Knowledge about CCS risk learnt from natural analogues

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Workshop on Confidence Building in the long-term effectiveness of Carbon Dioxide Capture and Geological Storage (SSGS) in Tokyo

Acknowledgement

- Part of this presentation is based on the METI funded international collaboration study for global environment
- Thanks to
  - METI
  - Collaborators
    - JPOWER
    - AIST
    - Waseda University
    - Lawrence Berkeley National Laboratory
    - Advisory board members

Contents of the presentation

- How natural analogues can help building confidence for CCS decision making (building confidence in long term effectiveness and safety).
- Our ongoing natural analogue study
- Promotion of international collaboration.

What is “Natural Analogue”?

- Natural phenomena or processes that are comparable to the industrial/technological processes, such as CCS.
- Useful to understand the physical/chemical process of
  - ►long-term phenomena for future forecast
  - ►wide scale and/or hazardous phenomena that can not be reproduced by the field tests
- Fill the gap, reduce unknowns and uncertainty about the fate of carbons injected to the geological formation
- Natural phenomena: Firm facts, information is open to public, people can review them

Characteristics of CO_2 leakage risk

- Risk = probability of the occurrence of the hazard * seriousness of the consequence
- Long-term phenomena (~1000 years), existence of unknowns, and high degree of uncertainty
  - Quantification of the risk is a quite hard job
- Relatively low impact
  - CO_2 is not toxic in low concentration
  - In terms of global environment, benefit (reduction of GHG emission) may overcome the risk
- … but, anxiety of the public may exist due to the high degree of uncertainty, unknowns
  - Operators, Government, and scientists should answer the question what we know and what we do not know

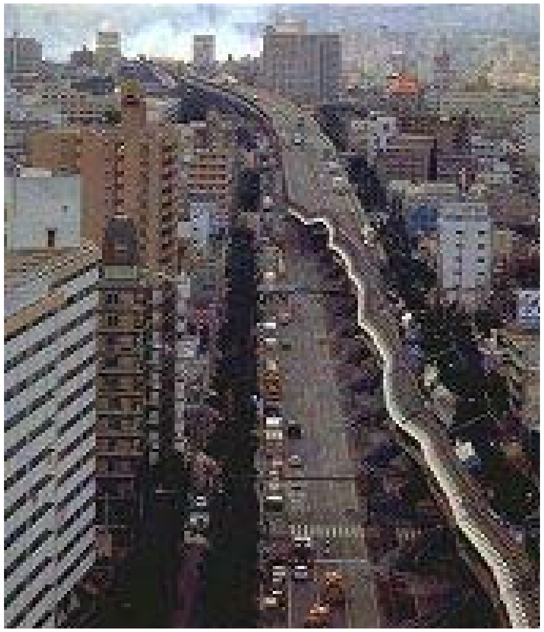
Natural risk and manmade risk

- Risk of a manmade system
  - Designer and operator should know the process of the hazard
  - Poor design, deviation from the rule, human factor, degradation of the system,…, cause the hazard
  - All of the process in the system “ought to be” under the control

Examples of “out of our control”

Natural risk and manmade risk

- Risk of a natural system
  - Broad unknowns and known uncertainty.
  - Basically, human being cannot control the hazard
  - Avoid the hazard to lower the probability of encounter
    - Leaving Tokyo to avoid earthquakes
  - Lower the seriousness with some countermeasure.
    - Apply the strict construction standard



Examples of survivor
and victims

CO_2 leakage risk is…

- Similar to the natural risks rather than manmade risk
  - CO2 is stored in natural geologic formation, not in steel container manufactured in a factory
  - Managing the once injected CO_2 is difficult
  - Intrinsic unknowns/uncertainty of the geological systems and uncertainty of the behavior of injected CO_2
  - Difficulty of the data acquisition, monitoring
  - Difficulty of the verification of models that are the design and future forecast tool

How to manage the risk?

- Minimize the probability: good site selection
  - Low probability of leakage
- Control the consequences:
  - Monitoring for early warning
  - Store in the low impact area
  - Remediation method (?)
- Reliable risk assessment and accepting the risk:
  - Risk must not be fatal, benefit should be higher than the expected risk
- Process of the leakage should be understood for any counter measures ⇐ Natural analogue

What we want to know from natural analogue?

- Stable storage and leakage, what makes difference?
- What is the dominant leakage pathways?
- What is the typical leakage pattern, spatially and temporally?
  - How wide the leakage area is?
  - How often the leakage event happen? How long does it last? How much is the leakage rate
- How CO_2 affect the fluid motion?
- How trapping mechanism work?
  - Mineralization, residual gas (capillary trapping), solubility trapping
- How geologic, geochemical, and geomechanical conditions influences the stability?
- How released CO_2 influences the human health and environment?

Different type of natural analogues

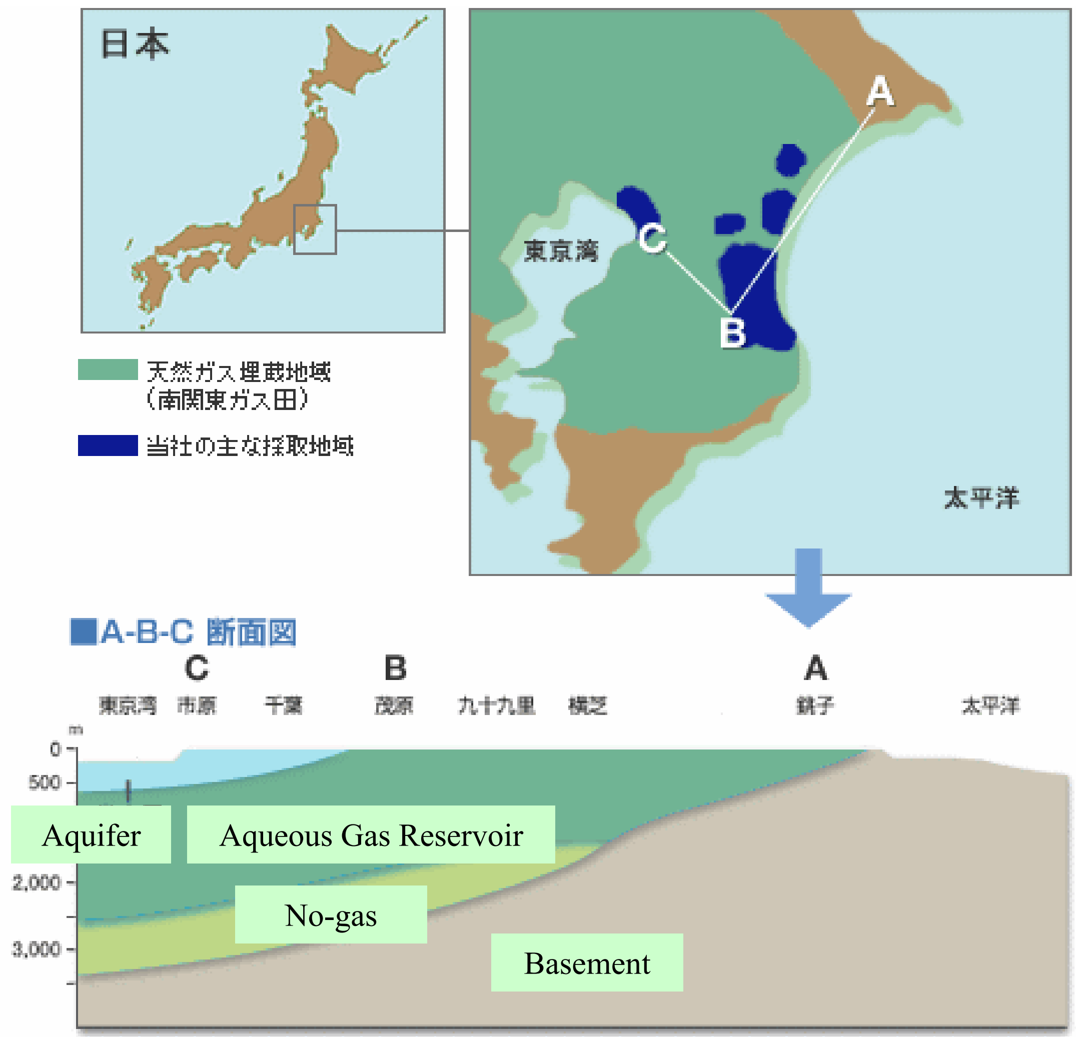
- Natural analogue of stable storage
  - Natural flammable gases and natural CO_2 fields
  - ⇒Conditions necessary for the stable storage
- Natural analogue of the leakage phenomena
  - Leaking gas reservoir and volcano-origin gas
  - ⇒Mechanism of the CO2 release
- Natural analogue of disasters and catastrophic release
  - Affect human health, local ecosystem, etc.
  - ⇒Impact of the CO2 release on the human health and eco-system

