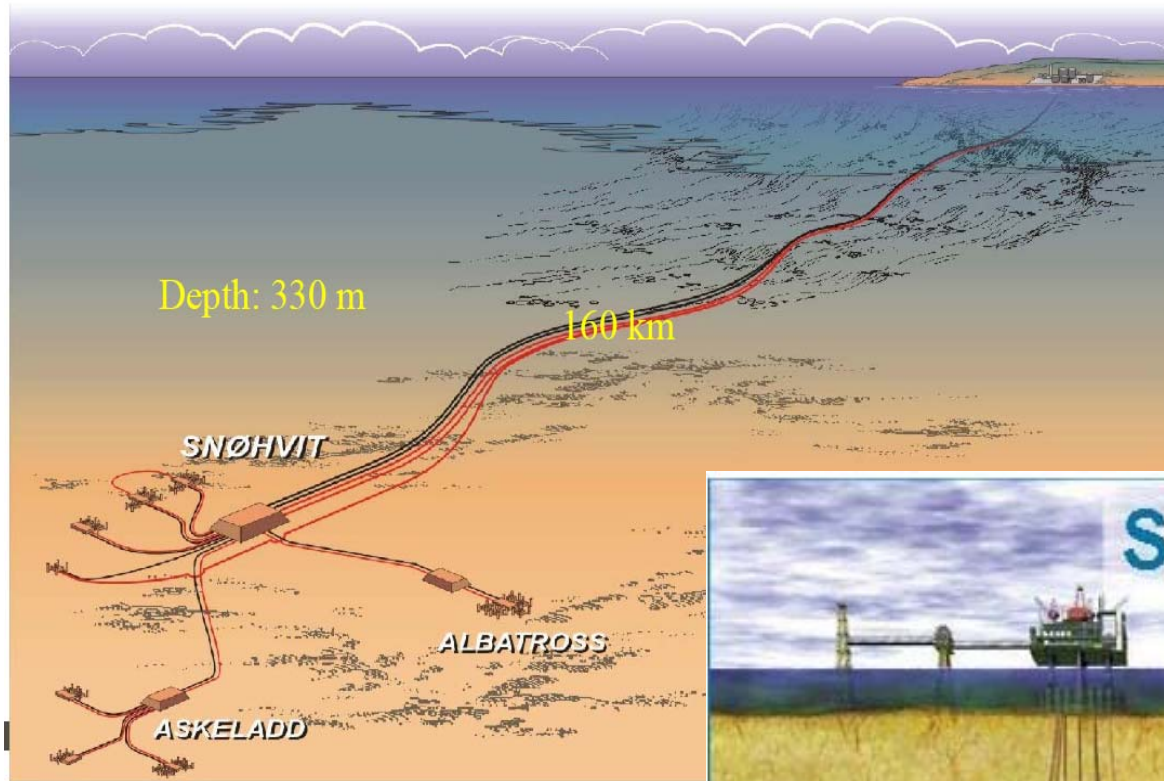


Tore A Torp, Dr.ing.,2009

- The locations for CO₂ storage in the world and China

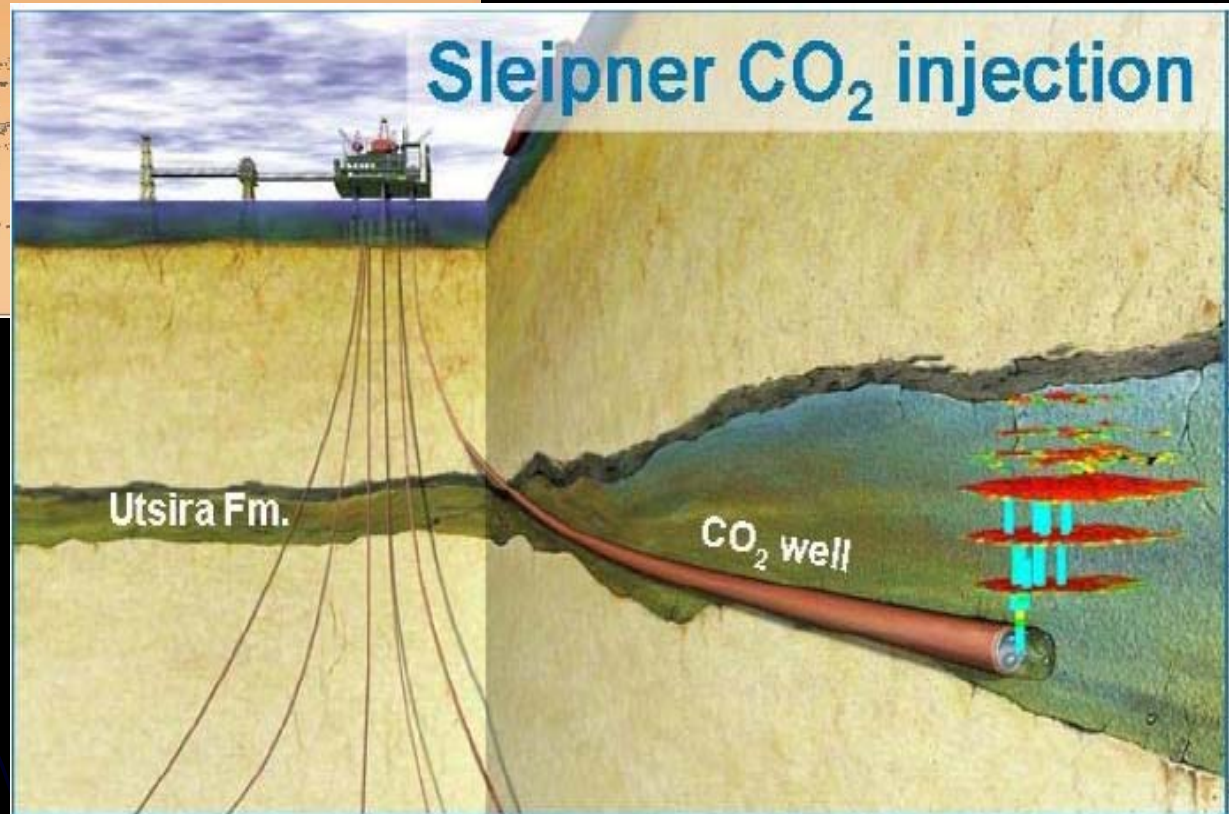
Li Mingyuan,2009

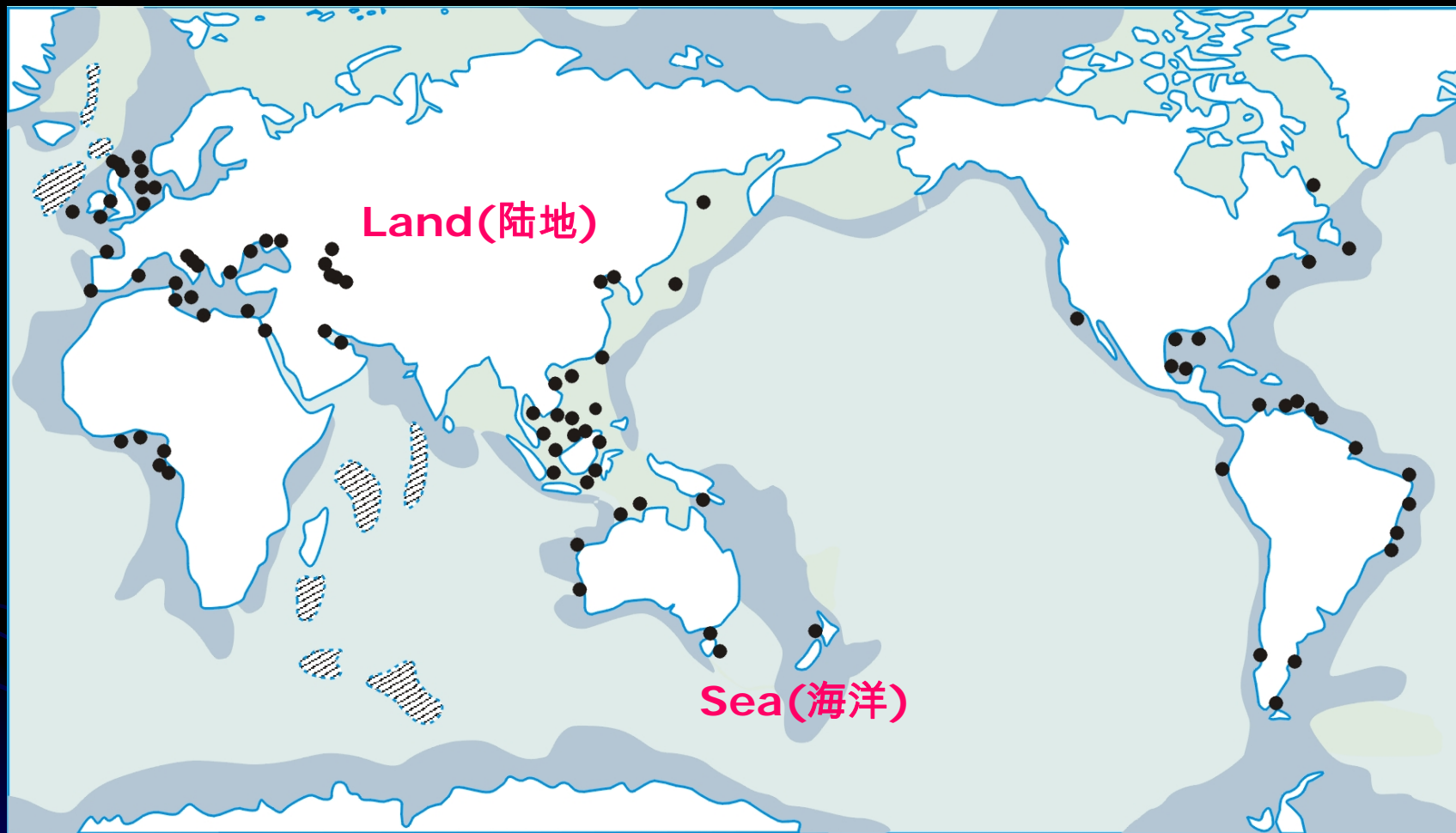
Snøhvit – All subsea



- Some countries bury their CO₂ deep in the sea

Offshore
storage
(海上封存)





