Discharge rate of volcanic eruptions as inferred from observed ground deformation and conduit flow models

Takeshi Nishimura (Geophysics, Tohoku Univ.)

G2-1 : Development of evaluation method of discharge rate

Purpose of this study

To Understand how the volcanic products are effused from the conduit.

This is most important to predict the spatio-temporal distributions of ash

1. Examine characteristic behaviors of tilt records that can capture macroscopic pressure changes of magma chambers during eruptions.

2. Magma flow models are examined to interpret the observed tilt records.

Gas bubble growth model (Scanndone & Giacomelli, 2001)

Shock tube model with magma fragmentation (Koyaguchi and Mitani, 2005)
Magma pressure driven model (e.g., Hreinsdóttir et al. , 2014)

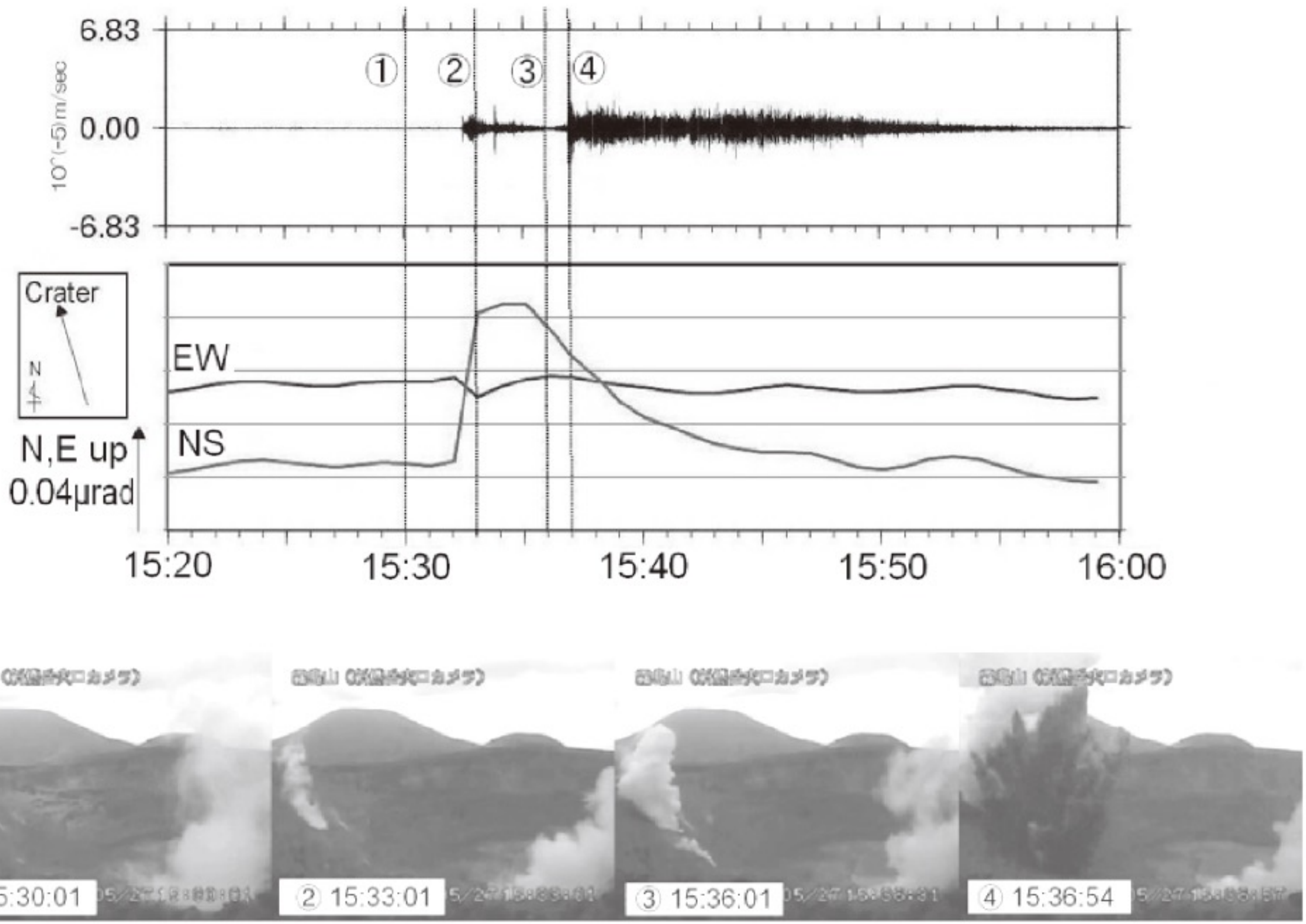
Pseudo-Gas model (Nishimura et al., 1998)