Natural CO_2 and other gas field

- Huge amount of hydrocarbon is stored in geologic formation in gas form stably (more than millions of years)
  - $437Tm^3$ (minable deposit)
  - Methane (major part of natural gas) is easier to be released (light, small molecule, gas phase in higher pressure)
  - Other huge amount of methane should exist sparsely in many geologic formation
- Natural CO_2 reservoirs
  - Commercially used for EOR, beverage, etc.
  - McElmo Dome, CO 1.6Gt
  - Pisgah Anticline, MS, 200Mt
  - ...
- Some leaking events
  - through natural pathways,
  - manmade pathways (wells, etc.)
  - influence the local ecosystem (in some cases positively)

Minami-Kanto gas field, Japan

- Reservoir is tertiary-quanternary laminated sediment of sandstone and mudstone
  - Monocline, no cap rock
  - Area ~ 3500 km^2
- Deposit of 375Gm^3 (270Mt) aqueous methane gas
  - Biogenic origin
  - Solubility trap
  - Effect of residual gas trapping ?
- Example of gas storage in non-structural shallow aquifer



Kanto Natural Gas Development
http://www.gasukai.co.jp/gas/maizou.html

Leakage phenomenon happened in Minami Kanto gas field

- Leaked natural gas from an aqueous methane gas field blasted a museum building, and killed one person.

Woman killed in museum explosion

The Asahi Shimbun

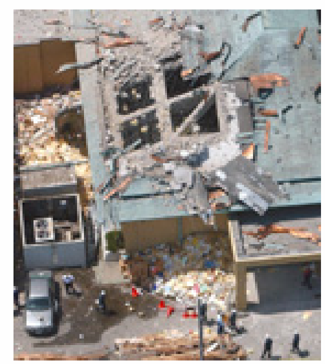
(Asahi Shimbun. July 31, 2004)

A colleague is critically injured with burns to 90% of his body.

KUJUKURI, Chiba Prefecture–A woman curator was killed and a colleague critically injured Friday in an explosion at a municipal museum here hailing the local sardine industry, police officials said.

Temporary workers Seiko Nagata, 66, and Hideomi Kawashima, 63, arrived at the Kujukuri Iwashi Hakubutsukan, or sardine museum, at 8:30 a.m. to open shop by 9 a.m., police said.

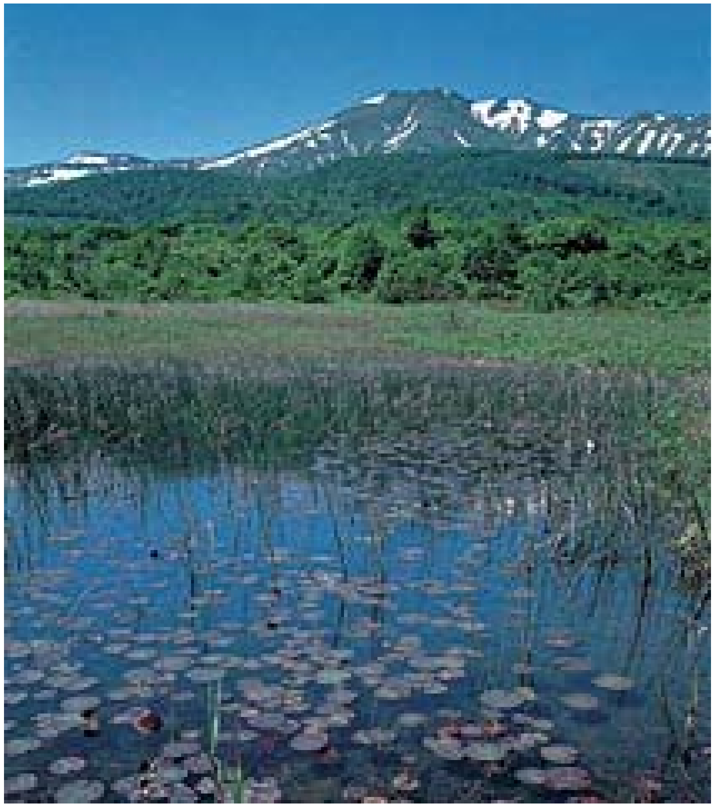
After the blast, which witnesses likened to an earthquake, Nagata was pulled from the rubble.



Firefighters at the scene of the explosion at the sardine museum in Kujukuri, Chiba Prefecture, on Friday

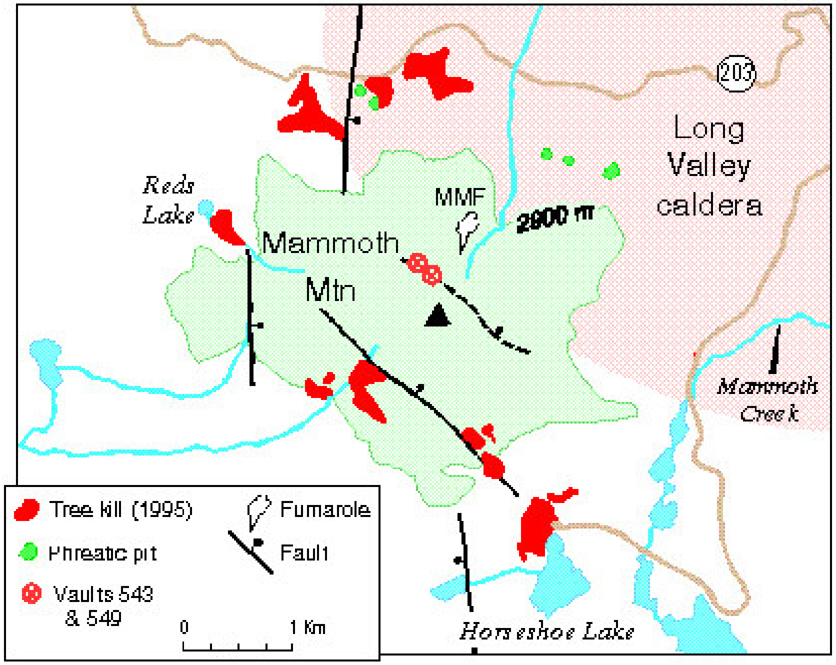
Hakkouda Mt., Japan

- 3 soldiers were killed in a small concave by high concentration CO2 (1997)
- Concentration is 15-20% (next day)
- Effect of the small amount highly concentrated gas release, effect of the topography



Mammoth Mt., CA

- Volcanic origin CO_2 was released after the earthquake swarm
  - Tree kills, some skiers have been overwhelmed in snow pits
  - Flux is depleting but still high
  - Analogue of the leaking faults, impact on the local ecosystem and human health