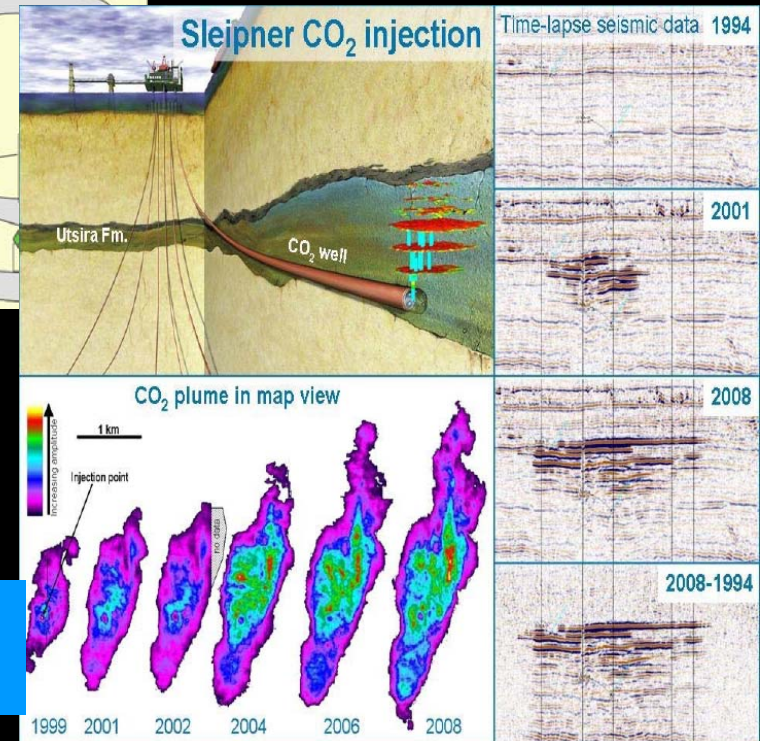
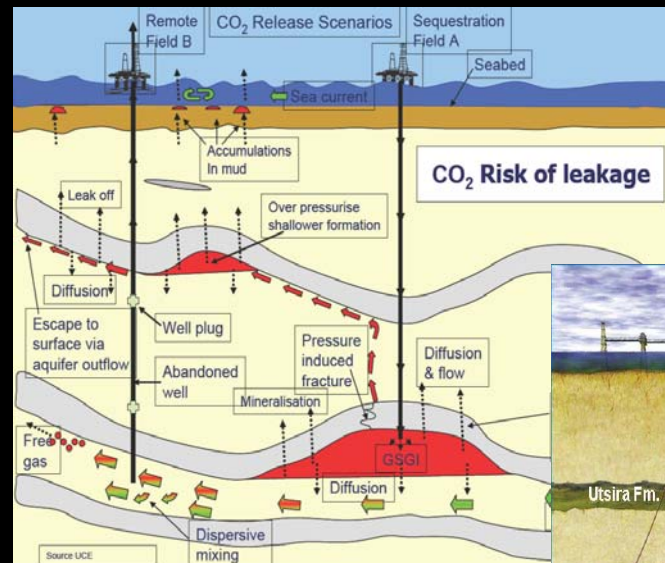
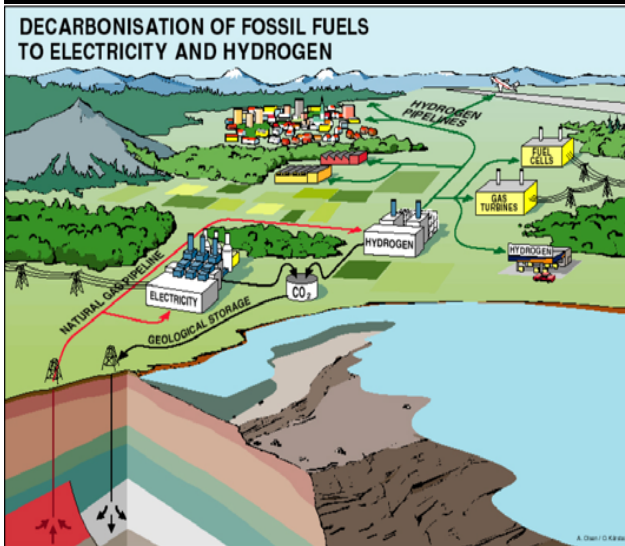
- We have larger sea areas without people living there
(海域面积更加广阔且无人居住)

Outline

- **The basic steps for offshore geological storage**
海上地质封存的基本步骤
- The main exploration and evaluation geophysical methods
封存目标探测与评价的常用地球物理方法
- The related engineering apparatus for geological storage
相关工程设施

The basic steps for offshore geological storage

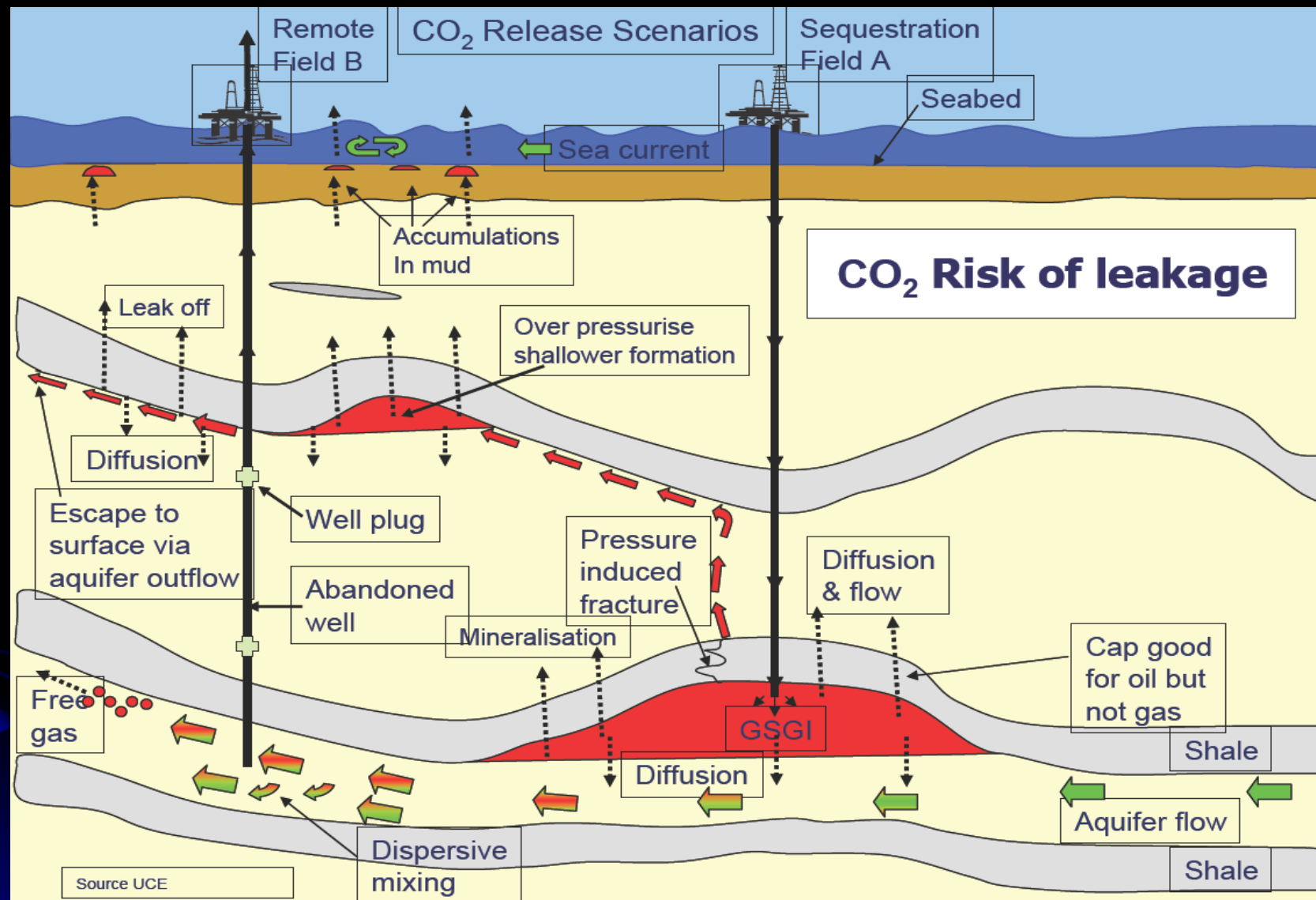
海上地质封存的基本步骤



Capture, Collection and Compression

Finding a good reservoir

Injection and Monitoring



- Not everywhere is feasible for CO2 storage, we must use some tools to help us.

Place suitable for CO₂ storage

- depleted hydrocarbon reservoirs
(开发枯竭的油气藏)
- deep saline aquifers
(深部咸水层)
- Coal bed
(煤床)
-
- Using some methods or tools to find the suitable places

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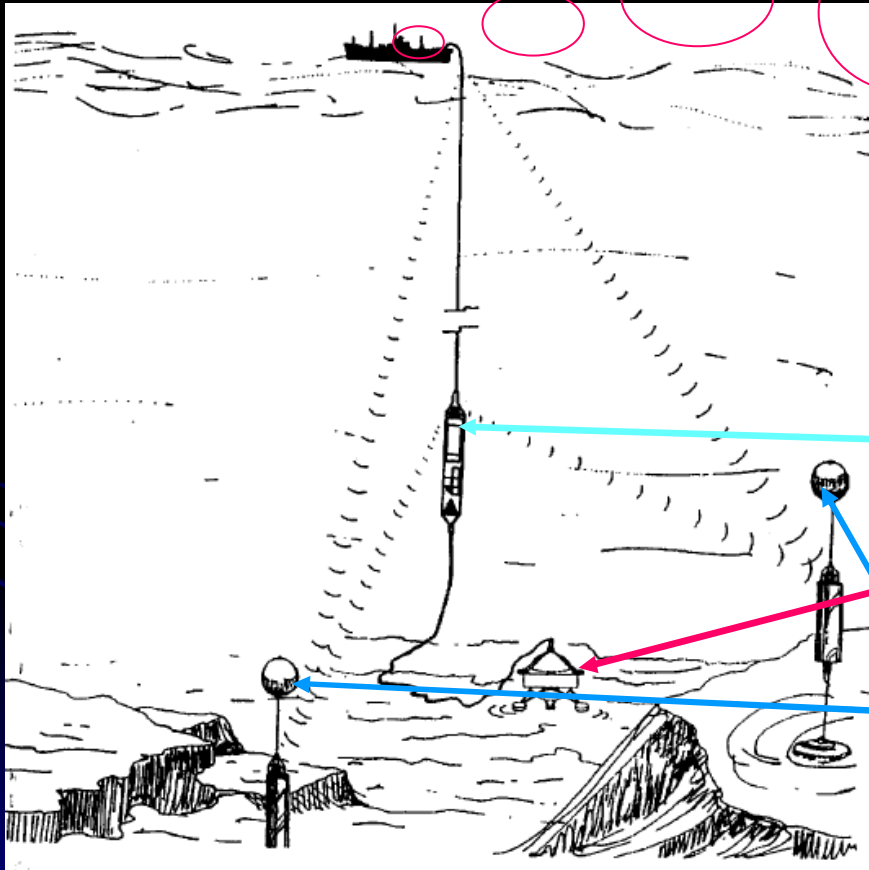
Methods used for target exploration and storage monitoring

Exploration methods 勘探方法	Physical principle 物理依据	Media Properties 物性条件	Investigation style 观测方式
Marine Gravity survey 海洋重力勘探	Gravity(万有引力) Centrifugal force(离心力)	Variation in density 密度分布差异	on board/deep tow 船上/深拖 continuous observation连续观测
Marine Geomagnetic survey 海洋磁法勘探	Magnetic field 地球磁场 磁性体产生的磁场	Magnetized opportunity 磁化率、剩余磁性 分布差异	on board/deep tow 船上/深拖 continuous observation连续观测
Seismic exploration 海洋地震勘探	Elastic wave reflection and deflection 弹性波(地震波/声波)反射和折射	Propagating speed 传播速度	on board/deep tow 船上/深拖 Continuous or point observation 连续/定点观测
Marine Electromagnetic 海洋电磁法勘探	Natural/direct current 自然/直流电场 electromagnetics电磁场	electricity 大地电流、视电阻率 磁导率	on board/deep tow 船上/深拖 Continuous/point investigation 连续/定点观测
Thermal measurement 海底热流测量	Geothermal flux 地热流量	Heat conductivity 热传导率	Sea floor investigation 海底热流量测量
Radioactive exploration 海洋放射性勘探	Radioactivity 放射性	Radioactive elements 放射性元素 释放射线差异	continuous observation 连续观测
logging 海洋测井	lithology 各种岩层物性	Lithological variation 各种物性	continuous observation 连续观测