Examination from tilt records

Small eruptions

Shinmoe-dake May 27, 2010　Phreatic explosion

K. KATO AND H. YAMASATO: THE 2011 ERUPTIVE ACTIVITY OF SHINMOEDAKE VOLCANO



Ontake-san Sept. 28, 2014
Phreatic explosion

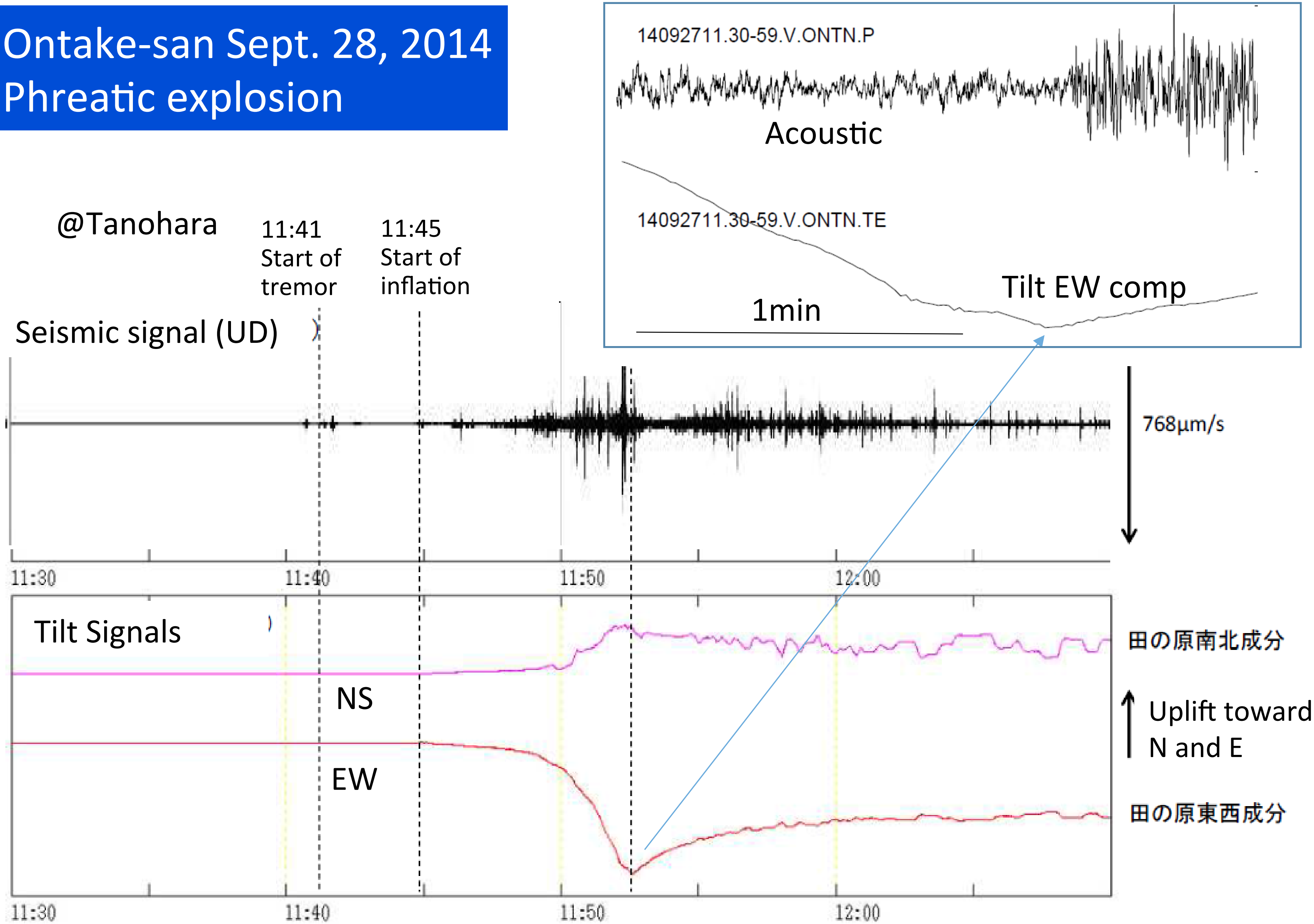
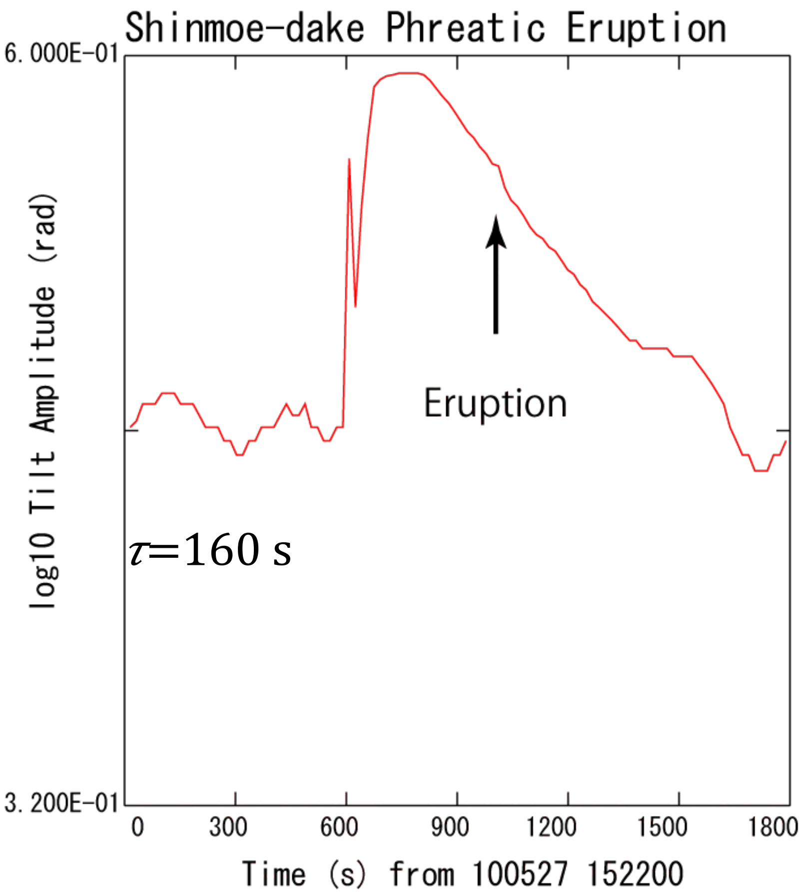