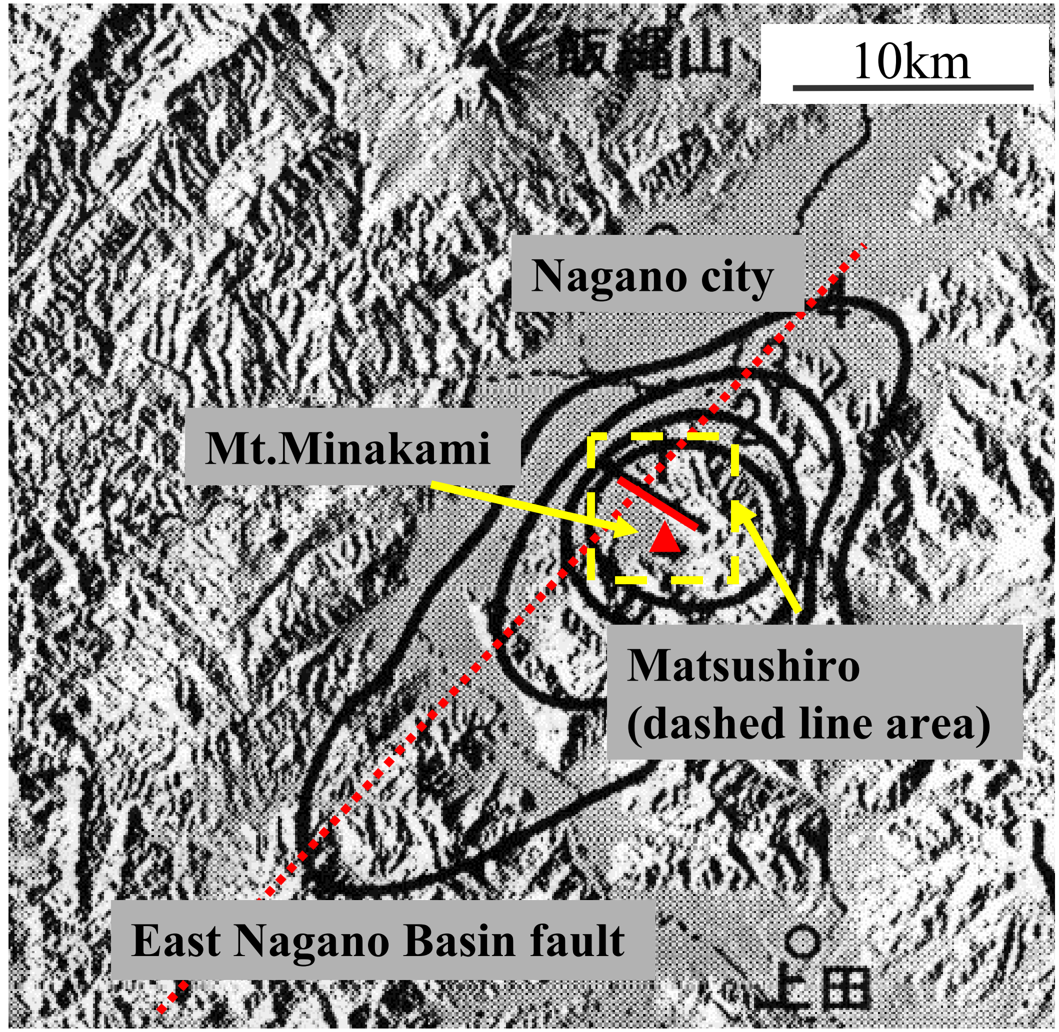


Catastrophic release cases

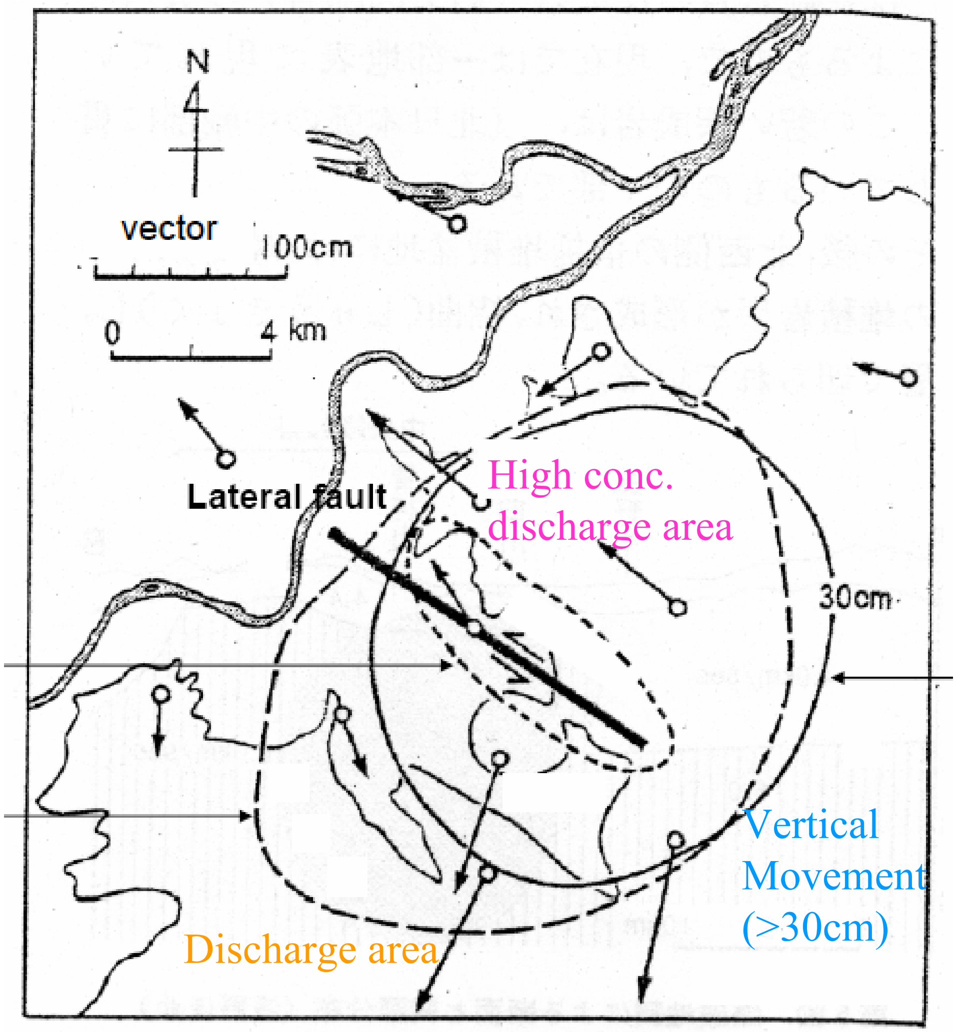
- Lake Nyos, Cameroon
  - Tropical crater lake
  - Sudden relase from the bottom of the lake killed 37 in 1984 and 1700 in 1985 (volume is 1.24MMton)
  - Mehcanism is not comparable to geological storage
- Dieng, Indonasia
  - 1979, rapid release associated with phreatic eruption due to the fracture opening caused by pressure buildup before the eruption
  - 200kton CO2 is released rapidly and 142 people were killed
  - Similar incident happened in 1940's
- Analogue of post release CO_2 behavior and impact

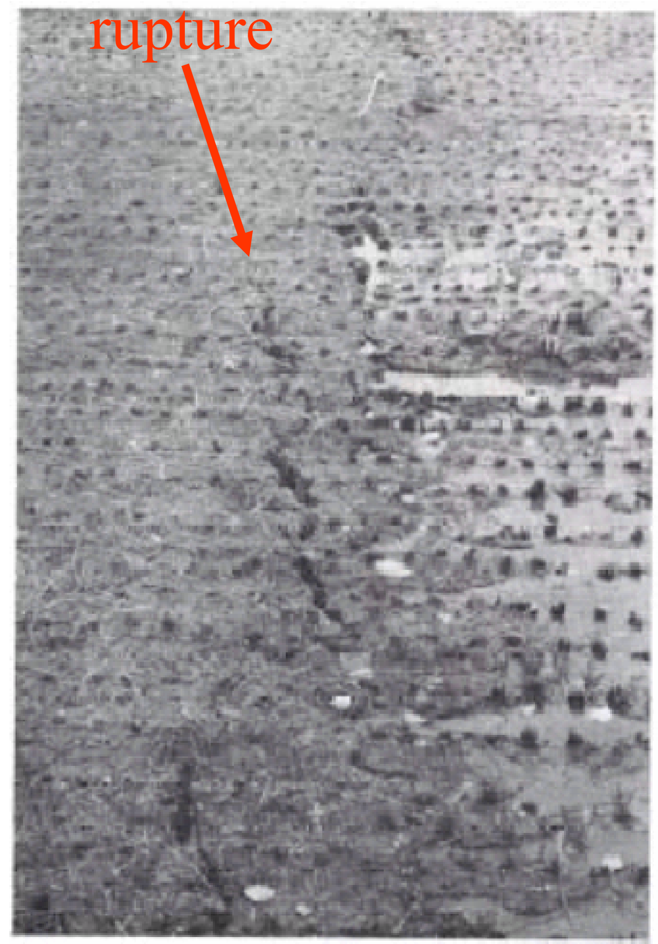
Matsushiro Earthquake Swarm (1965-1967)

