Precise Repeat Gravity Measurement for Estimation of Mass Balance in a Geothermal Reservoir

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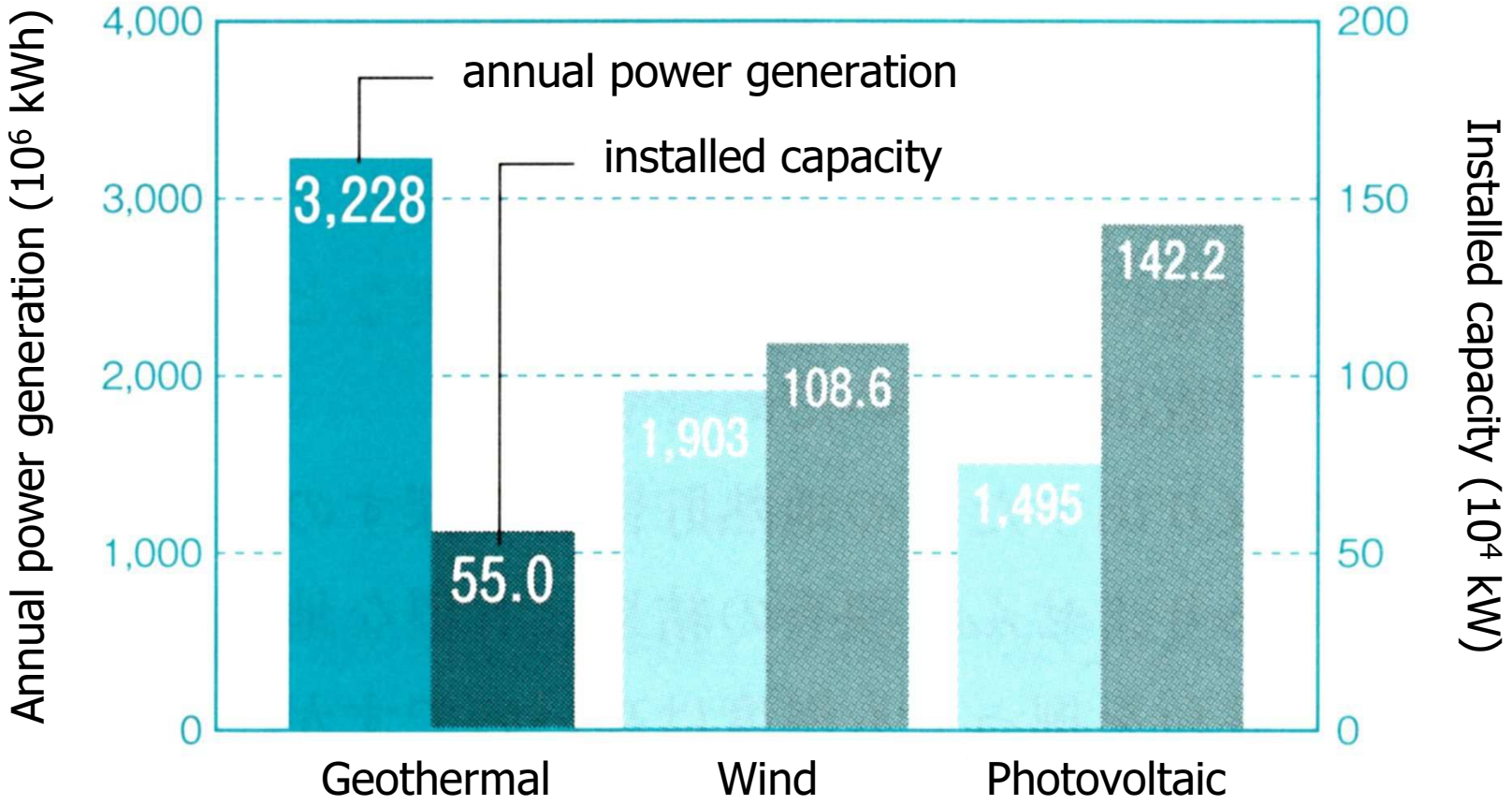
First of all …

- We really appreciate the great supports from the people of Chinese Taipei, Asian countries, and around the world for Japan, especially Tohoku Area, damaged by the Great East Japan Earthquake.

Geothermal energy for power generation

- After the Great East Japan Earthquake and the Fukushima No. 1 nuclear power plant accident, the Japanese government plans to increase the amount of renewable energy for electric power supply.
- Geothermal energy is one of the renewable energies and is more stable as a power source compared to any other natural energy like solar or wind.

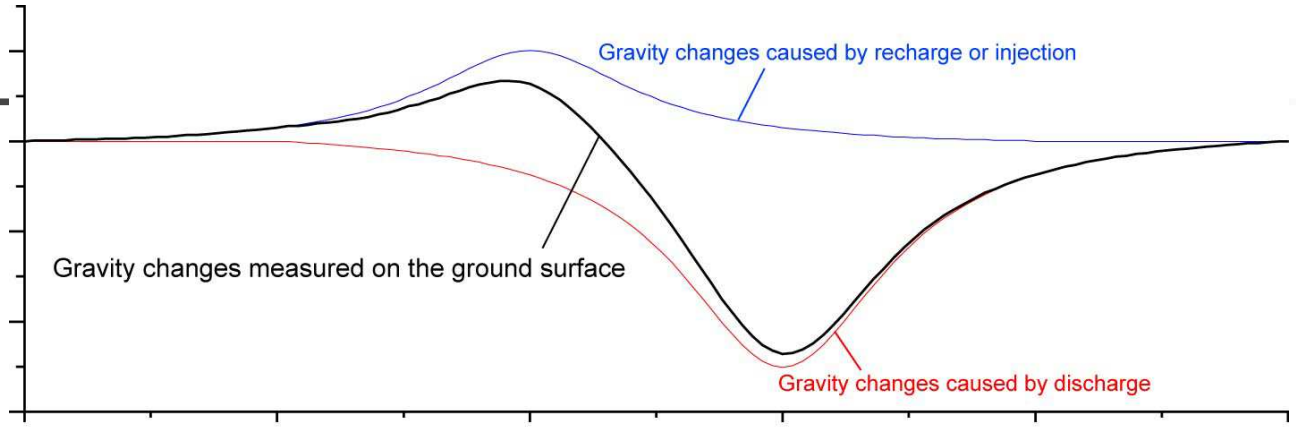
Annual power generations and installed capacities of renewable energies in 2007 in Japan

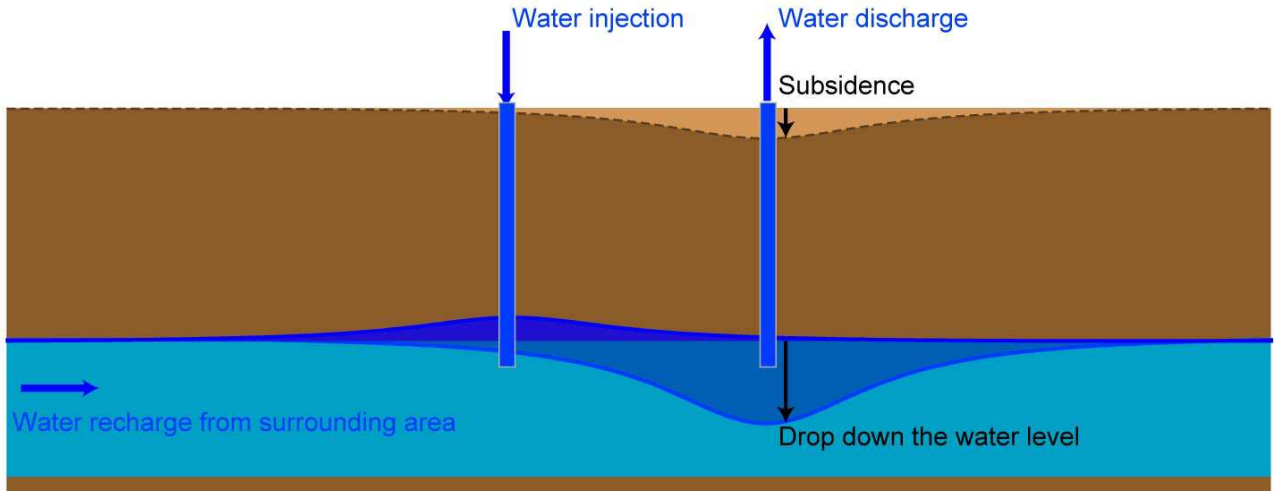


(from OHM, 2011 July)

- However, in order to ensure its sustainability, some geothermal reservoir monitoring techniques are required because a geothermal reservoir is a ‘natural’ boiler and its specification is not designed artificially.
- Precise repeat gravity measurement, which is also called as “repeat microgravity measurement”, is one of the suitable methods for geothermal reservoir monitoring.