Marine Gravity survey 海洋重力勘探



On board gravimeter



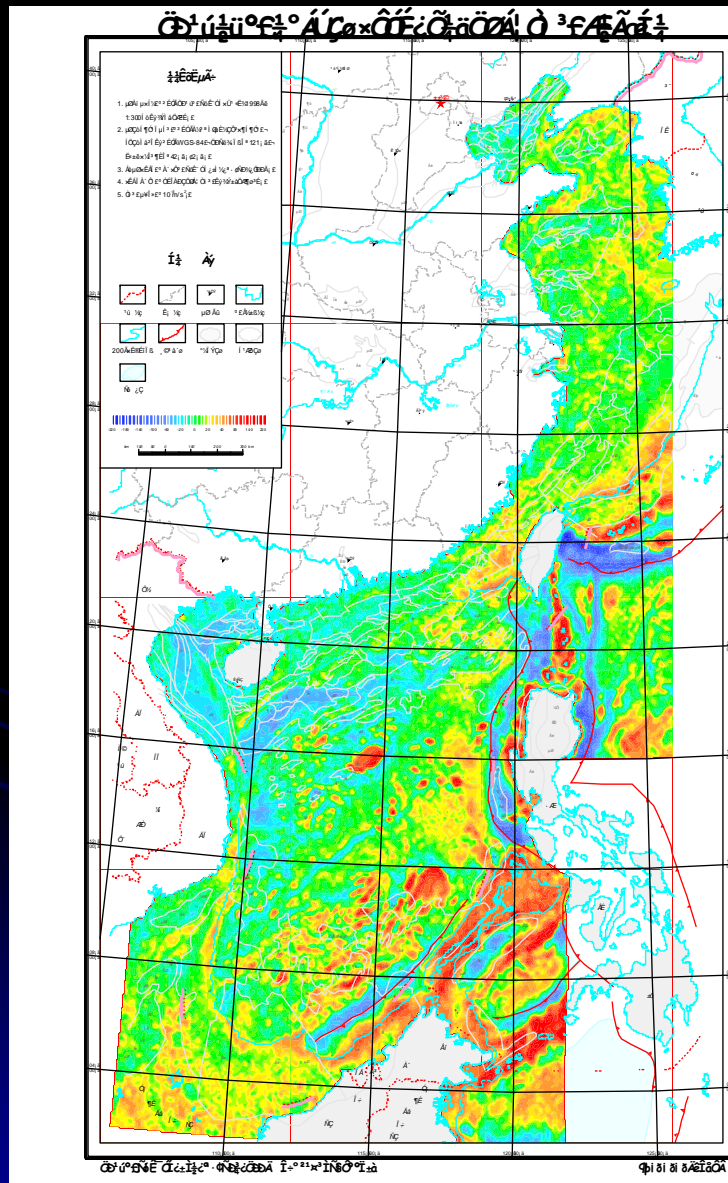
Sonar emitter

LaCoste&Romberg gravimeter

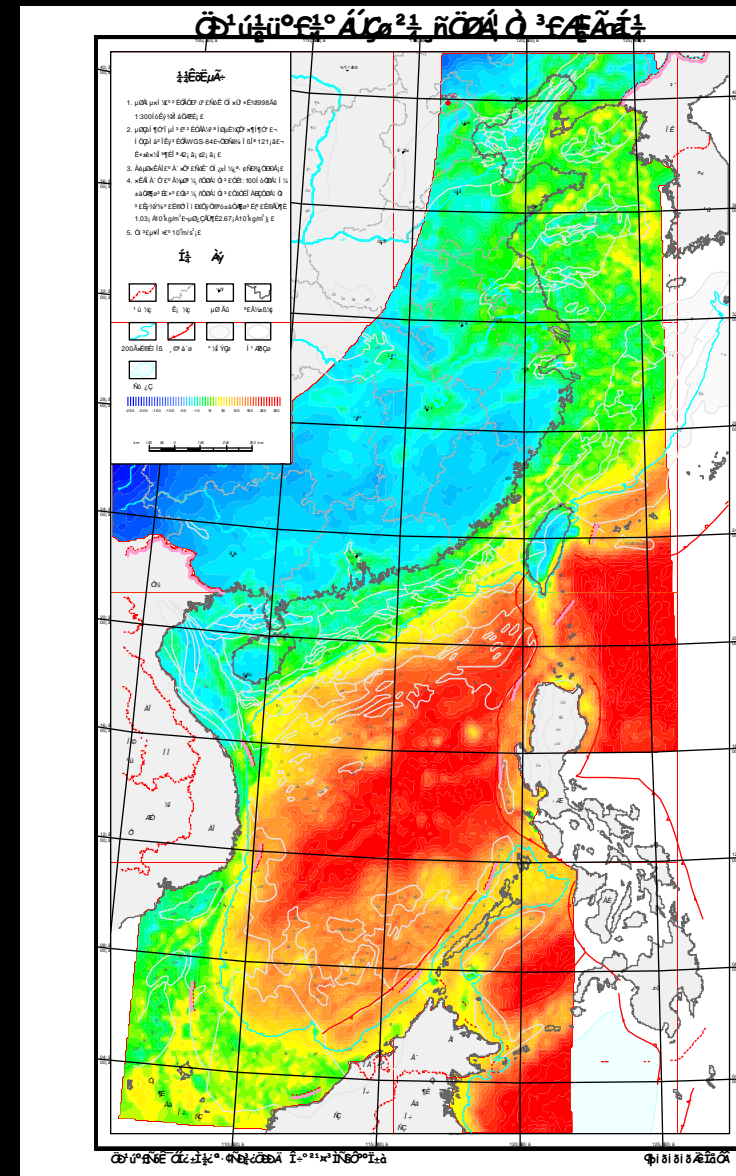
transponder

- Deep tow point gravimeter

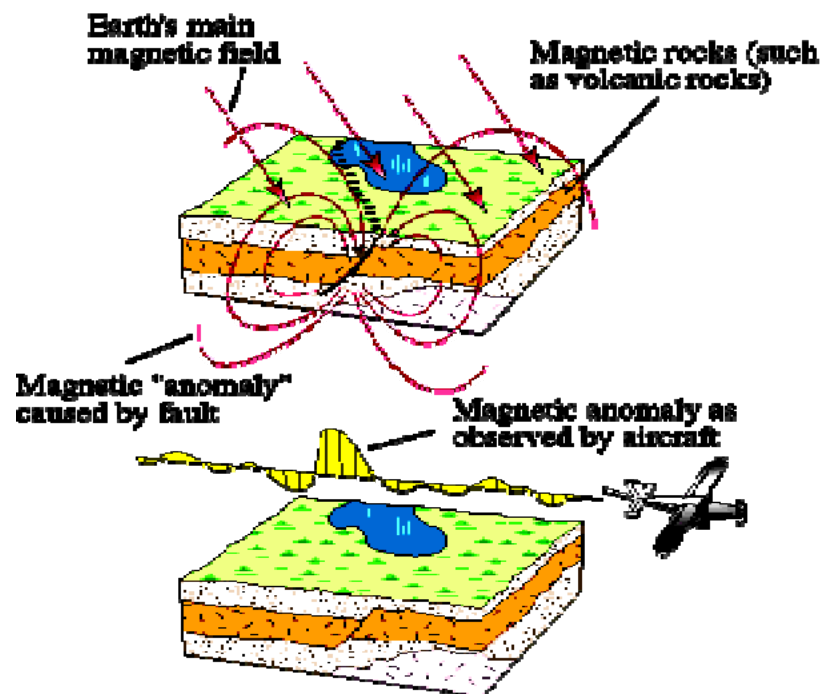
Related figures used for analysis



Wang et al., 2000

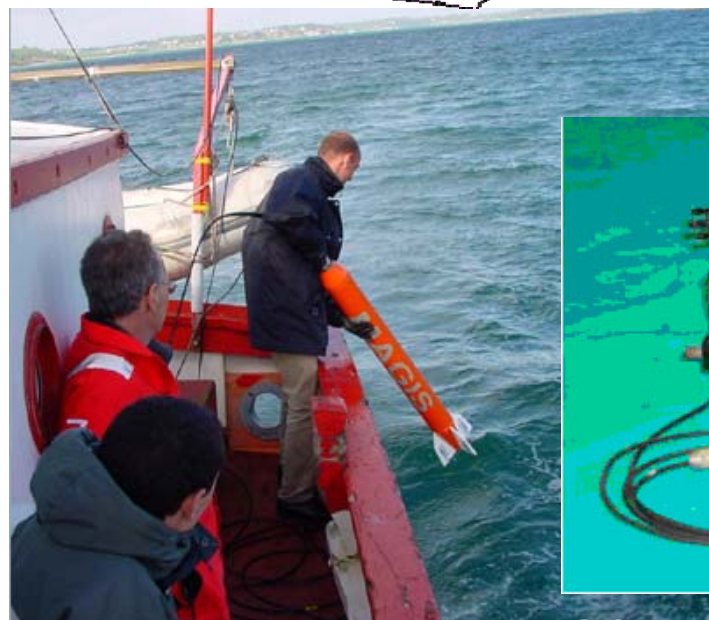


- Free air Gravity Anomaly(自由空间重力异常)
- Buguer Gravity Anomaly(自由空间重力异常)