- 60,000 earthquakes were felt and additional 600,000 unfelt tremors were recorded during five-year period (JMA,1968)
- During the swarm, ten million tons of CO_2 bearing water discharged at the surface through newly created surface ruptures in a short period (several months)
  - ► Estimated mass of CO_2 ... Some hundreds thousand of tons
- Impact on human health, ecosystem, is not reported
- Lessons of
  - ► Leakage from reactivated fault (opened fault by pressure change)
  - ► Relatively rapid cease of the leakage
  - ► Slight long term phenomena (40 years from the earthquake, what has been changed?)
  - ► Low impact phenomena



Location: suburb of Nagano city
Land use: agricultural, residential
Geology: NE-SW major reverse fault and conjugated strike-slip fault
fan sediment(surface), volcanic rock(basement), lava dome

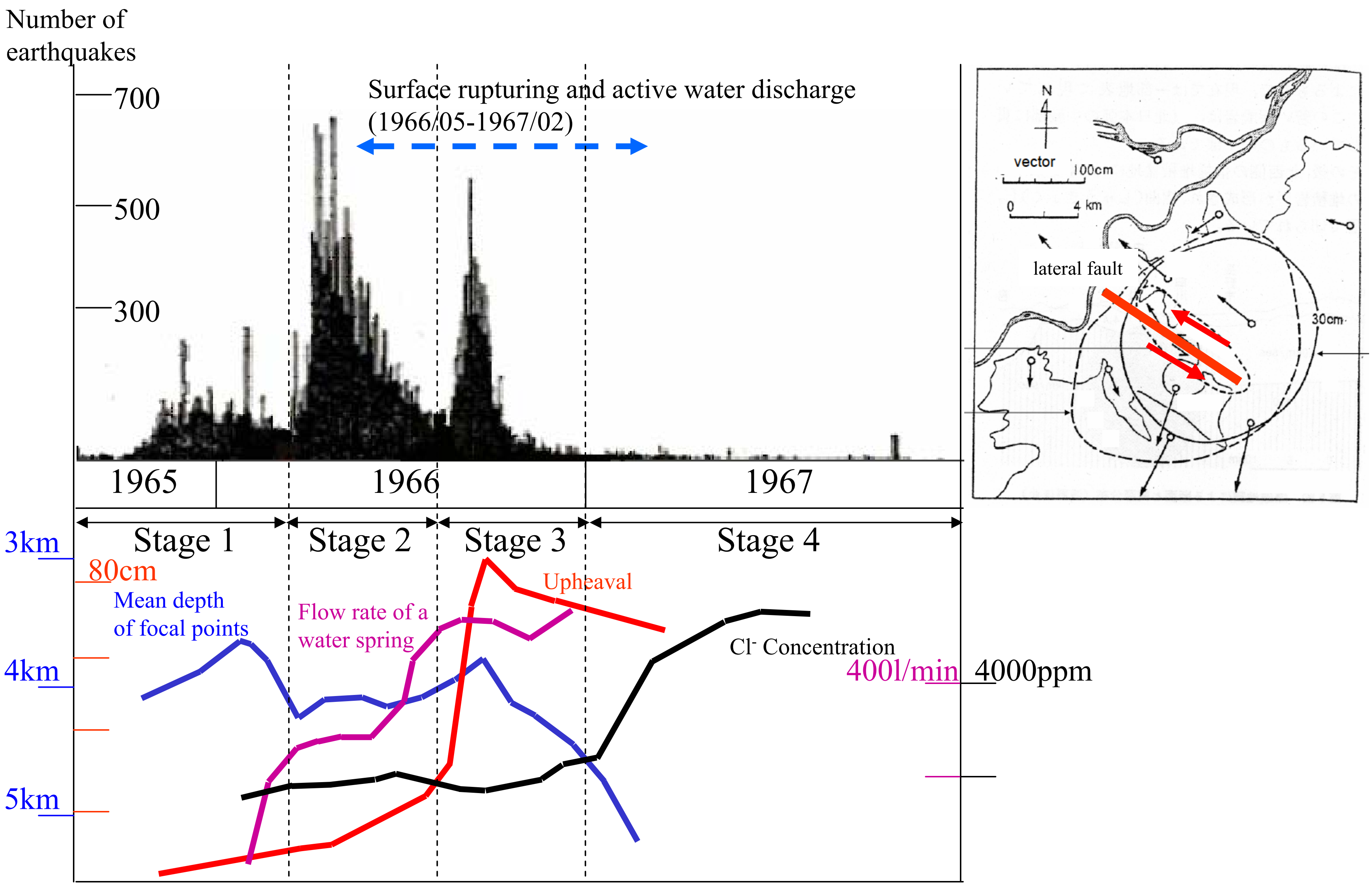




Nakamura(1971)

One probable cause of the swarm:

- water intrusion from great depth
- dilatancy reactivated the fault system



Time series change of seismicity, uplift, spring discharge, and salinity (1965-1967). (After JMA 1968, Tsukahara and Yoshida 2005)

Our study

Geochemistry

Supply of CO_2 bearing water from deep formations

Dissolution of carbonate cap by increased acidity

Pore pressure increment and reactivation of faults (enhancement of permeability and earthquakes)

Degassing from water

Creation of Carbonate cap

Fluid pressure release due to outflow, degassing and dilatancy of faults

Stabilization (current state)

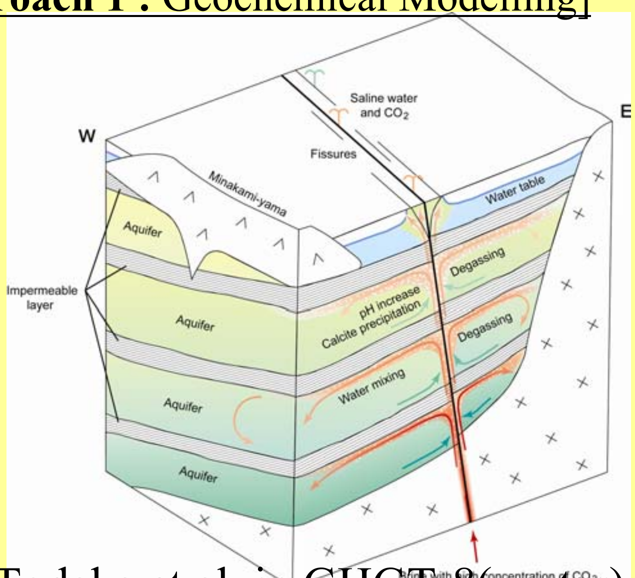
Geomechanics

[Approach 3 : Geochemical survey]

-Soil gas concentration

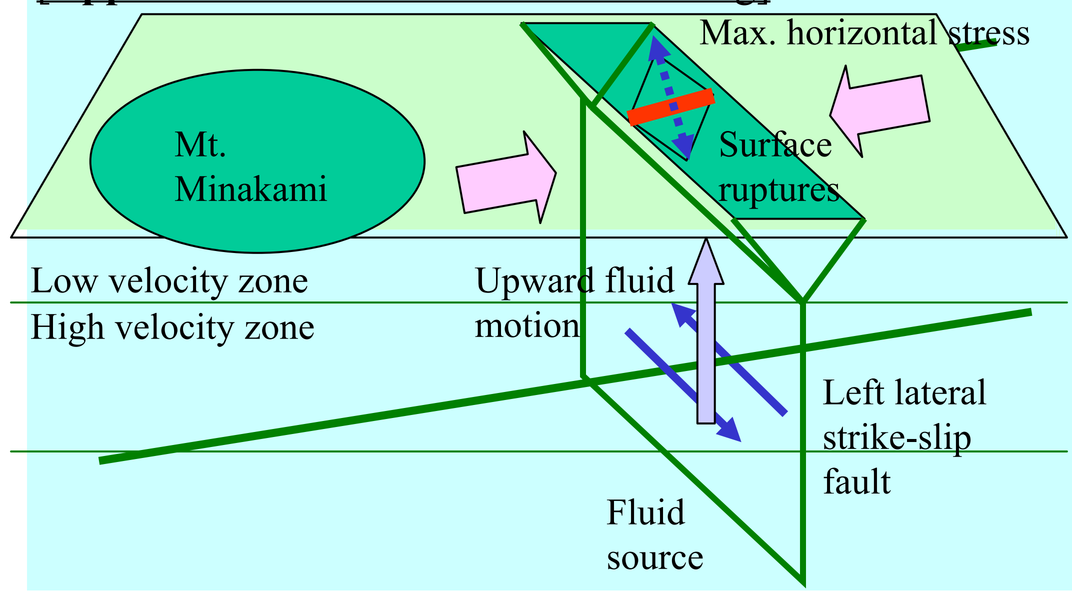
-CO2 flux

[Approach 1 : Geochemical Modelling]