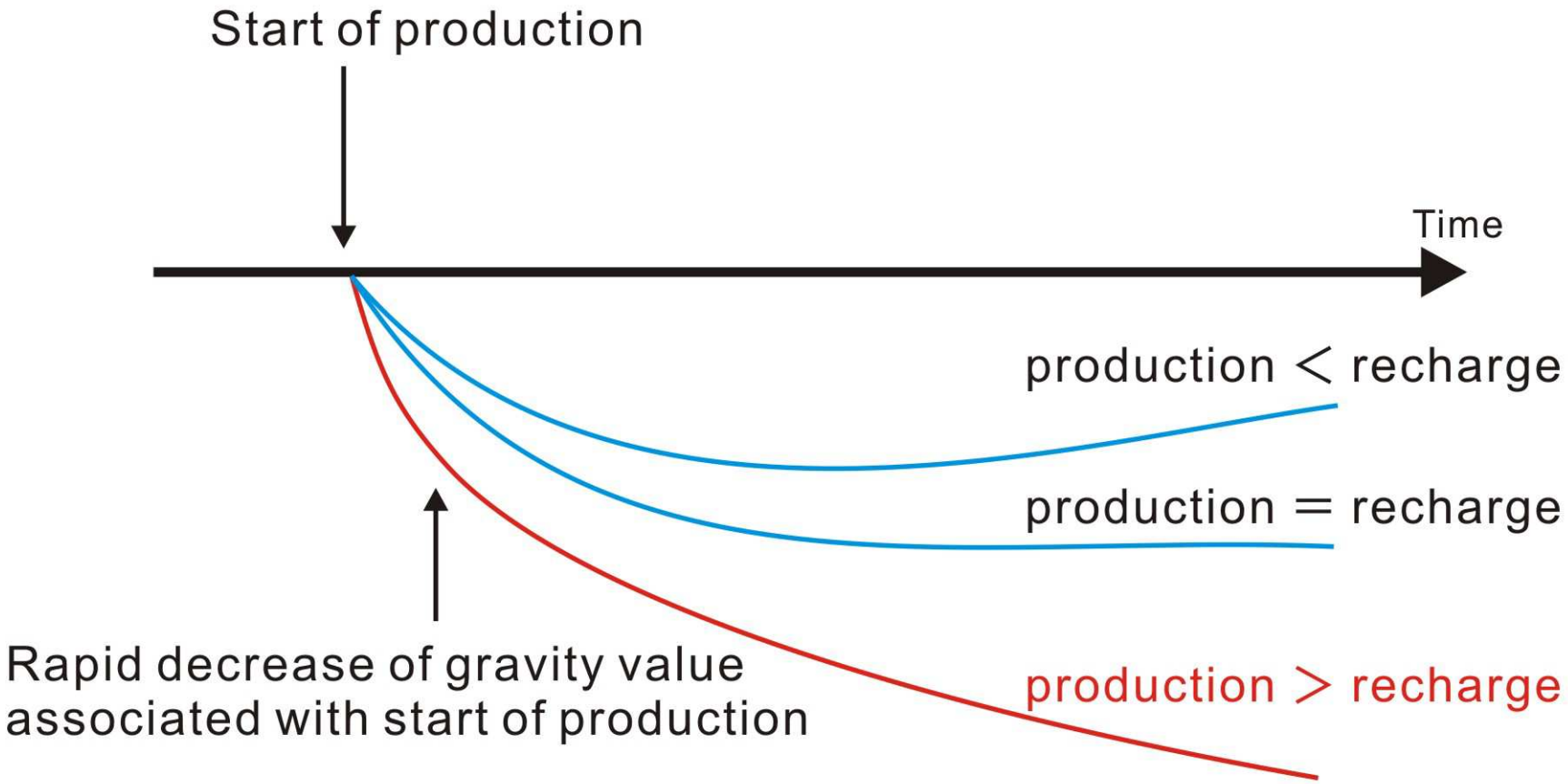
Precise repeat gravity measurement





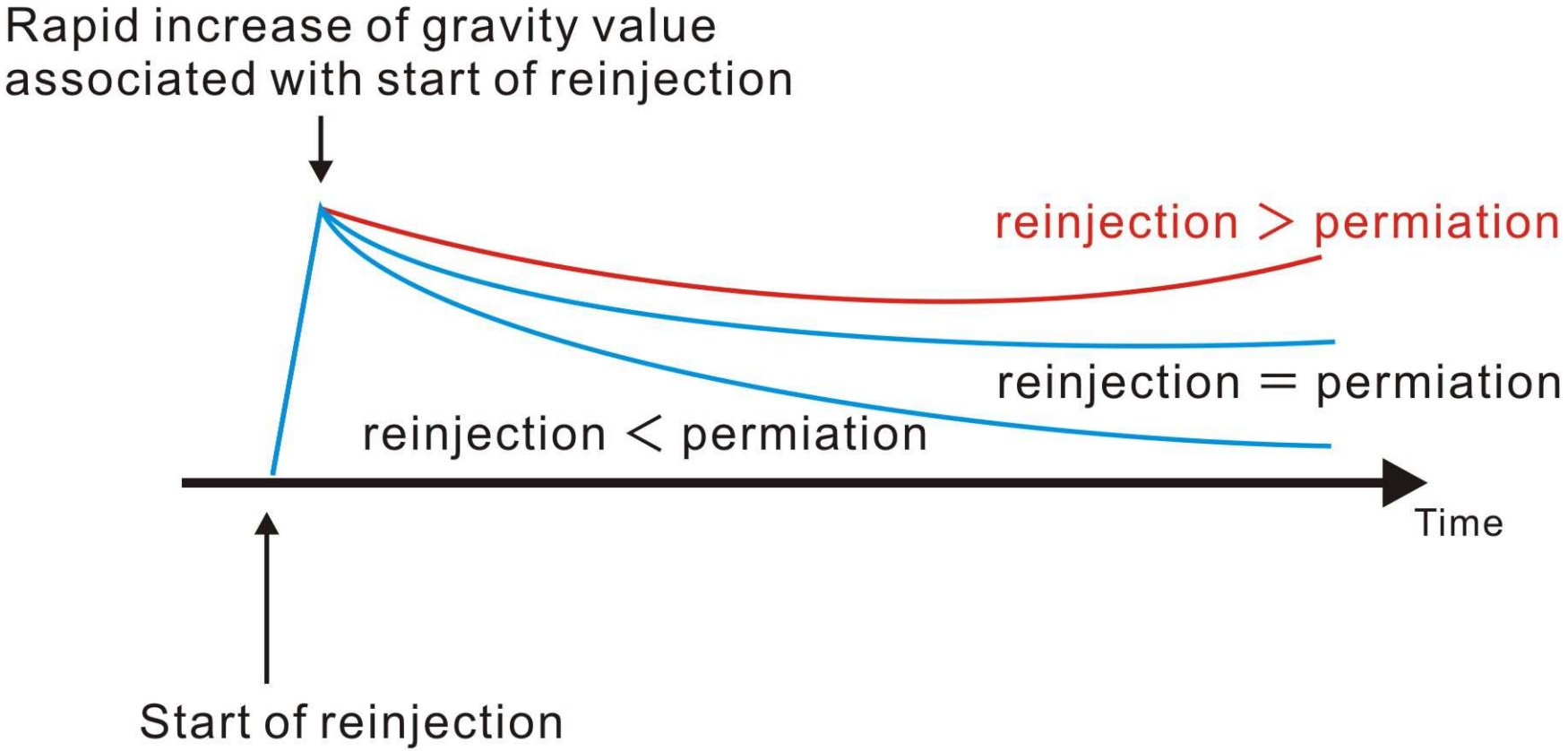
Gravity change caused by production and reinjection of geothermal fluid.