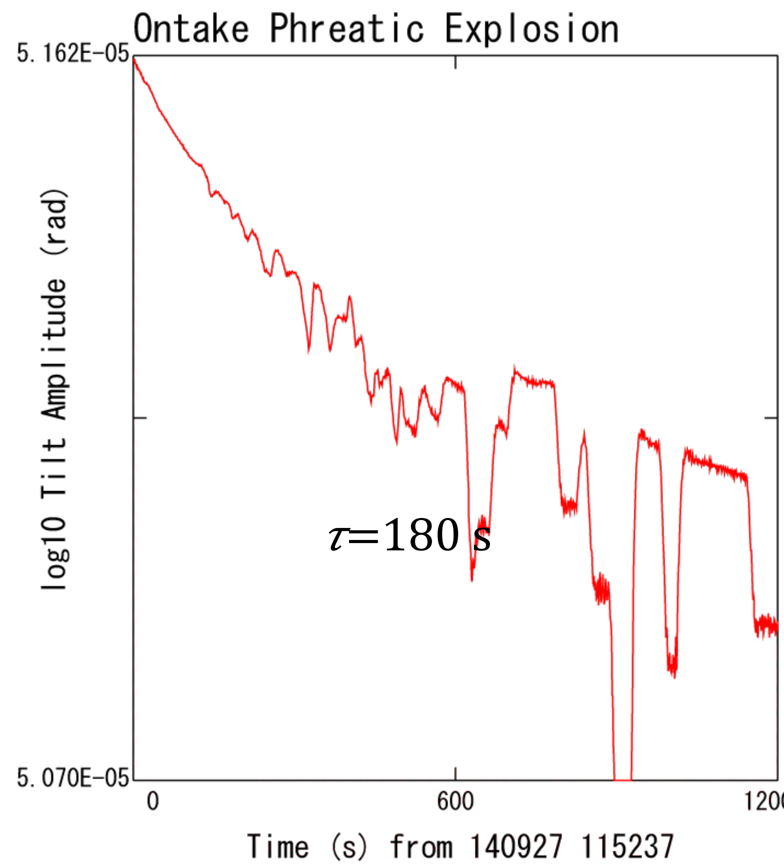
図４　御嶽山　噴火発生時の震動データ及び傾斜データの状況
（Volcanic Activity Data by JMA)

Tilt signals from the occurrence of eruption (semi-log plot)