Marine Geomagnetic survey 海洋磁法勘探

Sun Zhen/孙珍 et al., 2011

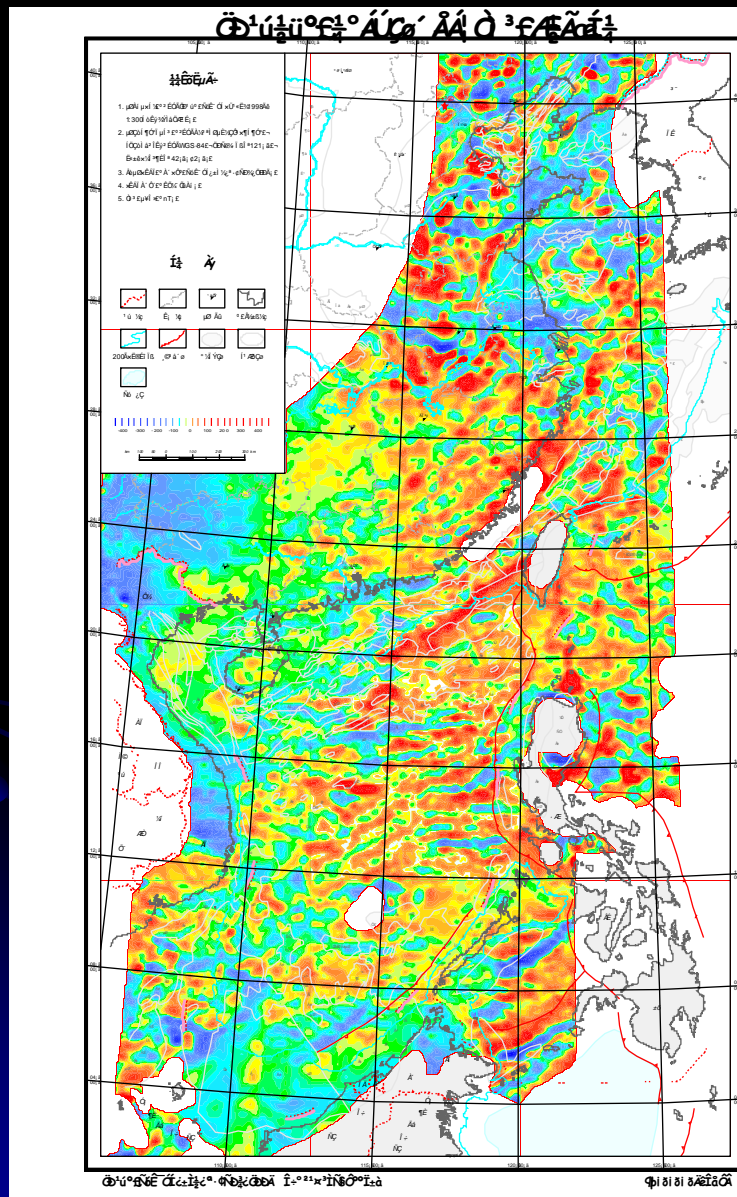


the magnetic sensor

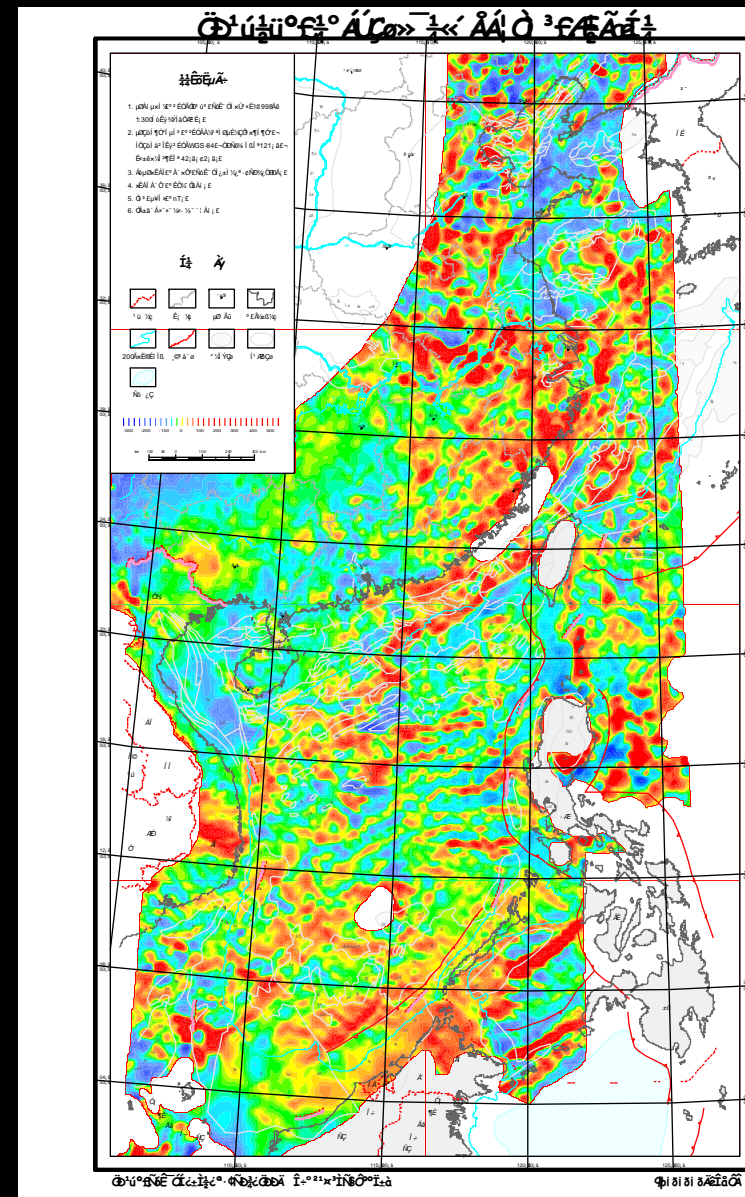
GSM-19T proton precession
(质子旋进磁力仪)

• gradient apparatus (磁力梯度仪)

Related figures used for analysis

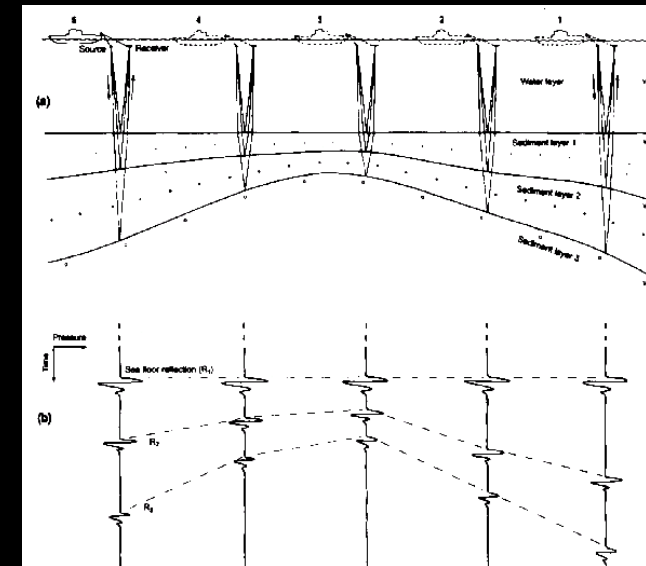
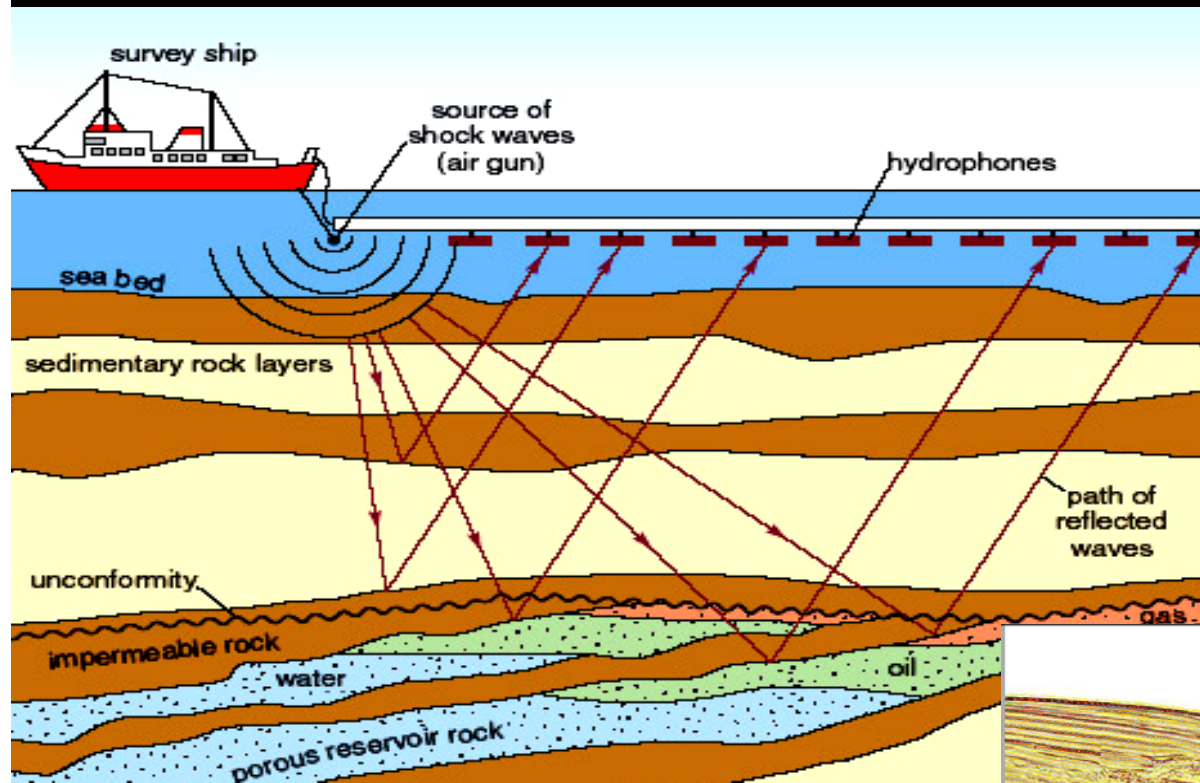


Wang et al., 2000



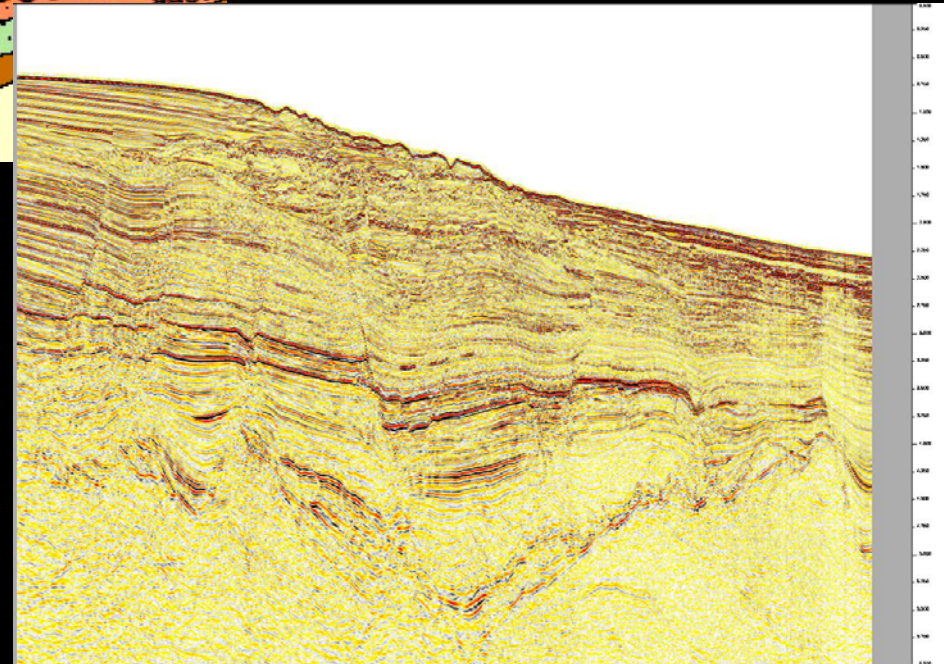
- Magnetic anomaly and anomaly reduced to the pole

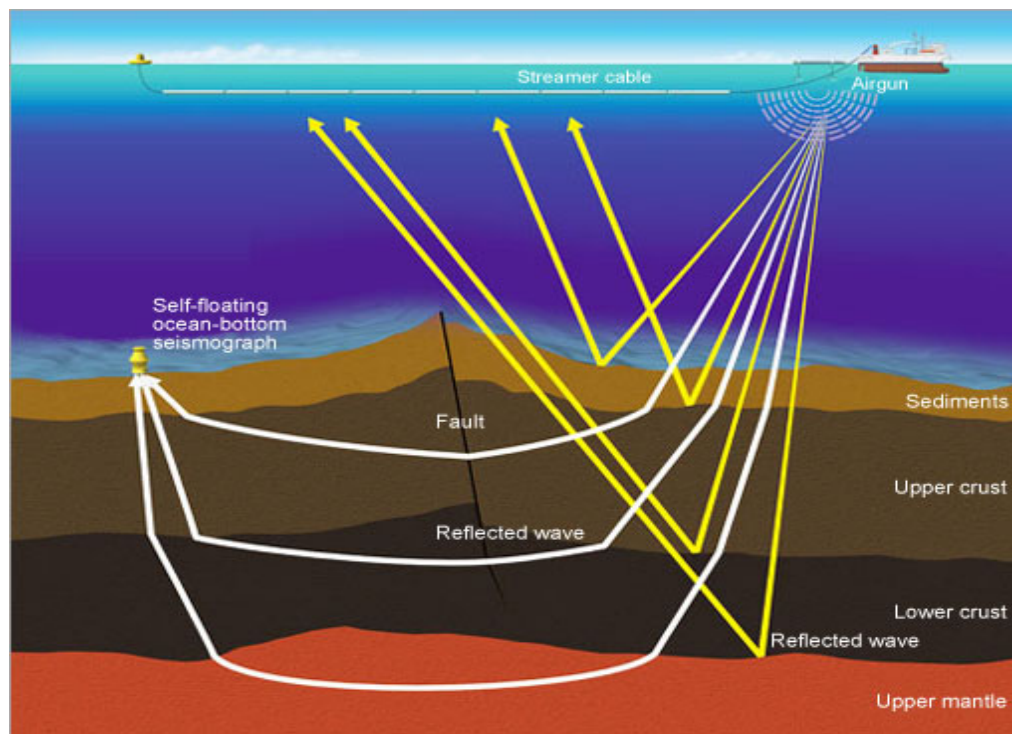
Seismic exploration (地震探测)



