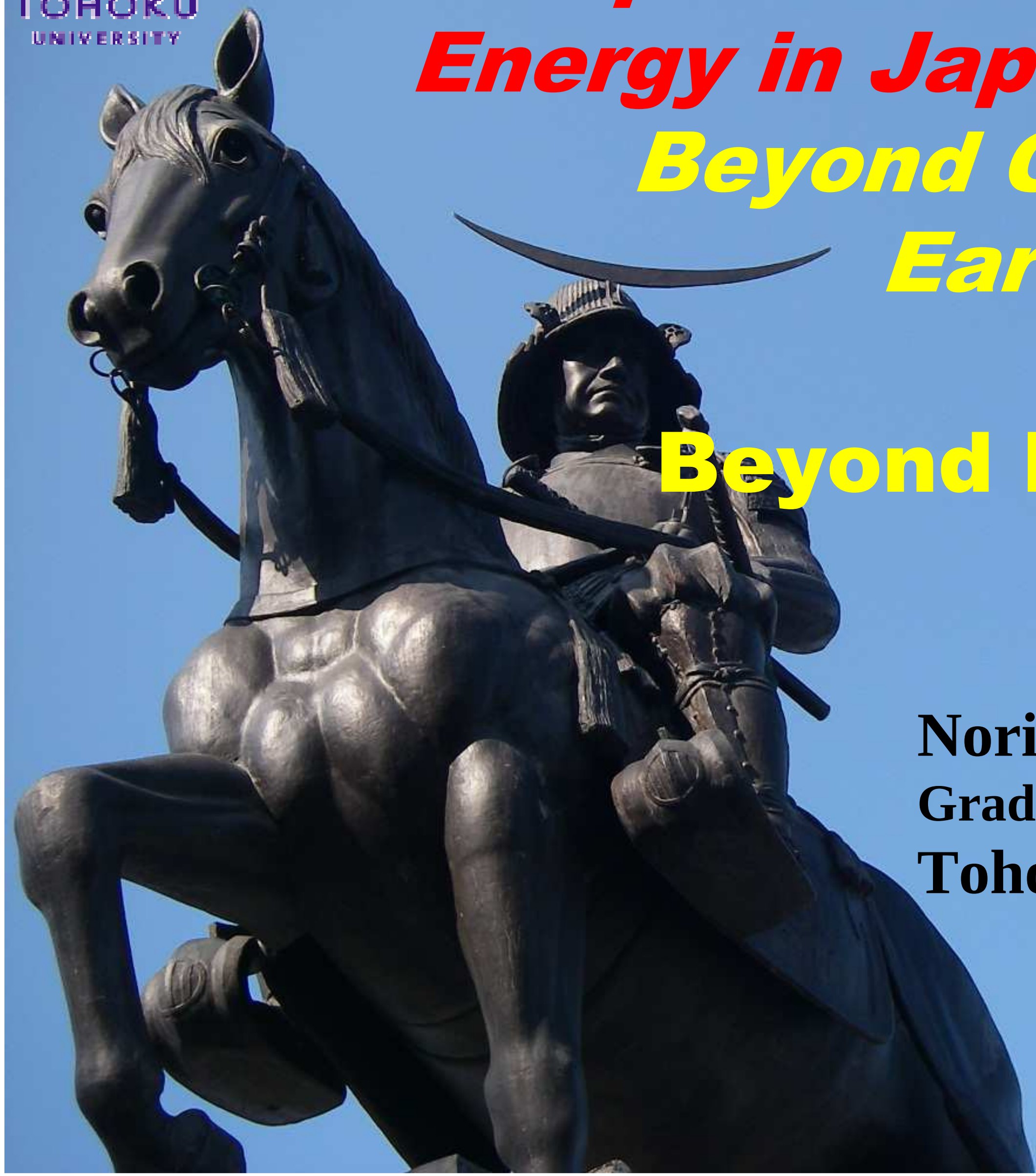
Perspective on Geothermal Energy in Japan: Beyond Great East Japan Earthquake & Beyond Brittle Project



Noriyoshi TSUCHIYA
Graduate School of Environmental Studies
Tohoku University
環境科学研究科
東北大学

2011

3.11

14:46

(Japan Time)

Great East Japan Earthquake

& Tsunami

M. 9.0

Destroyed Train

After Tsunami


2011 年 3 月 29 日 7 午後
11 月 2010
3 月 2011
© 2011 ZENRIN
© 2011 Geocentre Consulting
画像取得日: 2011 年 3 月 30 日
38° 36'11.12" N 141° 30'03.88" E 標高 7 m
高度 689 m
©2010 Google

3.11 : Tohoku University

Coach on the roof

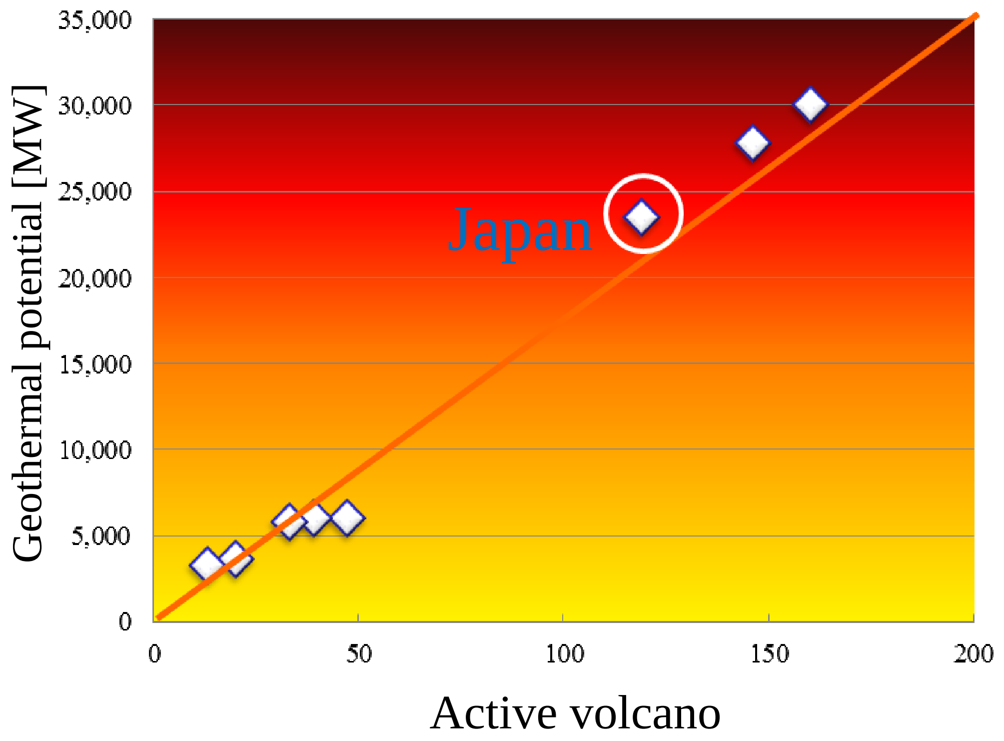
Fishing Boat on the road

Distribution of Volcano

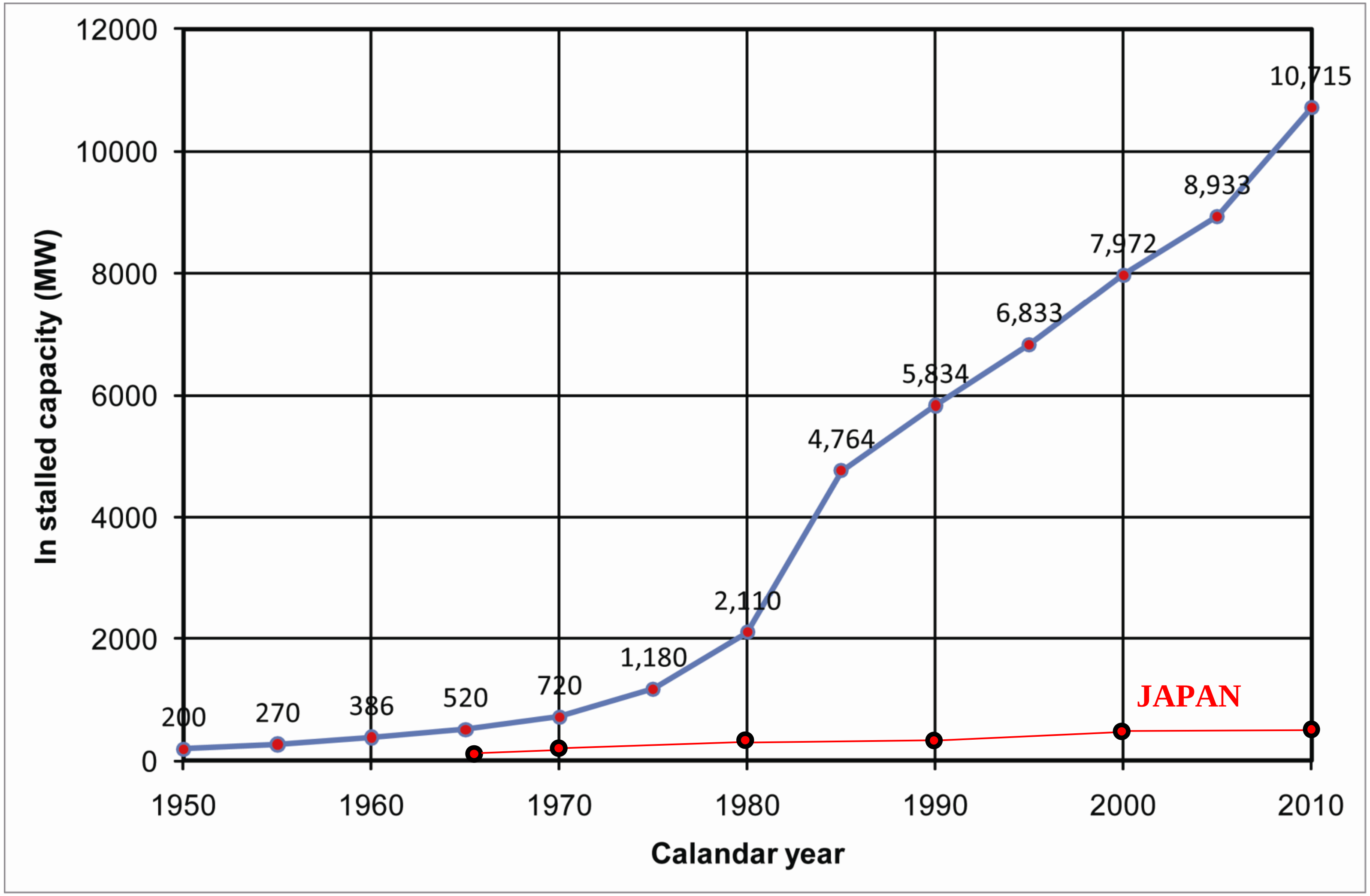
Geothermal Potential
Japan is 3rd

country	Active Volcano	Geothermal Potential [MW]
USA	160	30,000
Indonesia	146	27,790
Japan	119	23,470
Philippine	47	6,000
Mexico	39	6,000
Iceland	33	5,800
New Zealand	20	3,650
Italy	13	3,270

Stefansson (2005)



