Basin analysis and Prediction of the development of anomalous fluid pressure at depths in the Western Foothills of Taiwan

Wataru Tanikawa, Toshihiko Shimamoto (Kyoto University in Japan)
Wheng-Kung Wey, Wei-Yu Wu (Chinese Petroleum Corporation)
Ching-Weei Lin, Wen-Chi Lai (Cheng-Kong University in Taiwan)
Wei-Min Donald Chen, Jih-Hao Hung (National Central University in Taiwan)

PURPOSE

Estimation to hydraulic properties

→permeability structure / porosity distribution / specific storage

at the depth of the Western Foothills in Taiwan

→sedimentary basin / focal area / accretionary prism

by the way of surface samples and laboratory result!

INPORTANCE

① Application for

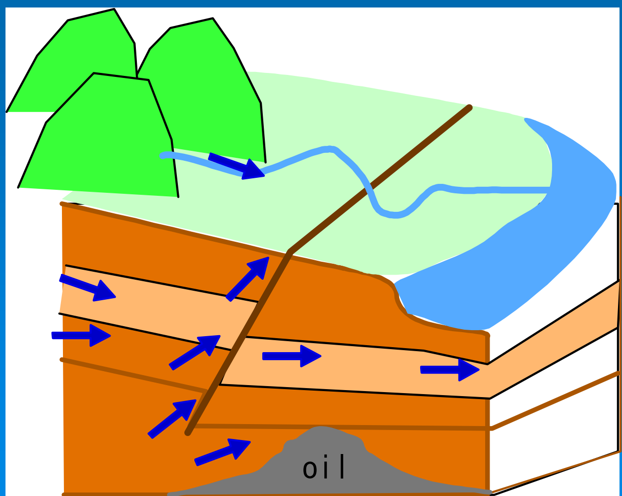
⇒fluid / oil transport system of the basin / fault zone at depth

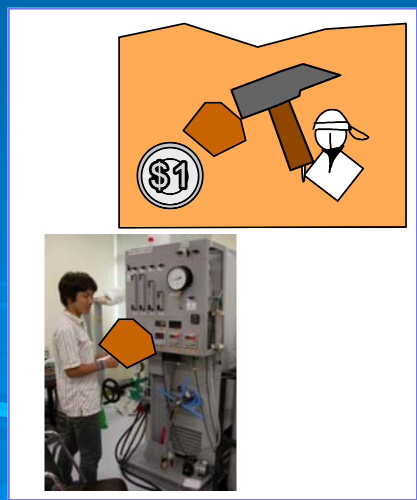
⇒fault mechanism (ex. Thermal pressurization)

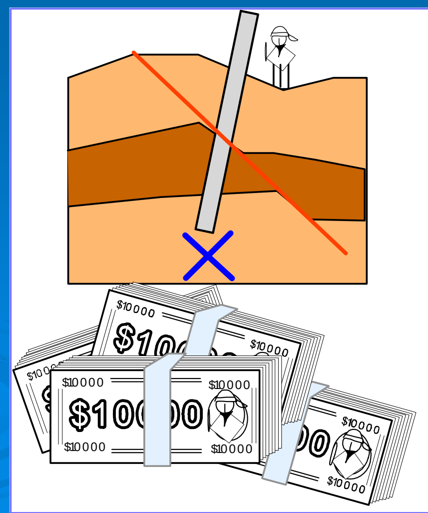
② Help borehole test (in-situ test)

⇒In-situ test has a limit to cost and observation of internal structure

⇒laboratory tests and surface samples are CHEAPER!!

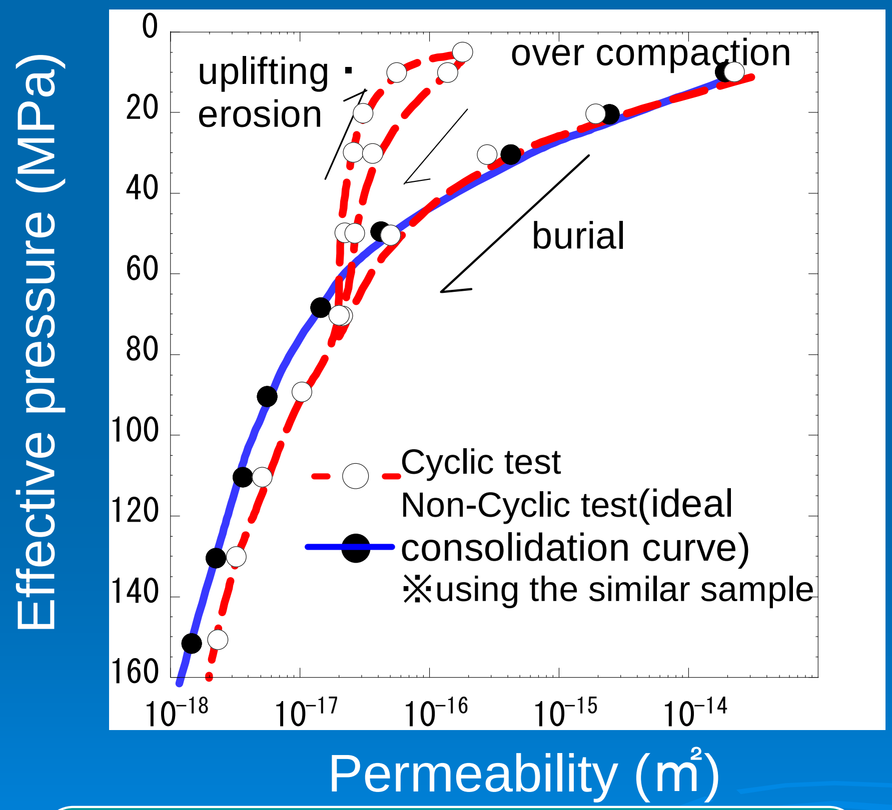




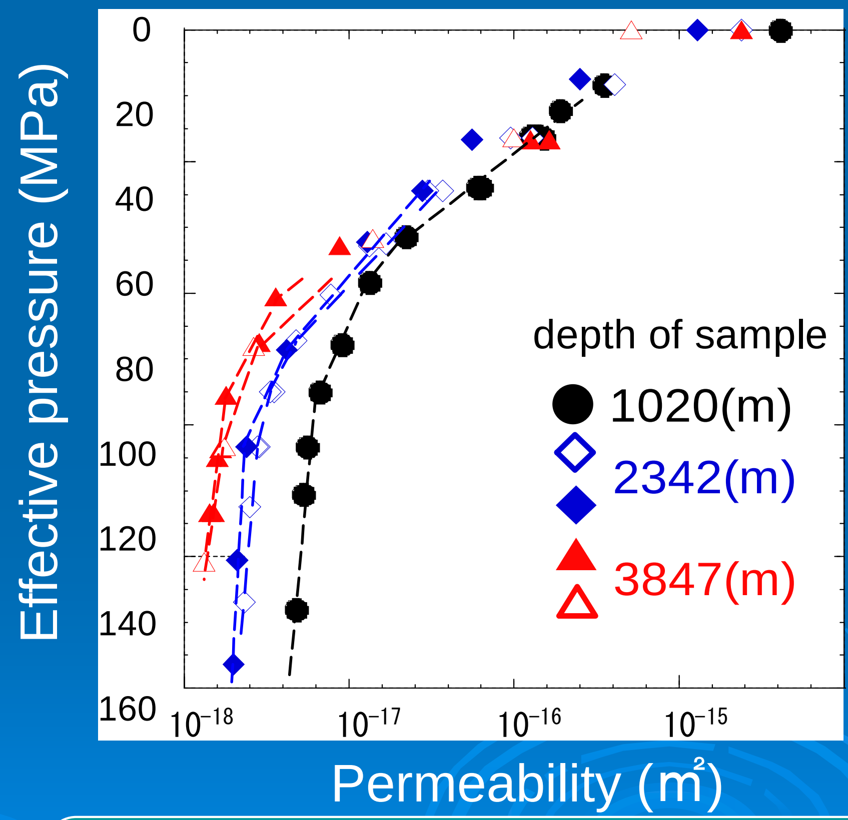


How to apply laboratory result to the real depth of nature？
(in the case of sedimentary rock)

①Reproduce the depth condition ⇒ Generation of Temperature and Pressure
②Evaluate the overconsolidation affected by previous loading
③Evaluate of time dependent – compaction ⇒ Comparison different ages of samples
④Estimate the abnormal fluid pressure
⇒ analysis to the development of the sedimentary basins