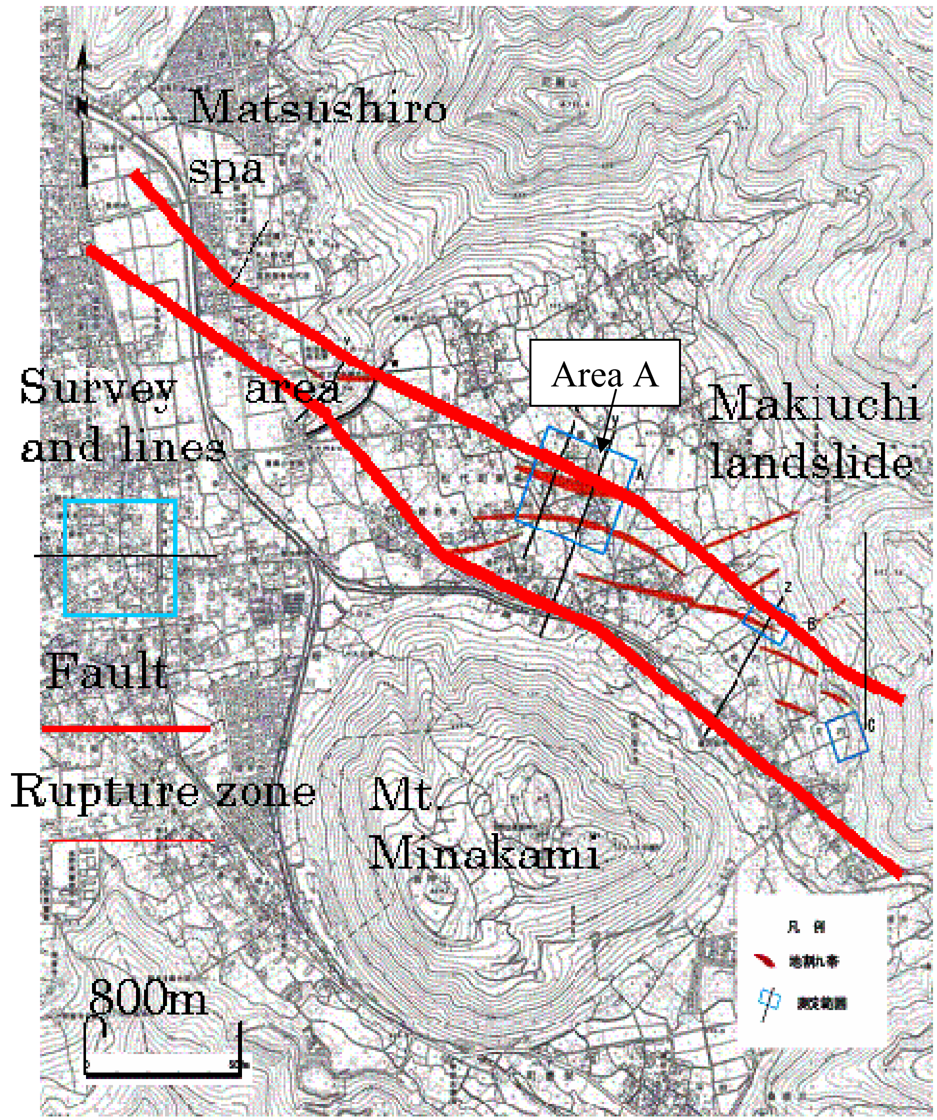
See Todaka et al. in GHGT-8(poster)

[Approach 2 : Geomechanical Modelling]



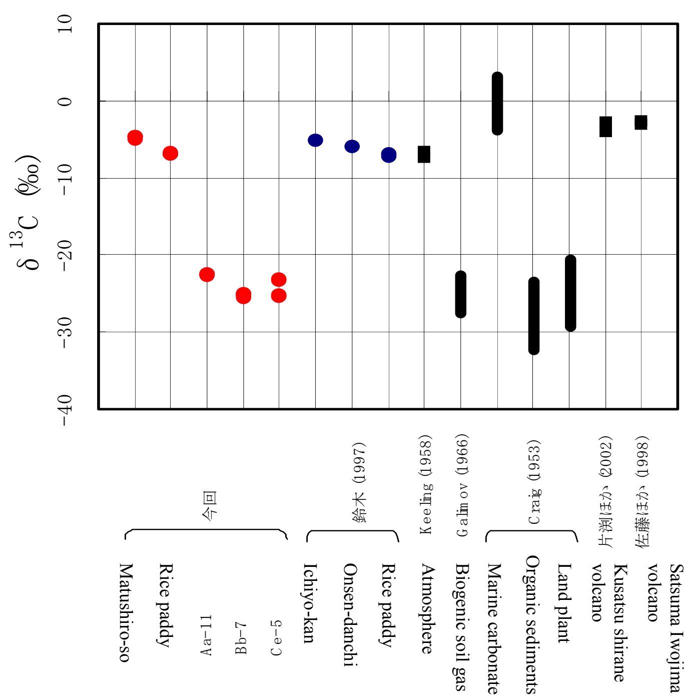
Geochemical Surveys

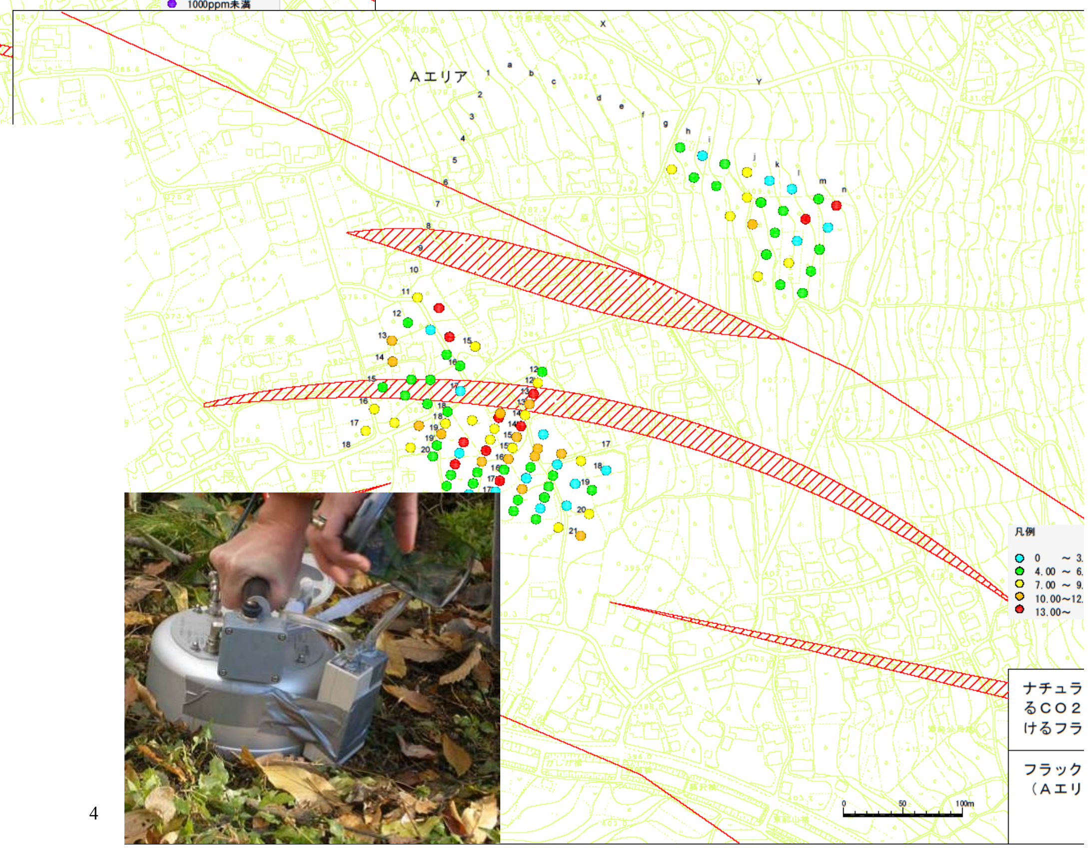
- New soil gas and CO_2 flux measurements along the fault line conducted in 2005
- $^{12}C/^{13}C$ ratio analysis of CO_2 including spa water
- Vertical distribution of CO_2 will be measured by resistivity measurement and boring in 2006