Expected gravity change



Temporal gravity change (production area)

Expected gravity change

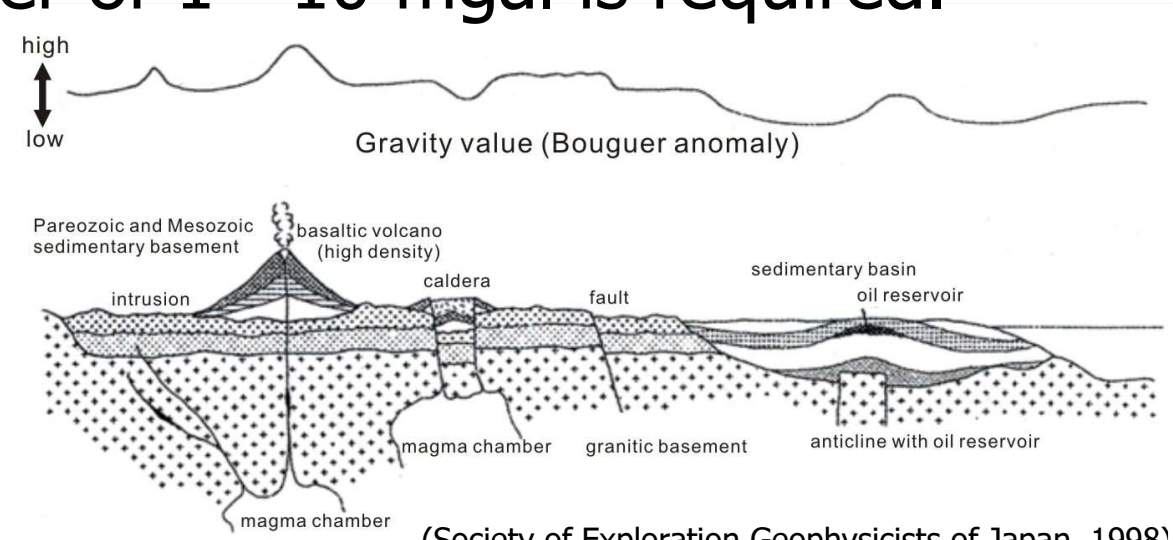


Temporal gravity change (reinjection area)

In order to detect the gravity change caused by subsurface structures …

- gal (or Gal): acceleration in cgs unit.
  1 μgal$=1\times10^{-6}$ gal 9.8 m/s$^2=980$ gal

- Gravity measurement with a precision of the order of 1 - 10 mgal is required.



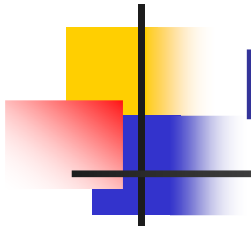
(Society of Exploration Geophysicists of Japan, 1998)

In order to detect the gravity change caused by the mass change in a geothermal reservoir …

- Gravity measurement with a precision of the order of 1 - 10 μ gal is required.

- It is just the same order of measurement accuracy of conventional gravimeters both relative and absolute.

This is one of the reasons complicating an application of this technique.



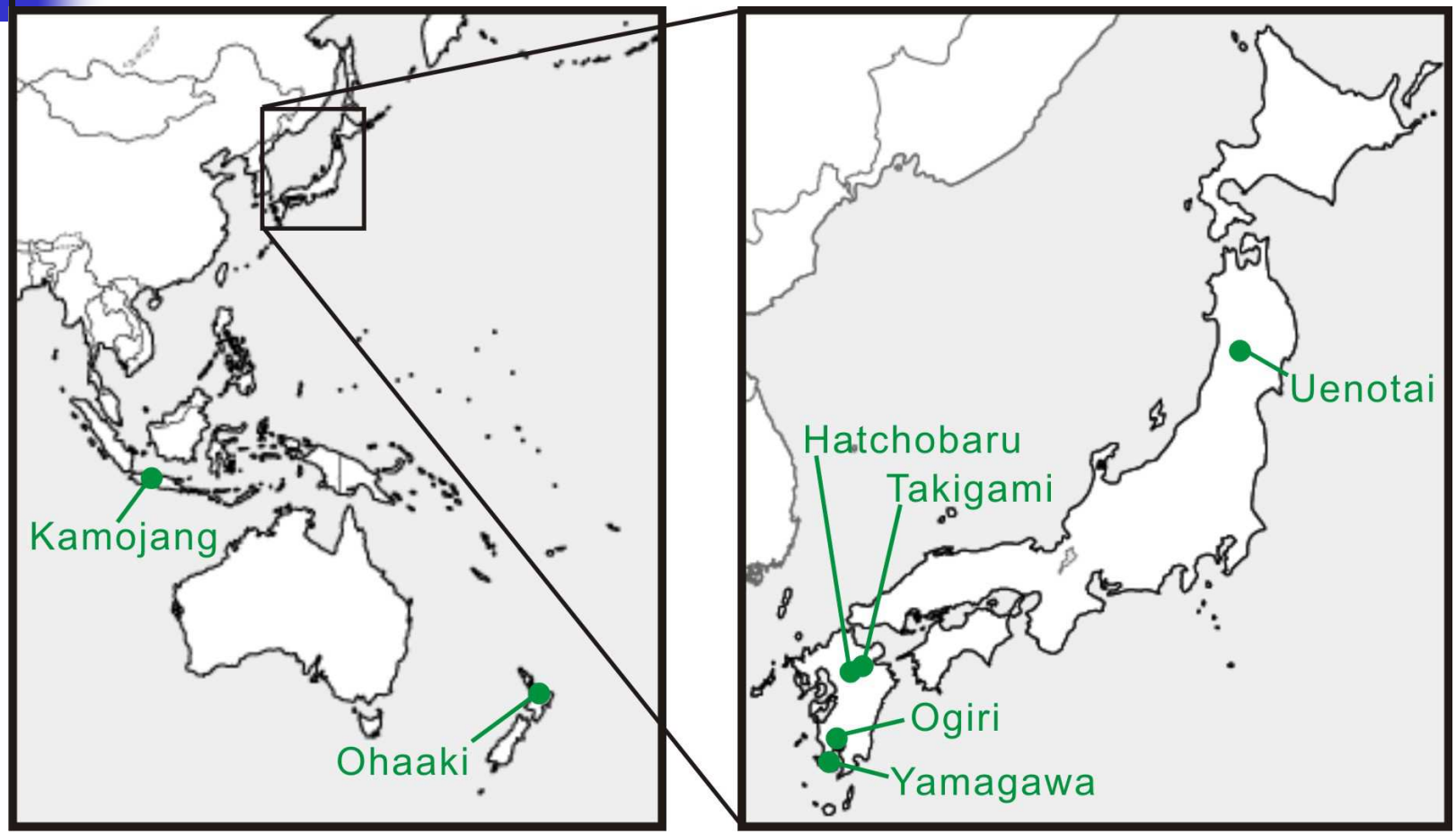
Previous study

- Allis and Hunt (1986) carried out the repeat microgravity measurement in the Wairakei geothermal field, New Zealand.
- They detected up to about 1000 μgal (= 10.0 $\times$ 10^{-6} m/s) of gravity decrease in the production area after 30 years of the commencement of power generation at Wairakei Geothermal Power Station.

