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Modeling Coseismic Groundwater Level Change with the Constraint of Gravity Data

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1. Introduction ～Stations～

Tono Research Institute of Earthquake Science (TRIES) is operating various observations with borehole type instruments for the better understanding of the earthquake phenomena (Fig.1). Groundwater levels (GWL) are one of those observations. We also observe absolute gravity by FG-5 gravimeter (Fig.4) to detect the signals from earthquakes. Mizunami Underground Research Laboratory (MIU) of Japan Atomic Energy Agency (JAEA) had finished the deep shafts (500 m) and several galleries for the research of the deep geological repository of nuclear waste. MIU also observes GWL for their purpose. In those wells, two types of GWL changes has been observed. One is long term decrease along the excavation of the shafts, and another is the earthquake related changes. However, the gravity changes seemed incompatible with those GWL changes.

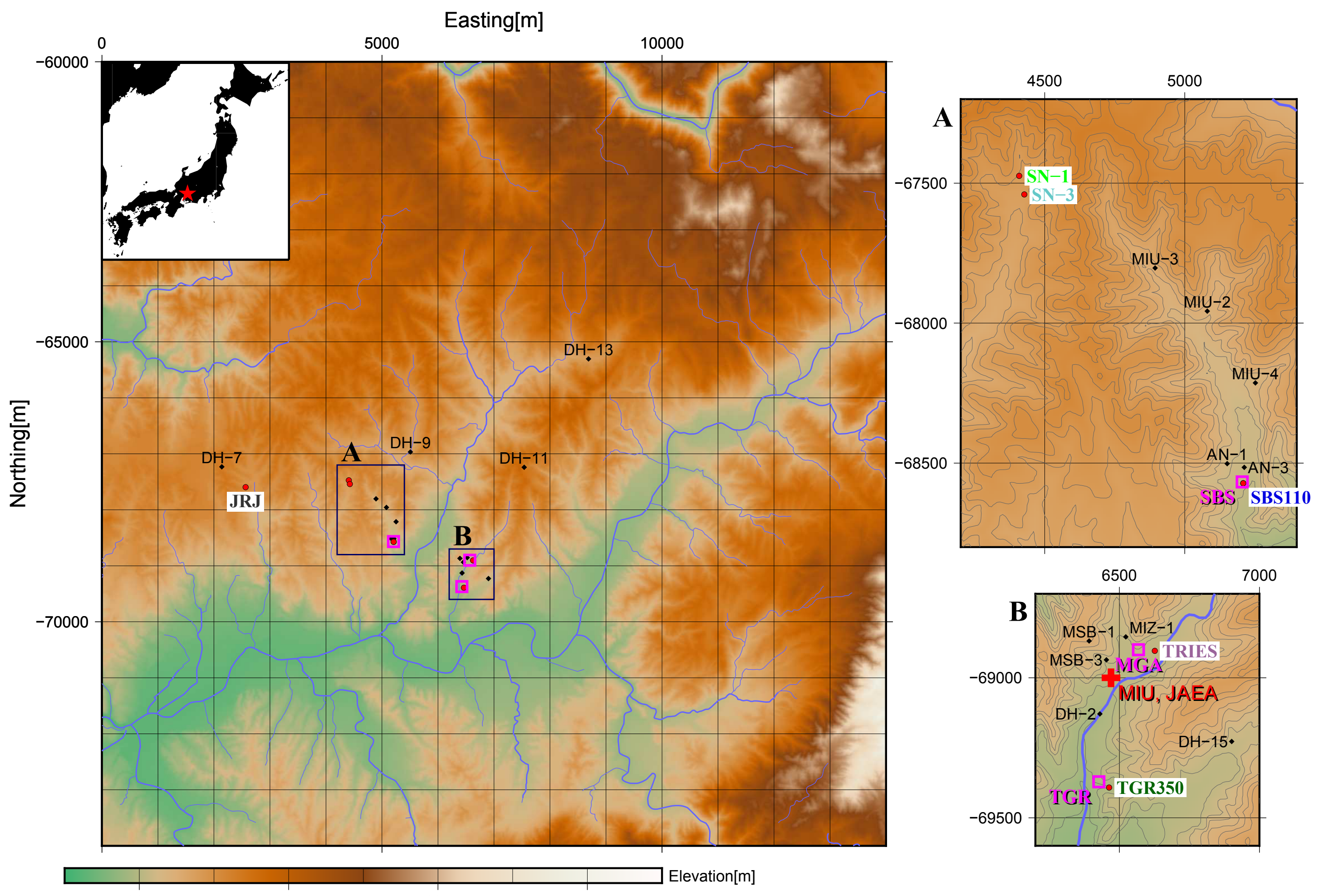

Fig.1

Station distribution of GWL (red circles and black diamonds indicate the wells of TRIES and JAEA, respectively) and the absolute gravity (pink open squares). The GWL of the JAEA stations are observed by Multi-Packer System. The wells of TRIES are open.