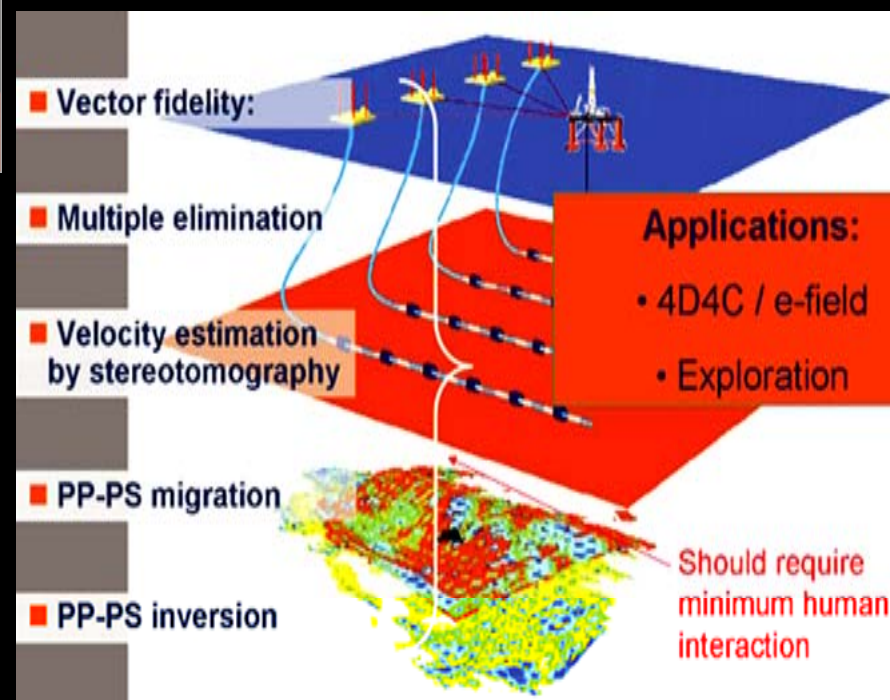
Sun Zhen/孙珍 et al., 2011

- See the deep with the help of seismic



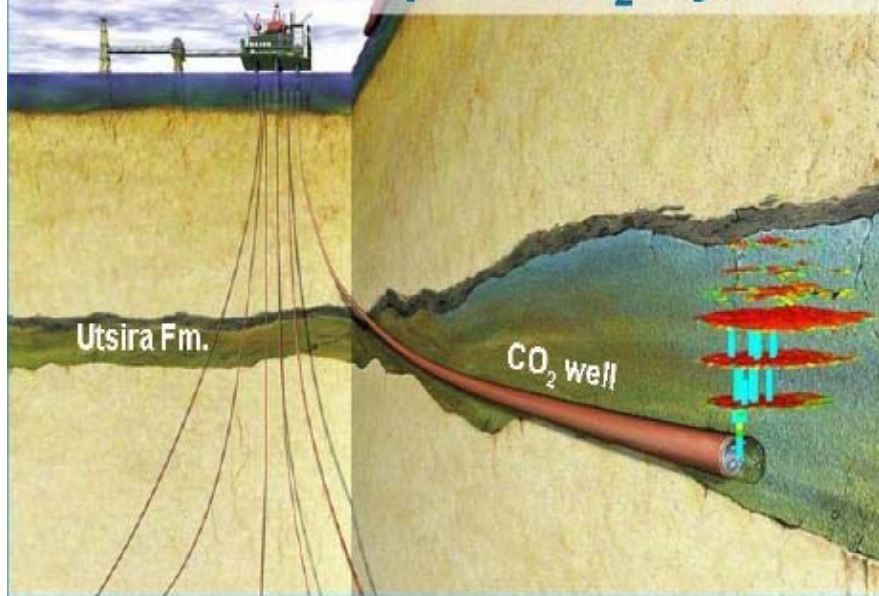


- OBS (Ocean bottom seismometer) detect the deep reflected wave to construct the deep structure
- (海底地震仪检测深反射地震波，建立深部结构)

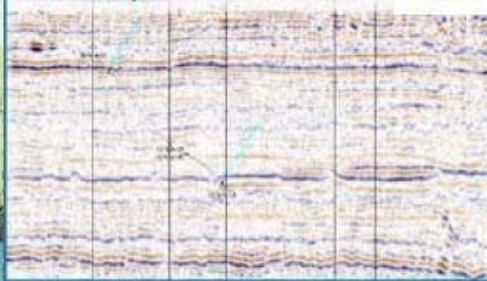


Sun /孙珍 et al., 2011

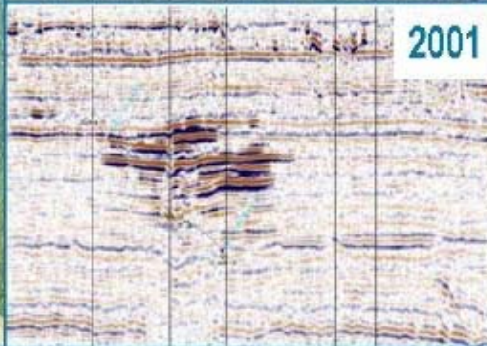
Sleipner CO₂ injection



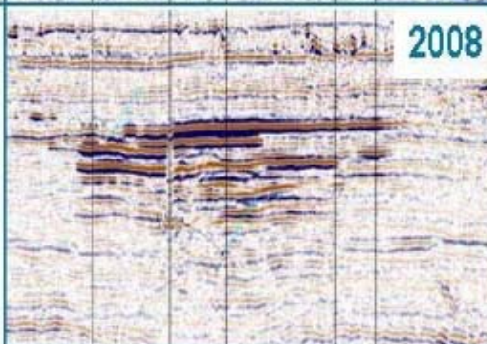
Time-lapse seismic data 1994



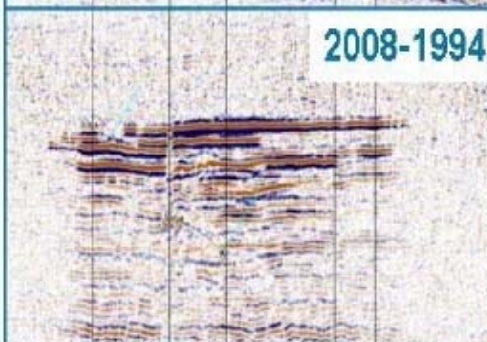
2001



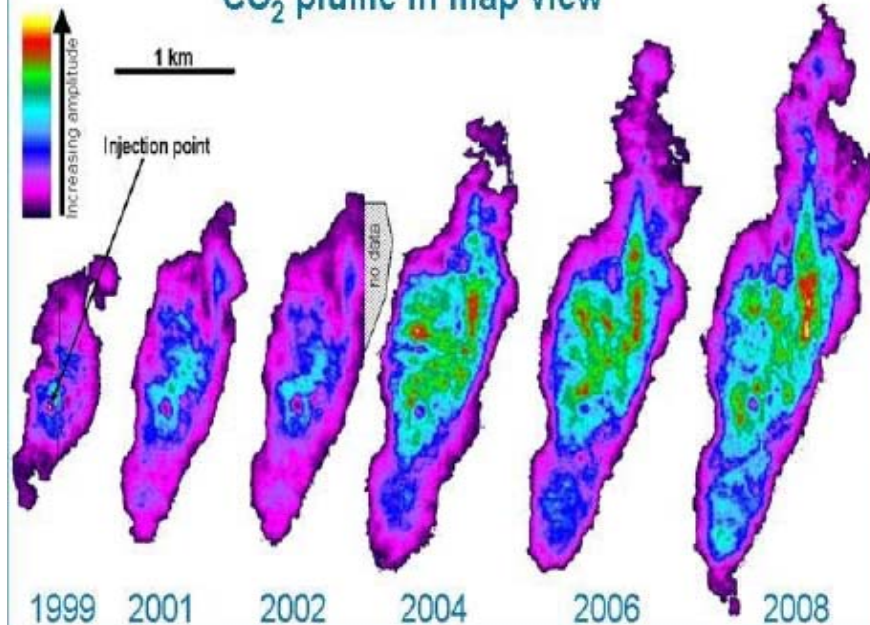
2008



2008-1994



CO₂ plume in map view



- Monitoring the injection site with 4D seismic
- 4维地震检测CO₂的注入与地质封存所造成的深部地层变化)

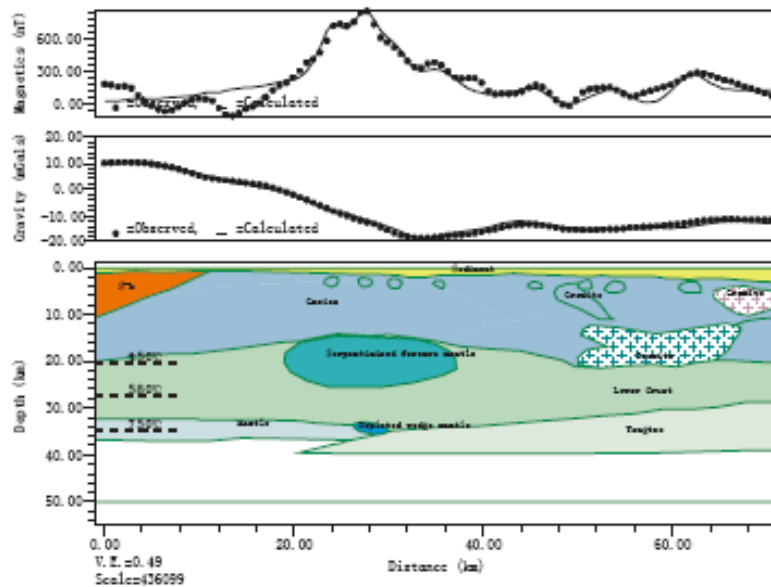


图 8-4 苏鲁超高压变质带重磁剖面-I 模拟

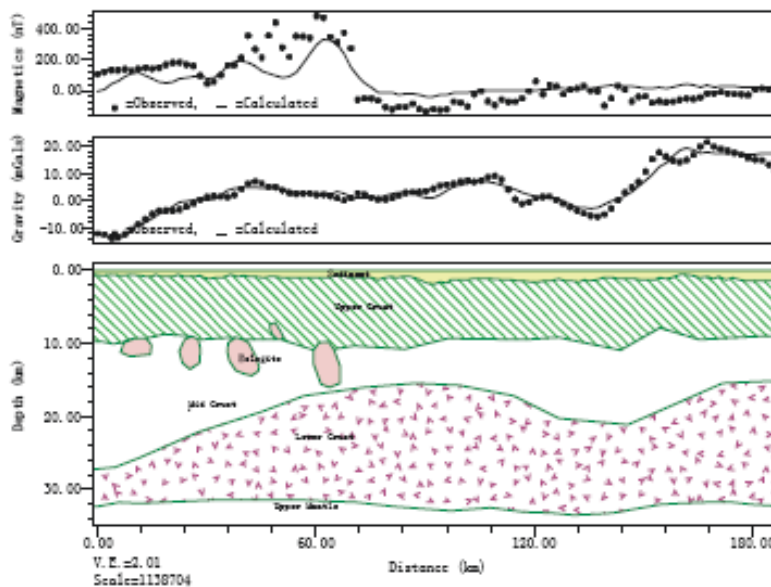


图 8-5 苏鲁超高压变质带重磁剖面-II 模拟

Combined inversion (联合反演)

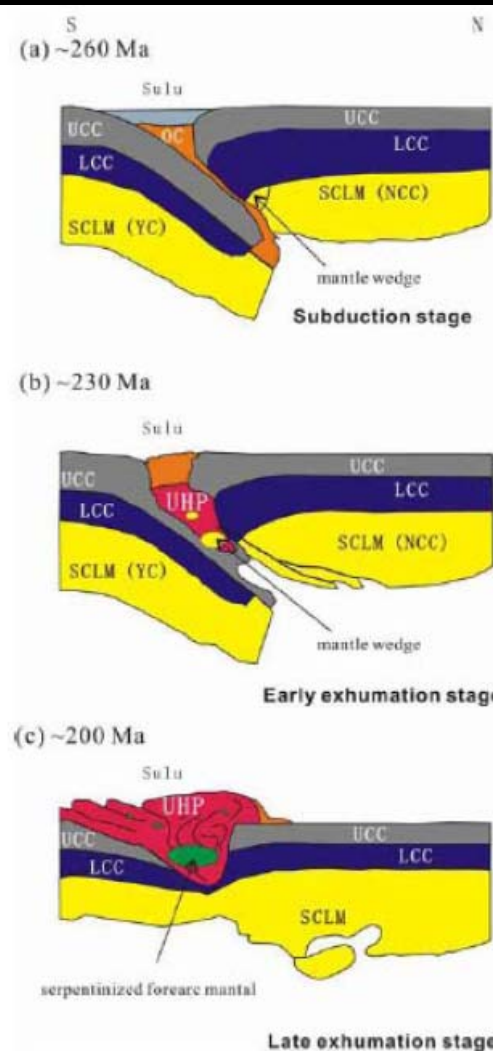
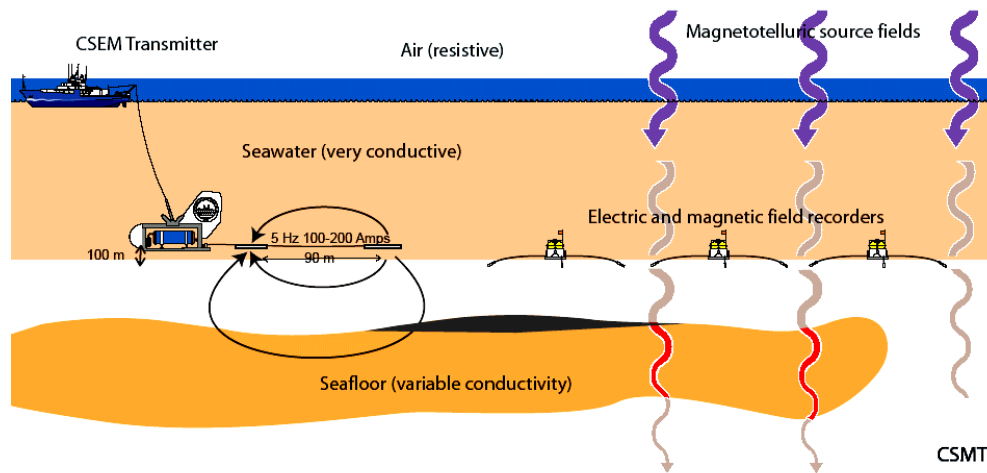