Study on the repeat gravity measurement in Japan

- Kyushu University and National Institute of Advanced Industrial Science and Technology have been mainly conducting the studies on the precise repeat gravity measurement for geothermal reservoir monitoring in Japan.
- We have studied the precise repeat gravity measurement since 1990, and have conducted the measurements at 5 domestic and 2 overseas geothermal power station fields.

Locations of the measurement areas by Kyushu University



Hybrid microgravity measurement

- First, we had used some relative gravimeters (Scintrex CG-3 and CG-3M) for the measurements.
- The gravity measurement by a relative gravimeter requires a gravitational reference station where the gravity value is stable, that is, the gravity change is smaller than the measurement precision).

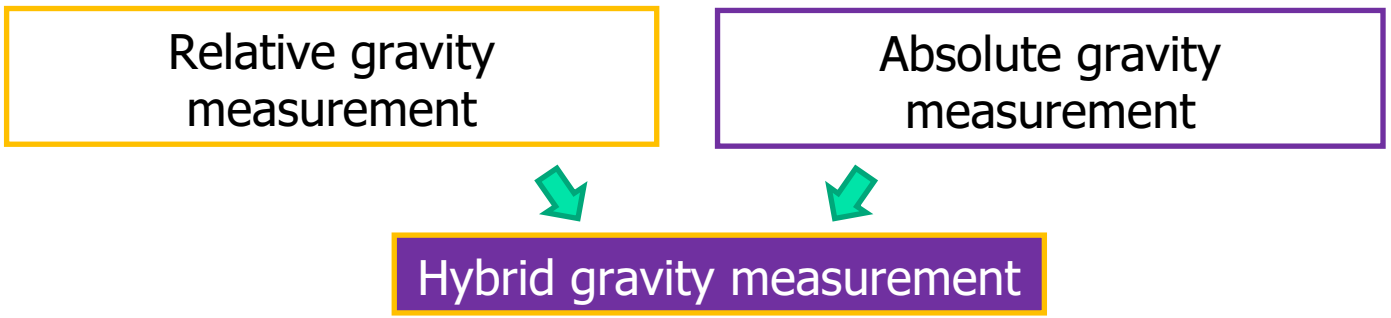
- In order to evaluate the stability of the gravity value at the reference stations in the geothermal power station fields, we introduced an absolute gravimeter (Micro-g LaCoste A10) in 2008.
- And we have applied the combination measurements of the absolute gravimeter and relative gravimeters (Scintrex CG-5 and CG-3+), which is called “the hybrid microgravity measurements”, to Takigami and Kamojang.

Measurement by a relative gravimeter (Scintrex CG-5)

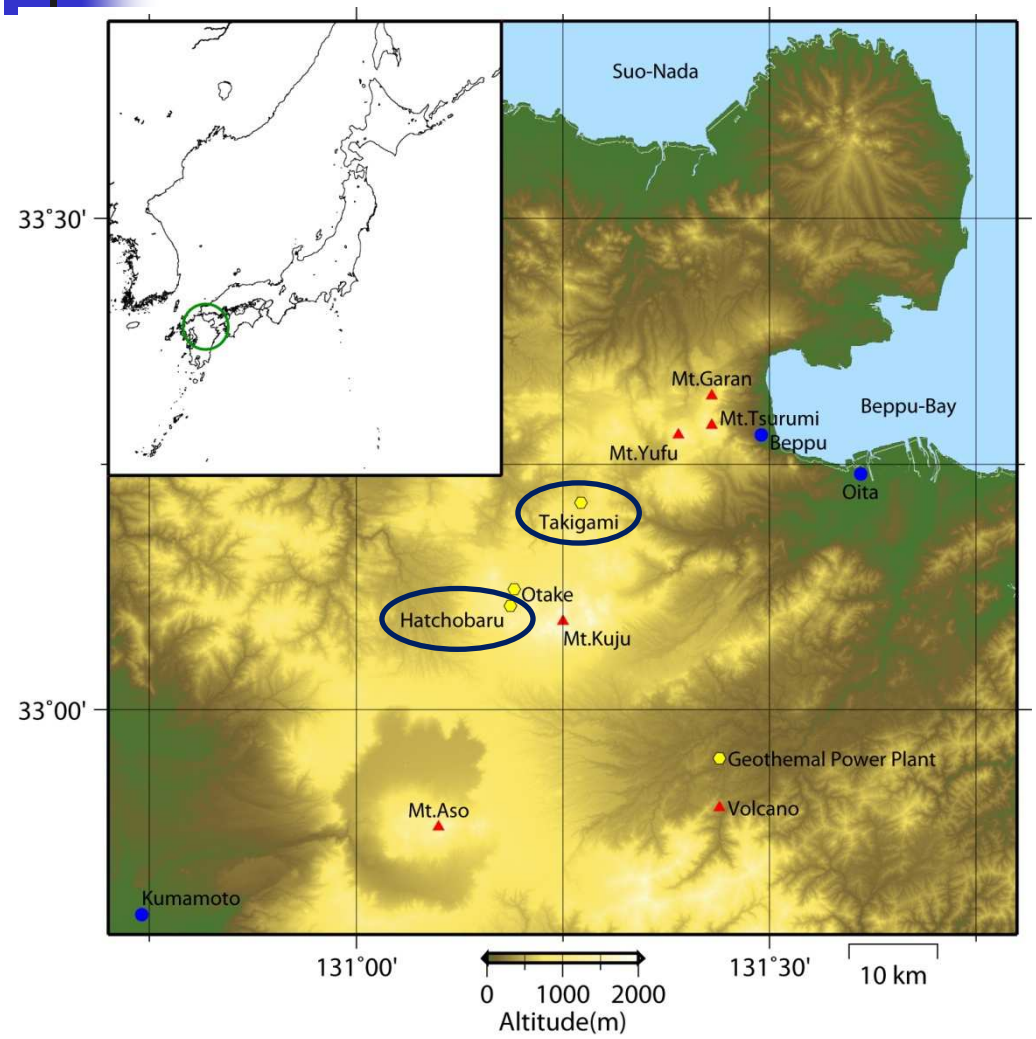
Measurement by an absolute gravimeter (Micro-g LaCoste A10)

Advantages and disadvantages of two kinds of gravimeters

	Relative gravimeter	**Absolute gravimeter**
portability	○ good	not good
Measurement time	○ short (about 10 min.)	long (about 1 hour)
Footprint	○ small	wide
Systematic error	easy to mix in	○ difficult to mix in
Reference station	required	○ not required
Price	○ cheaper	expensive