2. Data

Seismic related GWL change was first recognized at DH-2. Asai (2006; Doctor Thesis) confirmed that the GWL change in DH-2 and TGR350 show almost same responses, then examined the comparison with the Earthquake data, observed at TGR350. Asai (2006) concluded that the coseismic GWL changes occur only when the strain and tilt change was above certain thresholds. Meanwhile, MIU started the excavation of two shafts in February 2005. The GWL in some wells started to decrease along the excavation. Gravity values don't decrease with the GWL decrease. It is also incompatible with the coseismic GWL changes. We tried to make a ground water flux model to explain the coseismic GWL increase and the gravity decrease simultaneously.

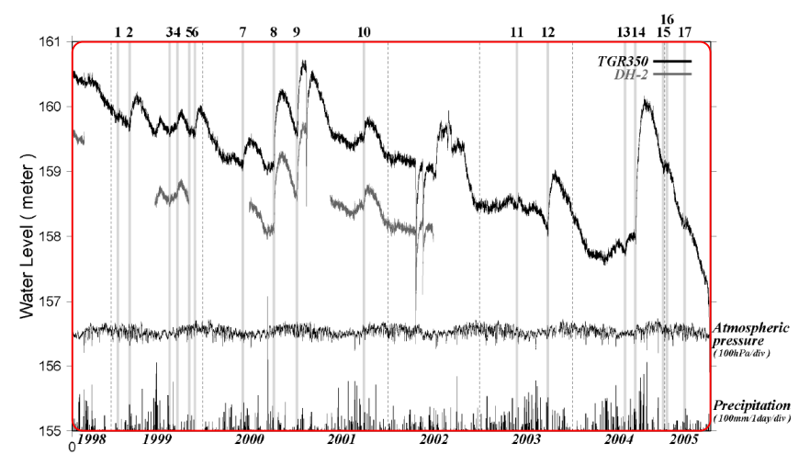

Fig.3

Coseismic GWL changes observed with earthquakes before the start of shaft excavation.

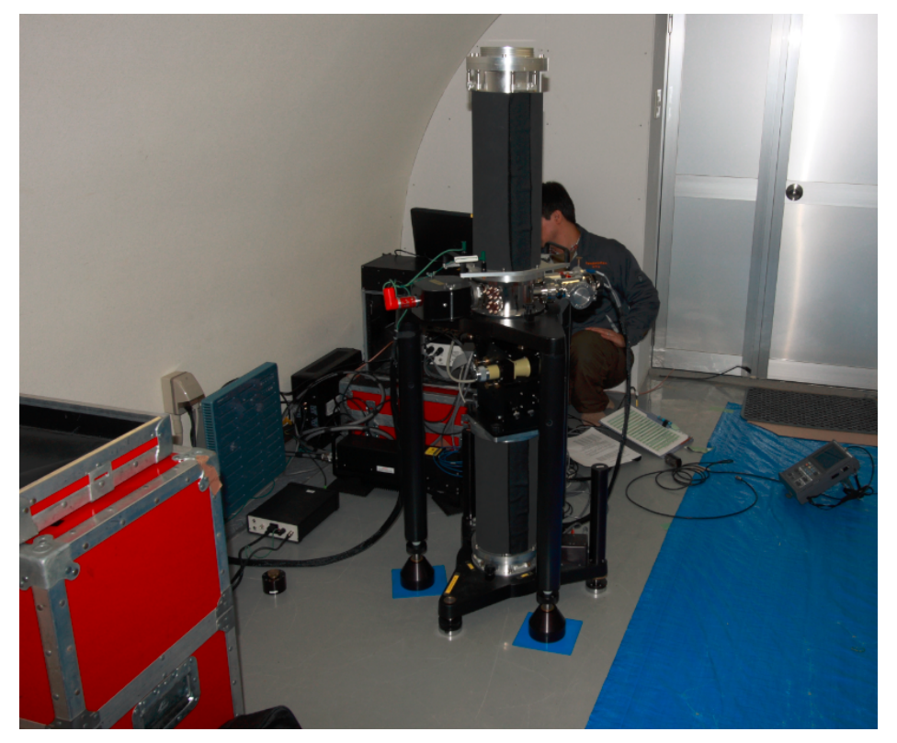

Fig.4

FG-5 absolute gravimeter (micro-g LaCoste Co. Ltd.)