图 8-6 苏鲁蛇纹石化弧前地幔形成过程模型示意图。

◆ Gravity, magnetics and seismic are often used together for inversion for the deep structures

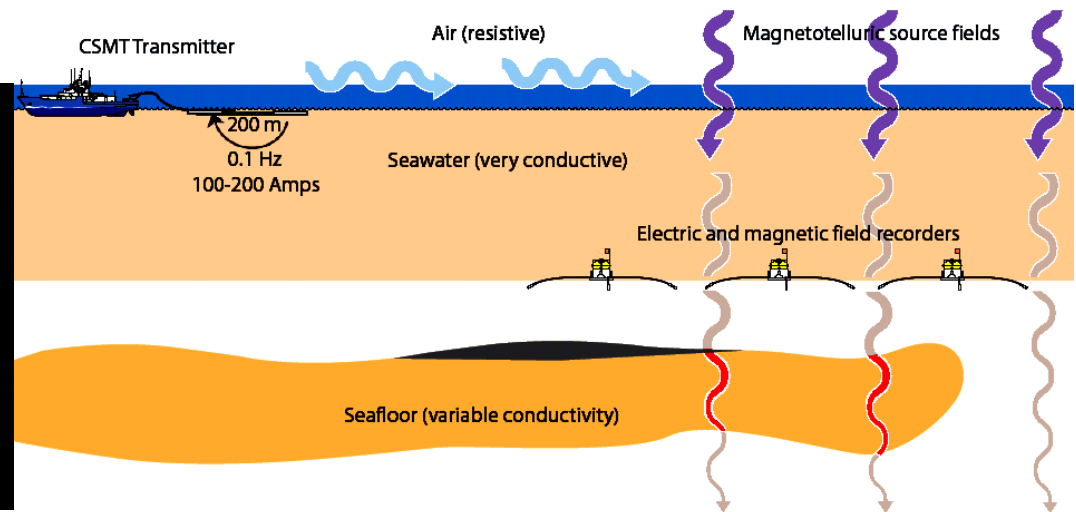
重磁联合反演获得深部结构，给出构造解释



Marine Electromagnetic 海洋电法勘探

CSEM style

海洋可控源电磁法
CSEM测量布置

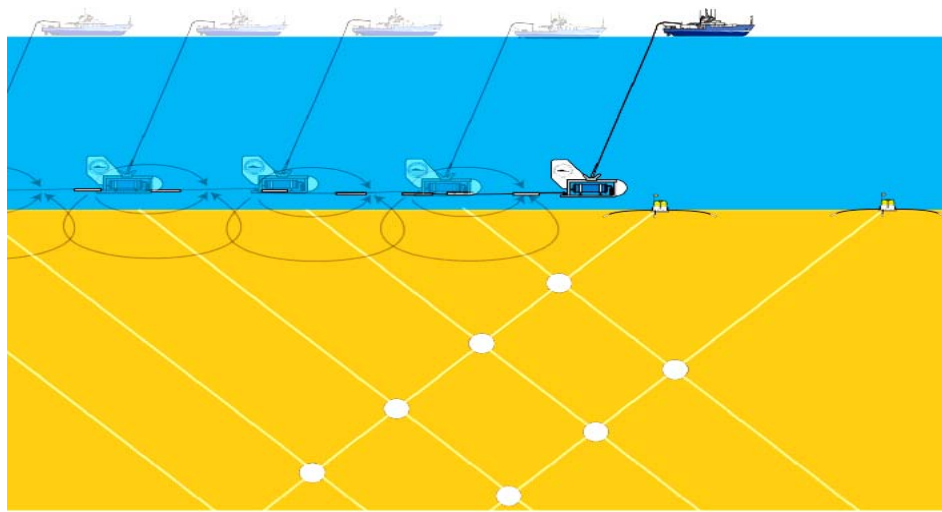


CSMT style

海洋可控源大地电磁法CSMT
测量布置

Continuous observation

海洋电磁法连续测量



Thermal measurement 海底热流测量



The probe was used for deep water measurement
实验1号2010印度洋航次
海底地热探针



Heat flow Probe

Methods used for storage monitoring

4D Seismic images-Fluid displacement

Gravimetry - Density change monitoring

Reservoir simulation tools -potential cap-rock pathways Gas

Geology –Rock strain monitoring

Geochemistry method -Gas Chemistry

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- **The related engineering apparatus for geological storage**
相关工程设施

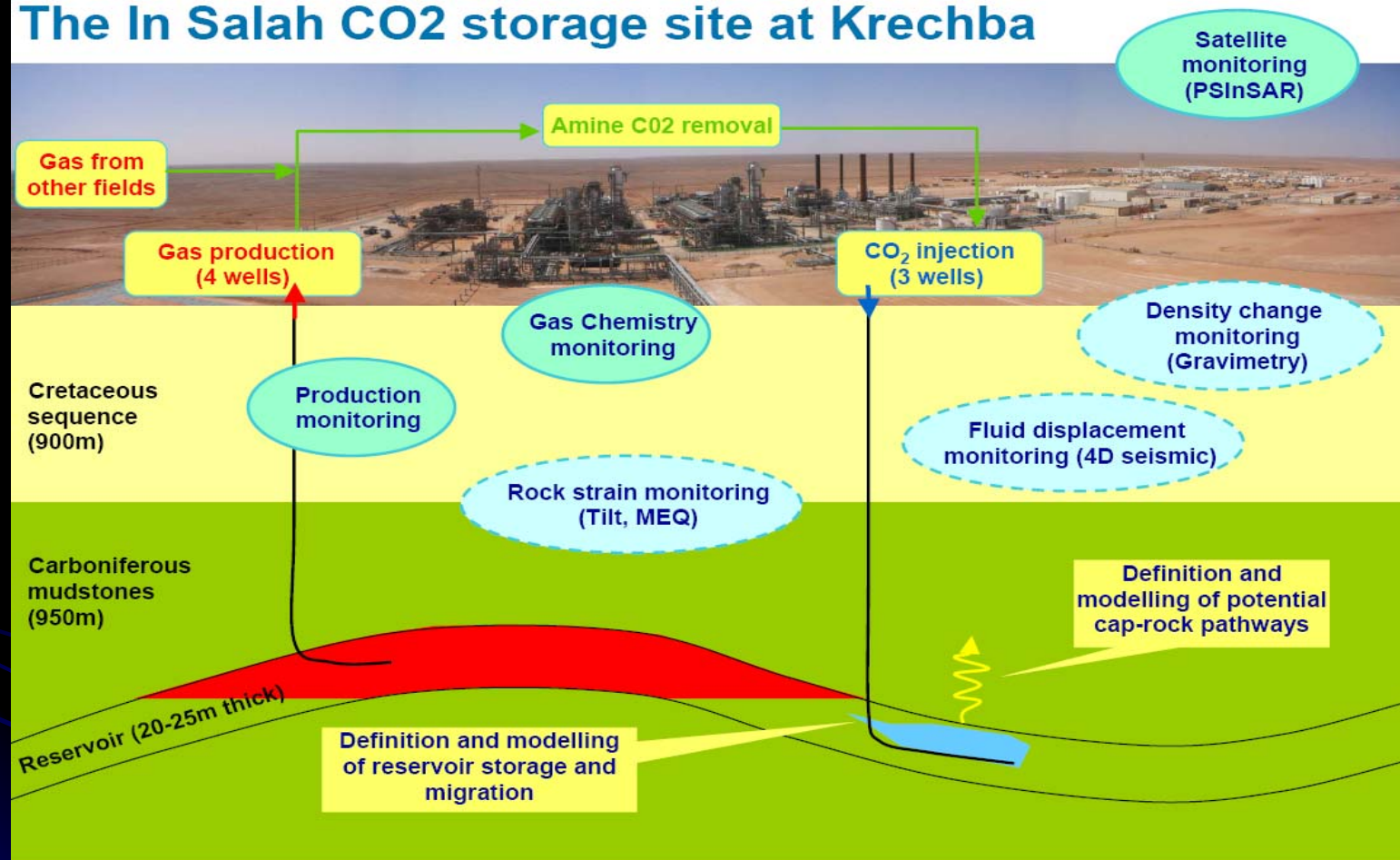
The related engineering apparatus for geological storage 相关工程设施

Compressors
platforms,
wells,
pipelines

The Sleipner field – CO₂ Treatment and Injection



The In Salah CO₂ storage site at Krechba



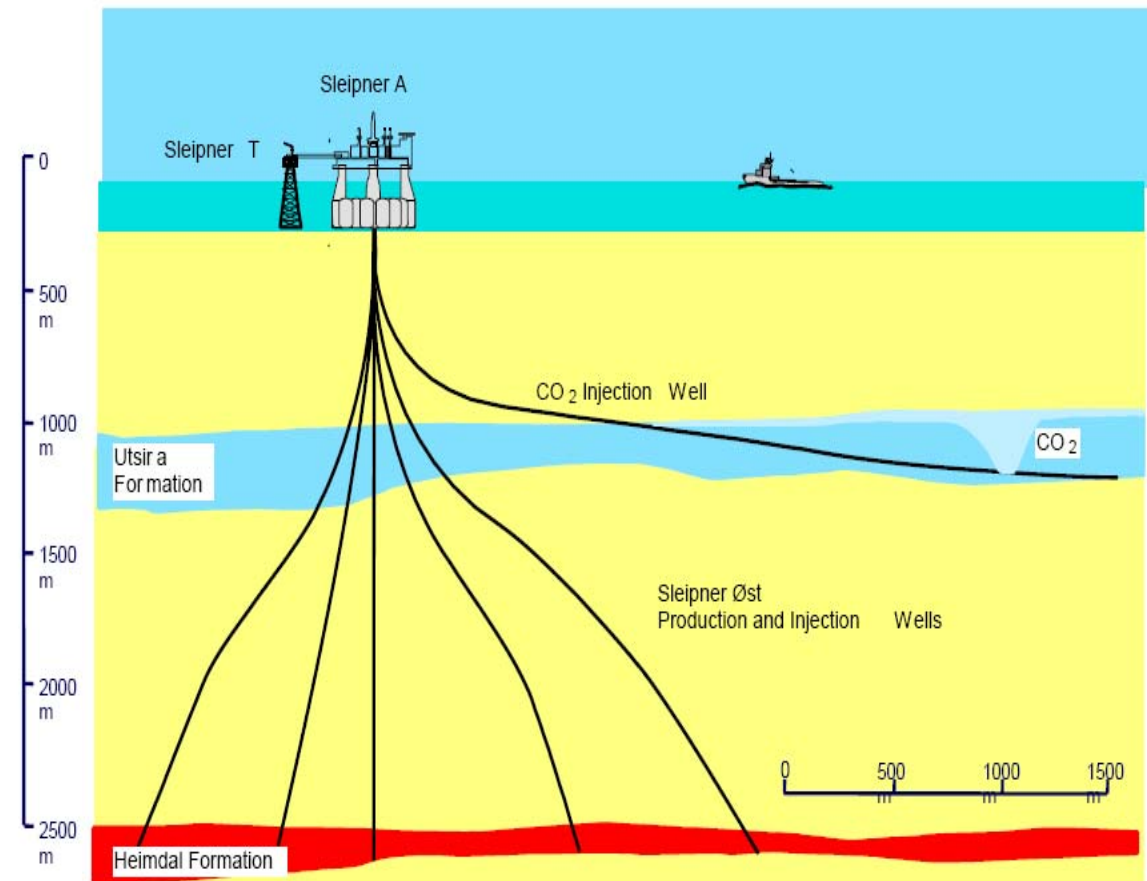
- On land system of CO₂ injection and storage
- 陆上的注入与封存系统