Case studies

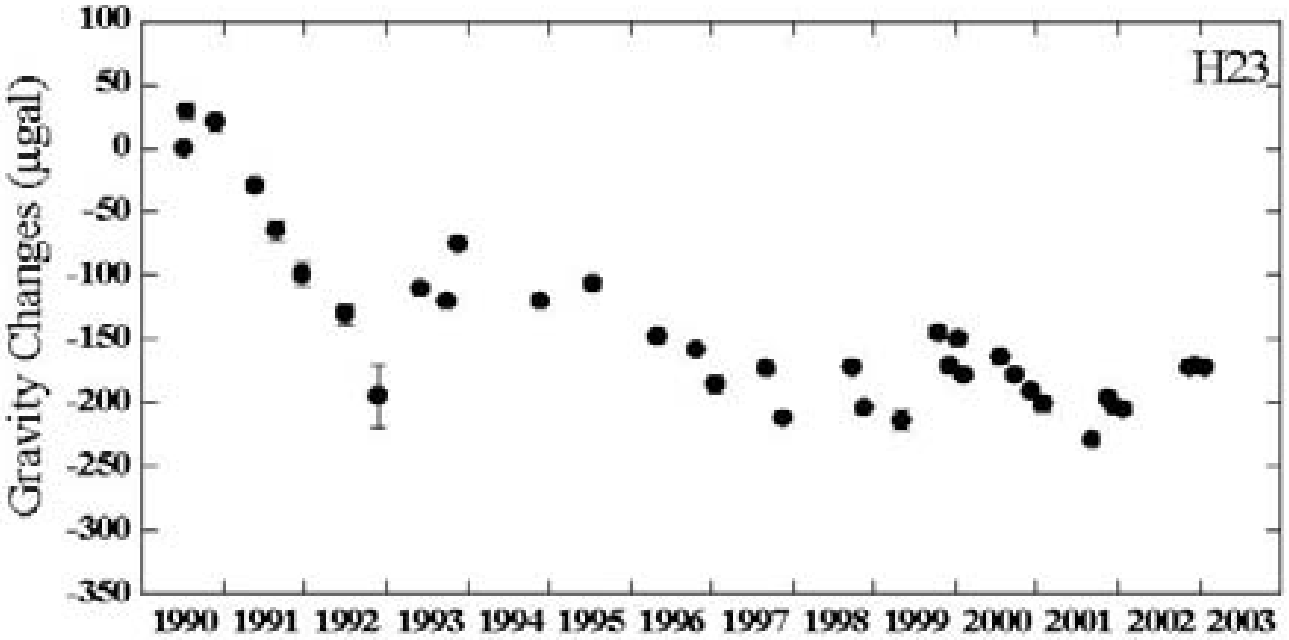


- Hatchobaru
- Takigami

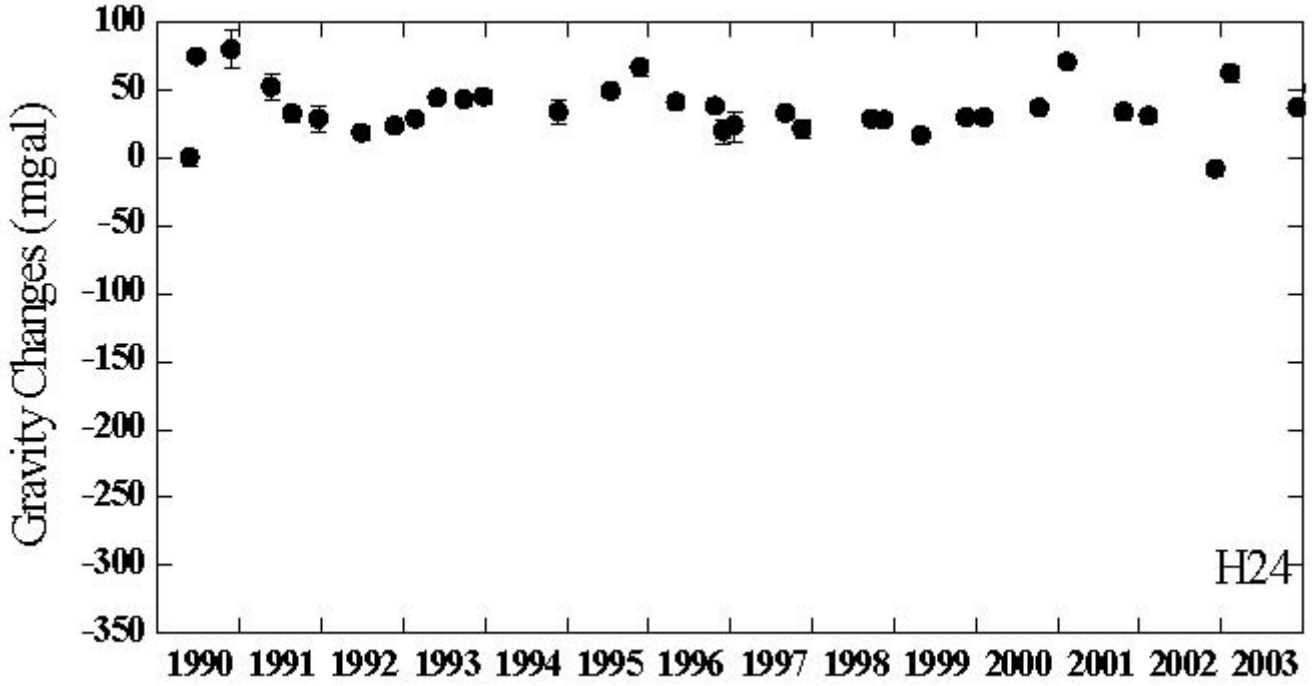
Hatchobaru Geothermal Power Station Area

Hatchobaru Power Station No.1 and No.2 Units of Kyushu Electric Power Co., Inc.

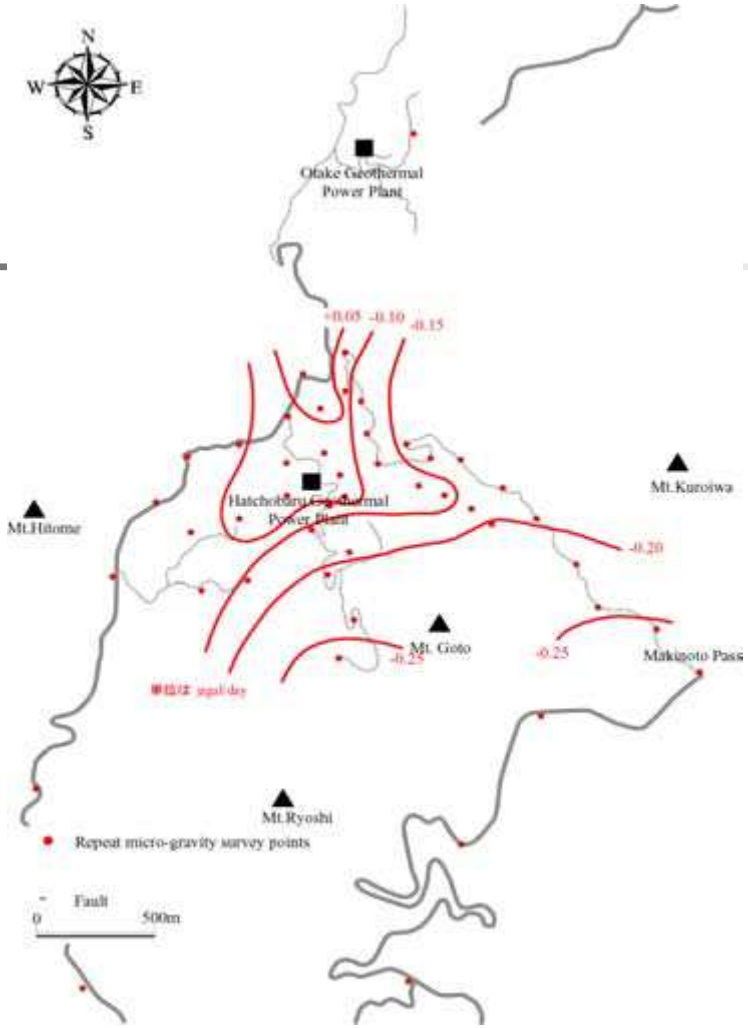
Location of the measurement stations (Ehara and Nishijima, 2010).



Example of gravity change in a production area after the commencement of Hatchobaru No.2 (Ehara and Nishijima, 2010).



Example of gravity change in a reinjection area after the commencement of Hatchobaru No.2 (Ehara and Nishijima, 2010).