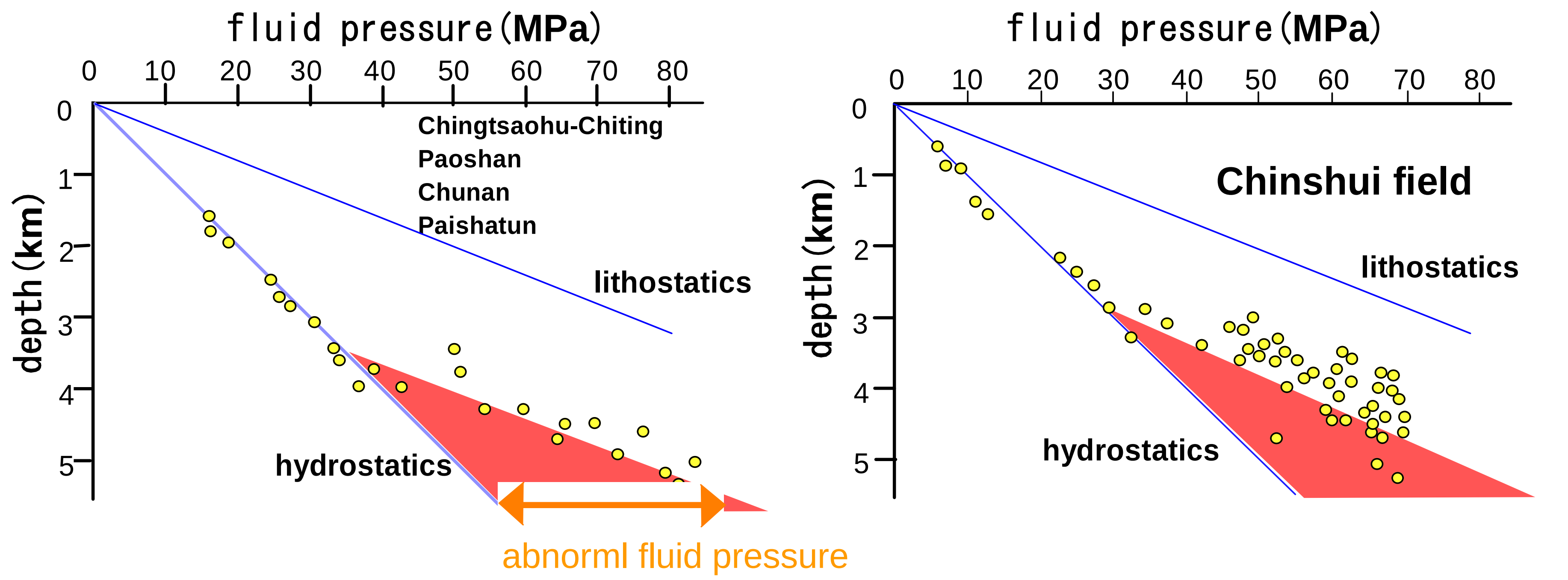


surface samples are over compacted and shows larger permeability than ideal consolidation curve.



older rocks showed lower permeability because of the time depending compaction effect

What's ABNORMAL FLUID PRESSURE?



abnormal fluid pressure
= fluid pressure - hydrostatic pressure

Generated from the depth 3～4km
Getting larger at the deeper

Fluid pressure data from boreholes at the northwest of Taiwan（Suppe & Wittke1977）

abnormal fluid	geopressure gradient	depth - Pe
×	hydrostatic	proportional
○	**lager than hydrostat**	×

Experimental data
Pe - Permeability
Pe - Porosit

We Can Guess...

depth - permeability

?

Why ABNORMAL PRESSURE generated in the depth?

①Fluid in a basin undrained by increasing loading pressure and decreasing permeability
  a. sedimentation
  b. tectonic loading

It depend on the sediment environment and permeability structure

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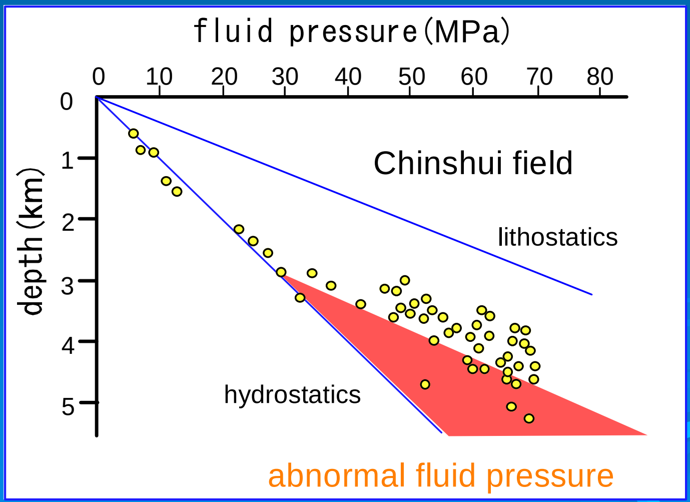
②Volume change in aquathermal expansion
  a. temperature gradient
  b. heat origin

③Fluid movement from subduction boundary (Rice 1992)

④Dehydration (diagenesis) effect
  a. smectite → illite + water
  b. gypsum → anhydrite + water
  c. hydrocarbon generation

effective if SEALING LAYER developed



we need to know PERMEABILITY STRUCTURE at a depth of the Western Foothills

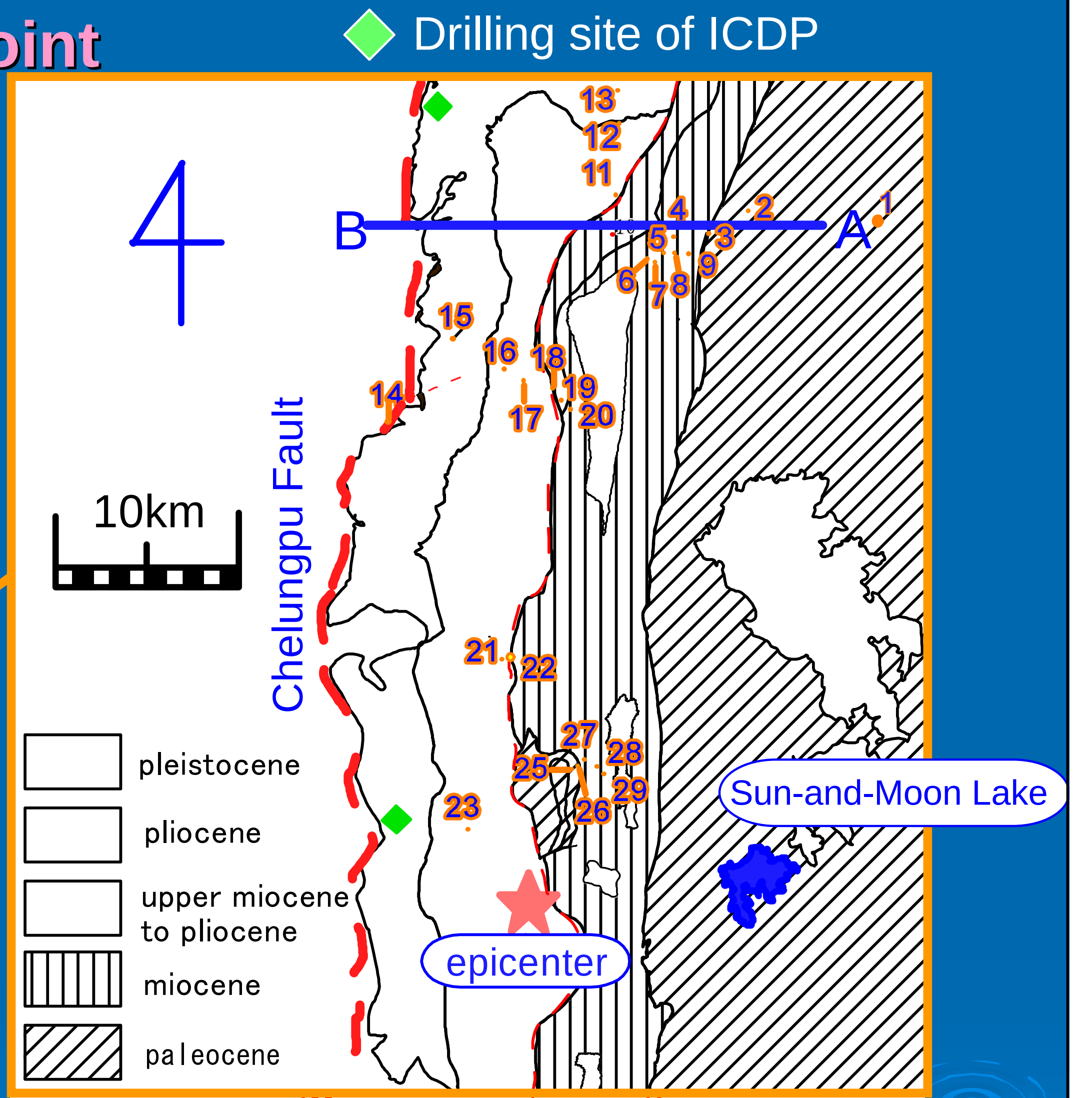
Study area and Sampling point

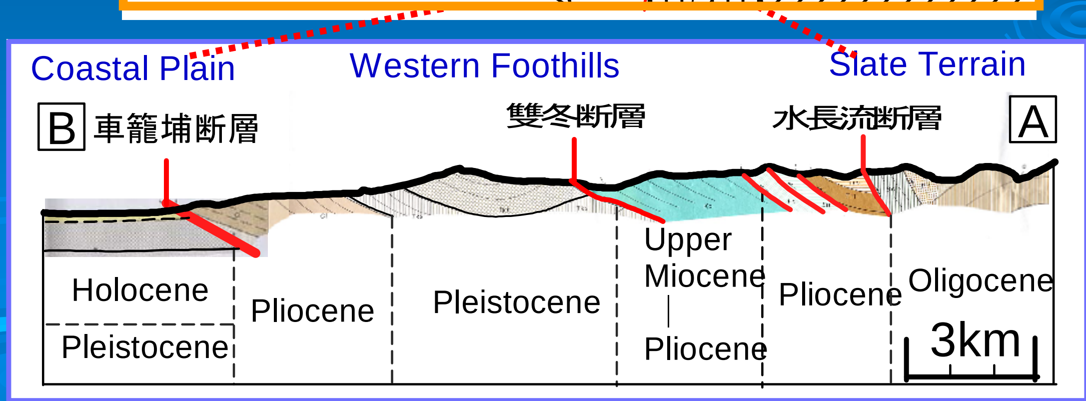
The Western Foothills

①sandstone rich sedimentary rock
②Pleistocene to Miocene
③take different ages of sample
（tectonic collision）
④1999 Chi-Chi earthquake
⑤oilfield ･･･ a lot of drill data