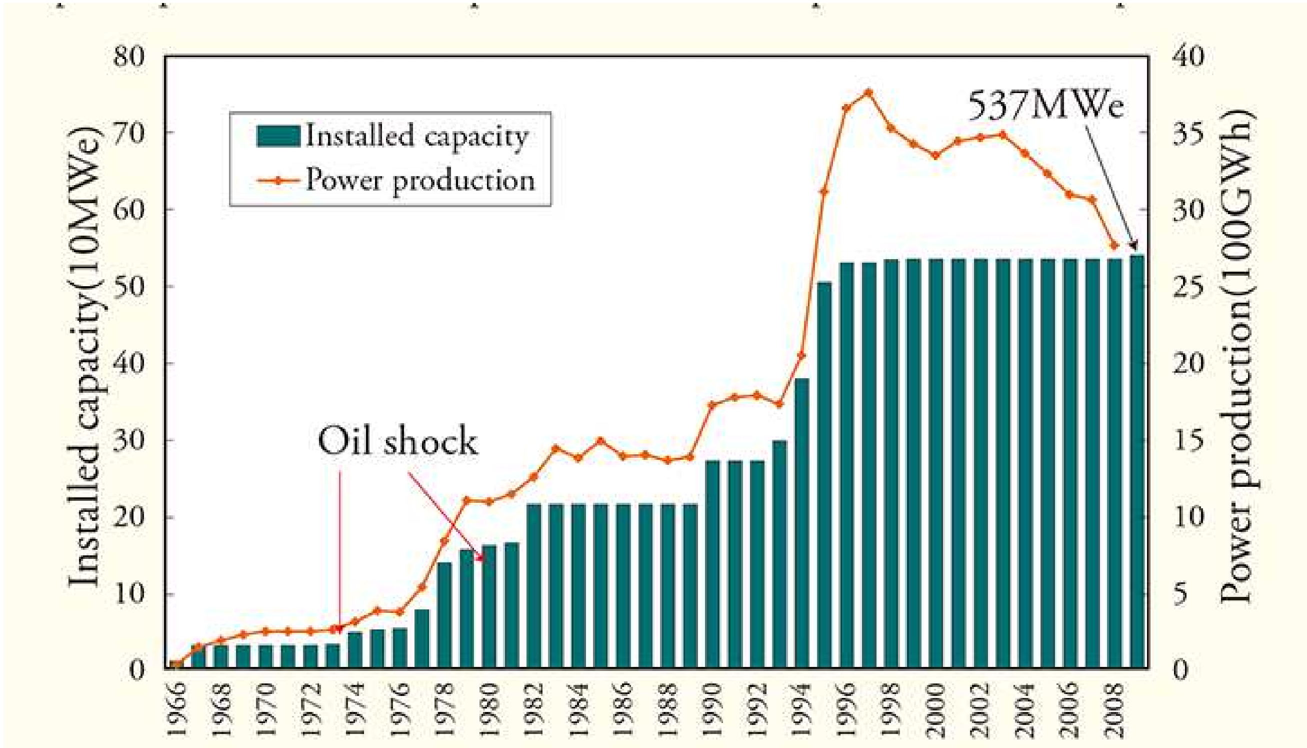
Geothermal Development in the World



（Lund et al., 2010）

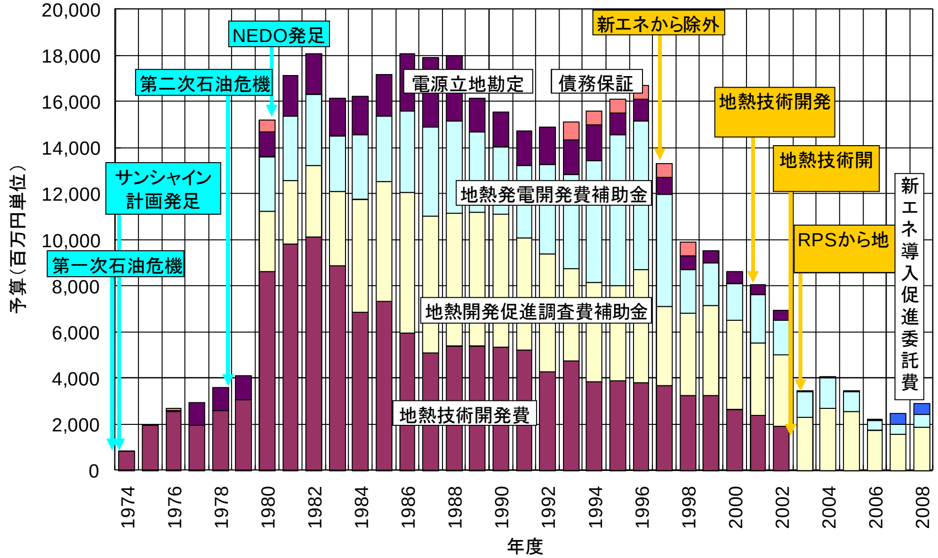
Geothermal fever

Lost Decade In Geothermal R&D In JAPAN

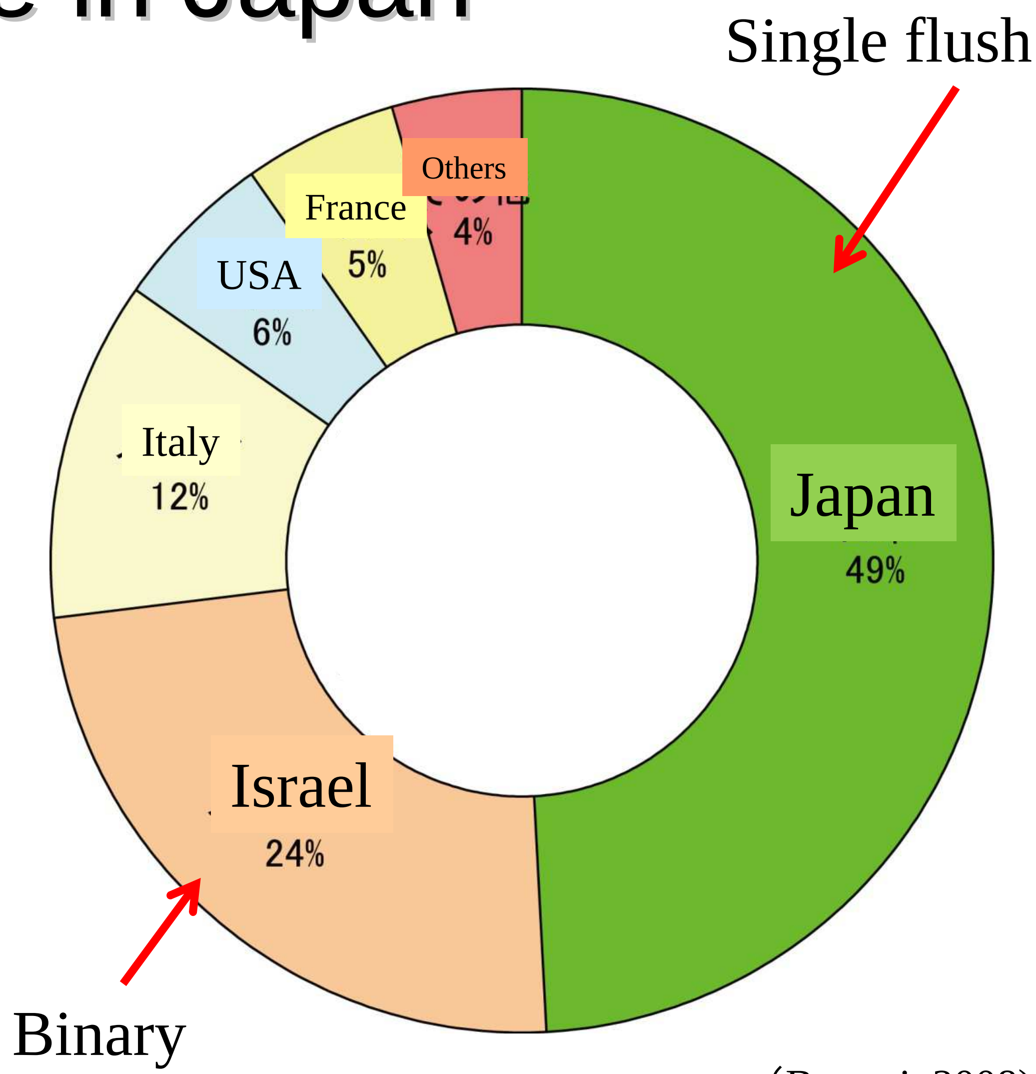


▲Capacity and power production of geothermal power plants in Japan (1967-2009)

Last geothermal power plant was only 3.3 MW in remote island since 1999.



Turbine in geothermal power plant (after 2000) was "Made in Japan"

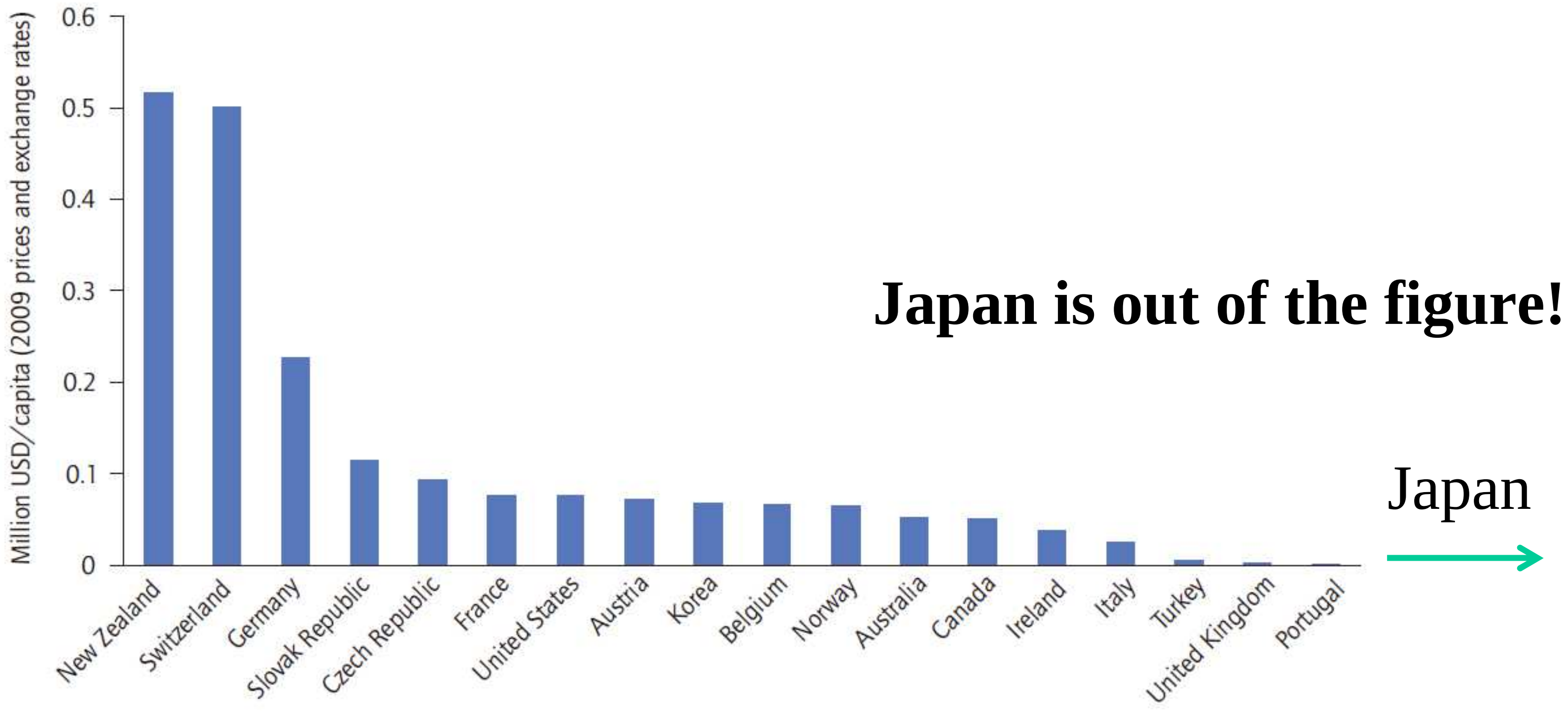


(Bertani, 2008)

No new domestic geothermal power plants after 1999, but 70% market of single flush type is occupied by three Japanese companies.

R&D budget for geothermal per capita

Figure 15: Public RD&D budget for geothermal energy, 2006-09 average (million USD per capita)



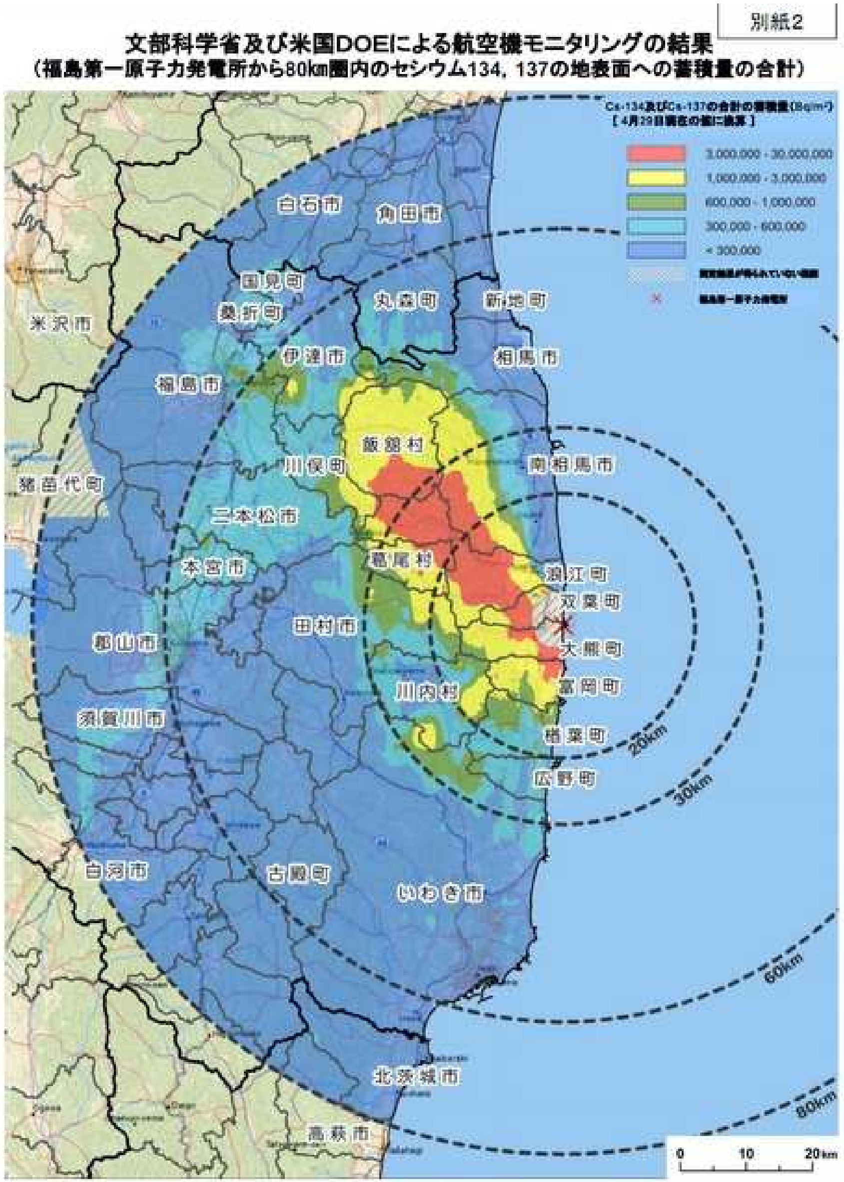
Note: Where available, 2010 estimates are also included. US Recovery Act Spending for geothermal energy in 2009 are not included. IEA countries without geothermal RD&D spending are not included the graph.

Source: (www.iea.org/stats/rd.asp).

(IEA, 2011 Technology Roadmap on Geothermal Heat and Power)

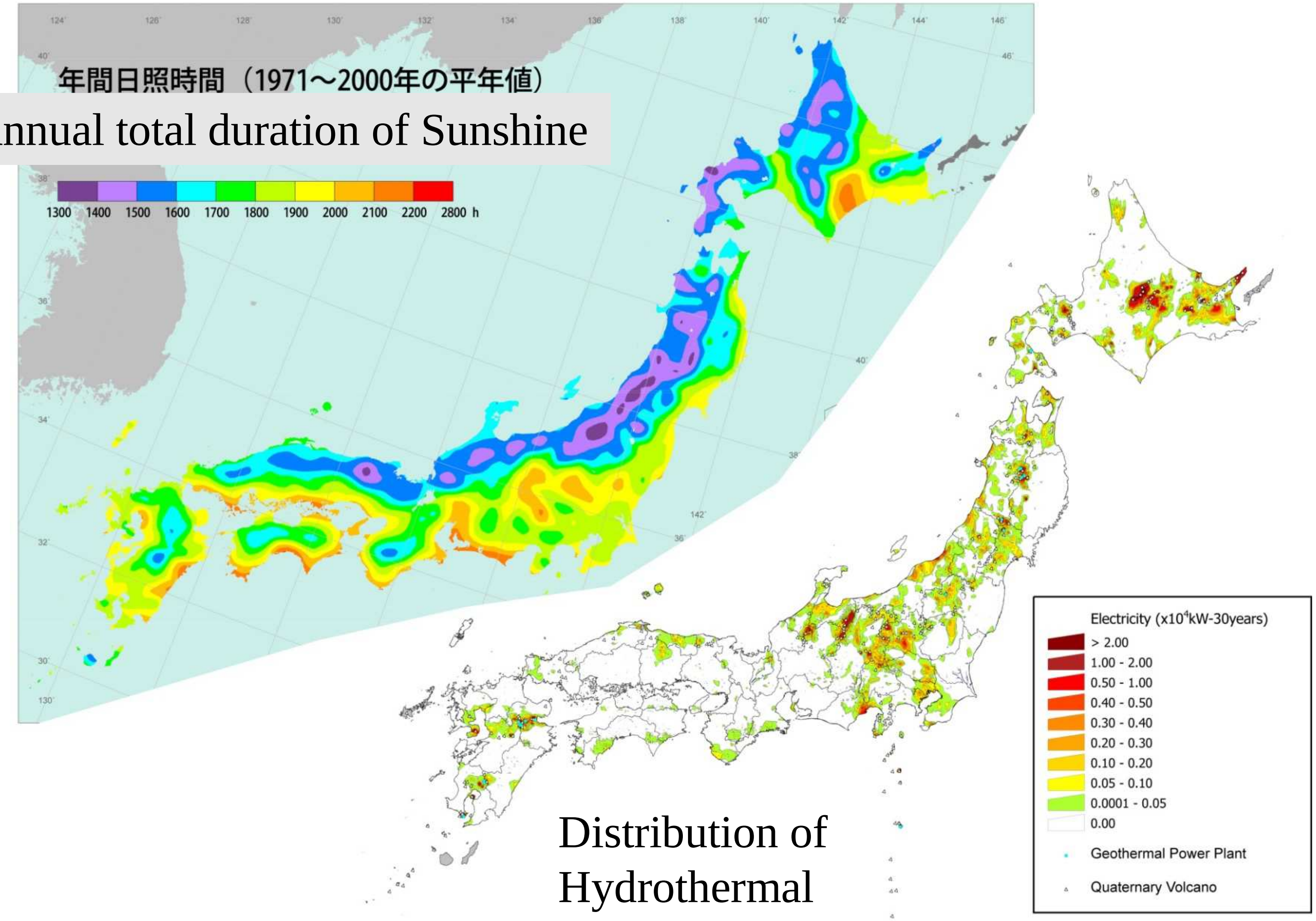
北原
No. 1
Reactor
No. 2
Reactor
No. 3
Reactor
No. 4
Reactor
© 2012 ZENRIN
Image © 2012 GeoEye
Google earth
画像取得日: 2011/3/19 2003 37° 25'18.08" N 141° 02'01.38" E 標高 10 m 高度 499 m
Image © 2012 GeoEye
画像取得日: 2011/3/19 2003 37° 25'16.45" N 141° 01'57.27" E 標高 10 m 高度 751 m

Drastic Change after 3.11 !