Gravity change from June 1990 to June 1992 at Hatchobaru geothermal field (Ehara and Nishijima, 2010).

Summary of Repeat gravity measurement at Hatchobaru

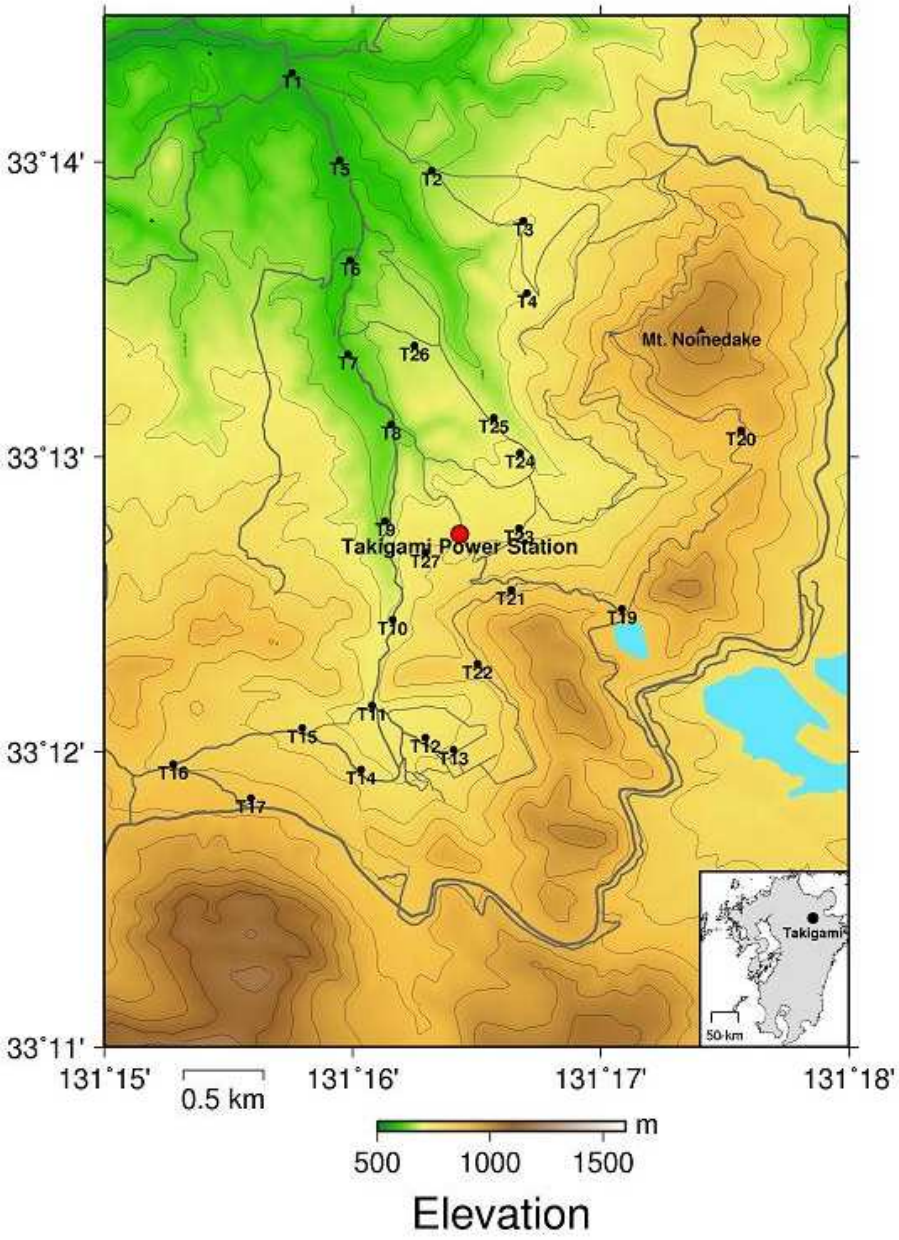
- We started the gravity measurement just before the commencement of the Hatchobaru No.2 Unit operation in 1990.
- As a result, we detected the different patterns of the temporal gravity changes between the production area and the reinjection area.

Summary of Repeat gravity measurement at Hatchobaru

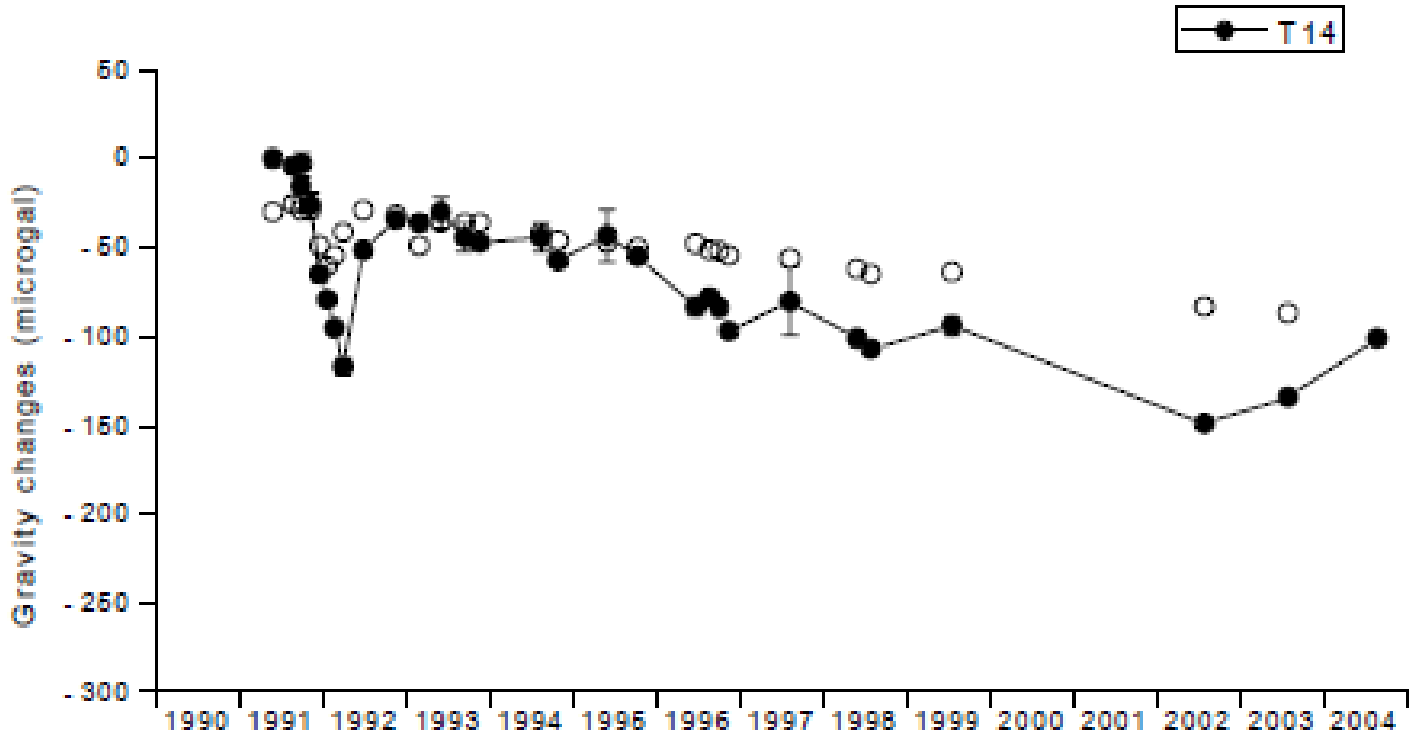
- The temporal gravity change at the production area was consistent with the change in reservoir pressure and that at the reinjection area was also accordant with the mass change of the reinjected fluid (Tagomori et al., 1996).
- Therefore, we concluded that the temporal gravity changes that reflected the mass change in the geothermal reservoir of the Hatchobaru geothermal area were detected.