Eurasian Plate

Philippine Sea Plate





METHODS

condition

- temperature room temperature(≒20℃)
- confining medium/pore fluid N2 gas
- confining pressure 0～200MPa
- sample size ϕ 20mm × L 10～50mm

Sample picture

Spacemen assembly

Pressure vessel and Piston

permeability

①steady flow method

Pp ＝ 0.2～2.0 MPa

K ＝ 10^{-14}～10^{-18} m^2 (higher permeability)

(1darcy = 10^{-12} m^2 ≒10^{-3}cm/sec)

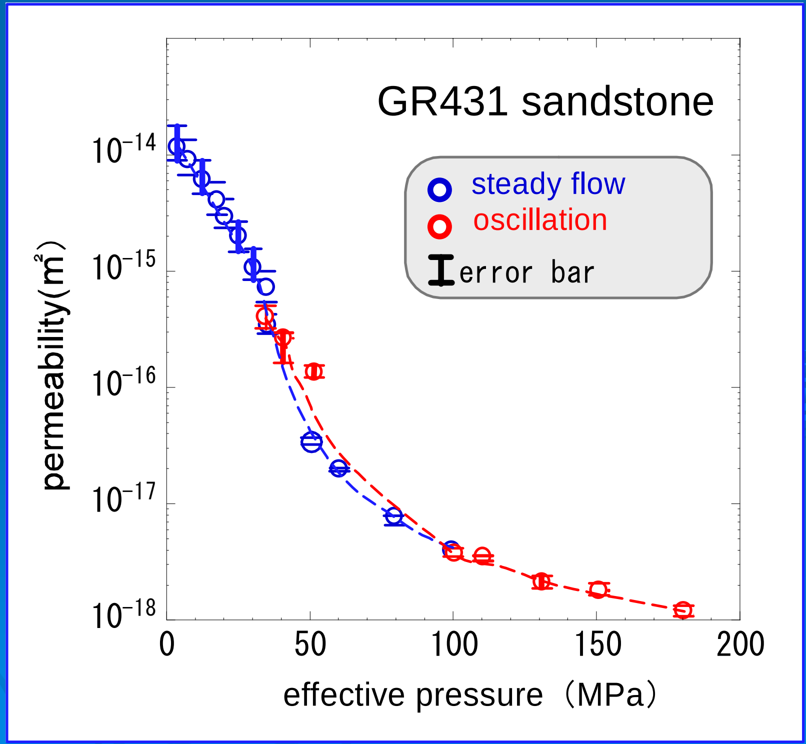
②pore pressure oscillation method（Kranz1990)

Pp ＝20 MPa (constant)

K ＝10^{-15}～10^{-21} m^2（lower permeability)

porosity

Comparison of two methods

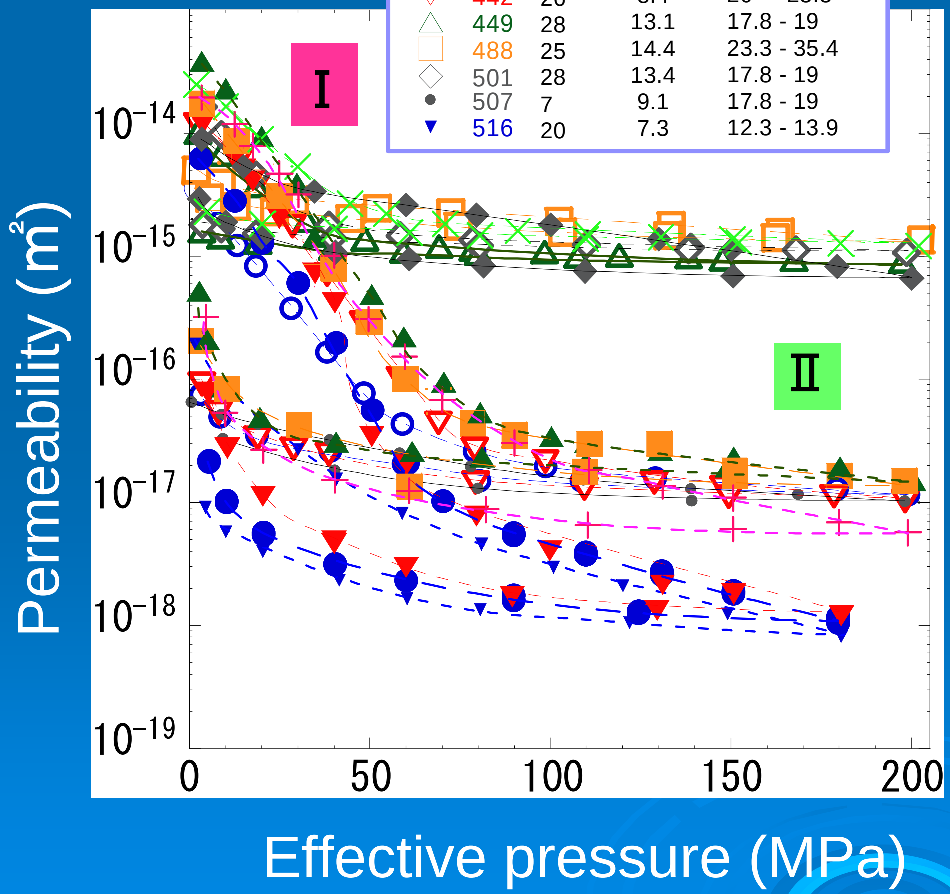


RESULTS of PERMEABILITY①

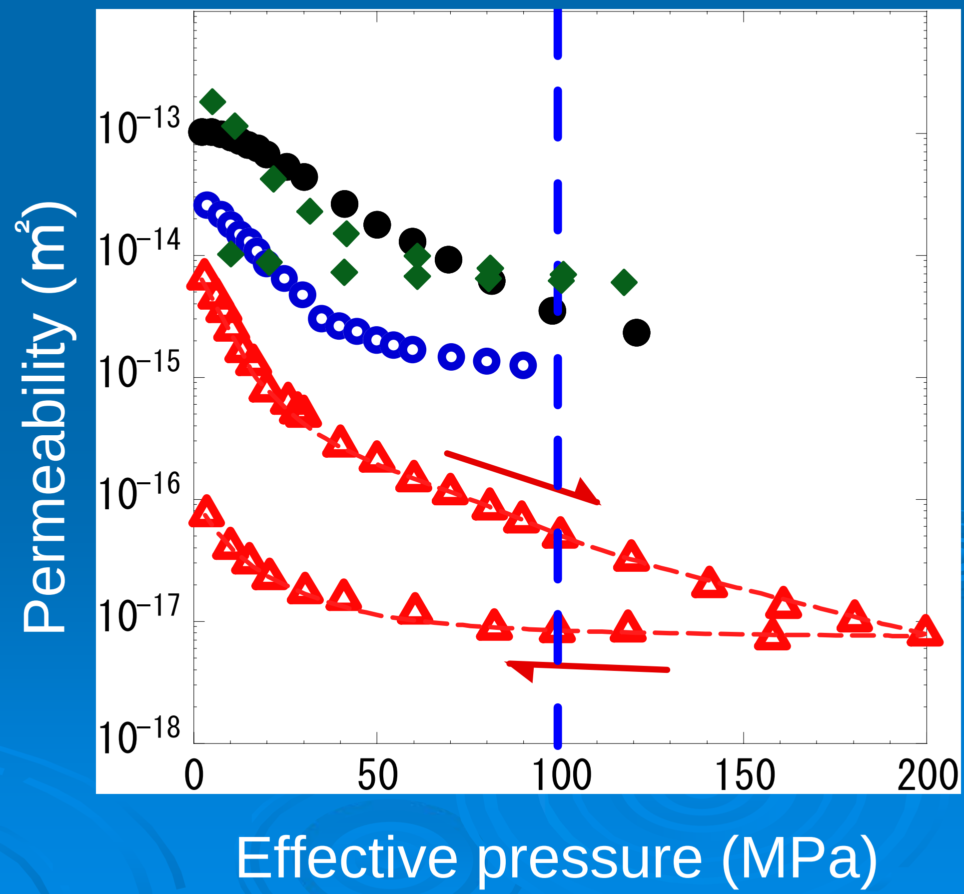
sandstone (10^{-14}〜10^{-18}㎡)

conglomerate（10^{-13}〜10^{-17}㎡）

	sampling point	initial porosity (%)	sedimentary age (Ma)
430	4	4.8	17.8 - 19.0
431	6	8.4	13.9 - 18
432	10	11.7	5.7 - 7.4
433	5	10.9	13.9 - 18
434	17	17.9	0 - 0.67
437	20	15.6	12.3 - 13.9
438	15	12	1.64 - 3.0
441	7	10.2	17.8 - 19
442	26	8.4	20 - 23.3
449	28	13.1	17.8 - 19
488	25	14.4	23.3 - 35.4
501	28	13.4	17.8 - 19
507	7	9.1	17.8 - 19
516	20	7.3	12.3 - 13.9