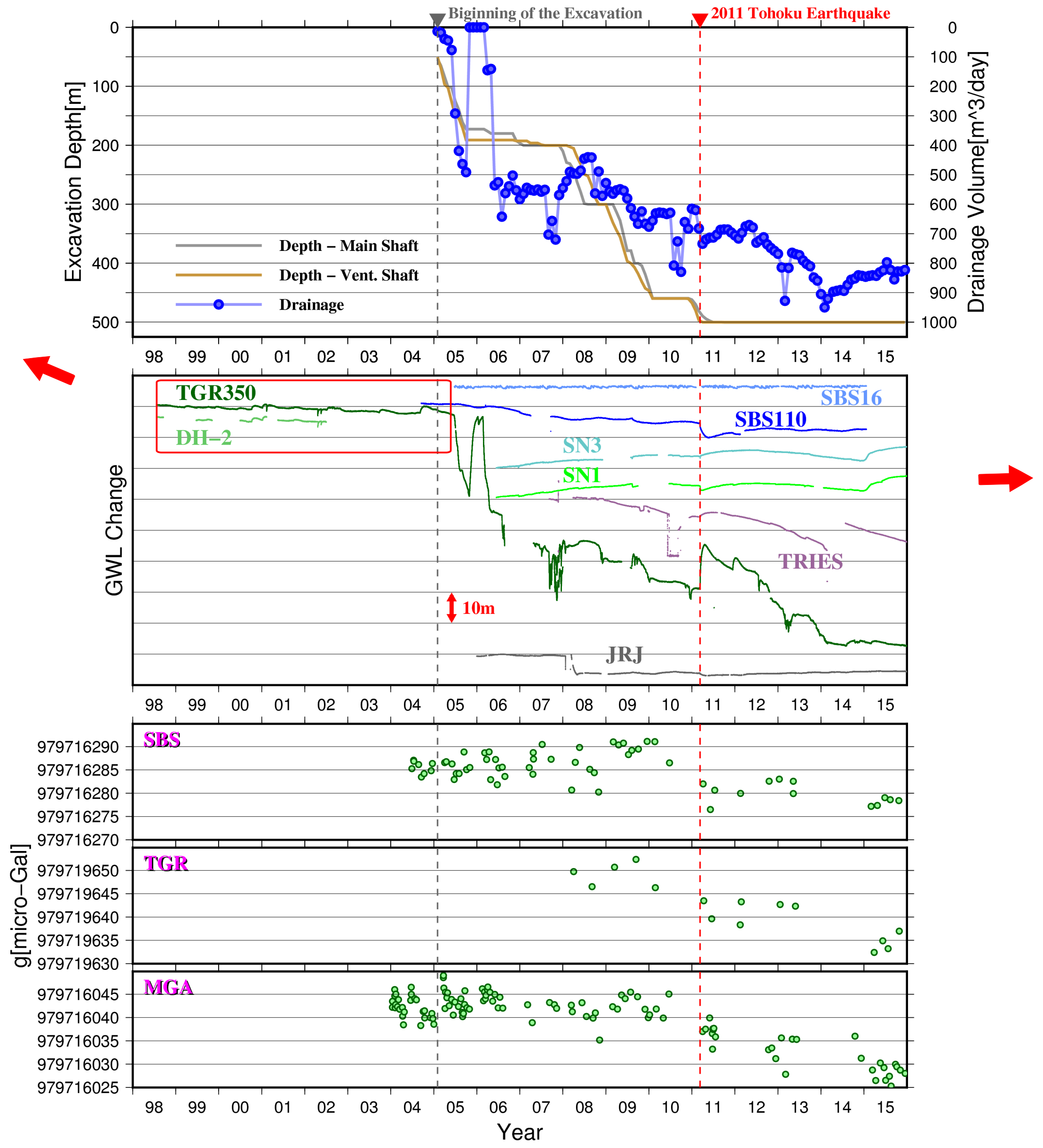

Fig.2

Time series of the excavation depth and the drainage volumes (top), GWL changes observed by TRIES (middle) and the absolute gravity observation data at three stations in the research area(bottom). The gravity effect of the mass relocation by the dislocation of the Tohoku Earthquake is nearly zero in the research area (Matsuo and Heki, 2011: GRL).