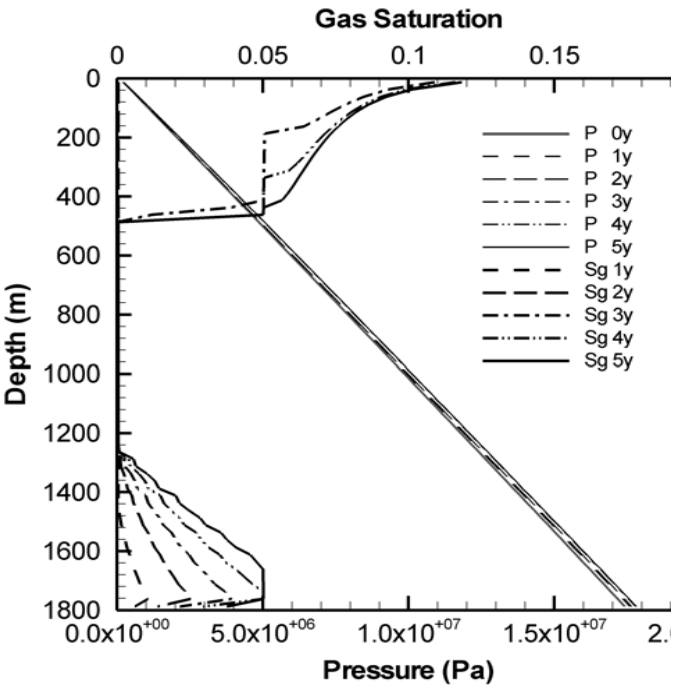
Soil gas and flux measurement

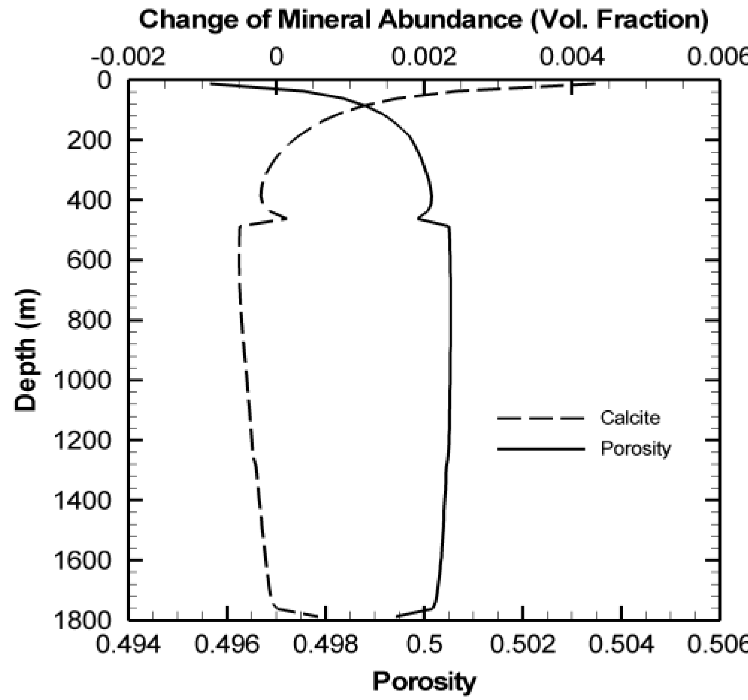
Understand the current condition (40 years, slight long-term phenomena)





Drilling, borehole logging and water sampling



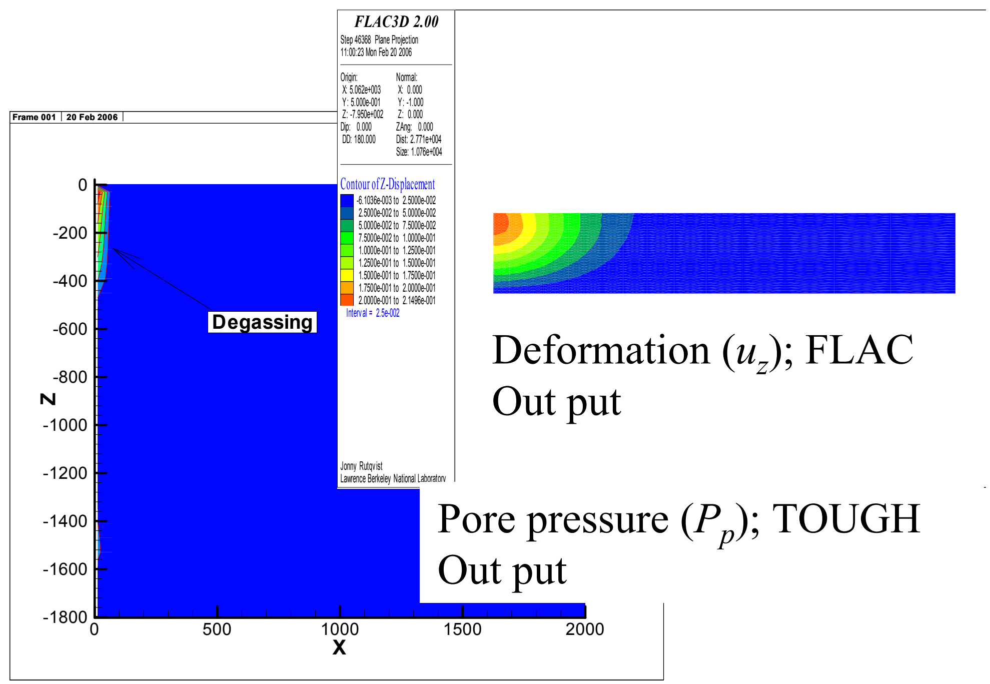


Verification of theory

Numerical modelling

Chemical coupling simulator -> precipitation of carbonate and permeability change

Mechanical coupled simulator => Effect on the fault, dynamic change of rock physics parameter



Deformation (u_z); FLAC Out put

Pore pressure (P_p); TOUGH Out put

Major findings from Matsushiro (tentative)

- Obvious example of the leakage through fault
  - Ground water intrusion into the fault may cause the earthquake
  - Did CO_2 play any role? Not clear so far
- Geology and Hydrology of shallow depth have significant effect
  - Currently very low flux on the surface, but deep origin CO_2 still exist in underground
  - Dilution and flushing reduce the concentrated leakage
  - Shallow water affect the precipitation and dissolution of the carbonate in pore space that can seal the leakage pathways