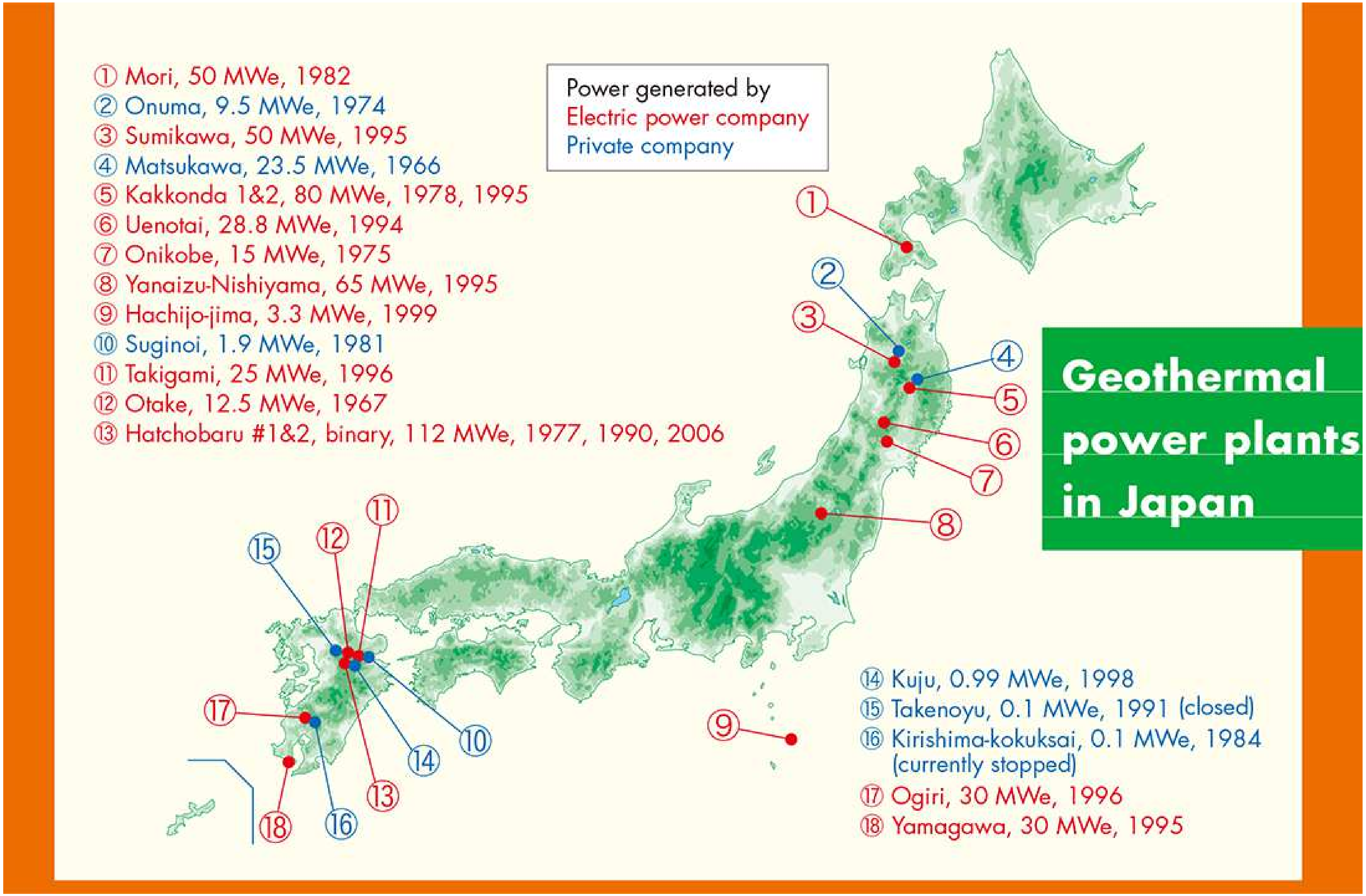
- Even now, more than 100,000 people cannot come back to their own home.
- WHO reported (Nov 2012) there is no statistic increase of cancer due to low level nuclear radiation in generally, BUT some amounts of increase can be estimated for thyroid cancer of children (not clear still now)
- **Geothermal is most promising sustainable and safety energy.**

Tohoku (Northeast Japan) 東北

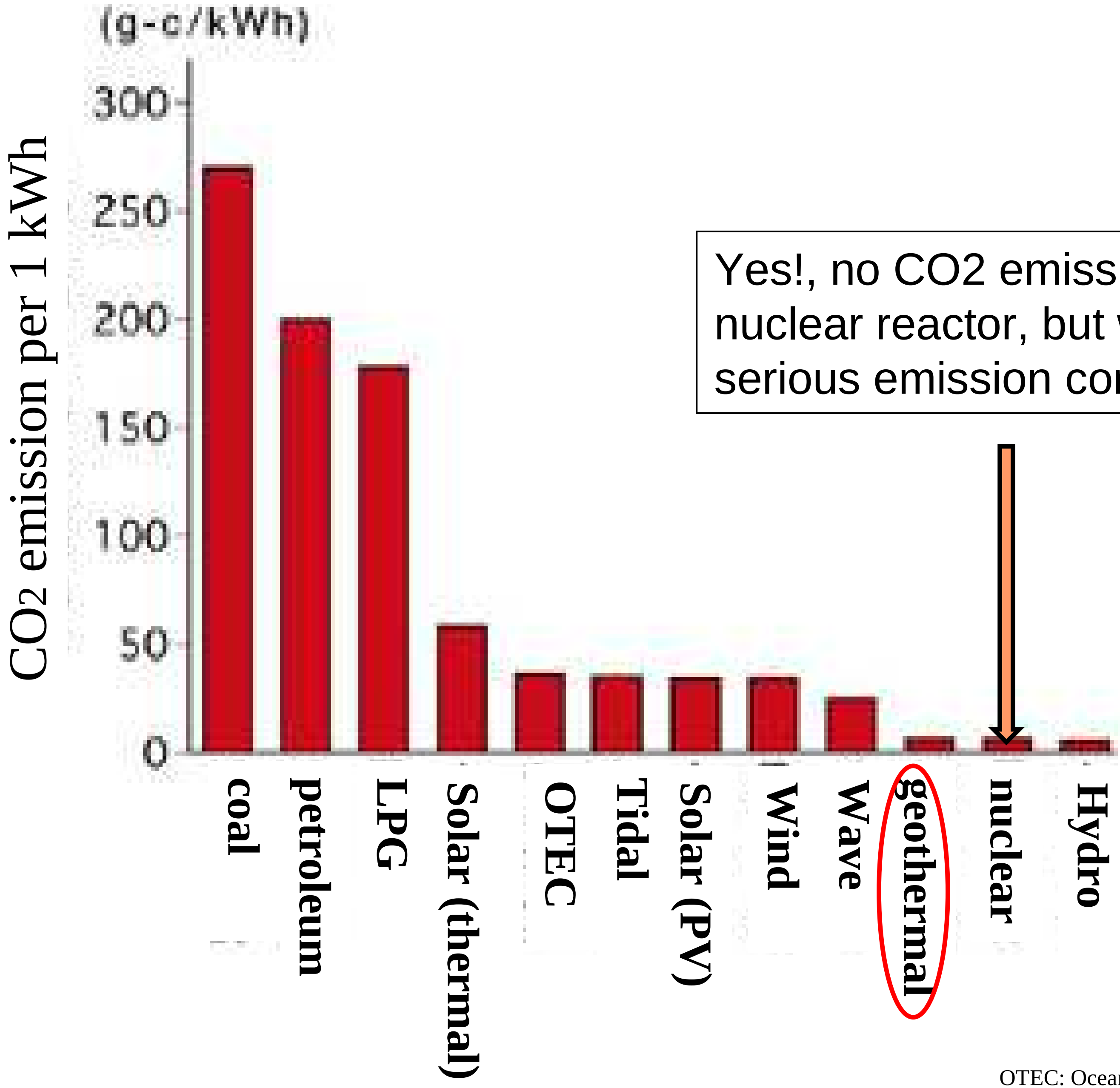


Annual total duration of Sunshine

Distribution of Hydrothermal potential more than 53℃


Geothermal power plants in Japan
Power generated by
Electric power company
Private company
① Mori, 50 MWe, 1982
② Onuma, 9.5 MWe, 1974
③ Sumikawa, 50 MWe, 1995
④ Matsukawa, 23.5 MWe, 1966
⑤ Kakkonda 1&2, 80 MWe, 1978, 1995
⑥ Uenotai, 28.8 MWe, 1994
⑦ Onikobe, 15 MWe, 1975
⑧ Yanaizu-Nishiyama, 65 MWe, 1995
⑨ Hachijo-jima, 3.3 MWe, 1999
⑩ Suginoi, 1.9 MWe, 1981
⑪ Takigami, 25 MWe, 1996
⑫ Otake, 12.5 MWe, 1967
⑬ Hatchobaru #1&2, binary, 112 MWe, 1977, 1990, 2006
⑭ Kuju, 0.99 MWe, 1998
⑮ Takenoyu, 0.1 MWe, 1991 (closed)
⑯ Kirishima-kokuksai, 0.1 MWe, 1984 (currently stopped)
⑰ Ogiri, 30 MWe, 1996
⑱ Yamagawa, 30 MWe, 1995

CO_2 emission

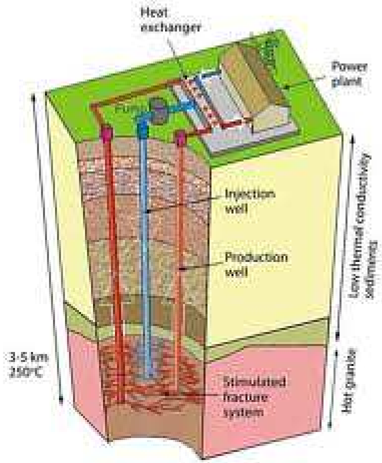


Yes!, no CO2 emission from nuclear reactor, but we know serious emission comes out!

OTEC: Ocean Thermal Energy Conversion

Geothermal Power Plant in the world

Cooper Basin
Hot Dry Rock



GPP is not only active continental margin,
Granite is heat source.

Electricity

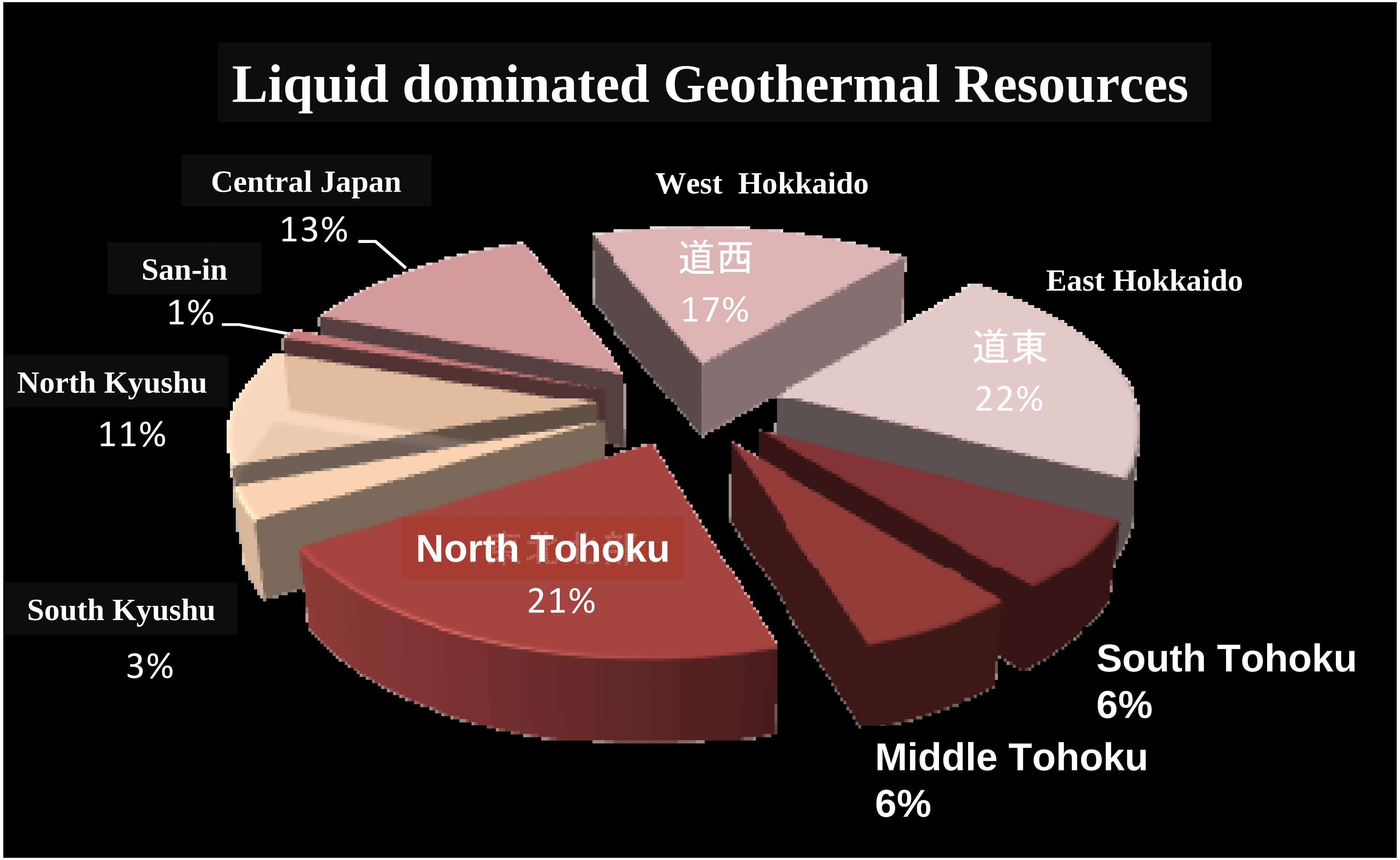
USA	16.6
Philippine	10.3
Indonesia	9.6
Mexico	7.0
Italy	5.5
Iceland	4.6
New Zealand	4.1
JAPAN	3.1
Kenya	1.4
El salvador	1.4
24 countries	67.2
	GWe