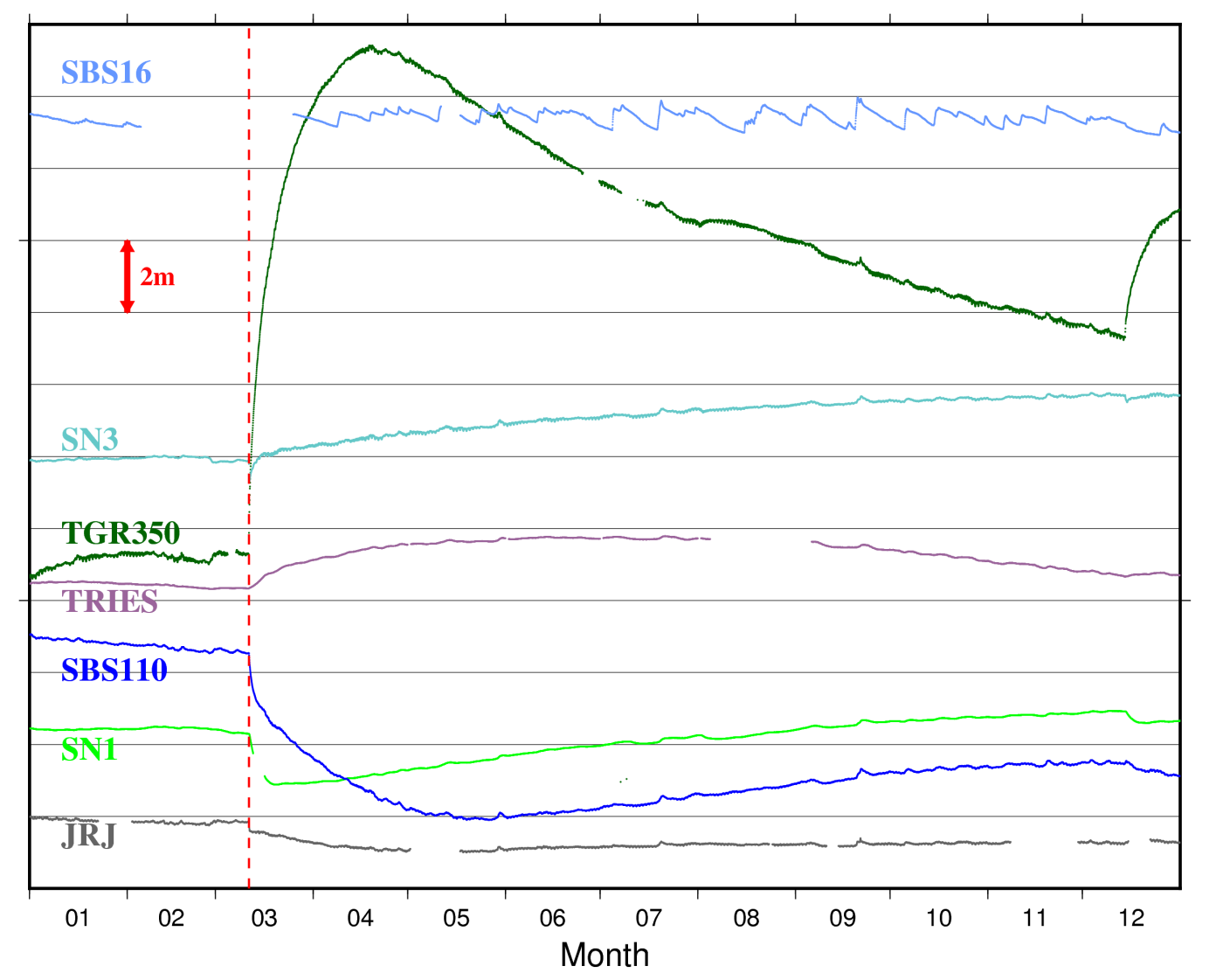

Fig.5

GWL changes in 2011. The largest response corresponds to the Tohoku Eartuquake

3. Hydraulic Geology

Gravity data can detect the underground mass transportations, however, it is impossible to find unique solution without a constraint. Because the hydraulic geological structure is fortunately well researched in the study area, we can examine some water flux pattern on it, and simulate the gravity values. Yanagizawa et al. (1995: J. Hydrology) simulated the shaft excavation effect around the Tono Mine (vicinity of SN series boreholes in Fig.2) by three-dimensional