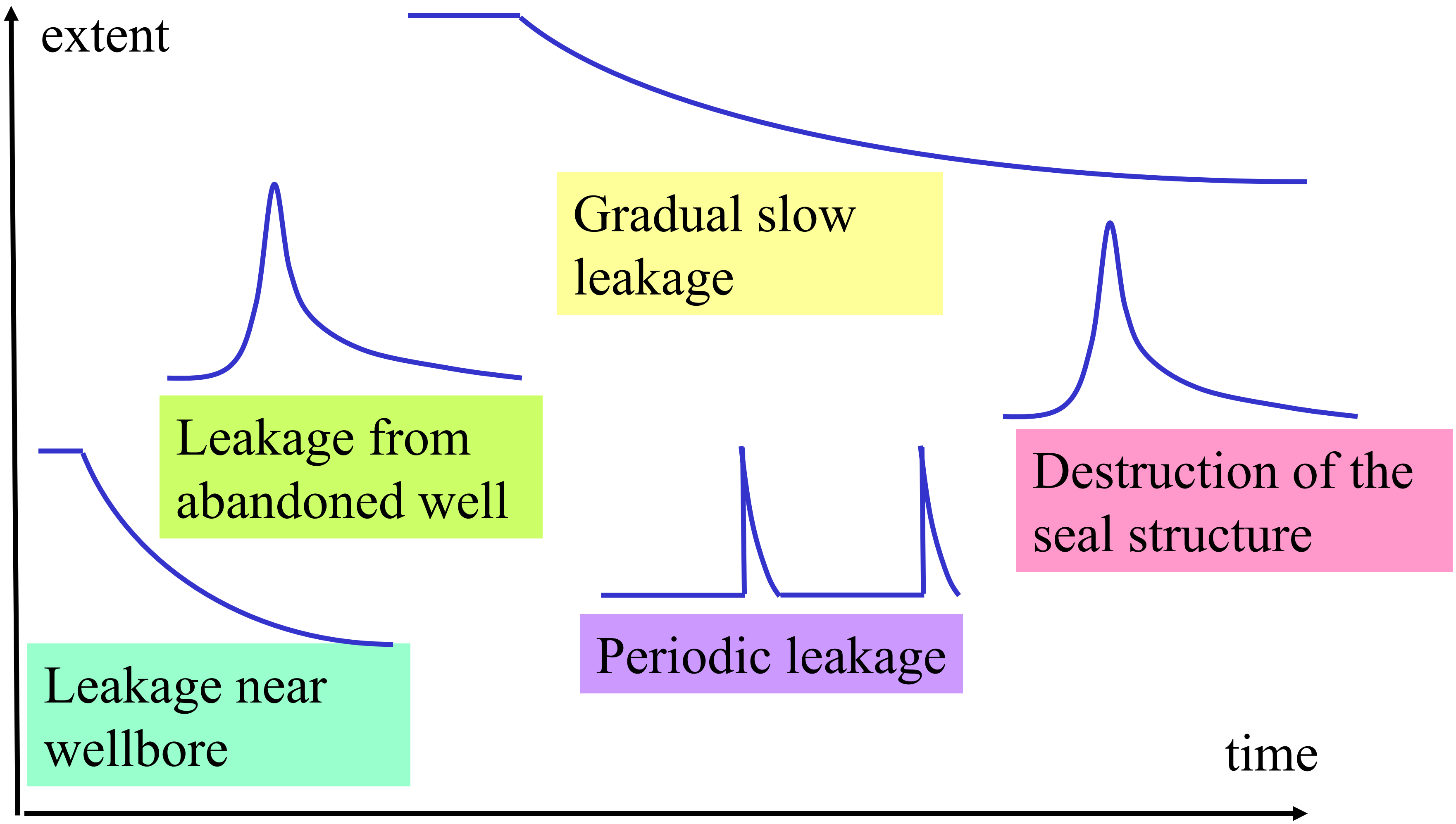
What learnt from the natural analogues

- Various spatial and temporal pattern of the leakages-
- Leakage pathway is highly affected by the heterogeneity and would be localized
- Fluid motion is basically very slow phenomena. Rapid phenomena are related to the destruction of the seal structure such as earthquake, volcanic, etc.
- Phenomena is dynamic; temporal change of leakage rate
- Impact is highly dependent on the surface/shallow conditions

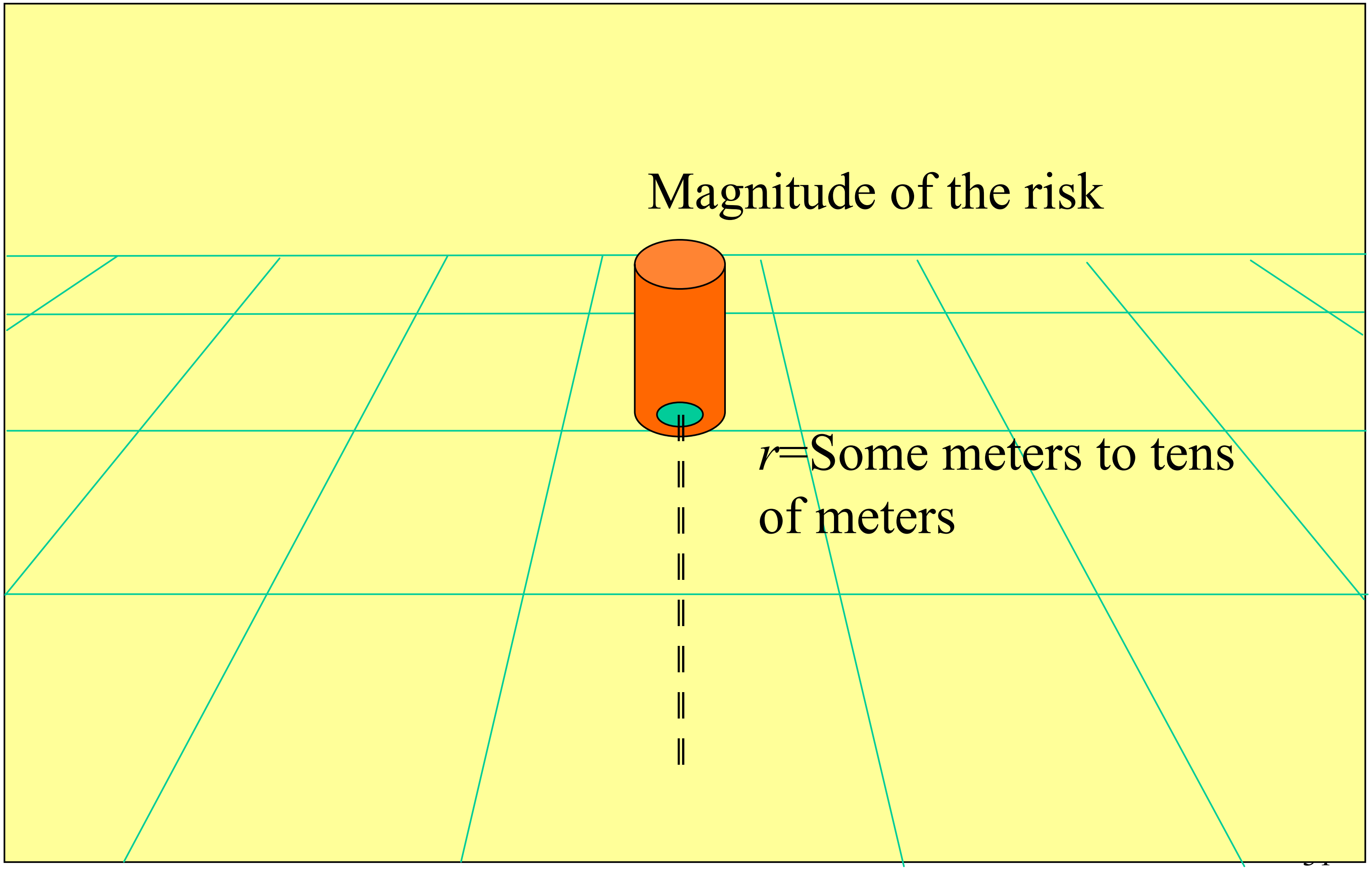
Type and pattern of the leakage

- Gradual, low rate, continuous, and spatially broad extent leakage
  - Total volume is huge in long duration
  - Damage the effectiveness of CCS as the GHG emission reduction
- Rapid, high rate, and spatially concentrated leakage
  - Impact on human health, safety, environment