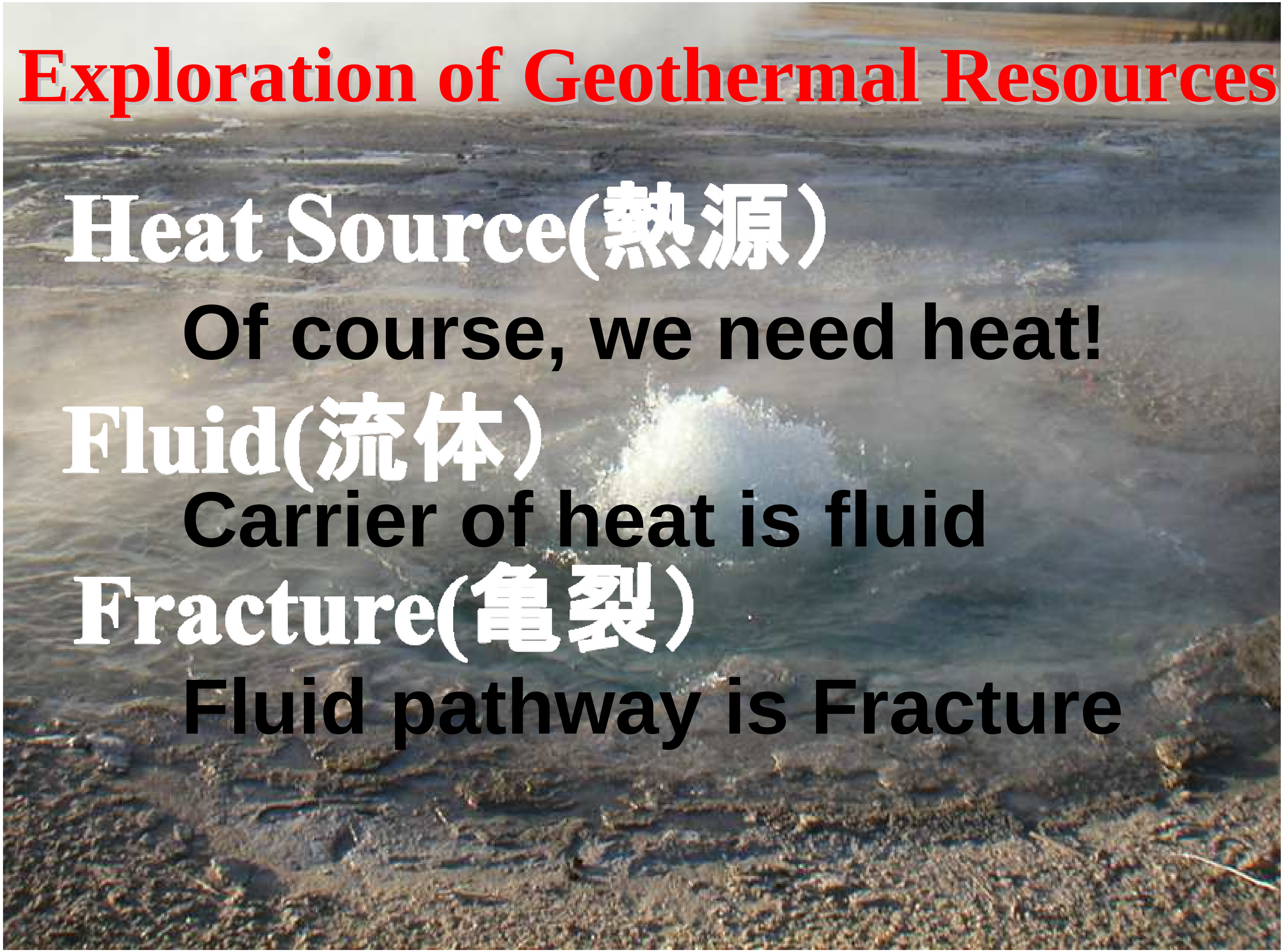
Direct Use

China	74.2
USA	56.5
Sweden	45.4
Turkey	36.7
JAPAN	25.6
Norway	25.2
Iceland	24.4
France	13.0
Germany	12.8
Holland	10.7
（78 countries）	438
	GWth

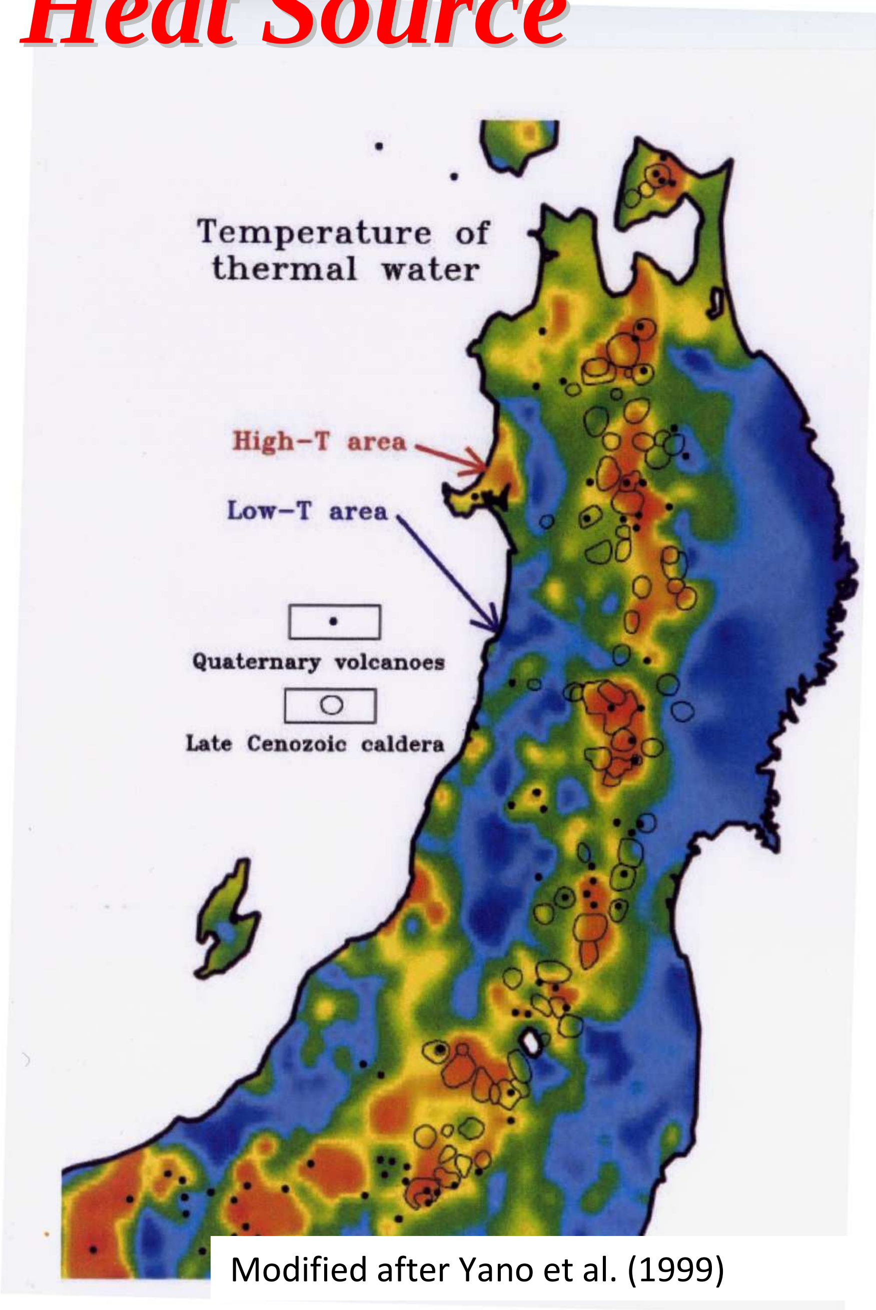
WGC 2010

Conventional geothermal resources **43% in Tohoku**

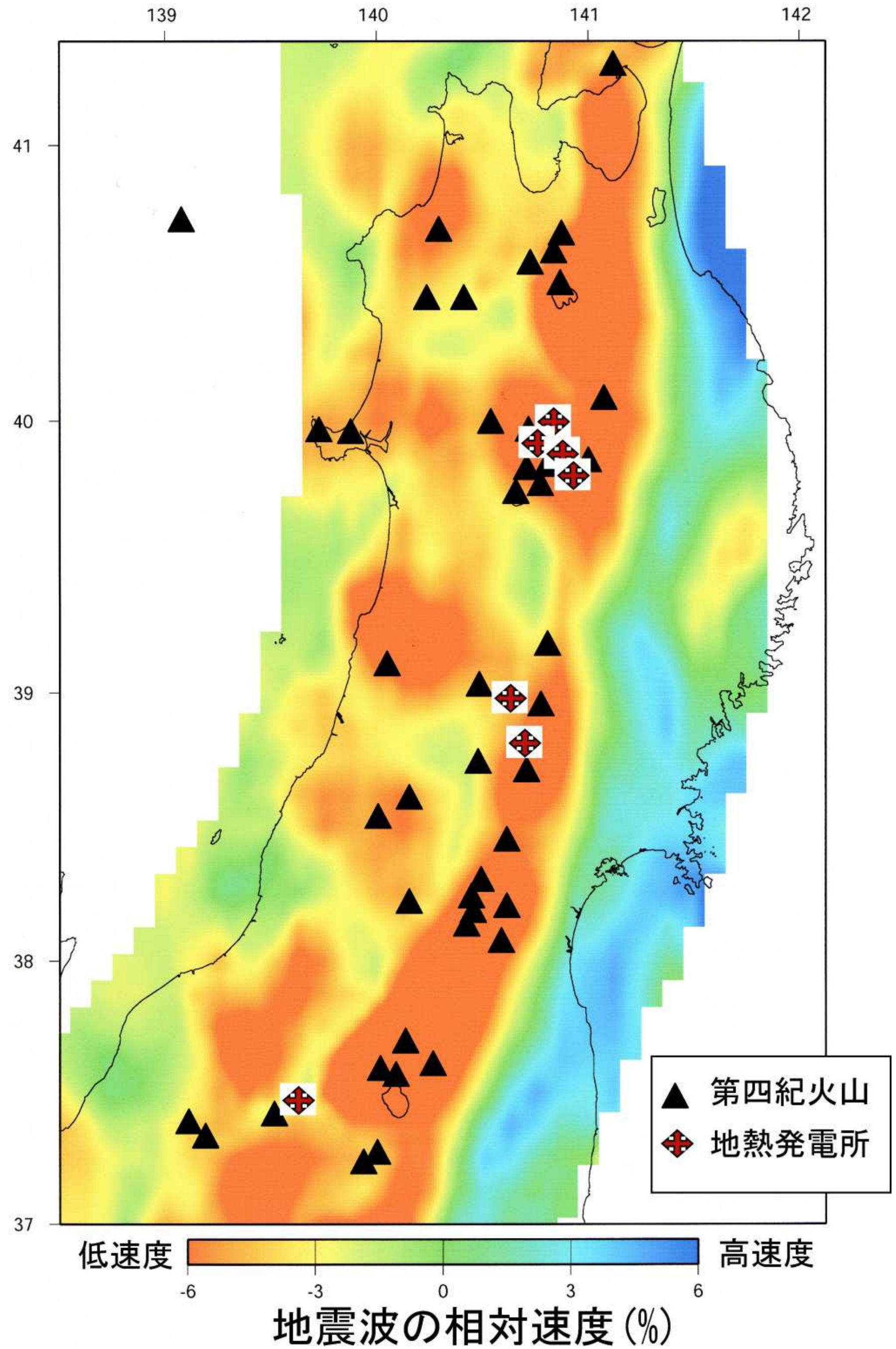



Exploration of Geothermal Resources
Heat Source(熱源）
Of course, we need heat!
Fluid(流体）
Carrier of heat is fluid
Fracture(亀裂）
Fluid pathway is Fracture

Heat Source

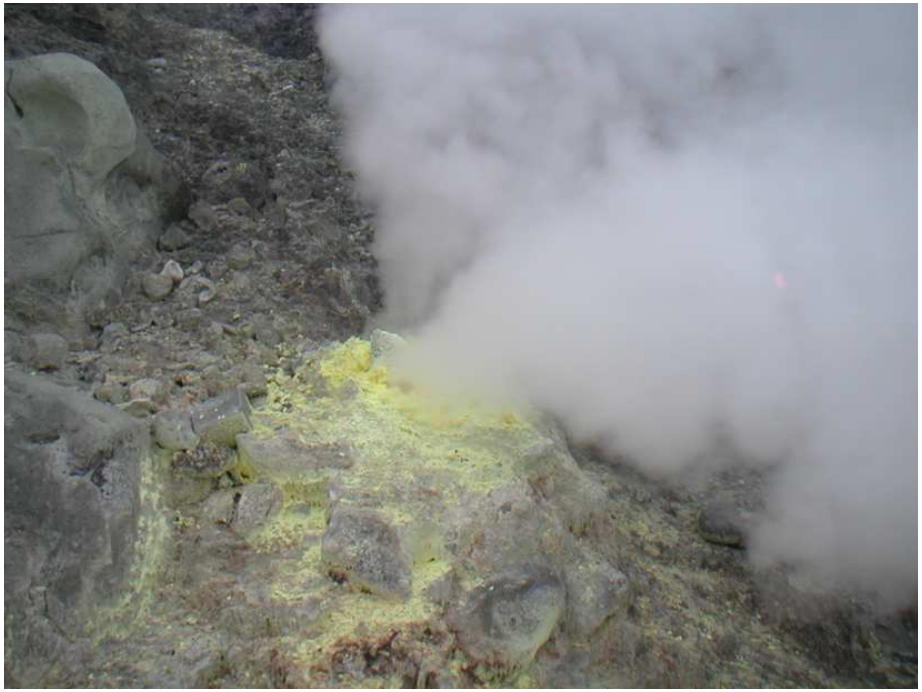


Modified after Yano et al. (1999)



Modified after Hasegawa and Nakajima(2004)

Geothermal Fluid



Chemical Reactions

Dissolution

Precipitation

Equilibrium

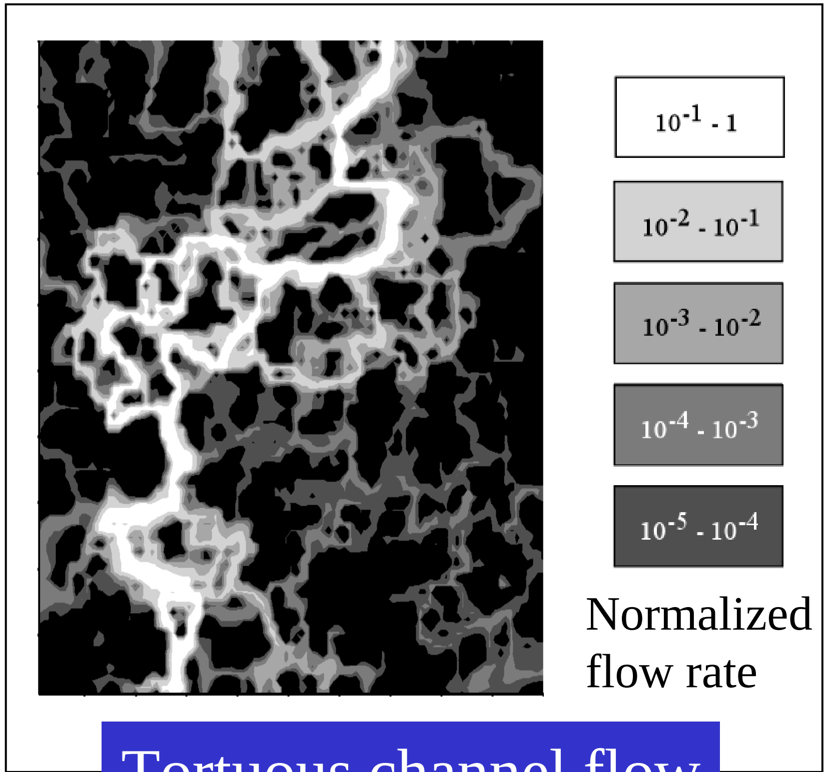
Kinetics

State of Equation

……..