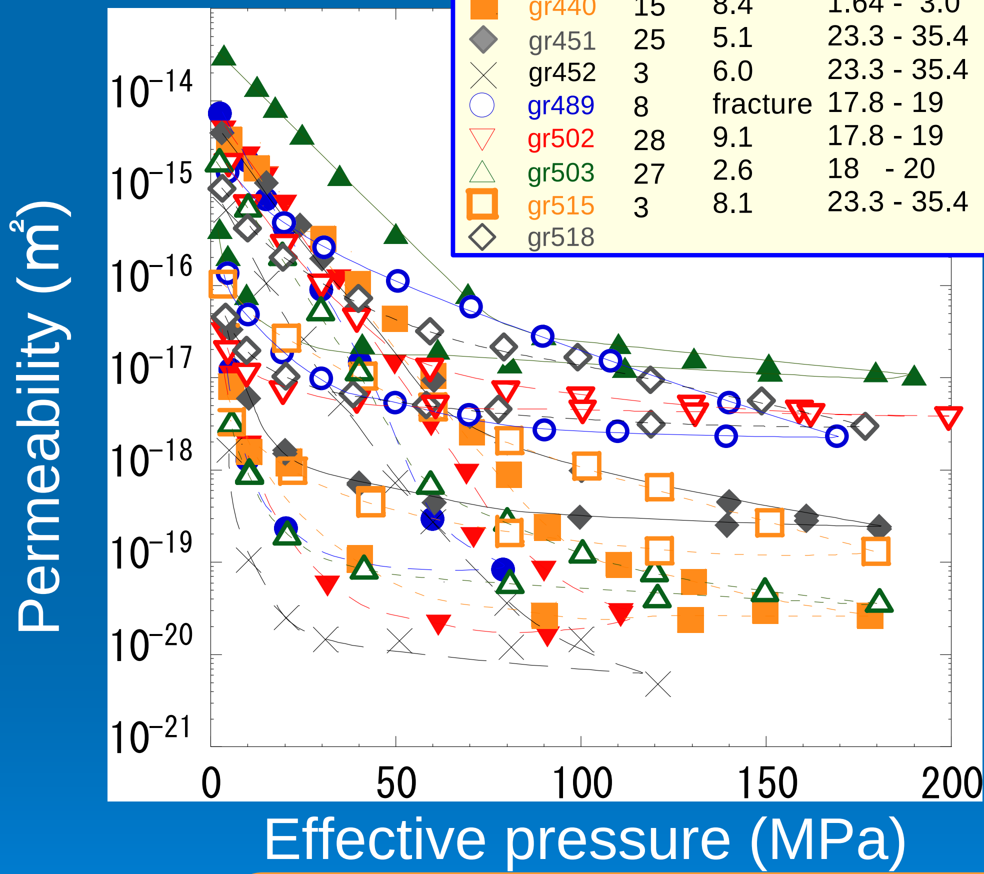
GR435 12 conglomerate
GR400 matrix in conglomerate
GR392 sandy matrix
GR535 12 conglomerate



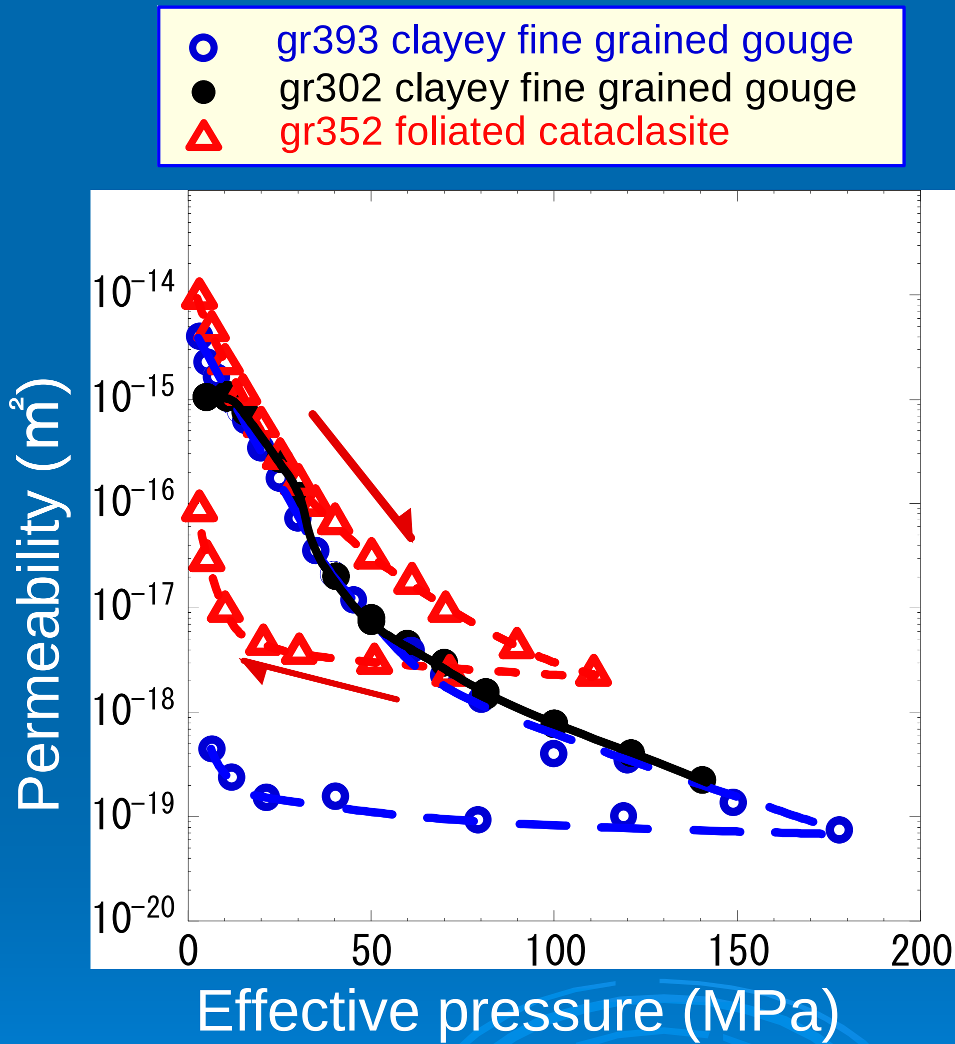
RESULTS of PERMEABILITY②

siltstone・shale（10^{-14}～10^{-21}m²）

	sampling location	Initial porosity(%)	age (Ma)
gr346	9		20 - 23.3
gr436	16	5.5	0 - 0.67
gr439	20	16.7	12.3 - 13.9
gr440	15	8.4	1.64 - 3.0
gr451	25	5.1	23.3 - 35.4
gr452	3	6.0	23.3 - 35.4
gr489	8	fracture	17.8 - 19
gr502	28	9.1	17.8 - 19
gr503	27	2.6	18 - 20
gr515	3	8.1	23.3 - 35.4
gr518			