finite element method. The permeability used in the study is measured values in several boreholes (Fig.6), and the simulated and the observed hydraulic heads were consistent. We can recognize aquifers on the granite top and in the sediment rocks. The distributions of the granite top is shown in Fig.7.

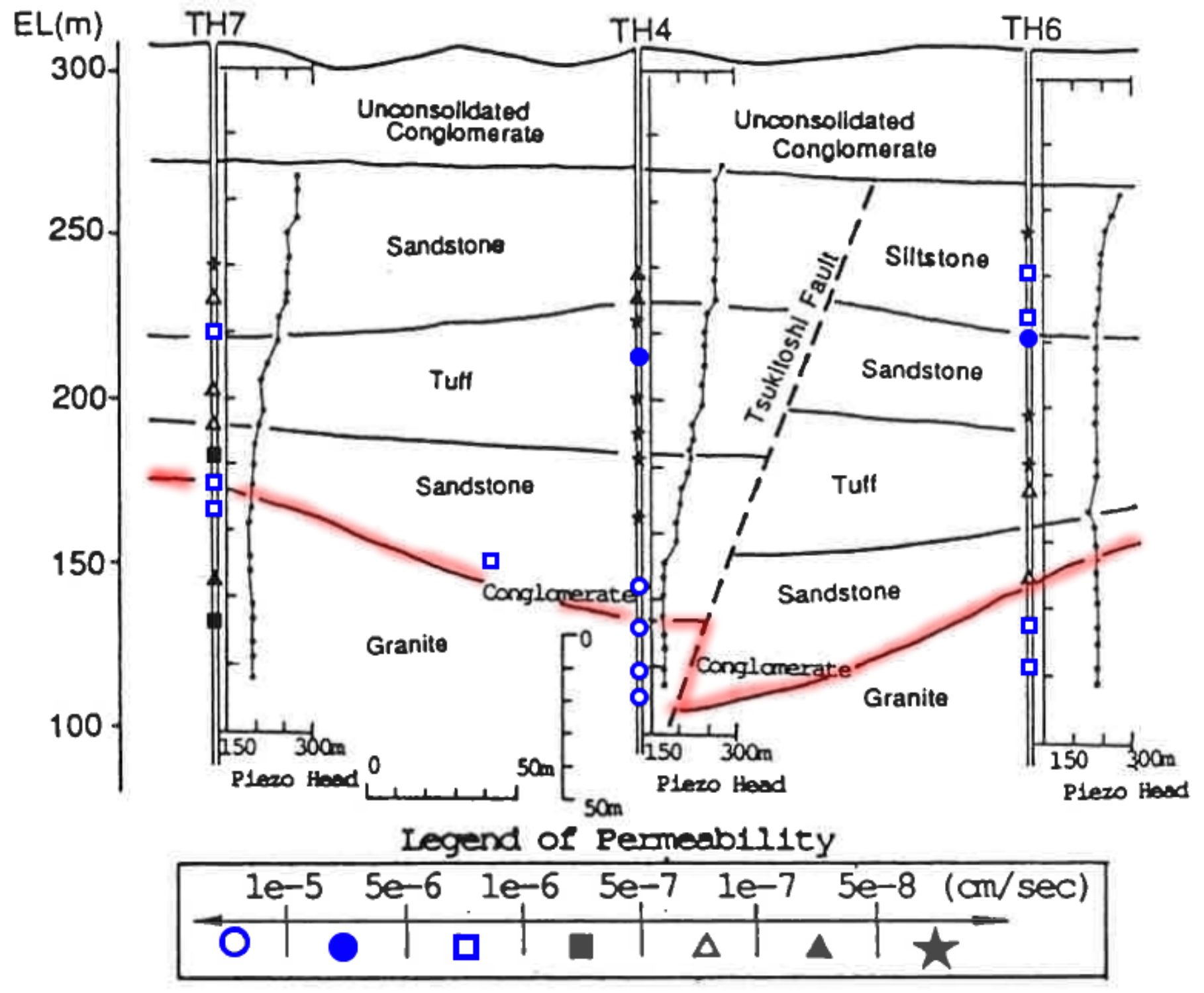

Fig.6

Representitive geological structure in the study area, with measured permeability values (modified from Yanagizawa et al., 1995). Blue simbols indicate relatively high permeabilities. Red line indicates the basement top, which destribution is shown in Fig.7.