The Sleipner field – CO₂ Treatment and Injection



In sleipner, a platform was used for compressing and injecting the CO₂ back to the strata

- 在Sleipner, 利用一座海上平台完成CO₂的分离、压缩和注入回地下圈闭








Some types of platform





Wells are not only injection wells, but also some monitoring wells

Map of JIP Monitoring sites

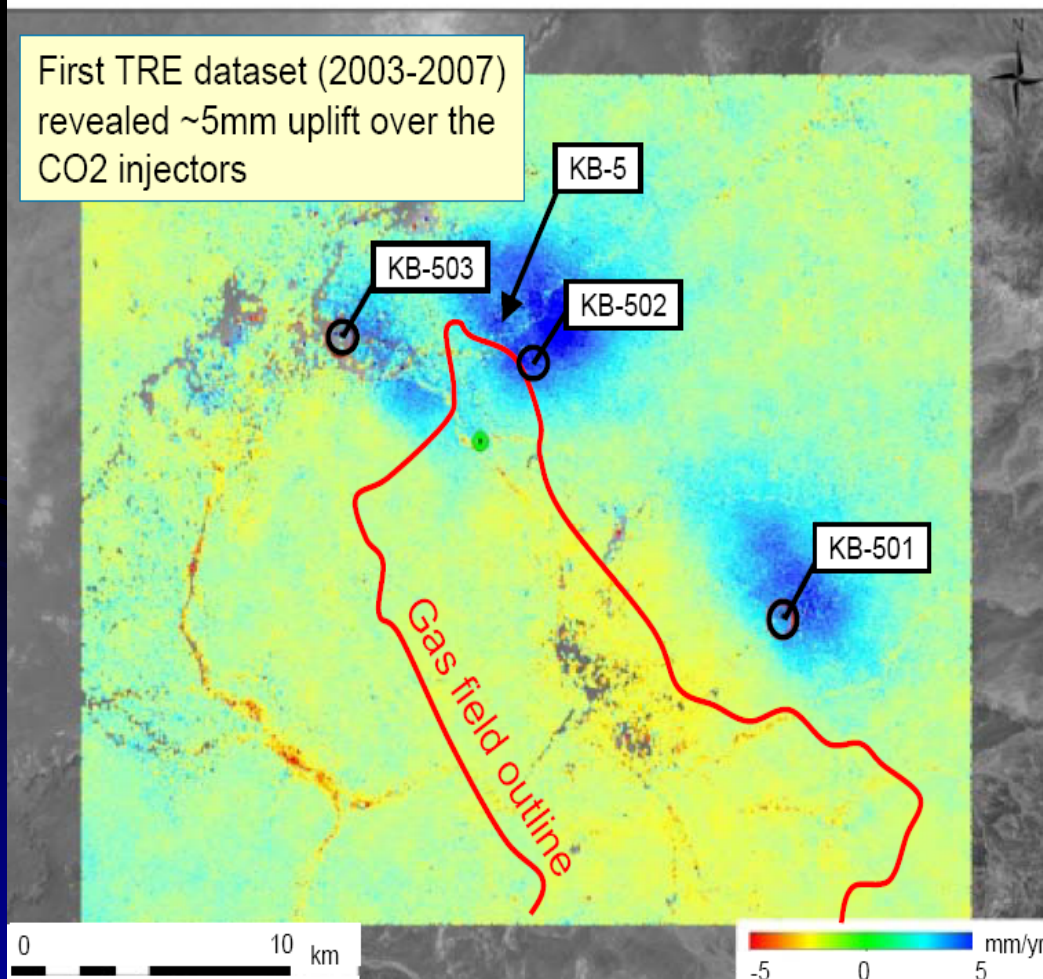
-  Microseismic Well
-  Aquifer Monitoring Well
-  CO₂ Injector
-  Barasol
-  Passive Gas Sensor

Tore A Torp, Dr.ing., 2009

Satellite Monitoring

Pioneering work by TRE and LBNL has demonstrated value of PSInSAR™ to record surface deformation related to subsurface injection:

- See Vasco et al. 2008 (Geophysics Journal, Vol. 73)



Ongoing monthly satellite surveys and surface calibration using tilt meters and DGPS (Pinnacle Technologies)



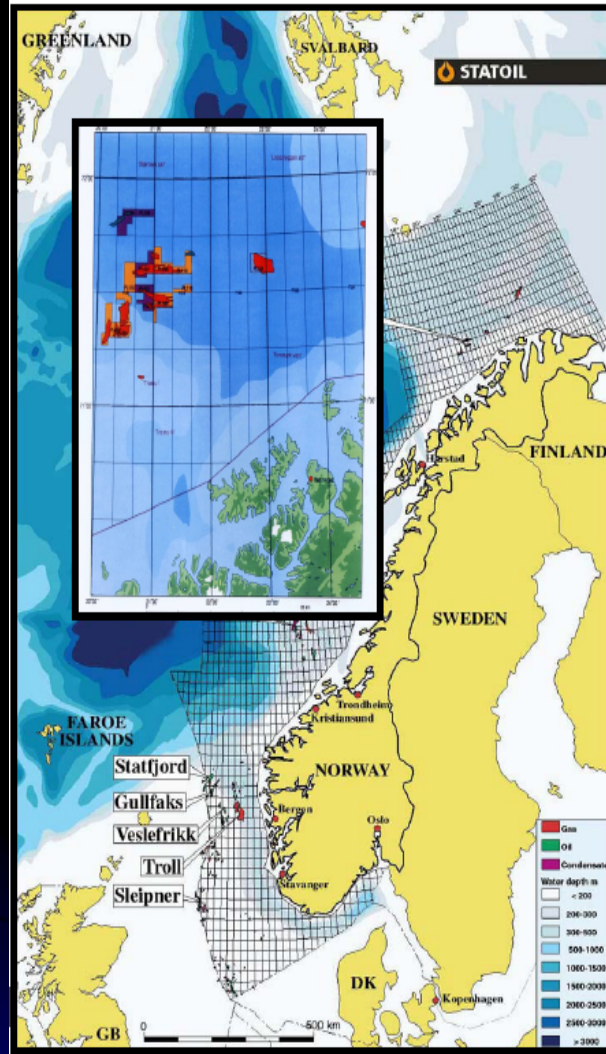
Tore A Torp, Dr.ing., 2009

Pipelines used in Snohvit

25

CO₂ transport

Snøhvit pipeline is 153 km with diameter of 0.2 m



Fields: Snøhvit, Albatross and Askeladd fields in the Barents Sea

Water depth: 250 – 340 m

Distance to shore: 140 km



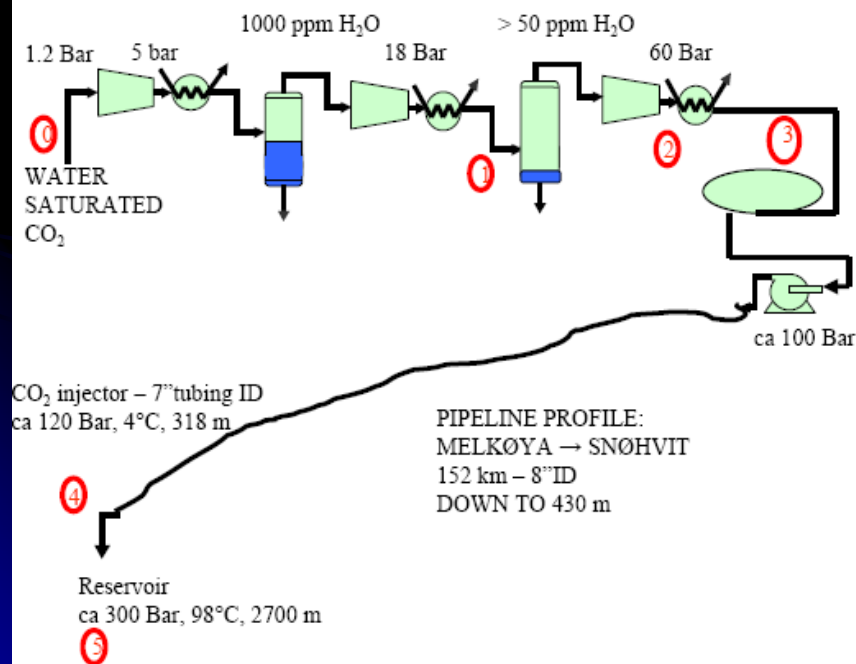
Tore A Torp, Dr.ing., 2009

Compressor and Pipelines used in Snohvit

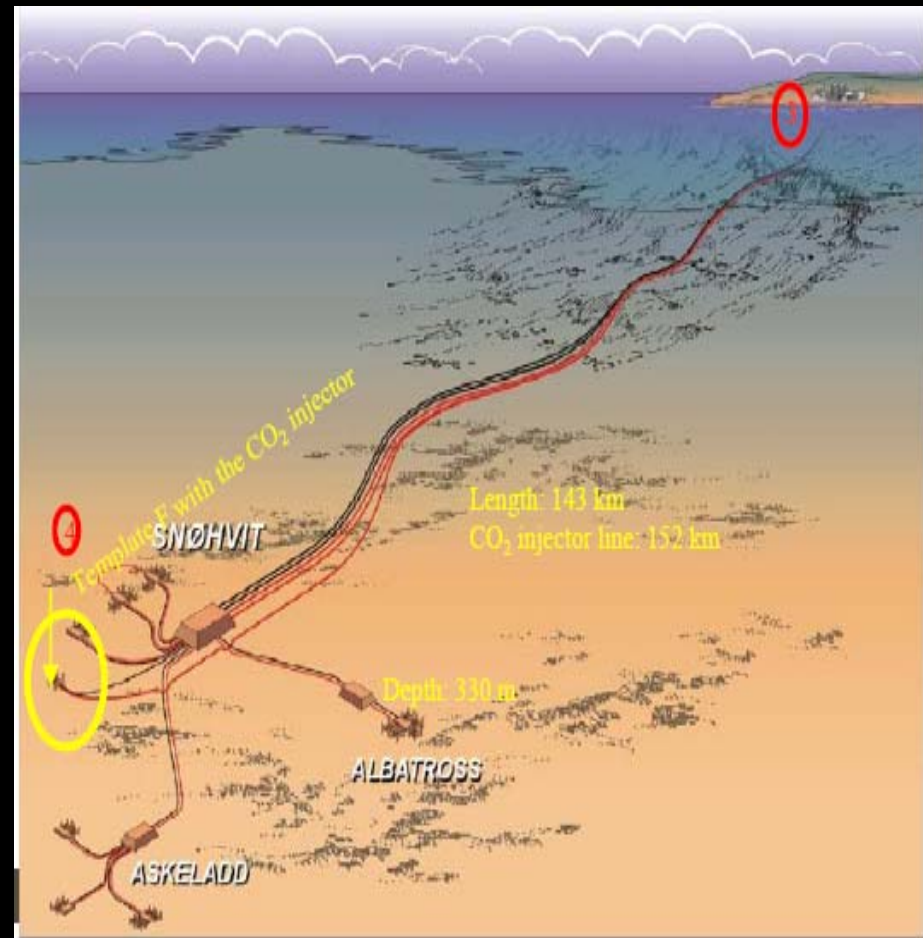
Snøhvit CO₂ injection

CO₂ phase diagram \Rightarrow

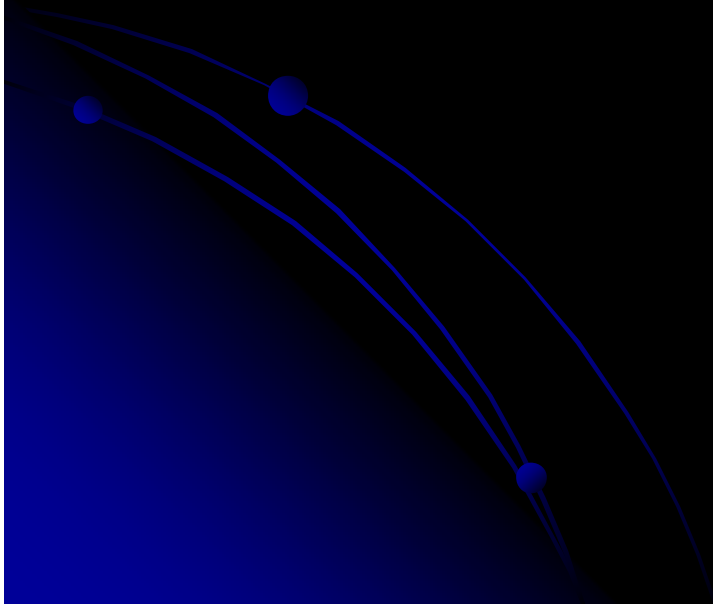
CO₂ injection system \Downarrow



Snohvit用到的压缩系统与管线



What's the next?