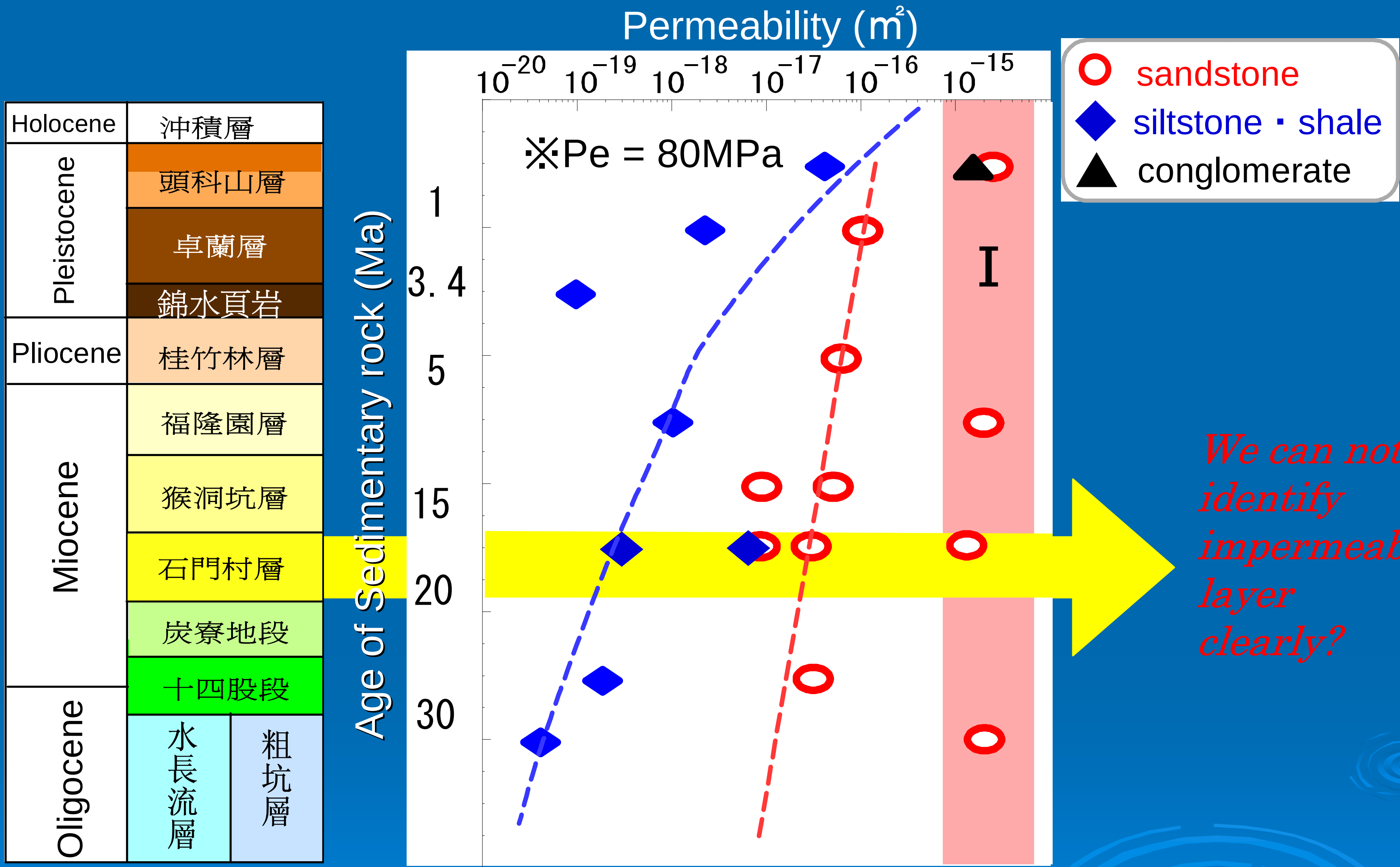


fault rock（Chelungpu Fault）
（10^{-14}～10^{-19}m²）



1. fault rock ≒ siltstone
2. sandstone can be classified into 2 groups
3. siltstone < sandstone < conglomerate → grain size

TIME-DEPENDENT COMPACTION



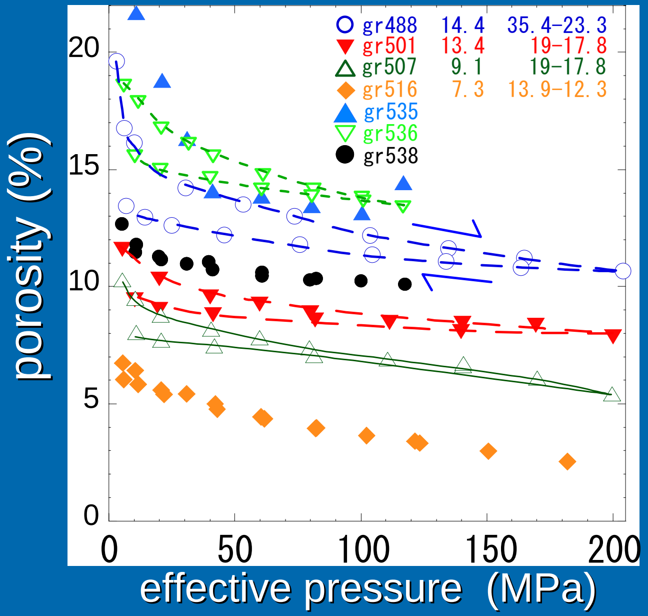
We can not identify impermeable layer clearly?

time-dependent compaction

（pressure solution/grain rearrangement/chemical cementation)

POROSITY and SPECIFIC STORAGE

sandstone



specific storage

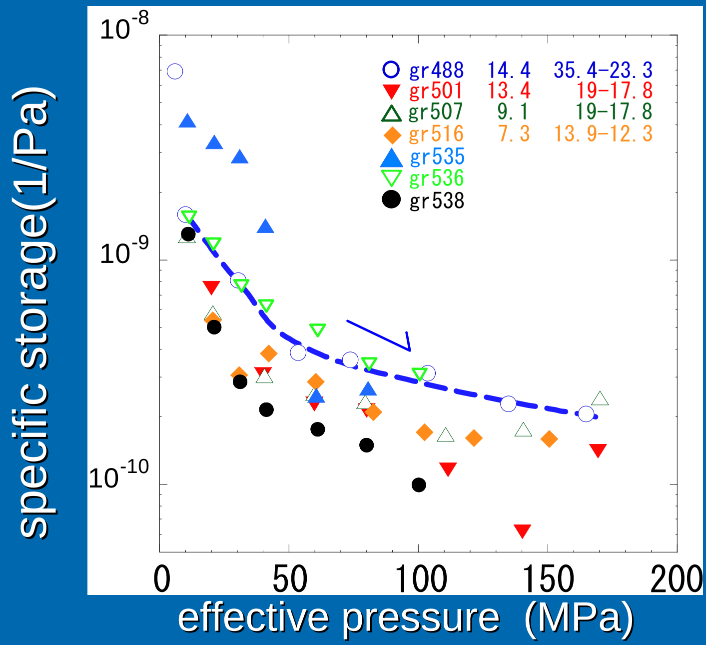
$$Ss = \frac{1}{1-\Phi}\frac{\Delta\Phi}{\Delta Pe} + \Phi\cdot\beta_f$$

Φ : porosity

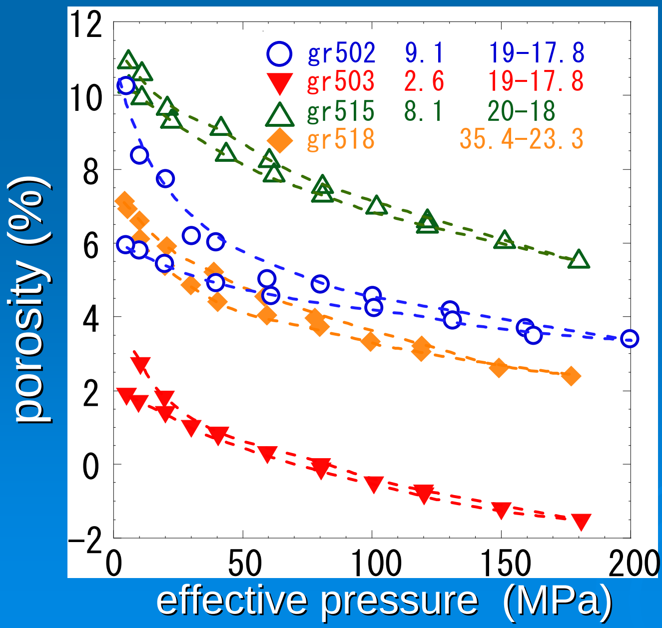
β f:compressibility of water

$=4.4*10^{-10}$

sandstone



siltstone

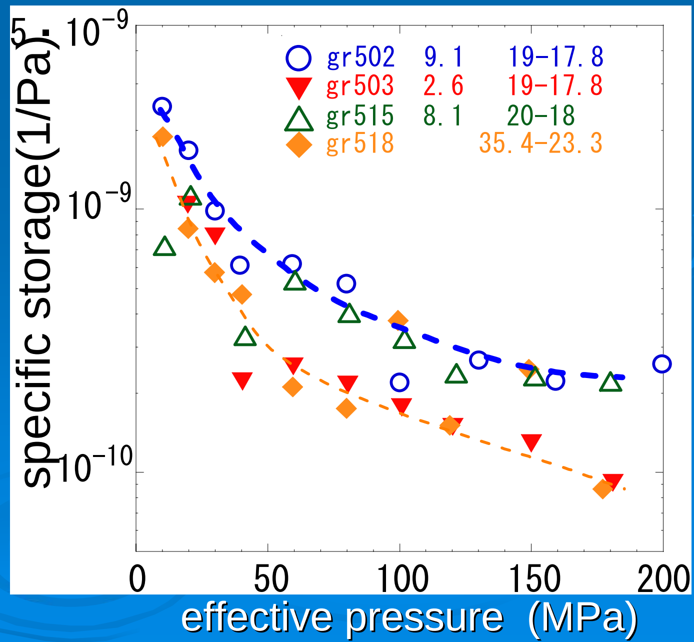


①these parameters have pressure sensitivity

②sandstone and siltstone showed similar values

③specific storage shows smaller change to Pe (1 ~ 2 order) compared to permeability

siltstone



GENERATION MECHANISM of ABNORMAL FLUID PRESSURE

① fluid undrained by decreasing permeability and increasing loading pressure

a. sedimentation

b. tectonic loading

② volume change in aquathermal expansion

a. temperature gradient

b. heat origin

③ fluid movement from subduction boundary (Rice 1992)