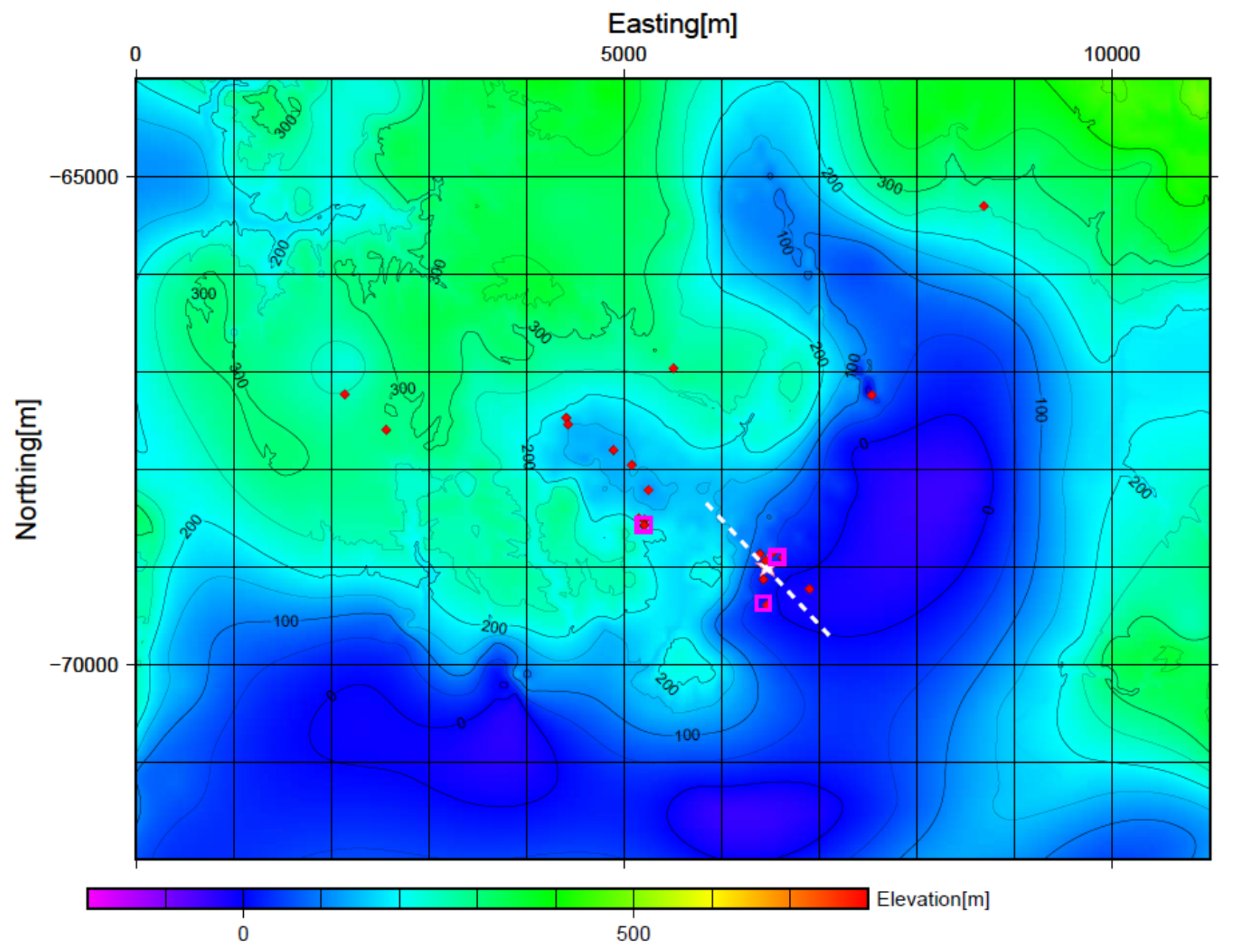

Fig.7

Distributions of the top depth of granite. Pink open squares, red diamonds and white star indicate gravity stations, GWL observation wells and the location of the main shaft of MIU, respectively. White line indicate the Main Shaft Fault (MSF). Many vertical cracks are recognized in the west side of the MSF.