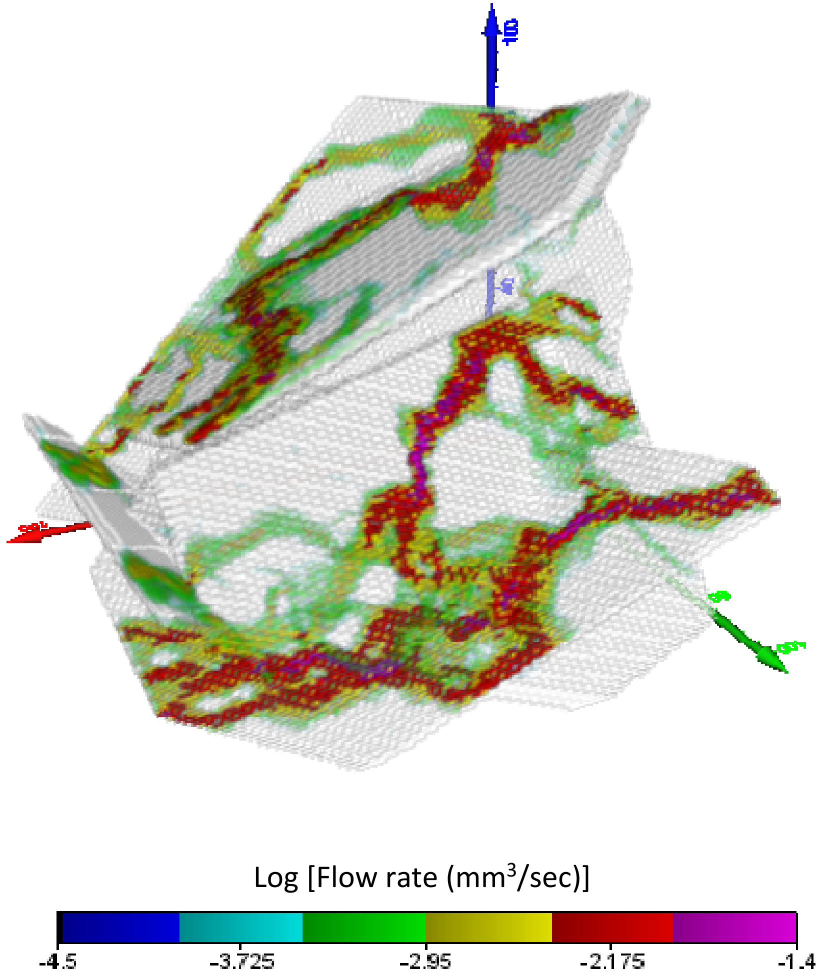
Fluid flow through *Fracture*

Preference (Channeling) Flow



Tortuous channel flow

3D model



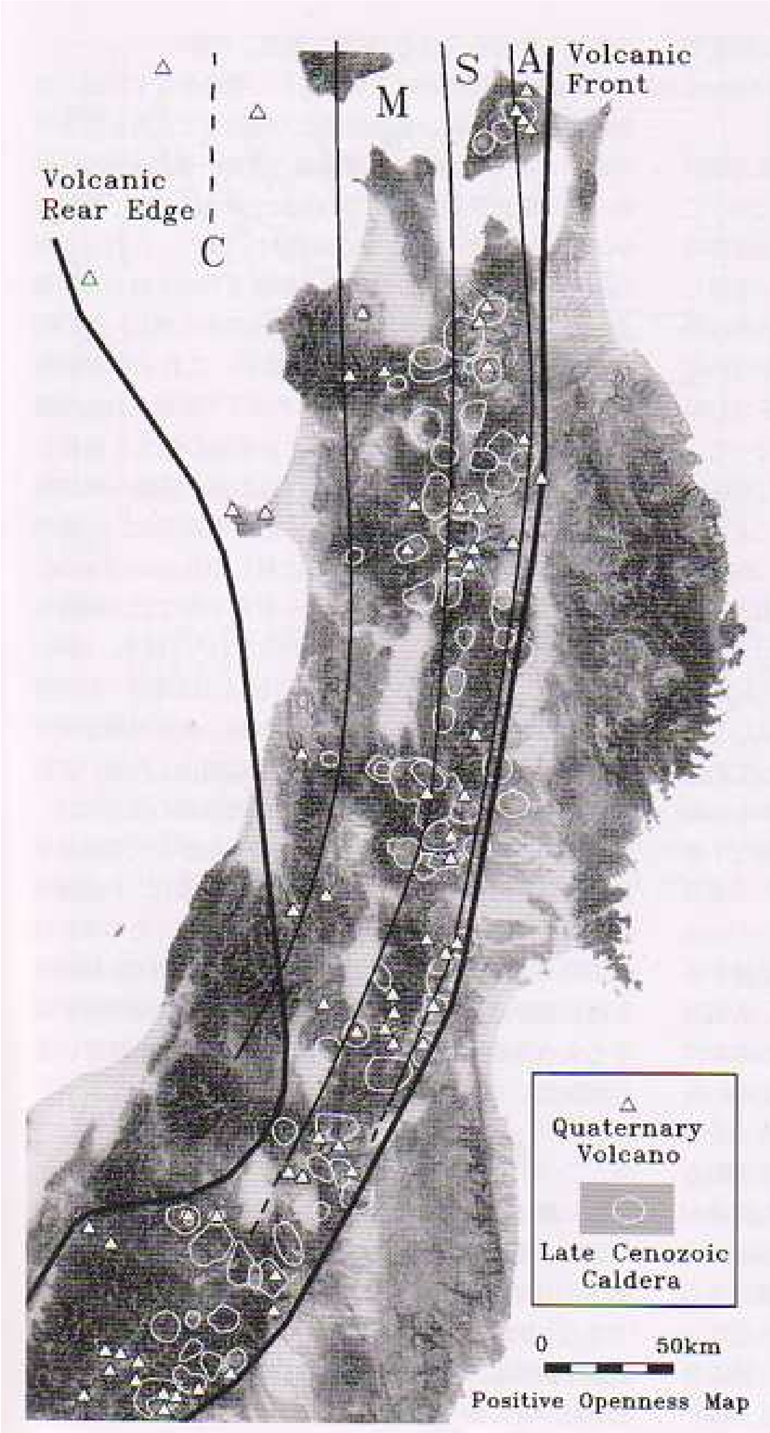
八丁原地熱発電所 Hacchobaru GPP in Kyushu

Table 1. Long-term power density achieved in some exploited geothermal fields (after Grant, 1996).

Field	Area (km^2)	MWe	MWe/km^2	Reservoir Temp.(°C)	
Larderello	180	400	2.2	250	**Italy**
Wairakei	15	150	10	250	**NZ**
The geysers	78	1000	13	250	**USA**
Ahuachapan	7	45	7	240	**El Salvador**
Tiwi	13	240	18	280	**Philippine**
Hatchobaru	3	110	37	260	**Japan**

Japan: Area is small, but density is great.

(maybe Chinese Taipei is the same setting….)



Not so large,
but so many

Moderate size based on geology:

……….10–30 MWe

Caldera Structure

吉田ら(2005)

Geothermal Energy

- Issues
- Geothermal Energy Politics

Principal Four Issues

- ***High Cost***

  Very long lead time (10-15 years), and high risk development due to uncertain of subsurface

- ***National Park***

  82 % of Geothermal Resources is in National Park

- ***Coexistence with ONSEN (hot spring)***

  ONSEN owners do not necessarily like side-effects
  (worth case: decrease or worst case: exhaust of hot water)

- ***Induced Seismicity***

  Scientifically uncertain problems, and Japanese people is now very sensitive in terms of “earthquake” and “seismic”

Principal Four Issues

- High Cost
- National Park
- Onsen
- Induced Seismicity

● *High Cost* 固定価格買取制度

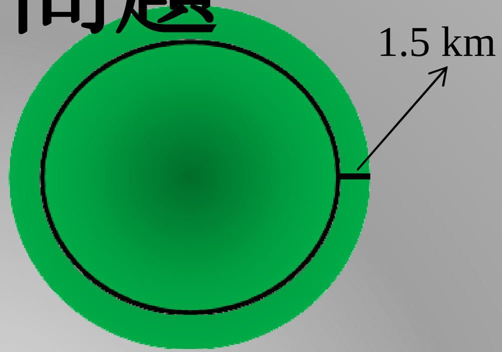
FIT: Feed-in Tariff

		JPY/1 kWh	NT$ / 1kWh	Duration
PV	< 10 kW	42	13.13	10 yr
	≧ 10 kW	42	13.13	20 yr
Wind	< 20 kW	57.75	18.05	20 yr
	≧20 KW	23.1	7.22	20 yr
Geothermal	< 15 MW	42	13.13	15 yr
	≧ 15MW	27.3	8.53	15 yr
small scale Hydro	< 200 kW	35.7	11.16	20 yr
	200 - 1000 kW	30.45	9.52	20 yr
	1000 - 30,000 kW	25.2	7.88	20 yr
Biomass	several resources	17.85 - 40.95	5 - 12	20 yr

1 NTD = 3.2 JPY

National Park 国立公園問題

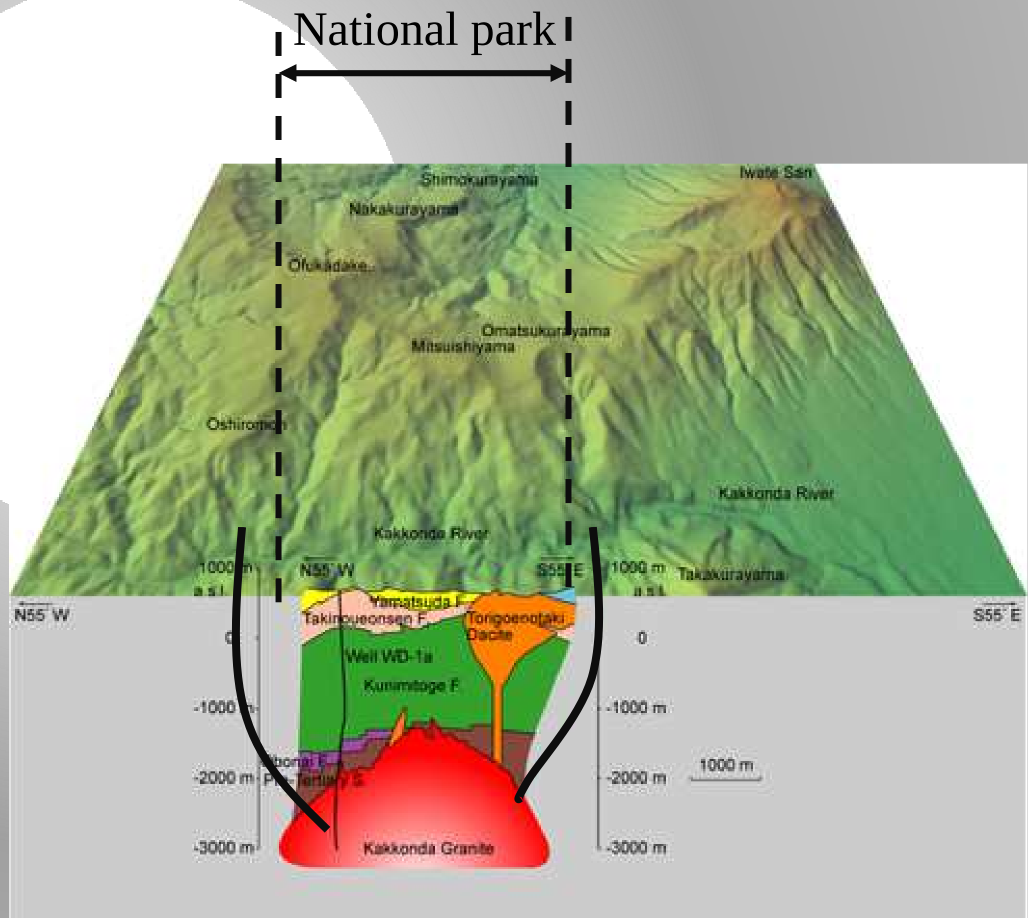
Ministry of Environment permitted geothermal development in National Park after 3.11



Incline drilling from outside of national park

and/or

Small scale (<3 MW) plant is available.