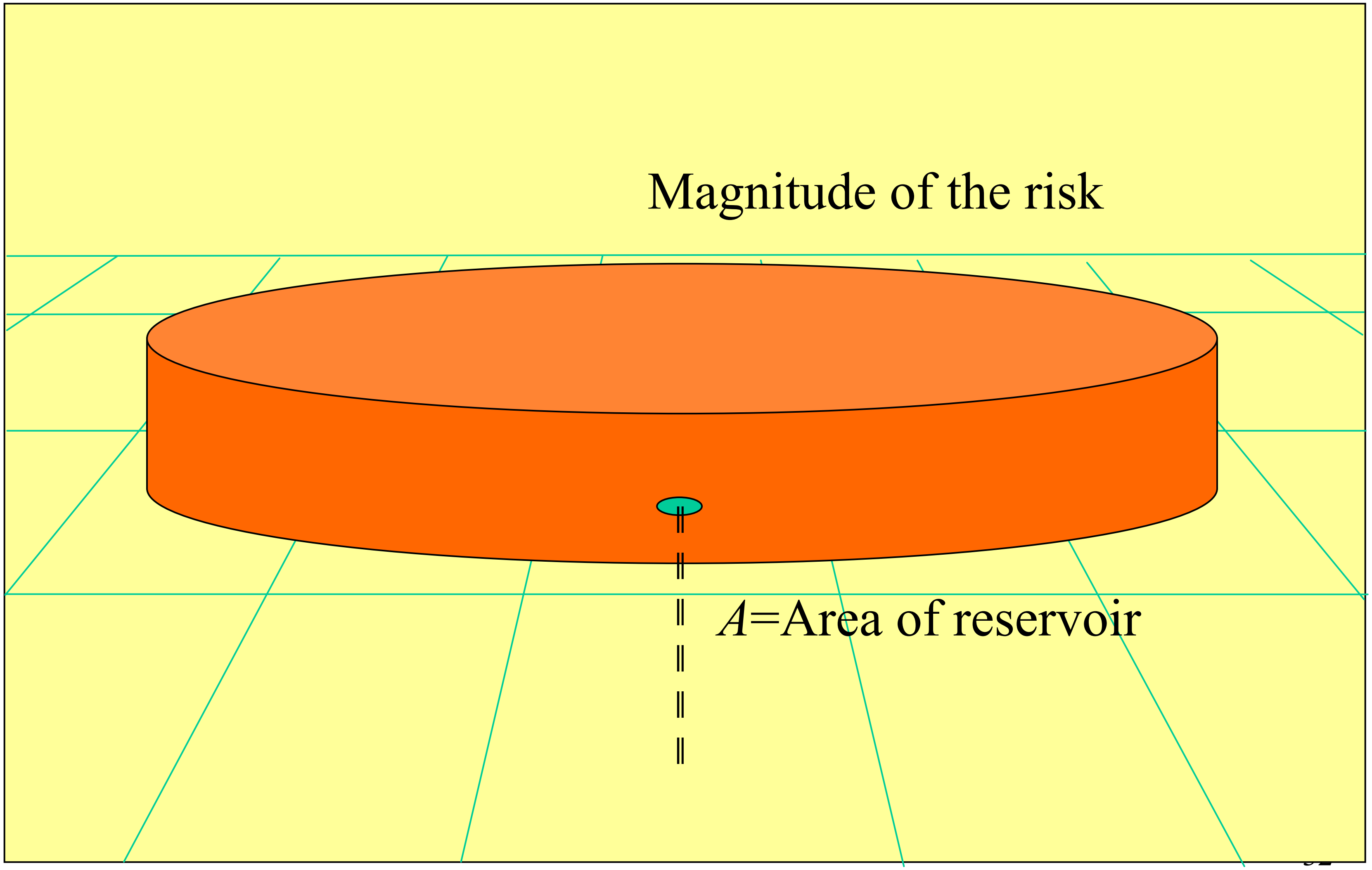
Different spatial and temporal variation of the leakage



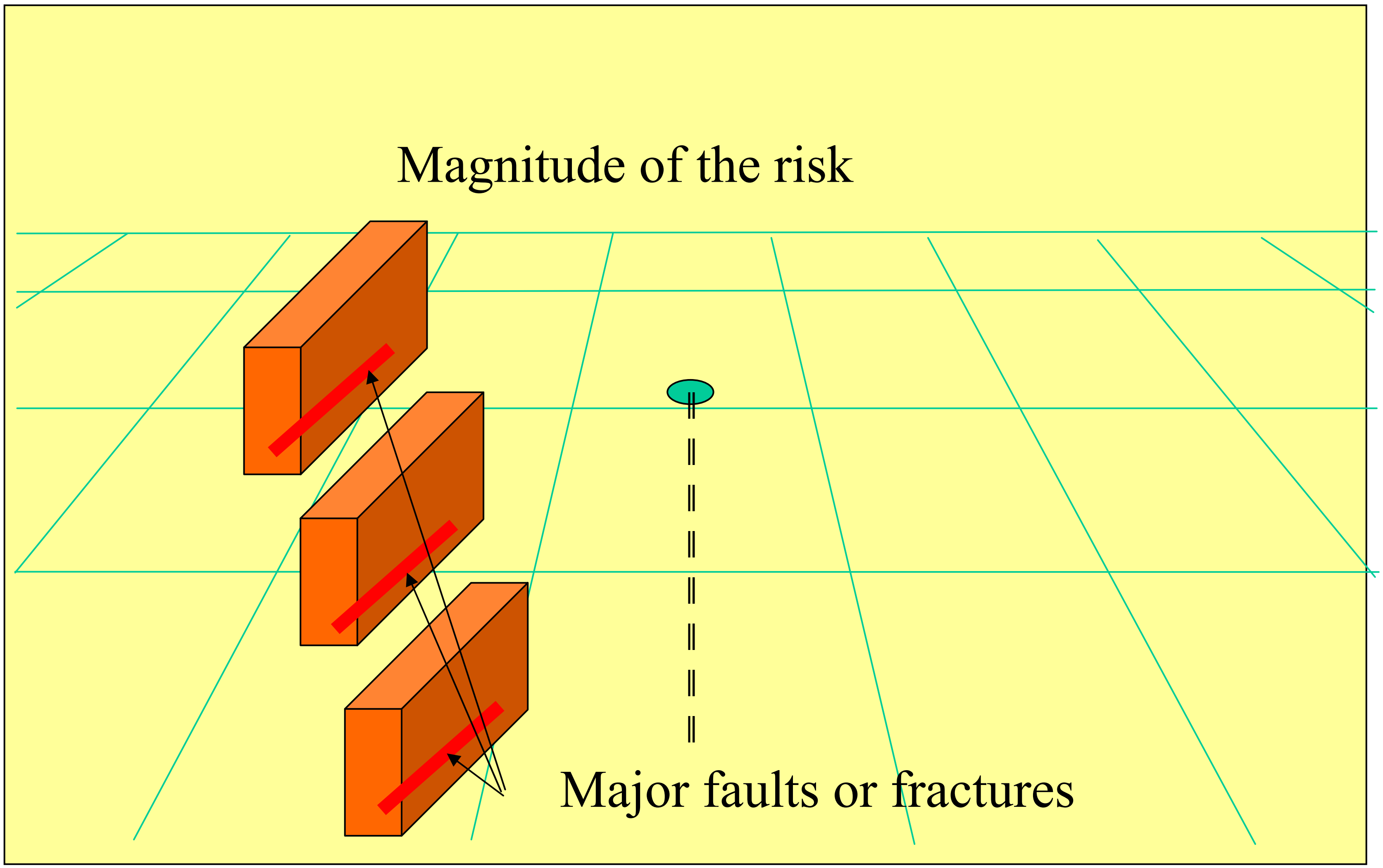
Spatial: near wellbore



Broad extent



Distinct leak pathways



From the science to engineering: Natural analogue as a design tool of the management

Condition of natural analogue sites

Factors X Y Z ….

-Site A … …. ….

-Site B … …. ….

-Site C … …. ….

Probability and consequence of natural analogue sites

Temp. Spat. Extent, Impact

-Site A … …. ….

-Site B … …. ….

-Site C … …. ….

Condition of CCS site

Factors X Y Z ….

Expected probability and consequences

Risk management options

For risk interpretation and management

Risk matrix of the CO2 leakage events based on natural analogue (if site is in the same condition…)

Consequence

Probability

	Detectable but no effects on human health and environment	Anxiety, discomfort, impact on env. recoverable in short time	Damage on human health and life, long-term impact on env.	Massive loss of life, unrecoverable change of eco-system
Likely	Prevention measures or design change to		Not allowable (abort the project)	
Slight likely	Monitoring, damage reduction measures			
Possible	Acceptable with monitoring of leakage			
Not likely	Acceptable without any countermeasures			

Condition of nmoth Mt.

Condition of Dieng

Condition of Matsushiro

Natural gas reservoirs

Conclusion

- Natural analogue is the strong method to understand the nature of the gas leakage phenomena
  - Controlled condition> Laboratory, field tests
  - Facing complexity of the mother nature > Natural analogue
- Natural analogue helps to reduce the unknown and degree of uncertainty of the fate of injected CO2
- Natural analogue study can give the idea and fundamental knowledge of the risk assessment and management.
- Good risk communication/education tool to show what we know, what we do not know => Strong support for confidence building