Takigami Geothermal Power Station Area

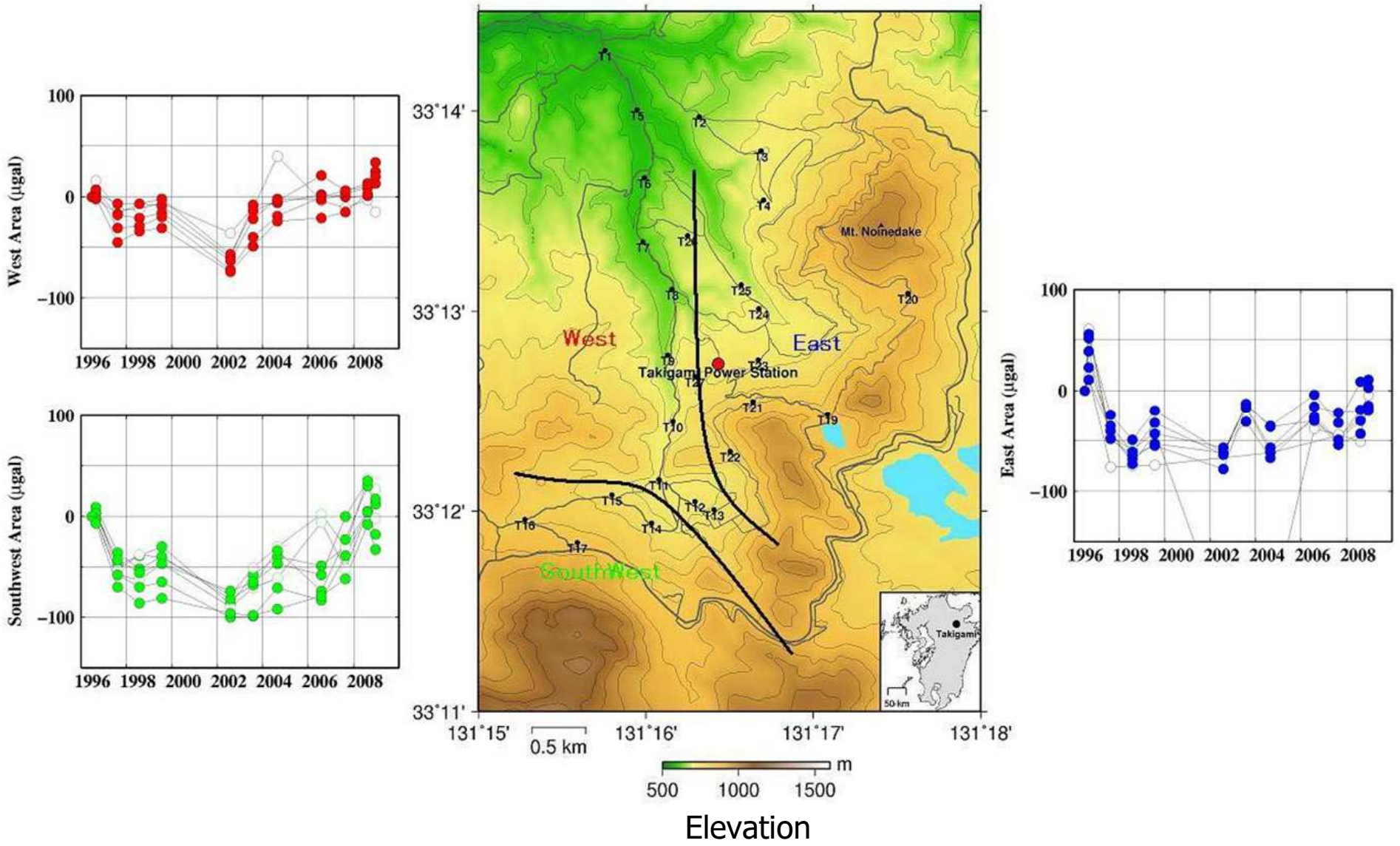
Takigami Power Station of Kyushu Electric Power Co., Inc. and Idemitsu Oita Geothermal Co., Ltd.



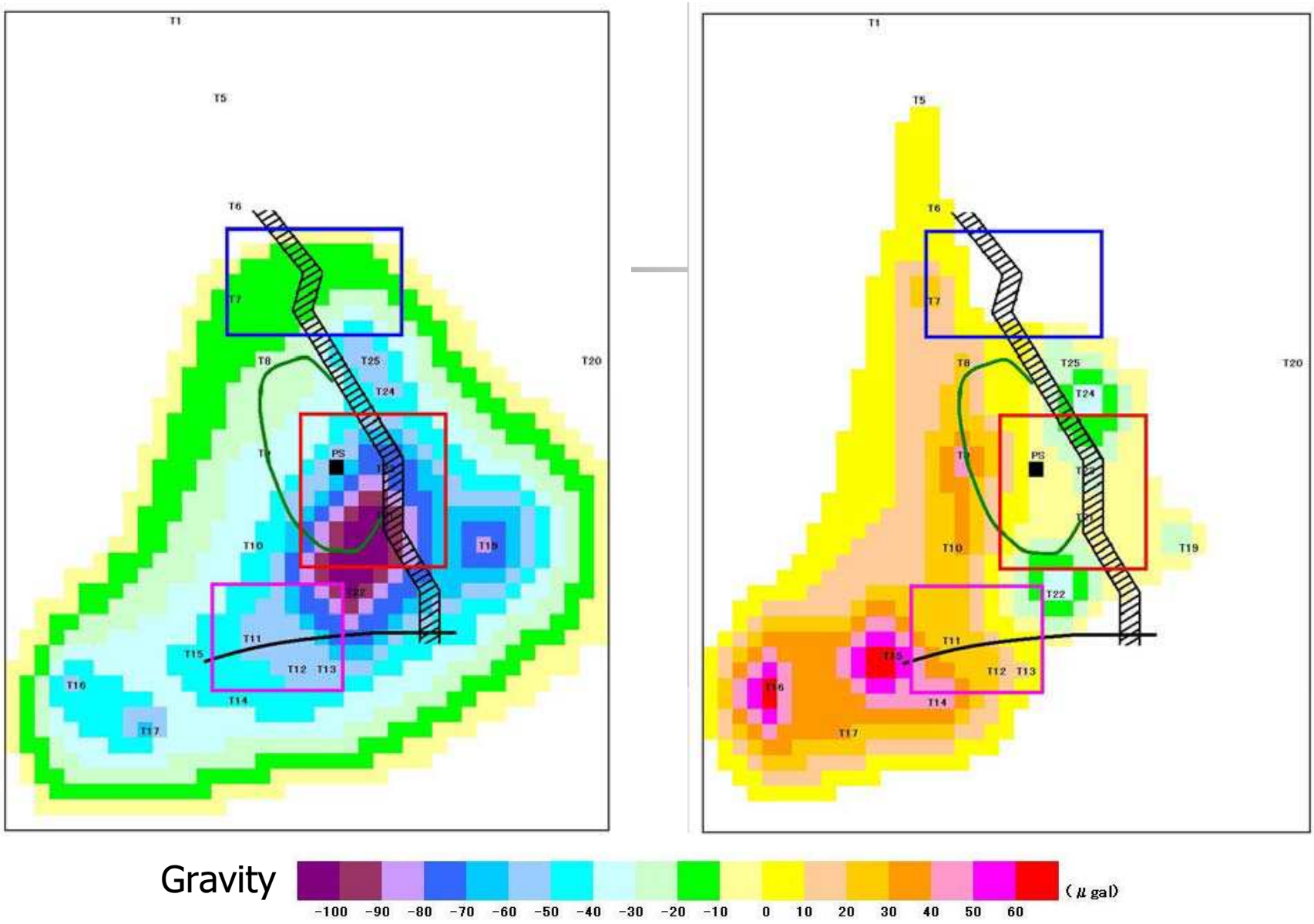
Location of the measurement stations (Nishijima et al., 2010).