We love ONSEN(温泉）

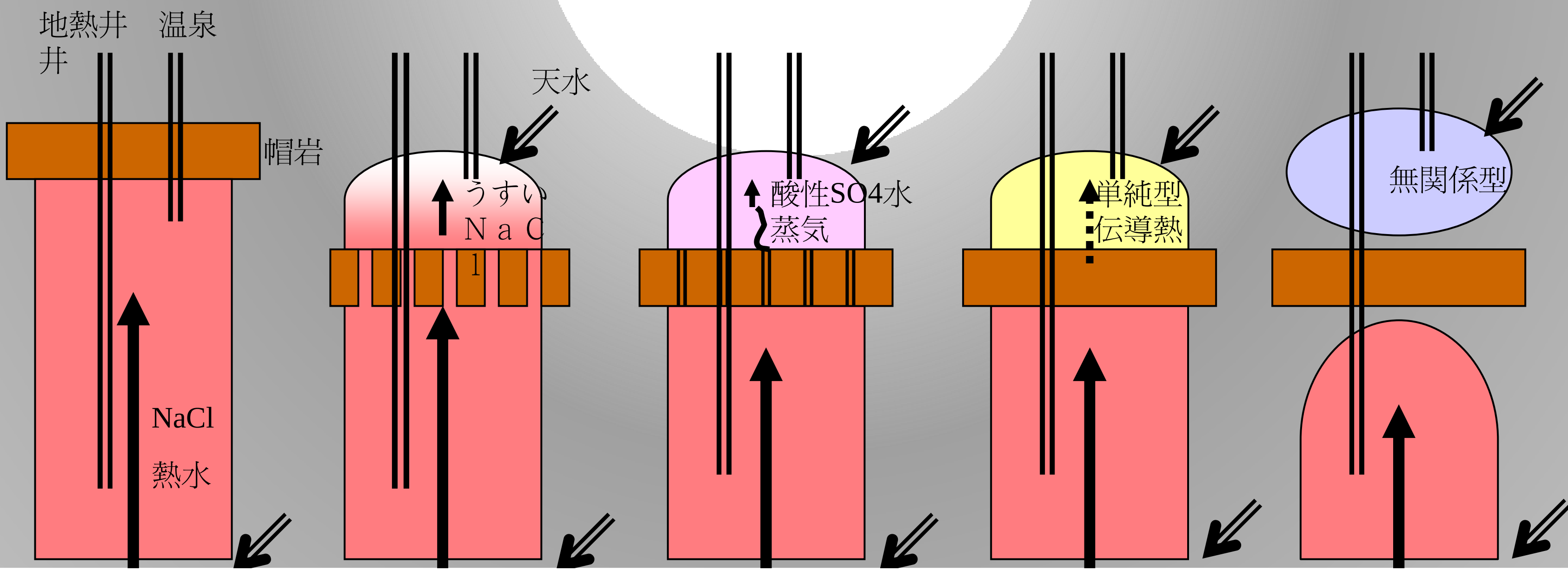
Coexistence with ONSEN (hot spring)

ONSEN power generation (100-300 kW):

powered by low temperature (< 100℃）hot water

ONSEN owners have economical benefit
(save energy and save money)

Science base assessment

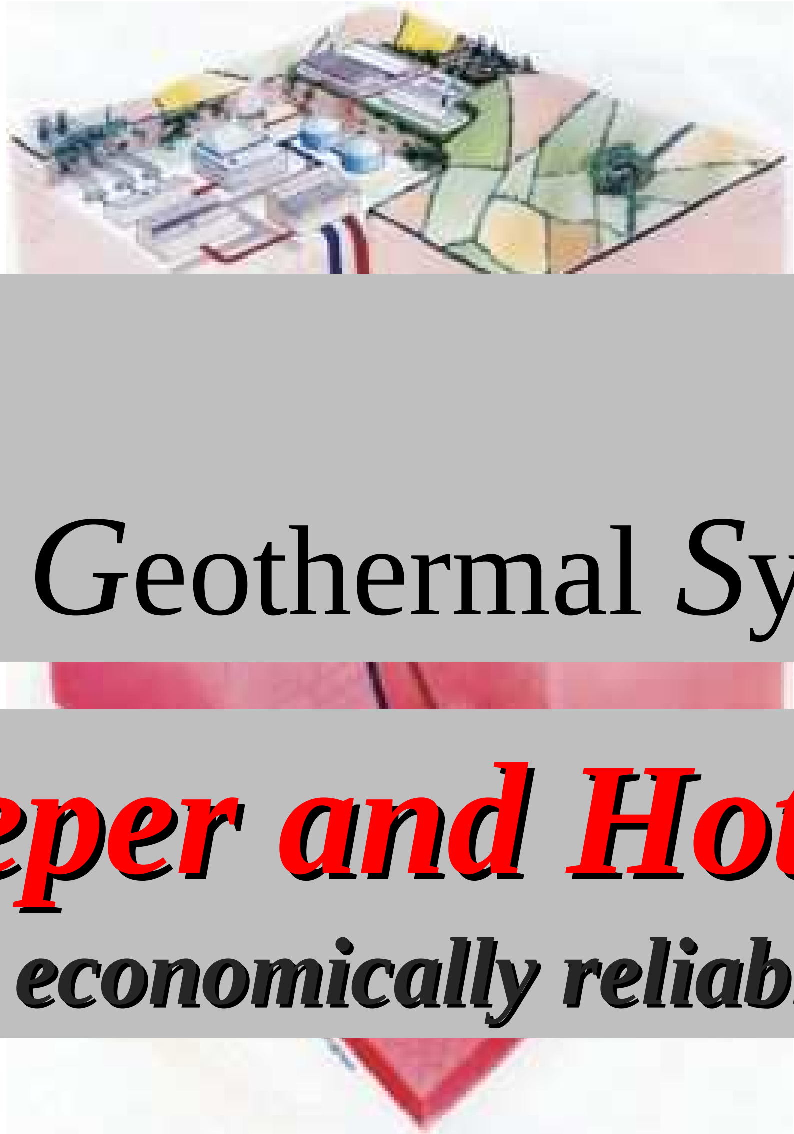


Principal Four Issues

- **Feed-In Tariff**
- **Environmentally Friendly Techniques**
- **Several activities**
- **New Research Needed**

東北地方地熱資源開発可能出力 検討地域


JBBP
Japan Beyond Brittle Project

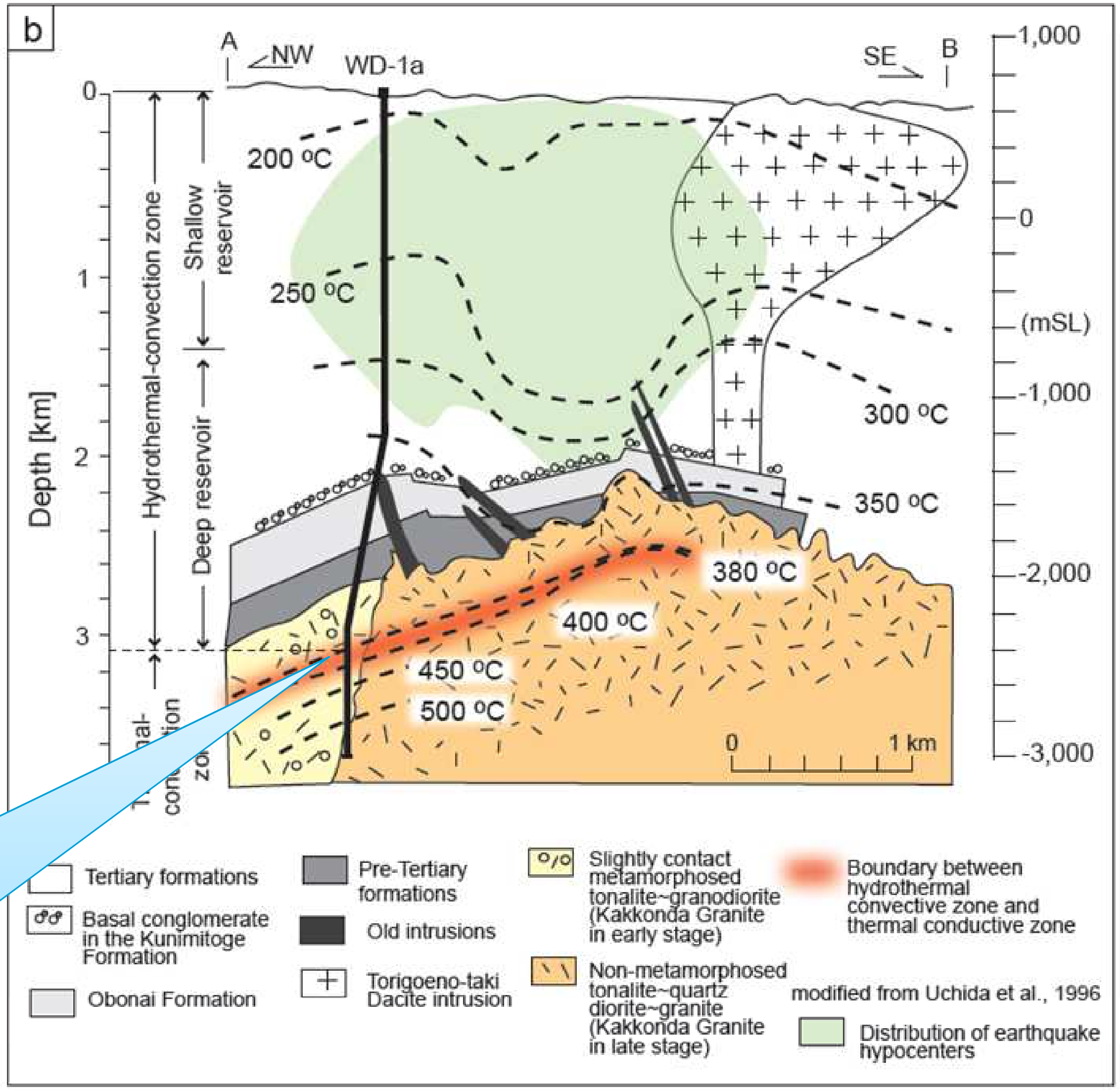


EGS

*E*nhanced *G*eothermal *S*ystem

Deeper and Hotter

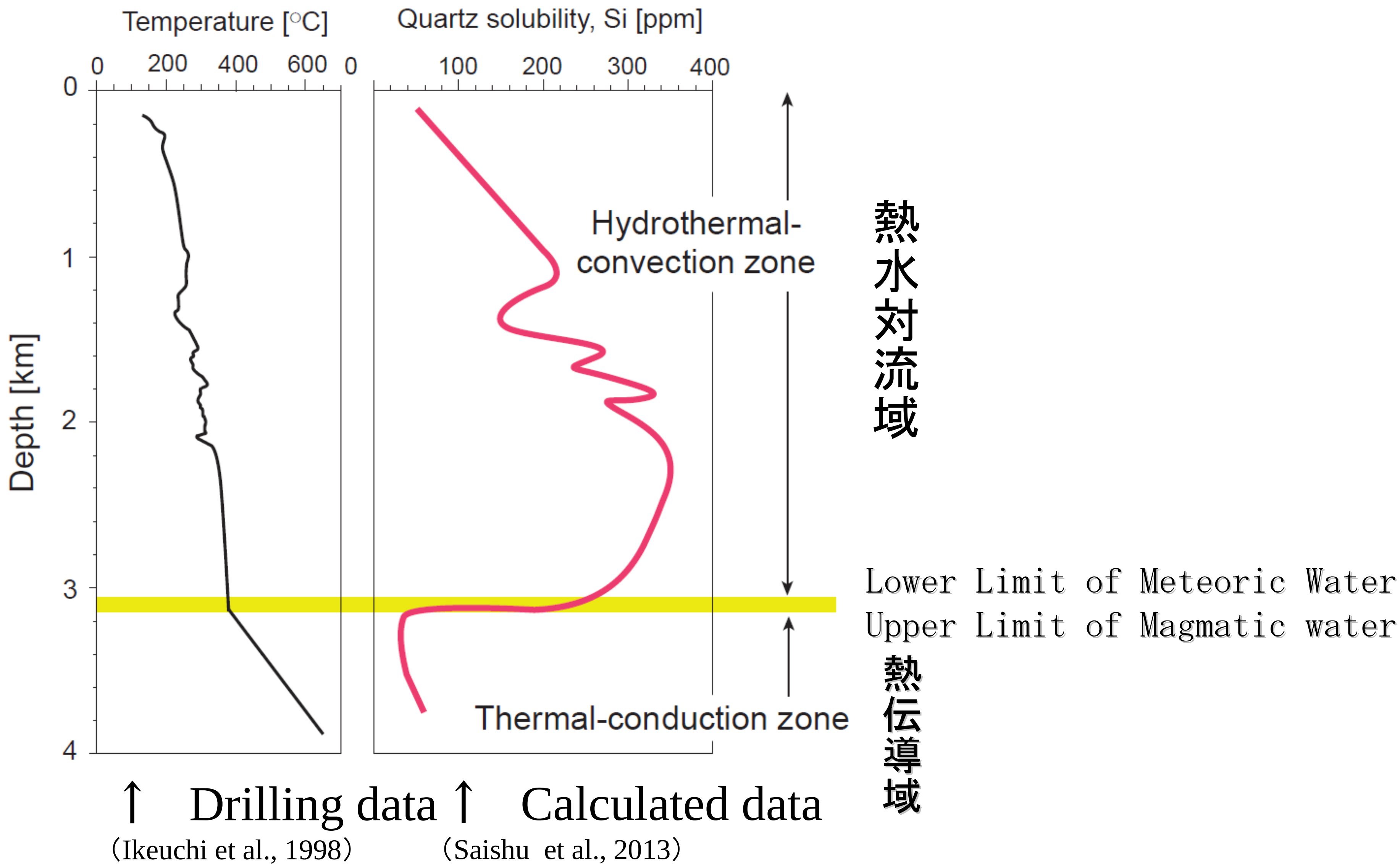
with economically reliability



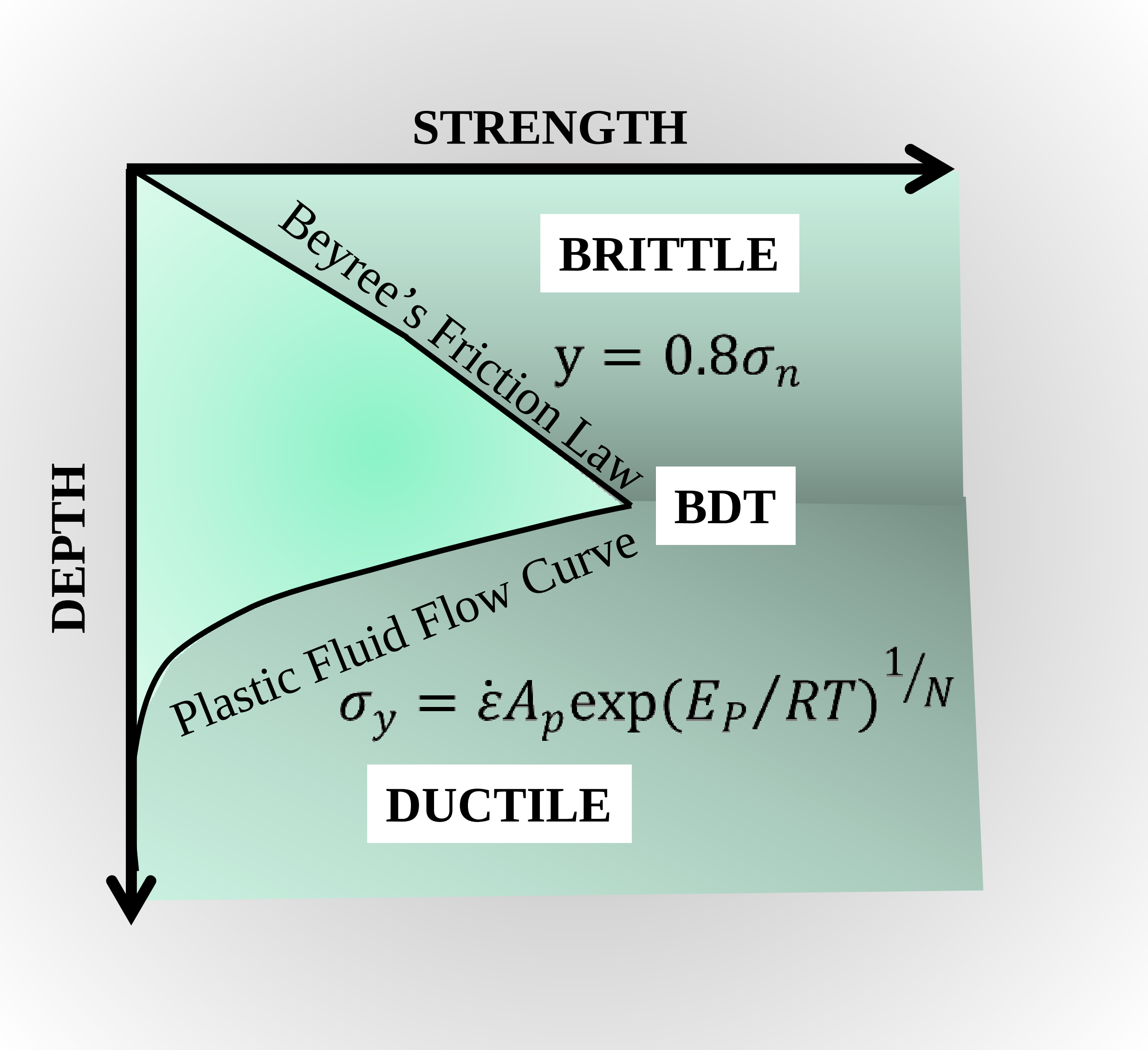
The well WD-1a

Drilling over the boundary of hydrothermal-convection zone and heat conduction zone (380 °C, 24 MPa)