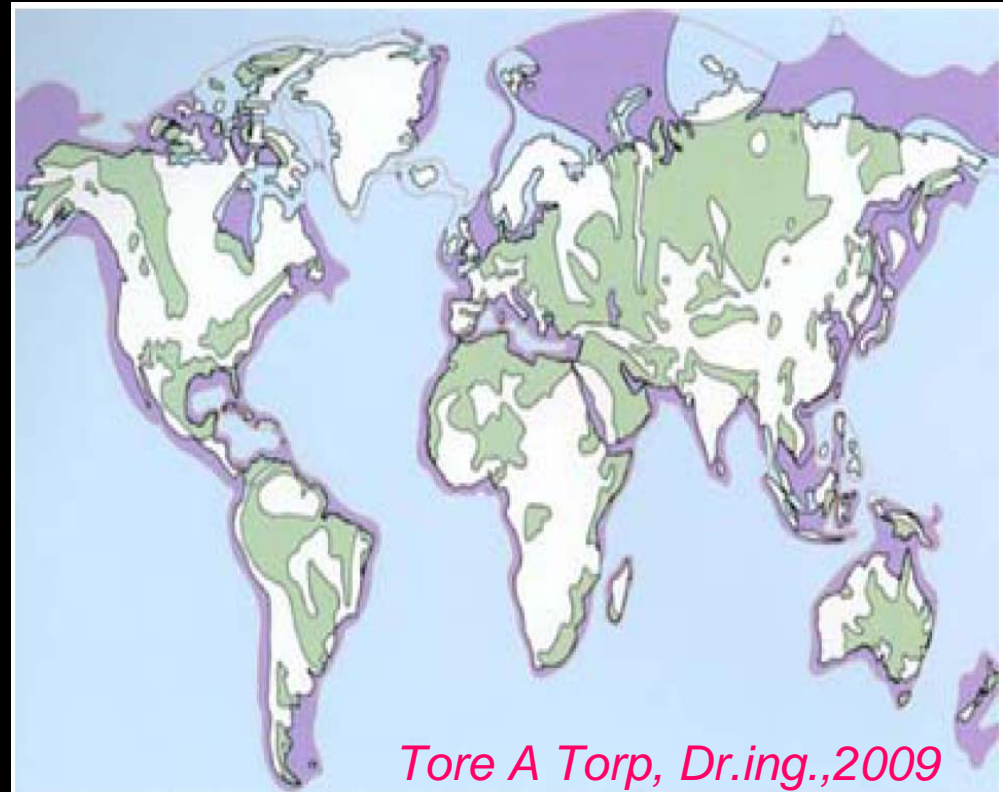
Worst case scenario
is business as usual!

Tore A Torp, Dr.ing., 2009

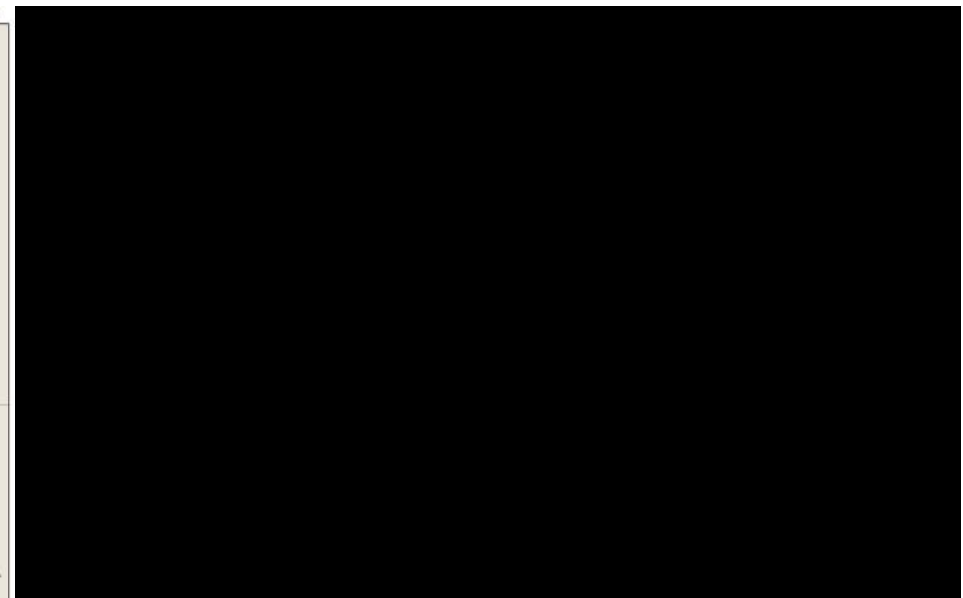
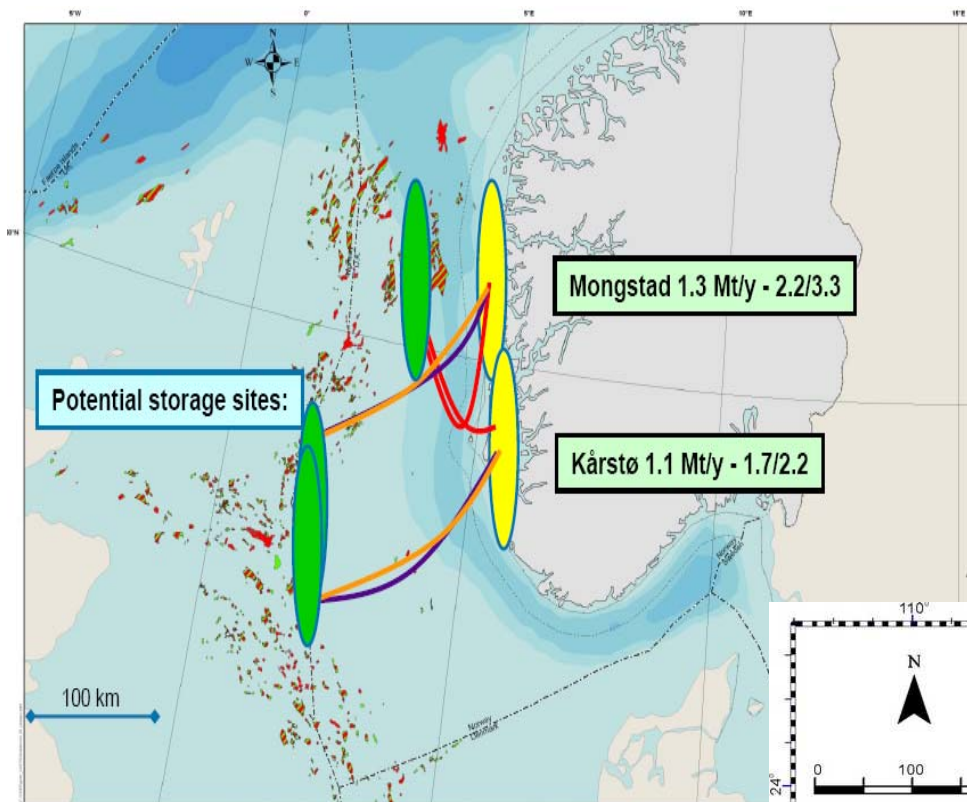
Need to get started now!

- Find more sites
for geological
storage

Development is
needed, but
decreasing the CO₂
is also necessary.

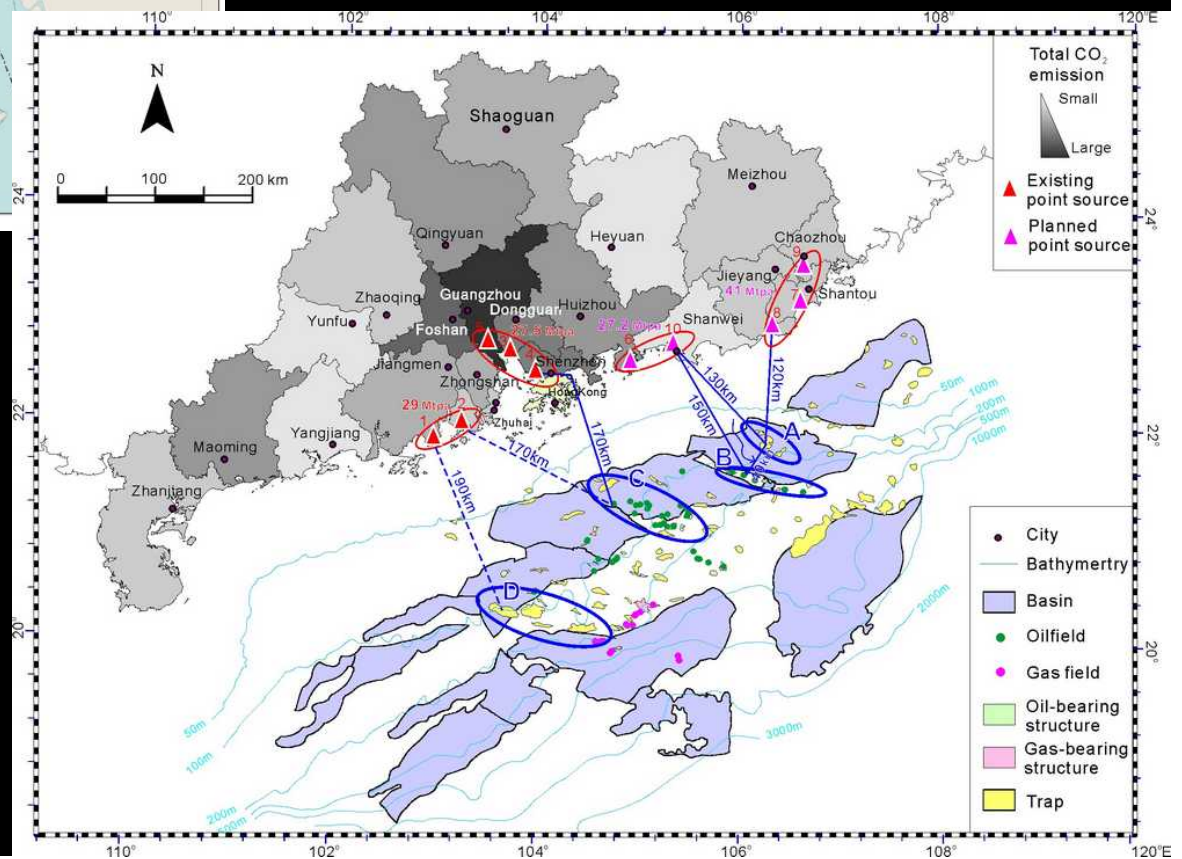


Tore A Torp, Dr.ing., 2009



Tore A Torp, Dr.ing., 2009

● Let's do it!



Enjoy your green time!