Shinmoe-dake, 2010



Ontake-san, 2014

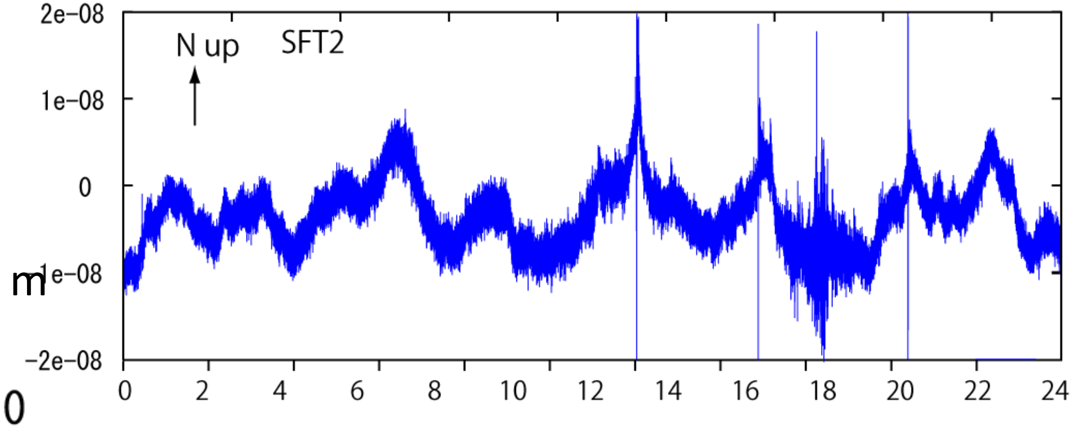


Exponential decay of the magma pressure $e^{-t/\tau}$

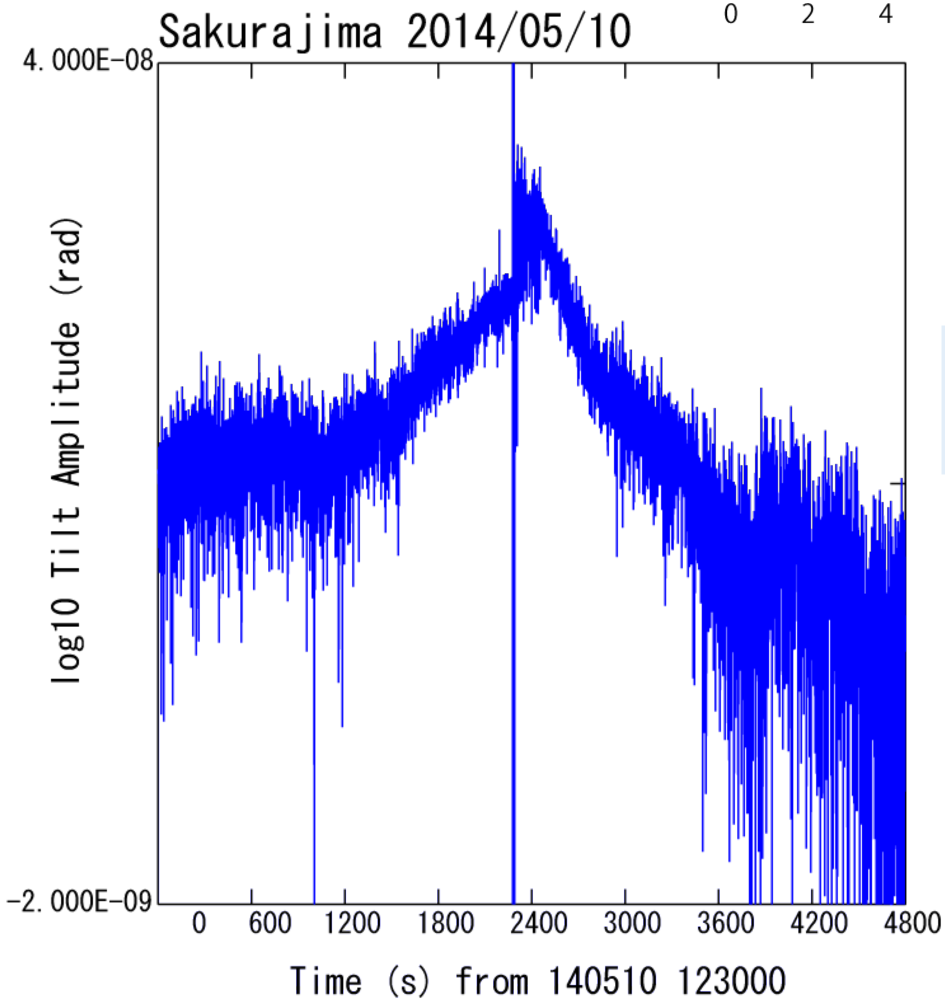
※Tilt meter response
Low pass (30s) filter

Sakurajima
13h07m on May 10, 2014

Column height 4500 m



JMA SFT2 at
3 km north of the crater



Exponential decay of pressure source

Pseudo-gas approximation model

$Q=\rho^{*} v^{*} S$

$$v^{*} = \sqrt{\gamma_m R_m T} = a_0 \left(\frac{2}{\gamma_m + 1}\right)^{1/2}$$