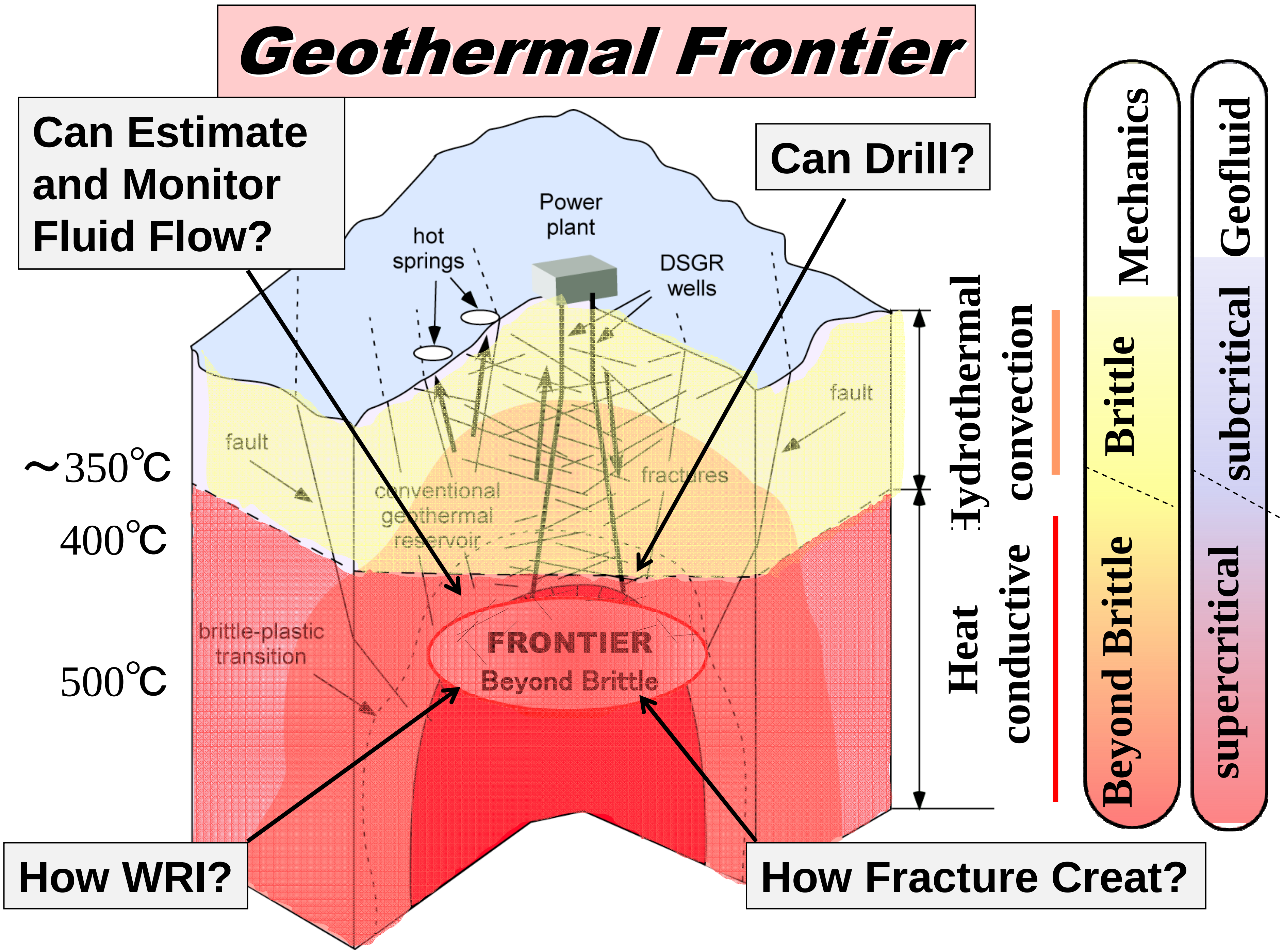
Permeability gap in the Earth's crust



Classical Definition of B-BDT-D



Kohlstedt (1980), Kirby (1980)



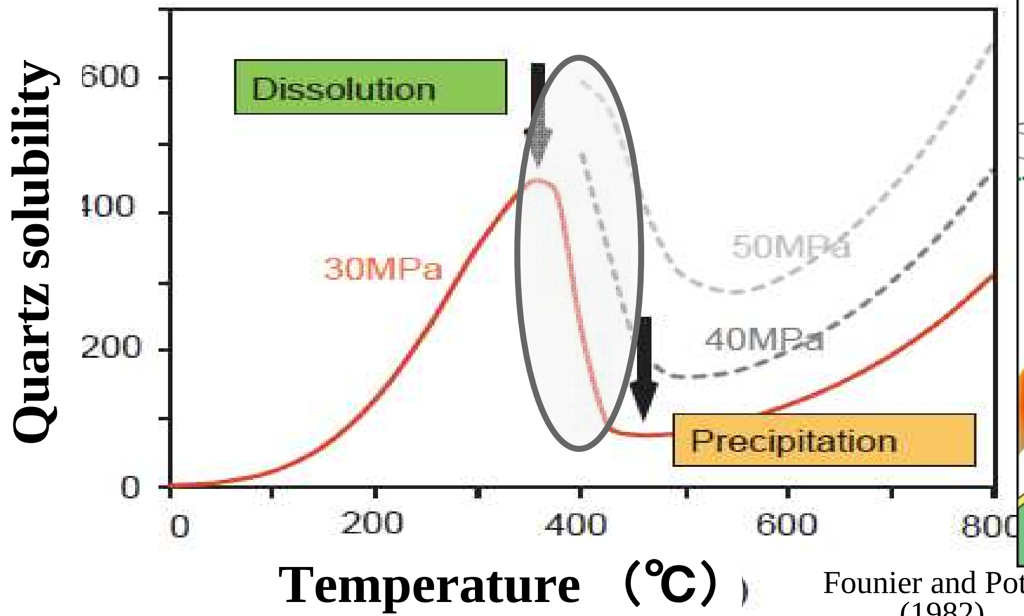
Geothermal Frontier
Can Estimate and Monitor Fluid Flow?
Can Drill?
Power plant
hot springs
DSGR wells
fault
fault
fractures
conventional geothermal reservoir
~350℃
400℃
500℃
brittle-plastic transition
FRONTIER
Beyond Brittle
How WRI?
How Fracture Creat?
Hydrothermal convection
Heat conductive
Mechanics
Brittle
Beyond Brittle
Geofluid
subcritical
supercritical

Beyond Brittle - Estimated future

- High enthalpy (High energy extraction)
- Weal water-rock Interaction (Prohibit silica scale)
- Universal Design (Site independent design)
- Low Risk for Induced Seismicity (Ductile Rock Mass)

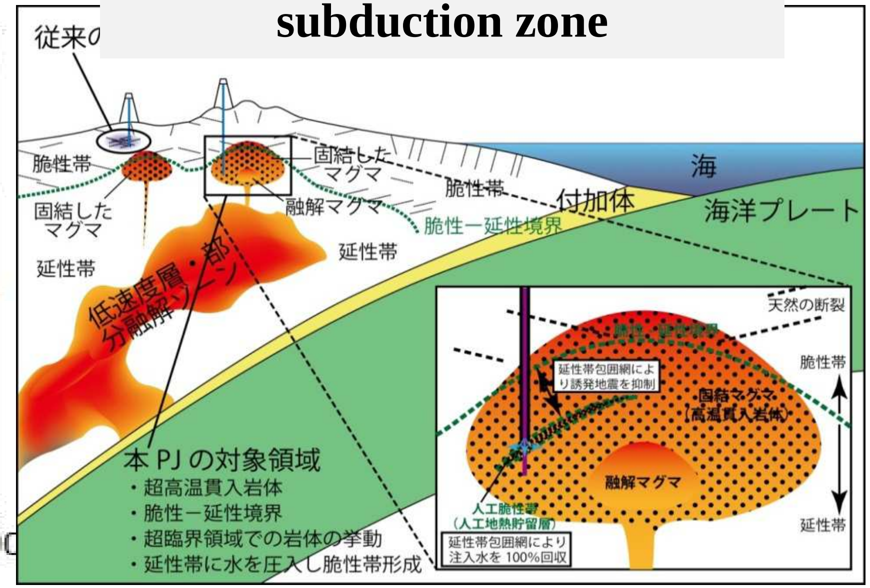
Aseismic zone due to ductile behavior

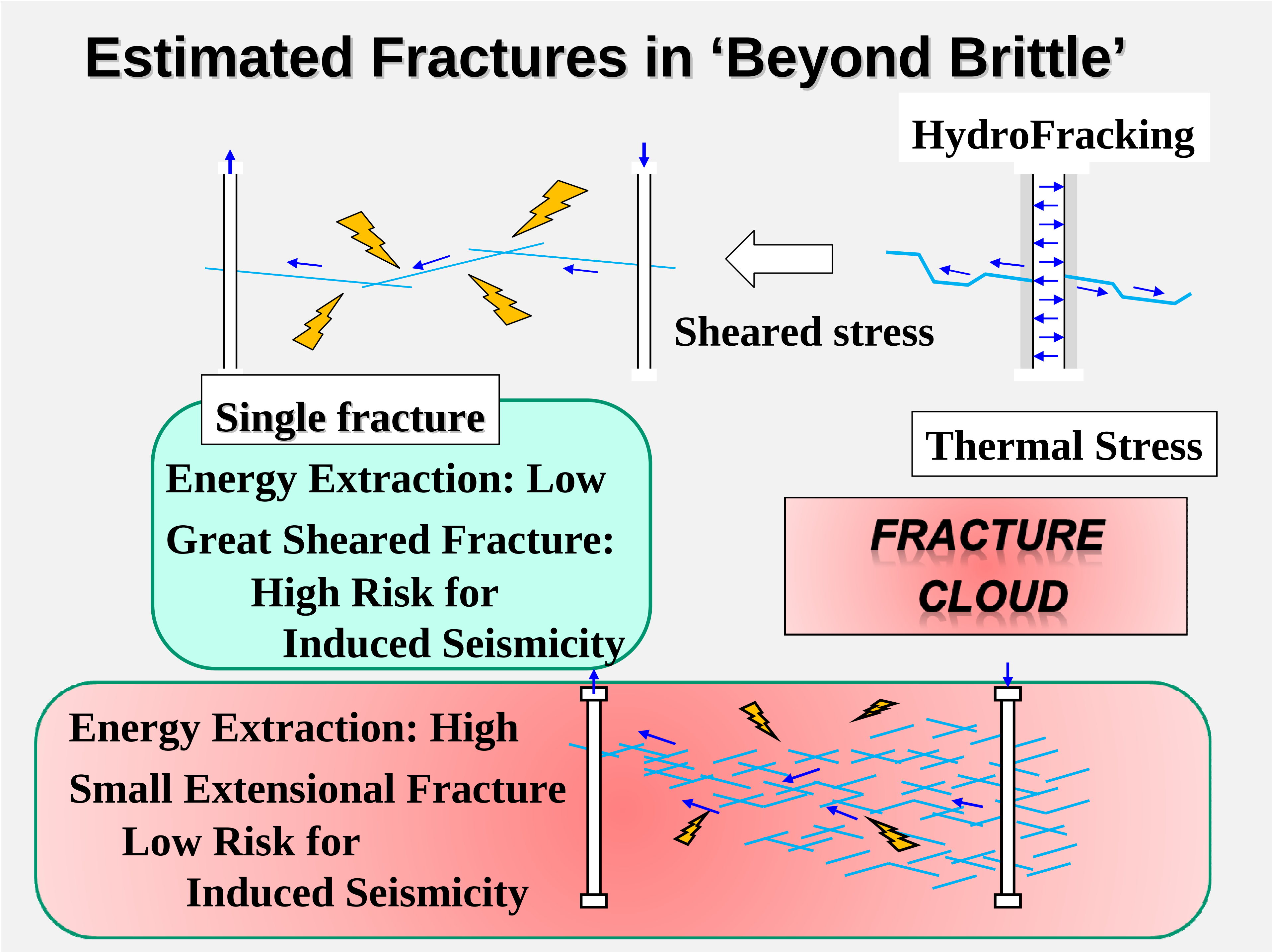
Drastic change of silica solubility in supercritical condition (380-430C)



Founier and Potter (1982)

High geotherm Island Arc and subduction zone




Estimated Fractures in 'Beyond Brittle'
HydroFracking
Sheared stress
Single fracture
Energy Extraction: Low
Great Sheared Fracture:
High Risk for
Induced Seismicity
Thermal Stress
FRACTURE
CLOUD
Energy Extraction: High
Small Extensional Fracture
Low Risk for
Induced Seismicity