4. Gravity Simulation

First, we must confirm that this coseismic gravity steps are caused by local phenomena, not by the 2011 off the Pacific coast of Tohoku Earthquake itself. The gravity effect of the mass transfar of the fault dislocation in the study area is about 0 microGal (Matsuo and Heki, 2011: GRL). As for the 1 cm of coseismic upheaval in the study area (GSI Japan, 2011), this is equivalent to the gravity decrease of 1 or 2 microGal. Thus, it can be said that the observed gravity decrease is caused by earthquake triggered phenomena.

Most of the GWL data is obtained in the granite body. Coseismic GWL responses are remarkable increase in area A of Fig.1. Known obvious aquifer is along the granite top. Thus, we examined the case that water flows from the granite top into the granite body. In this case, the opposite trend of the GWL and the gravity change can be explained. We calculated the gravity effect of the ground water drainage by simulating the drained zone as thin parallelepiped. Analytical solution of the gravity effect of parallelepiped is calculated by Banerjee and Gupta (1977: Geophysics). After testing various parameters for the porosity of the aquifer, GWL change in the aquifer and the depth of the GWL change (Fig.8), we found some cases which can explain the gravity decrease in the 2011 off the Pacific coast of Tohoku Earthquake (~ 10 microGals).

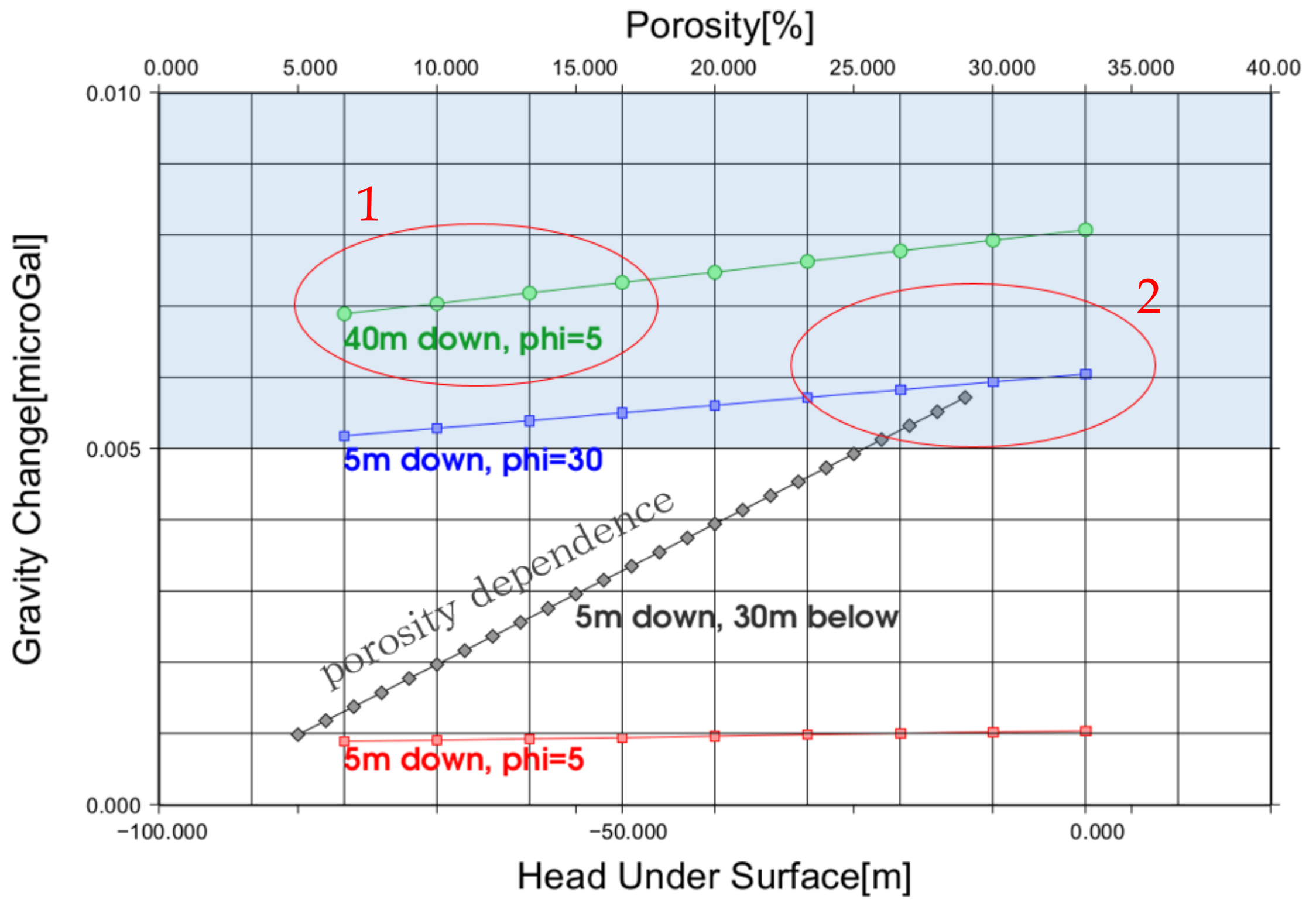

Fig.8

Calculated gravity effects for various GWL changes. Grey diamonds indicate the porosity dependence. Other three group of data indicate the situation of the attached parameters. The results inside the circle 1 simulate the situation of aquifer on granite, just under the MGA station.

5. Main Shaft Fault

Main Shaft Fault (MSF, Fig.7) was found during the excavation. Boring log of MIZ-1 indicates that this geological fault blocks water. This is consistent with the low sensitivity of neighboring boreholes such as TRIES (Fig.2, 5) and DH-15 (Fig.9). JAEA reports that there are many vertical cracks at the west side of the MSF.

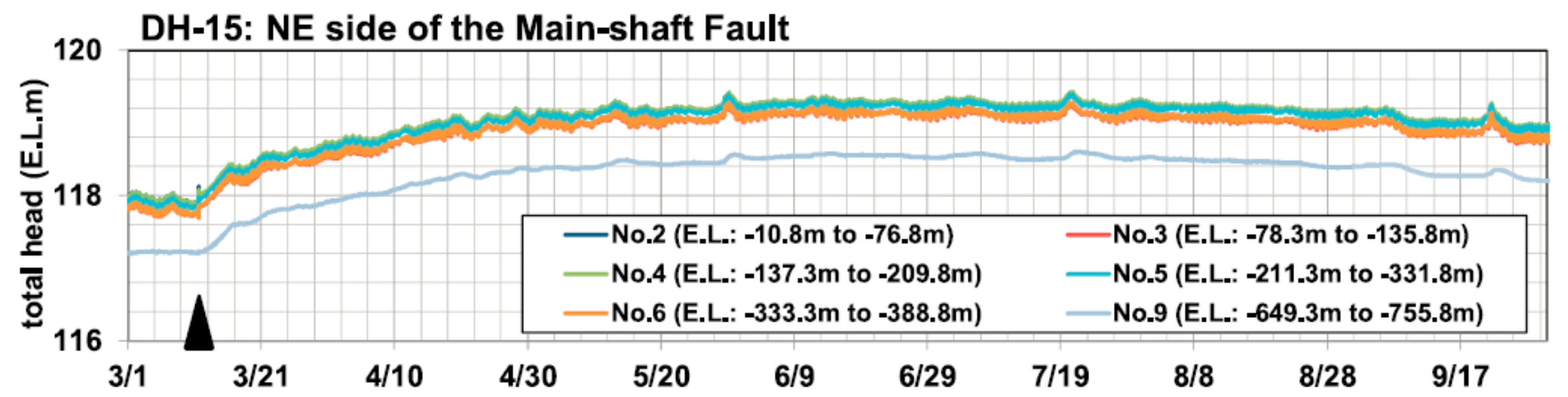

Fig.9

Coseismic GWL change at the DH-15 (Niwa et al., 2012: G^3).

6. Summary

1. The observed GWL and gravity data looked inconsistent.

2. Based on the Gravity change and the known hydraulic structure, we can propose one possible water flux model.

3. Observed gravity change was well exprained by the model, but we still can't exprain the observed GWL change, quantitatively.