④ dehydration (diagenesis) effect

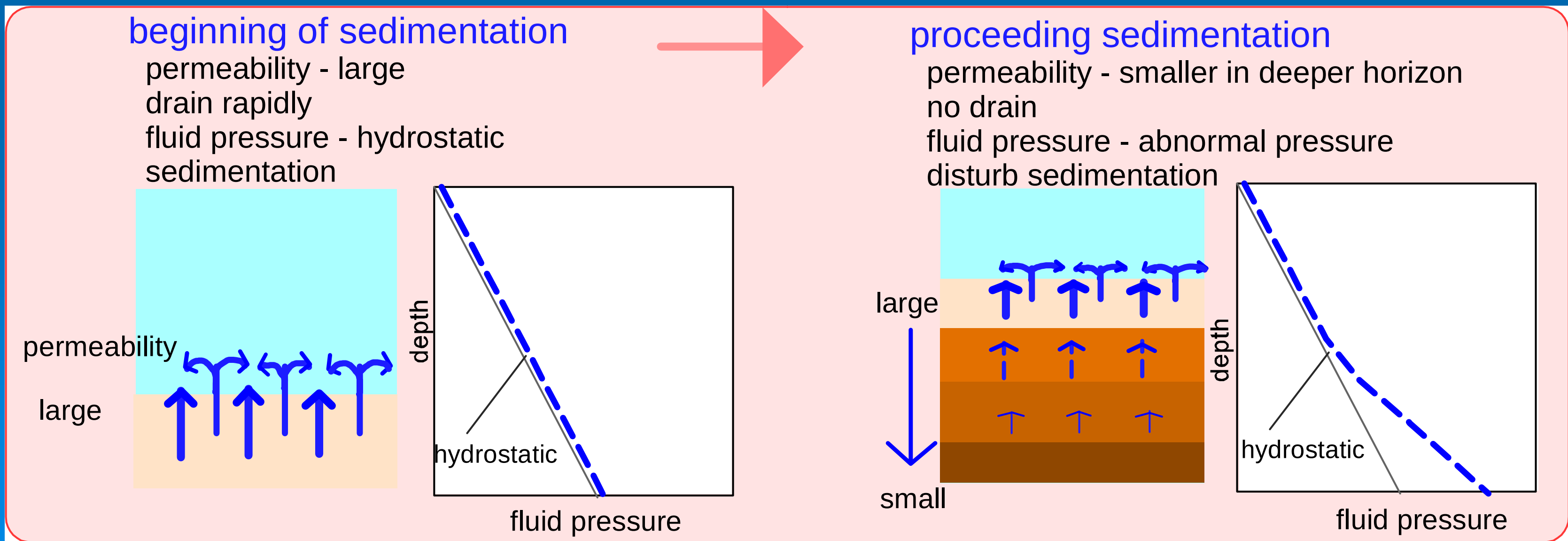
a. smectite → illite + water

b. gypsum → anhydrite + water

c. hydrocarbon generation

First of all we should evaluate Mechanism ① in the sedimentary basin

IMAGE of MECHANISM ① − a



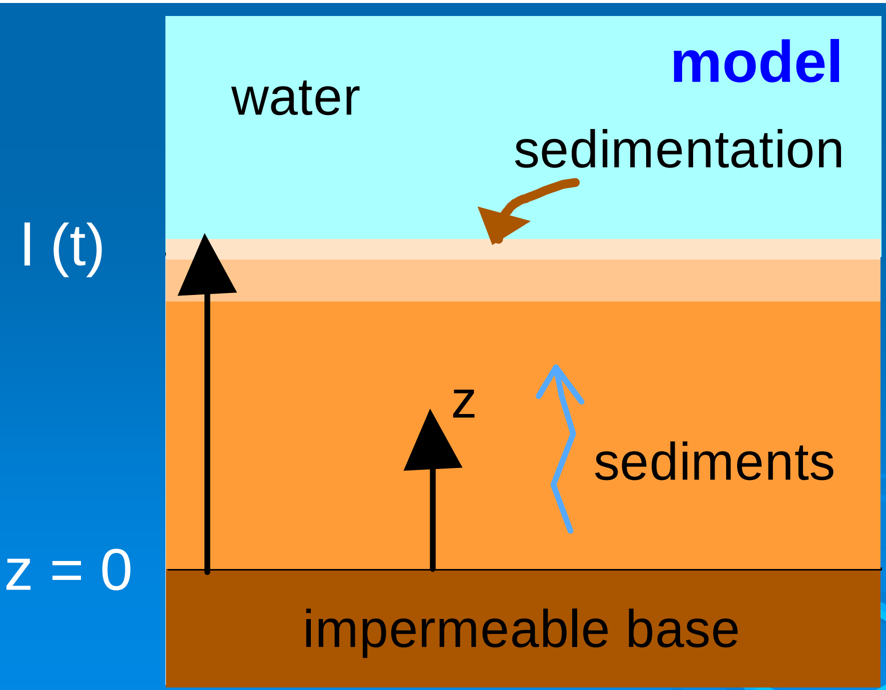
1-D NONLINEAR COMPACTION FLOW EQUATION

$$\underbrace{S_s \cdot \eta\left(\frac{\delta u}{\delta t} - \underbrace{g \cdot \rho_e \frac{\delta l}{\delta t}}_{\text{continuing sedimentation}}\right)}_{\text{compaction term}} = \underbrace{\frac{\delta}{\delta z}\left(K\frac{\delta u}{\delta z}\right)}_{\text{diffusion term}} + \underbrace{\gamma \Phi \frac{\delta T}{\delta t}}_{\text{temperature effect}} \Rightarrow \underbrace{u(z,t)}_{\text{abnormal pressure}}$$

Gibson 1958/Bethke and Corbet 1988/Luo and Vasseur 1992

Darcy's law	$V_z = -\frac{K}{\eta}\left(\frac{\delta p}{\delta z} + \rho_f \cdot g\right)$
effective pressures law	$P_e = P_c - p = g \cdot (l-x) \cdot \rho_e - u$
conservation law	$-\frac{\delta}{\delta z}(\rho_f \cdot g \cdot V_z)\Delta x \Delta y \Delta z = \frac{\delta}{\delta t}(\rho_f \cdot \Phi \cdot \Delta x \Delta y \Delta z)$

u:abnormal fluid pressure（Pa）
K:permeability（m^2）
η:fluid viscosity（Pa・s）
Ss:specific storage（1/Pa）
l:thickness of sediments（m）
ρ_e:effective density
= ρ (saturated rock density)- ρ_f(fluid density)
γ:coefficient of thermal expansibility of fluid
Φ:porosity
T:temperature（℃）

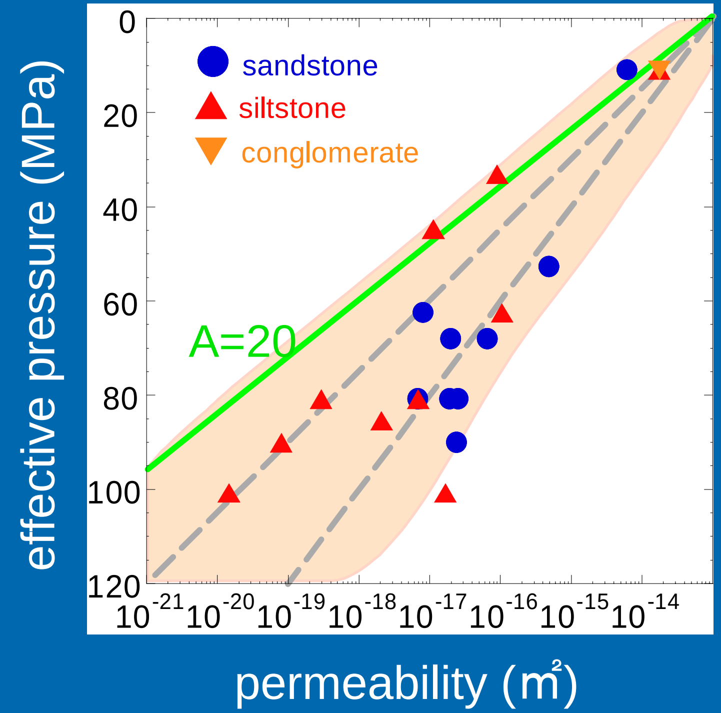


Assumption

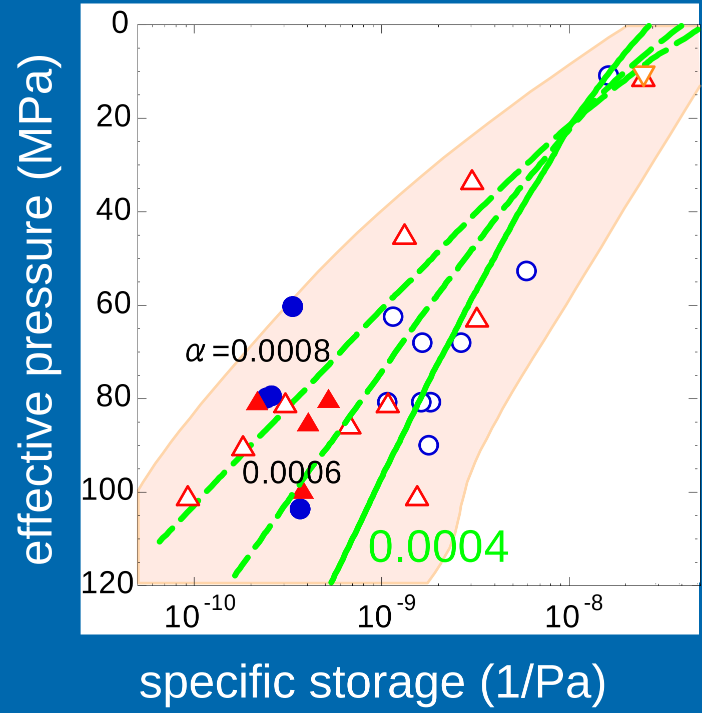
①permeability of base ＝ 0
②fluid moves upward (1 dimension)
③permeability does not show anisotropy
④temperature gradient = constant
⑤sedimentation rate = constant
⑥grain compressibility ≒ 0
⑦water viscosity = constant