12-17 March 2013
Tohoku University

International Continental Drilling Program
Japan Beyond Brittle Project

Science & Technology

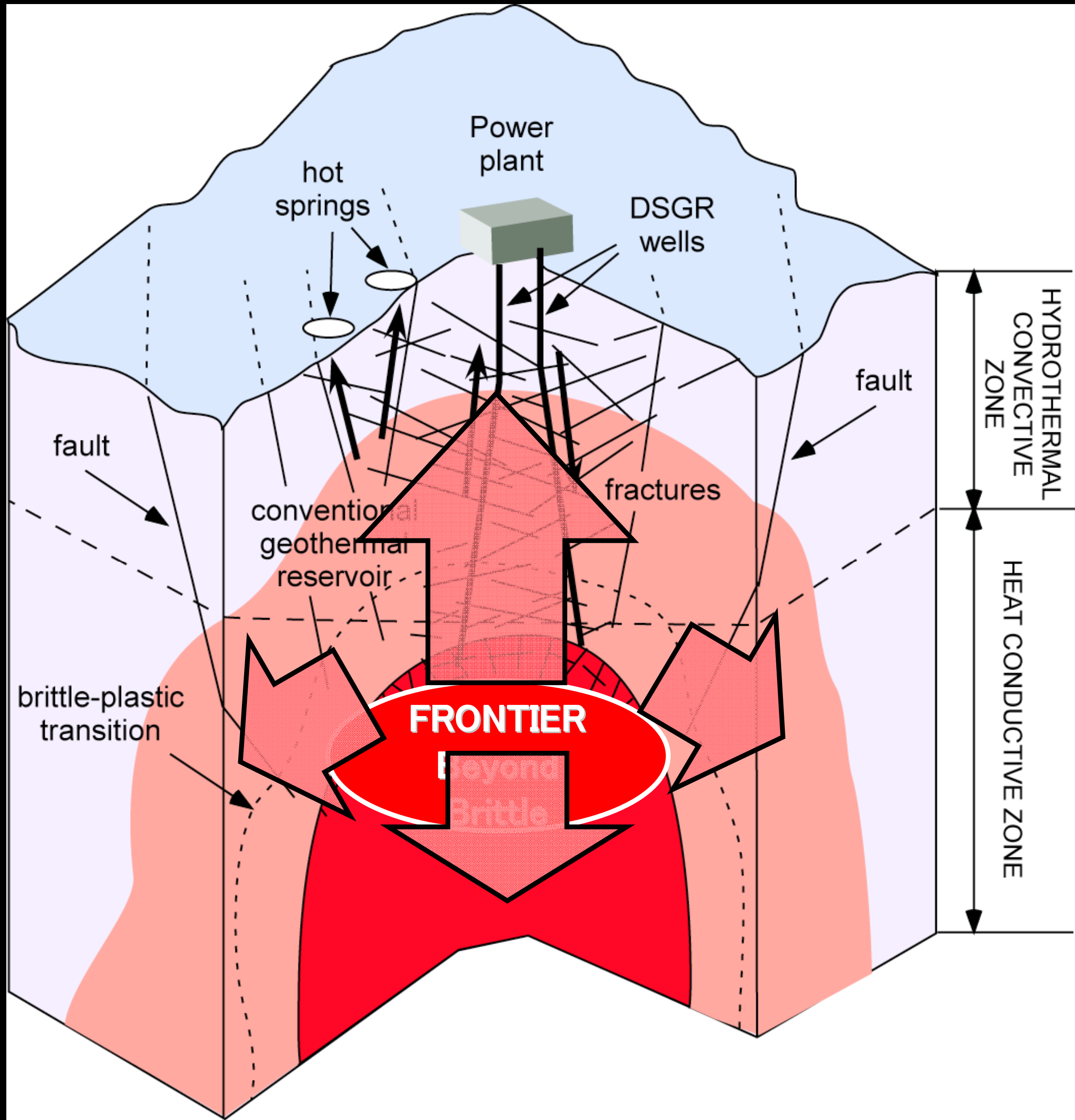
EGS:

Enhanced or

Engineered

Geothermal

System



Deep structure of Volcano

Mechanisms of Earthquake

Geothermal Frontier

Deeper Extension of Deep-Seated G.R.

Isolated Fracture Cloud in Ductile Rock Mass

Fracture Cloud

Type 1

350-400℃

- High Performance & Sustainability
- Low Silica Scale
- Cost effective

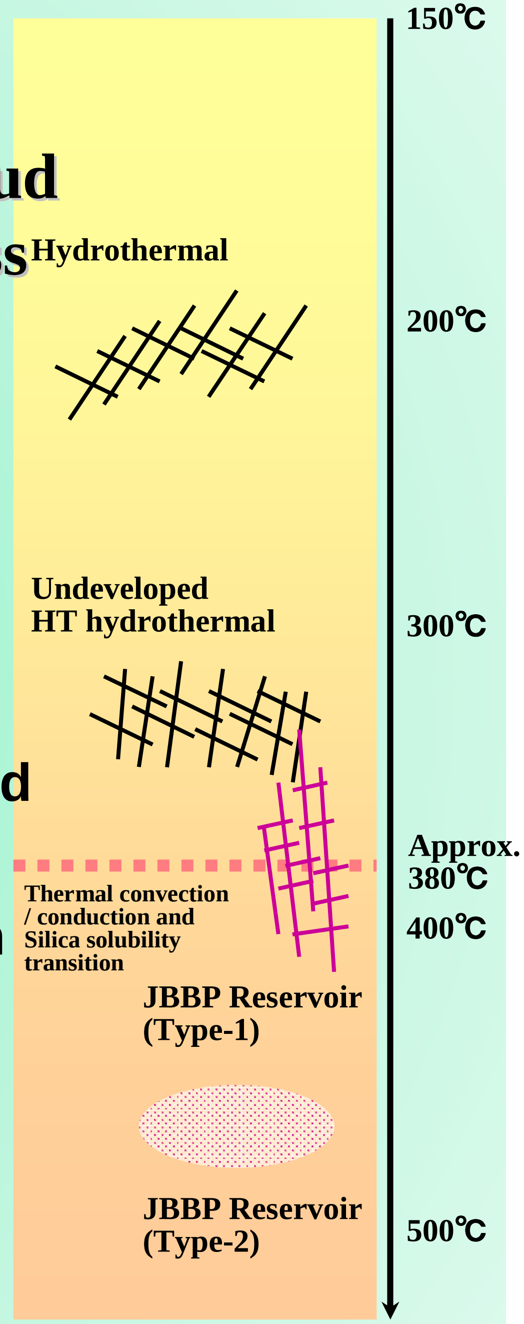
Realistic

Type 2

500℃

- High Enthalpy
- Universal Design
- Low Risk for Induced Seismicity
- Deep far from Onsen

Science Dream

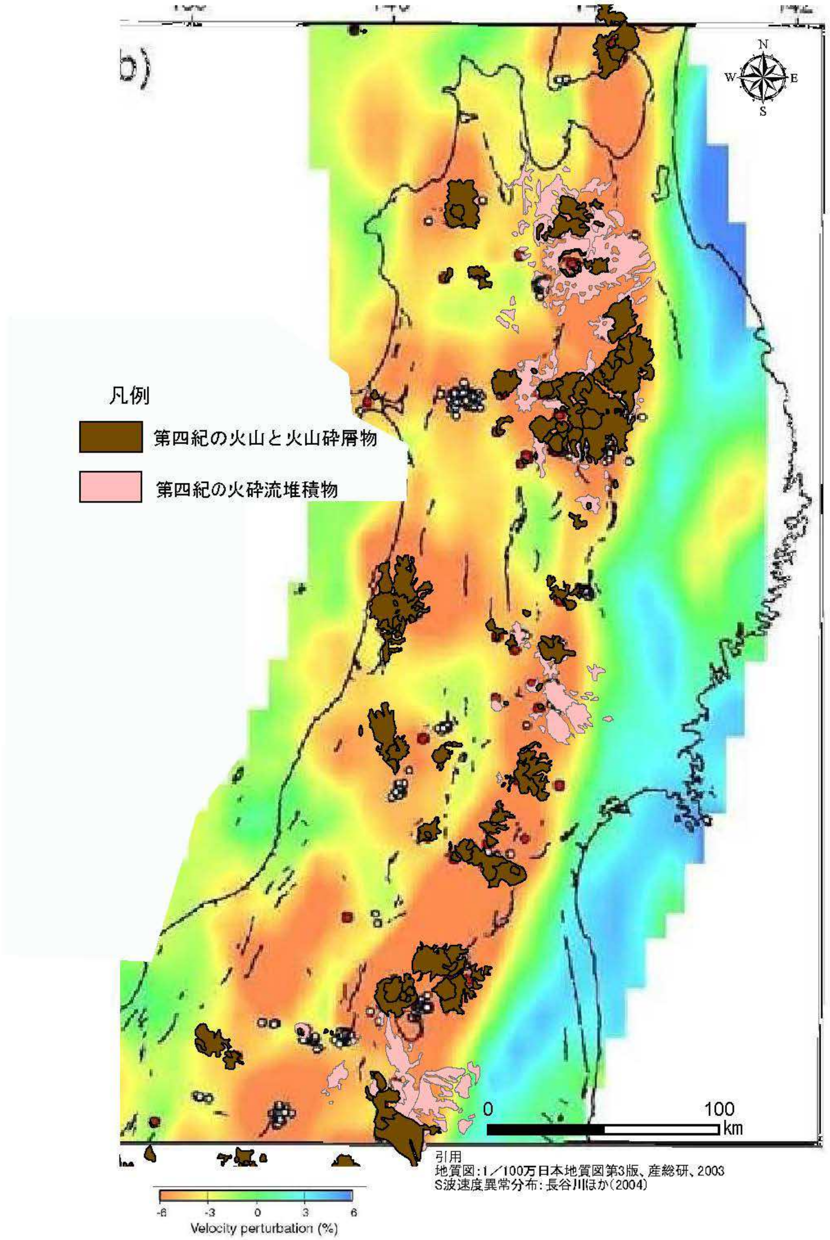


Beyond Brittle

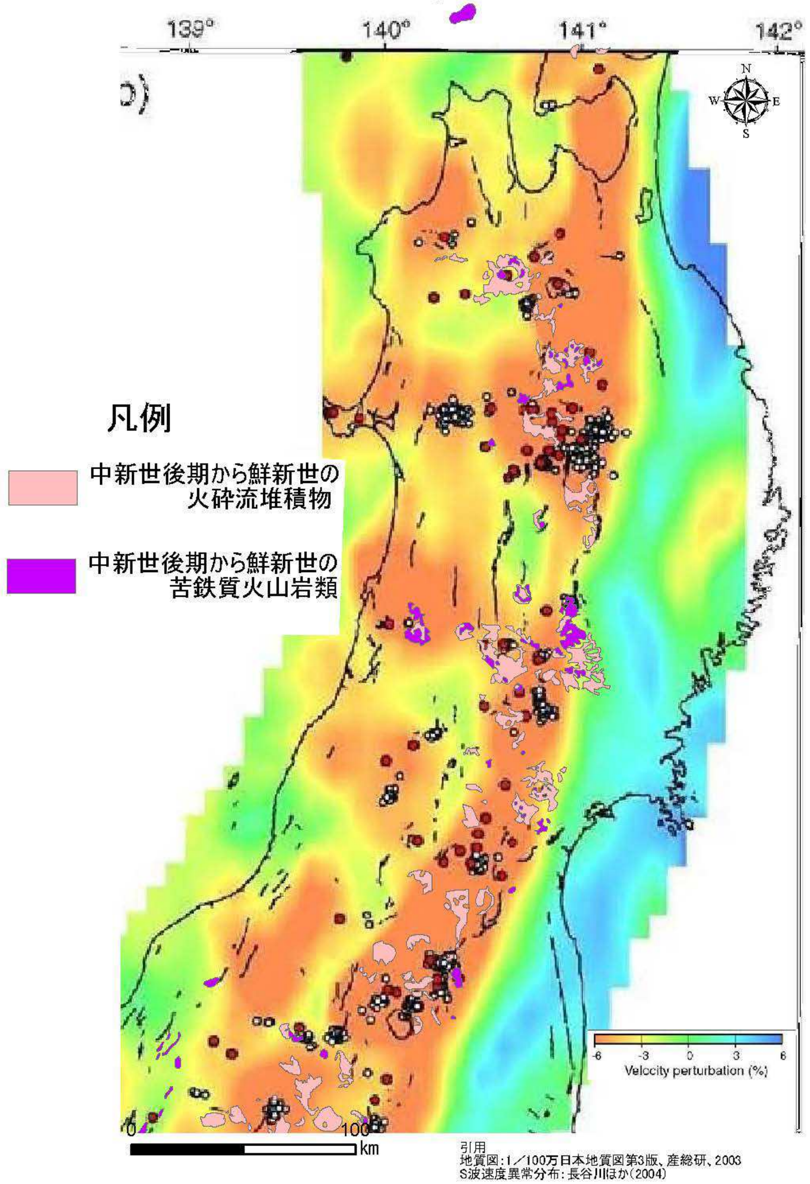

Geo thermal
地　　熱
Highly candidate
for sustainable
(safety) energy in Japan

ホットフィンガー

第四紀火山



中新世後期から鮮進世火山



日本の地熱地質の特徴

高温である

地質単元が比較的小さいが，地熱地帯は数多くある

既存地熱発電所

200℃-300℃の熱水を利用(平均250℃

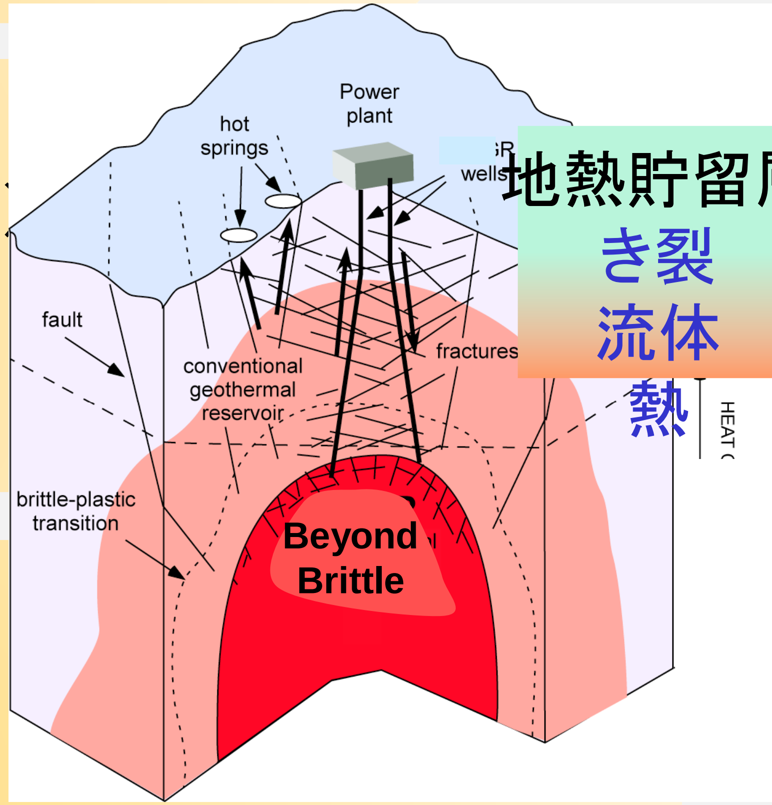
深度1000-2000 m　(平均**1500 m**)

350℃以上を使う商業井戸はない

地熱フロンティア

超臨界領域(374℃, 22MPa)

深度2500-3000 m



地熱貯留層

き裂

流体

熱

力学的には，脆性領域(Brittle)から延性(Ductile)へ遷移

BDT: Brittle Ductile Transition

フロンティアはBeyond Brittle　(脆性の向こう側)