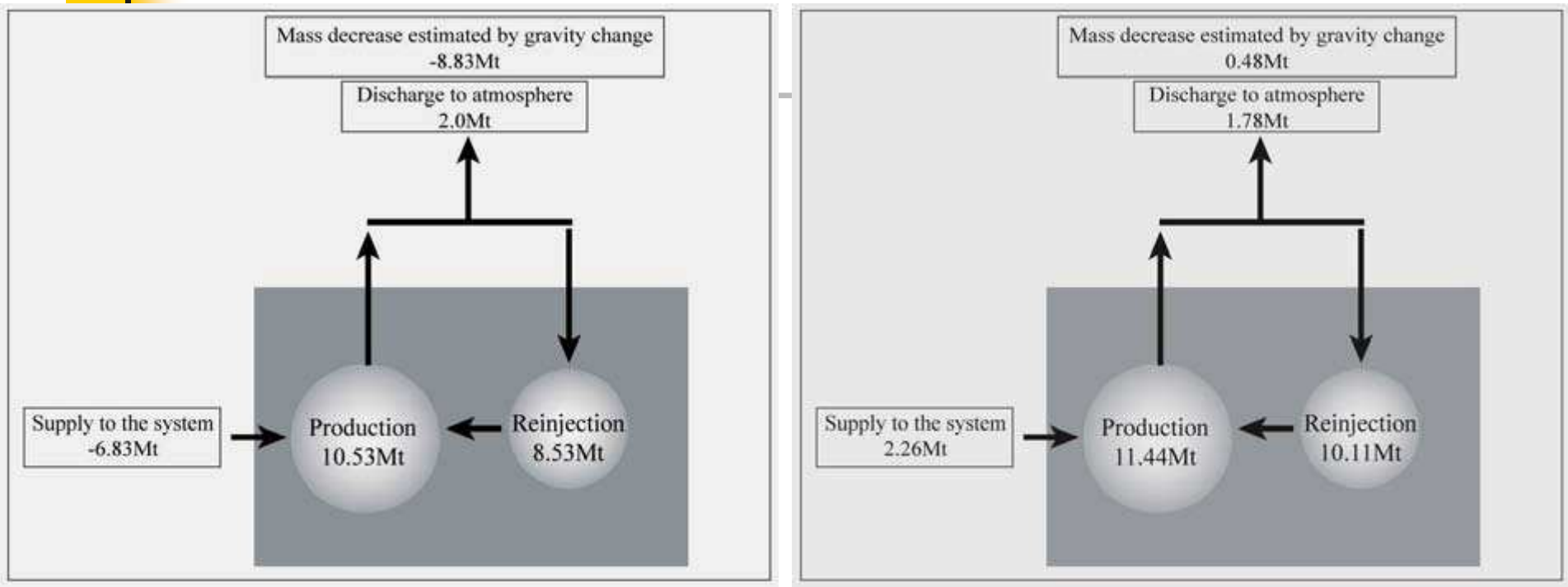
Comparison between the observed (●) and calculated (○) gravity changes at the Takigami geothermal field. (Ehara and Nishijima, 2010)



Distribution of typical patterns of residual gravity changes in the Takigami geothermal field (Nishijima et al., 2010).



Distribution of gravity changes from 1996 to 1997 (left) and from 2003 to 2007 (right) (Nishijima et al., 2010).



Mass balance based on the contour map of gravity changes at the Takigami geothermal field from 1996 to 1997 (left) and from 2003 to 2007 (right) (Nishijima et al., 2010).

Summary of Repeat gravity measurement at Takigami

- We have conducted the repeat microgravity measurements since 1991; it was 5 years before the commencement of operation of the Takigami geothermal power station. Therefore, we obtained the gravity data which were not affected by the production and reinjection of geothermal fluids and evaluated the background gravity change caused by the seasonal changes of shallow ground water level.

Summary of Repeat gravity measurement at Takigami

- We estimated the mass balance of the geothermal reservoir of the Takigami geothermal area by using a distribution map of the temporal gravity change with application of Gauss's Potential Theorem.

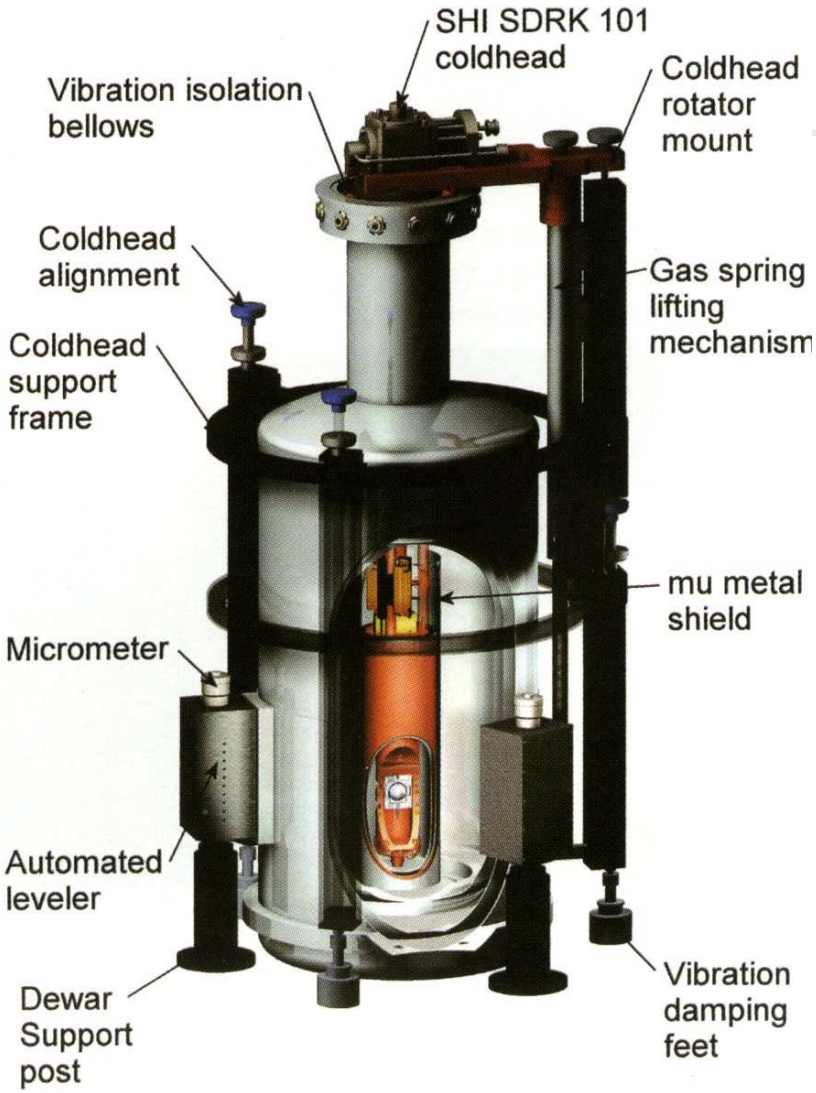
Future work

- New technology application to a gravimeter.

Breakthrough for the measurement accuracy of conventional gravimeters.

- Explanation of the temporal gravity change by using a geothermal reservoir simulator.

Superconducting gravimeter



GWR Instruments iGrav SG Meter

(Ikeda, 2010)

Difficulties of applying a superconducting gravimeter

- Improvement of measurement accuracy (μ gal → ngal).

New factors must be considered.

  - Atmospheric pressure change: about 430 ngal/hPa
  - Elevation change: about 300 ngal/mm

- Extremely expensive and high running cost, not compact (stationary type only), not battery-powered.

Fixed-point measurement.

- Thank you for your attention!