HYDRAULIC PROPERTY for CALCULATION

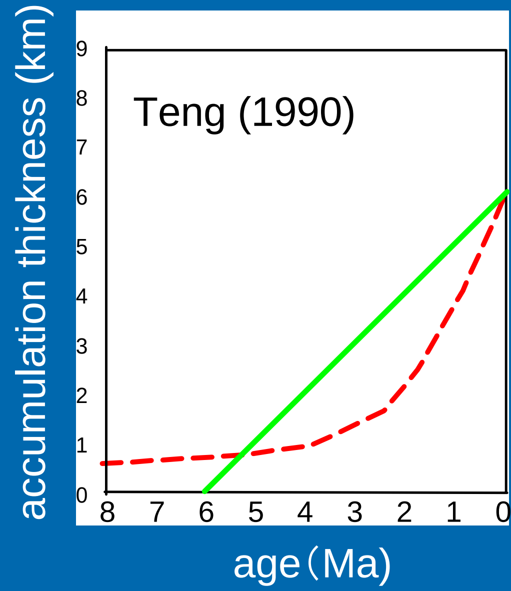
Permeability



Specific storage



Sedimentation rate



Temperature gradient

25～37 ℃/km
(Suppe & Wittke 1977)

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log-linear approximation

$$Pe = A \cdot \log\left(\frac{K}{K_0}\right) \qquad K_0 = 10^{-13}$$

$A = 20$ 12＜A＜20

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approximated from Athy's law

$$\Phi = \Phi_0 \cdot \exp\left(-\alpha \cdot \frac{Pe}{\rho_e \cdot g}\right)$$

$$Ss = \frac{1}{1-\Phi} \frac{\Delta \Phi}{\Delta Pe} + \Phi \cdot \beta_f$$

$\Phi_0 = 50$ (%)
$\rho_e = 1500$ (kg/m^3)
$g = 10$ (m/s^2)
β_f (flud compressibility) $= 4.4 \cdot 10^{-13}$

$\alpha = 0.0004$ 0.0004～α～0.0008

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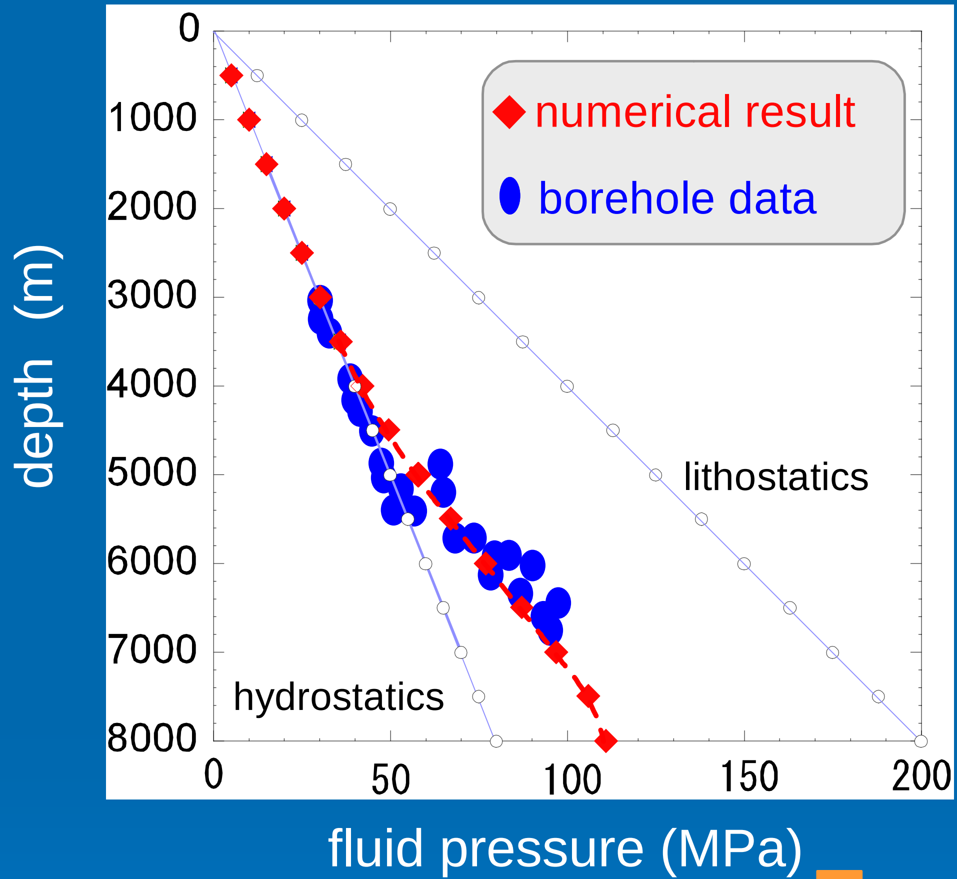
burial rate＝thickness／age
1000 （m/Ma）
temperature gradient
30 （℃/km）

$$Ss \cdot \eta\left(\frac{\delta u}{\delta t} - g \cdot \rho_e \frac{\delta l}{\delta t}\right) = \frac{\delta}{\delta z}\left(K \frac{\delta u}{\delta z}\right) + \gamma \Phi \frac{\delta T}{\delta t}$$

FLUID PRESSURE DISTRIBUTION

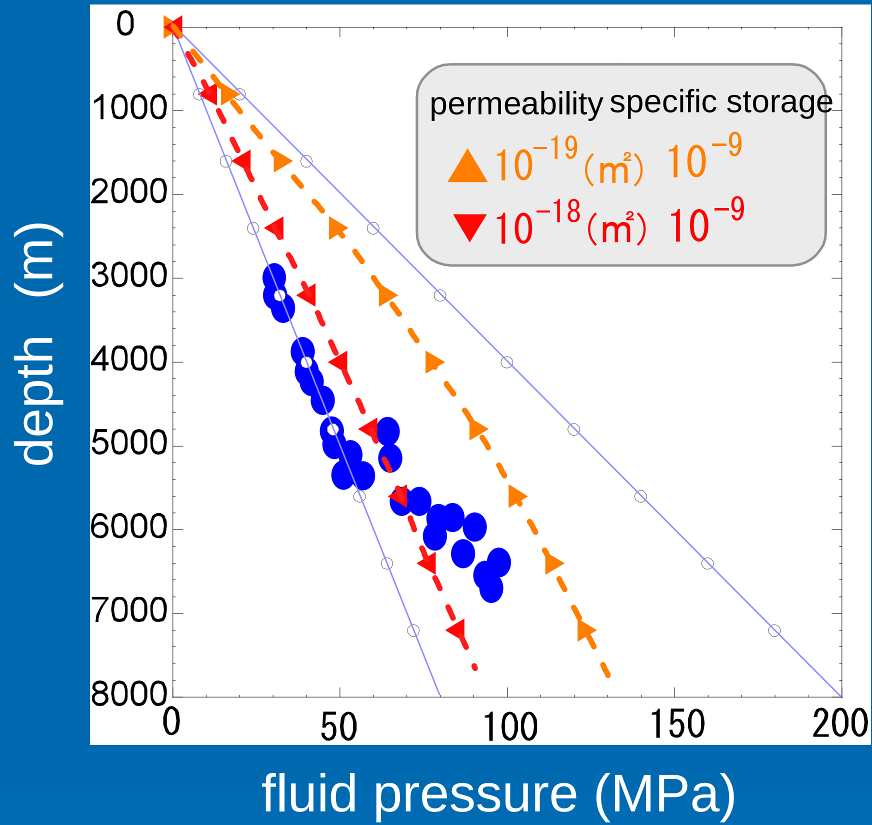
permeability・specific storage
change with pressure (our study)



α = 0.0004 A = 12 K0 = 10^{-13}

Predicted fluid pressure distribution showed similar result to the borehole data !!

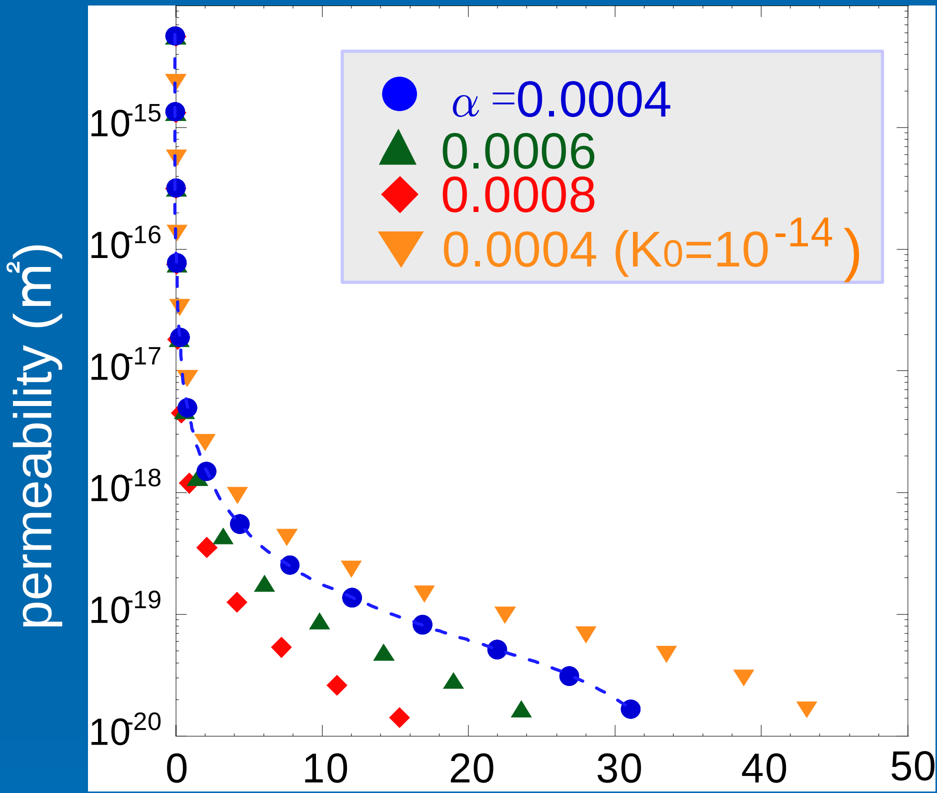
permeability / specific storage
assumed to be constant (Gibson 1958)



Pressure sensitivity for permeability is important !!

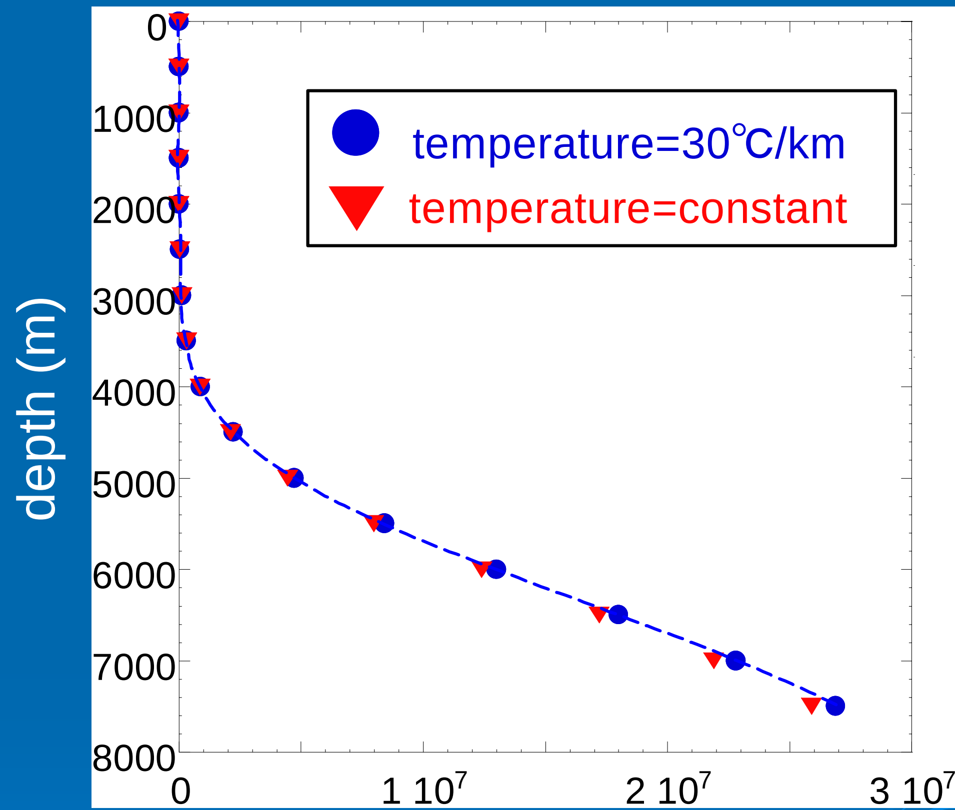
IN DETAILS

permeability
vs
abnormal pressure



abnormal fluid pressure (MPa)

influence of fluid volume
expansion
by temperature gradient



abnormal fluid pressure (MPa)

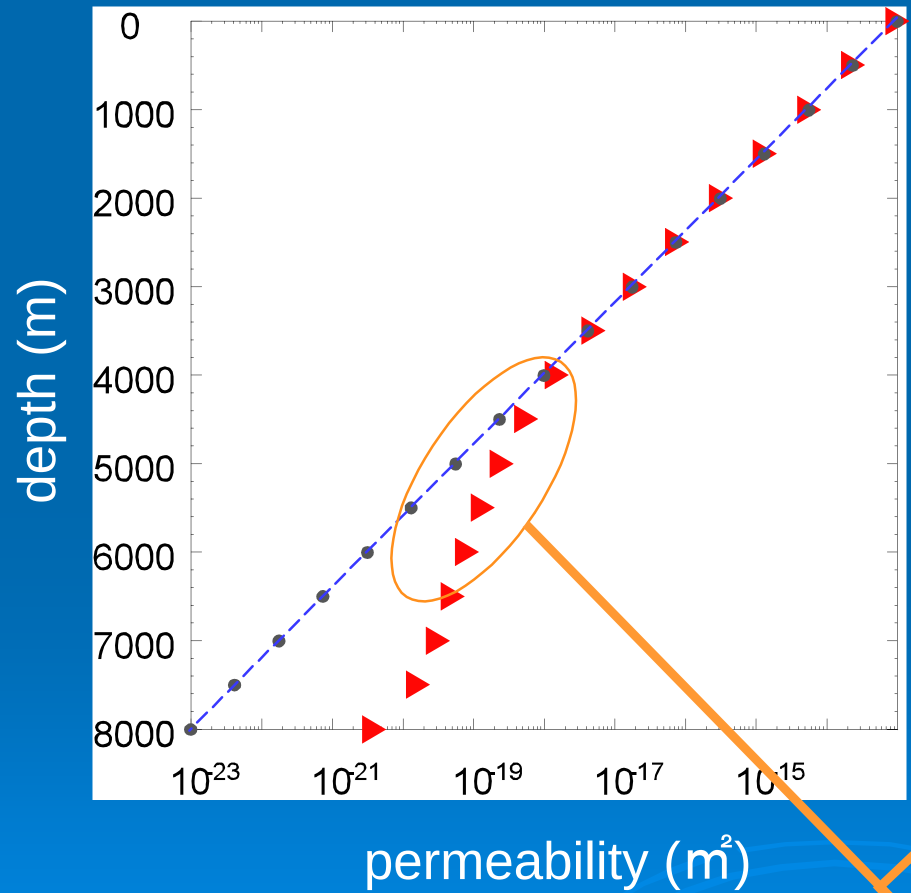
Abnormal pressure generated from
$10^{17} \sim 10^{18}$ m²

Temperature gradient has little influence to pressure generation（mostly by the effect of sedimentation）

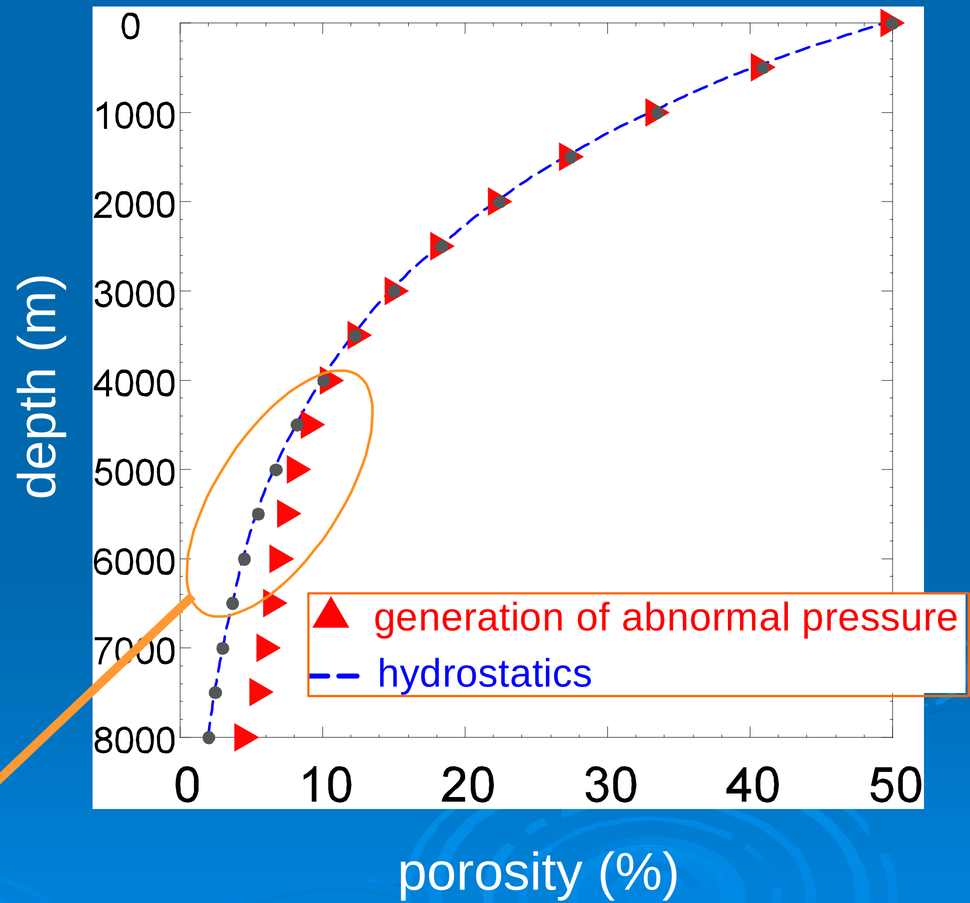
PERMEABILITY STRUCTURE at The Western Foothills

estimation of abnormal pressure → depth vs effective pressure → permeability - depth, porosity - depth

depth vs permeability



depth vs porosity



effect of abnormal fluid pressure

CONCLUSION

◆We measured permeability and porosity of sedimentary rocks in the Western Foothills at high pressure condition and estimated the hydraulic properties - effective pressure relationship in this area.

◆We estimated the fluid pressure distribution from one-dimensional compressional flow model and the result agreed with real borehole data.

◆We estimated the hydraulic properties (permeability / specific storage / porosity) at a depth of the Western Foothills.