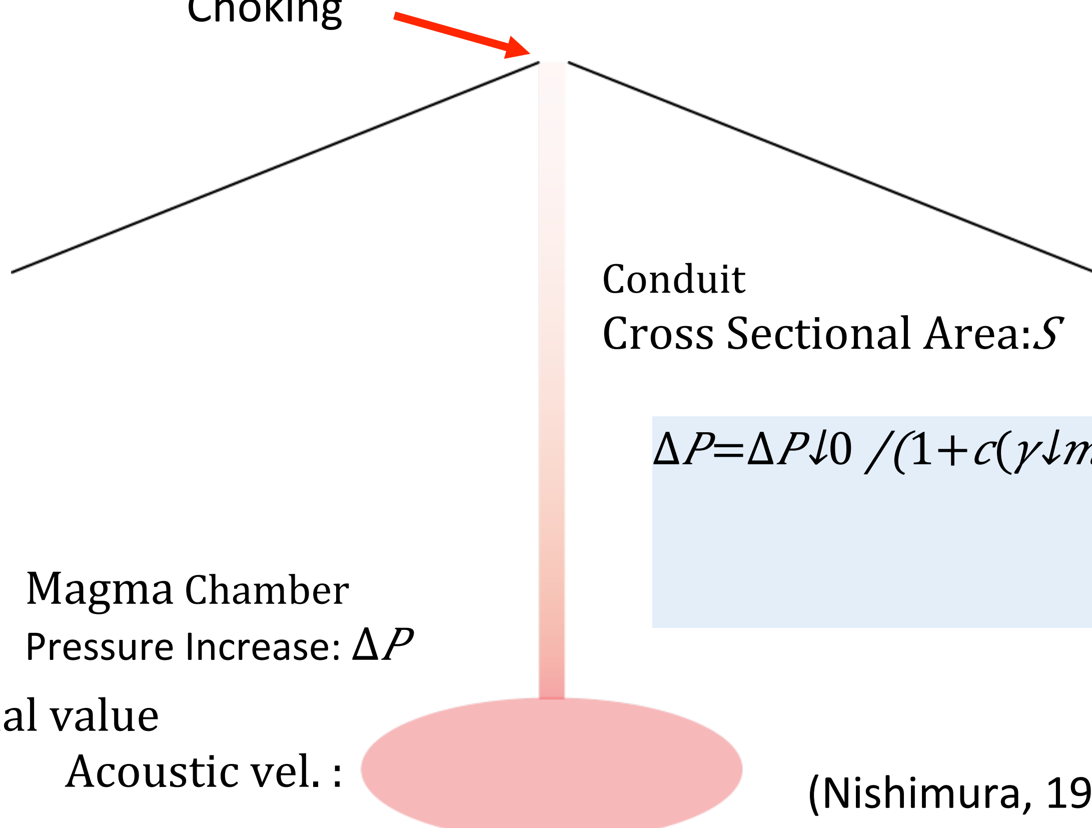
$$\rho^{*} = \rho_0 \left(\frac{2}{\gamma_m + 1}\right)^{\frac{1}{\gamma_m - 1}}$$

Pseudo Gas Approximation

Mass ratio of solid and gas parts
$m = M_s / M_g$

specific heat : $\gamma_m = C_{p,g} + mC_s / C$

gas constant: $R_m = R_g / 1+m$



$$\Delta P = \Delta P_0 / \left(1 + c(\gamma_m) \frac{v^{*} S}{V} t\right)^{\frac{2\gamma_m}{\gamma_m - 1}}$$

(Nishimura, 1998)

Examination from tilt records

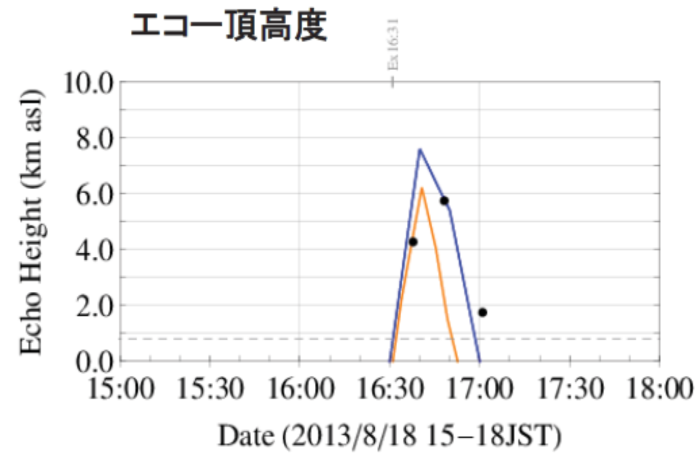
Large Eruptions

On Aug. 18, 2013

図１　桜島　18 日 16 時 31 分に昭和火口で発生した噴火の状況

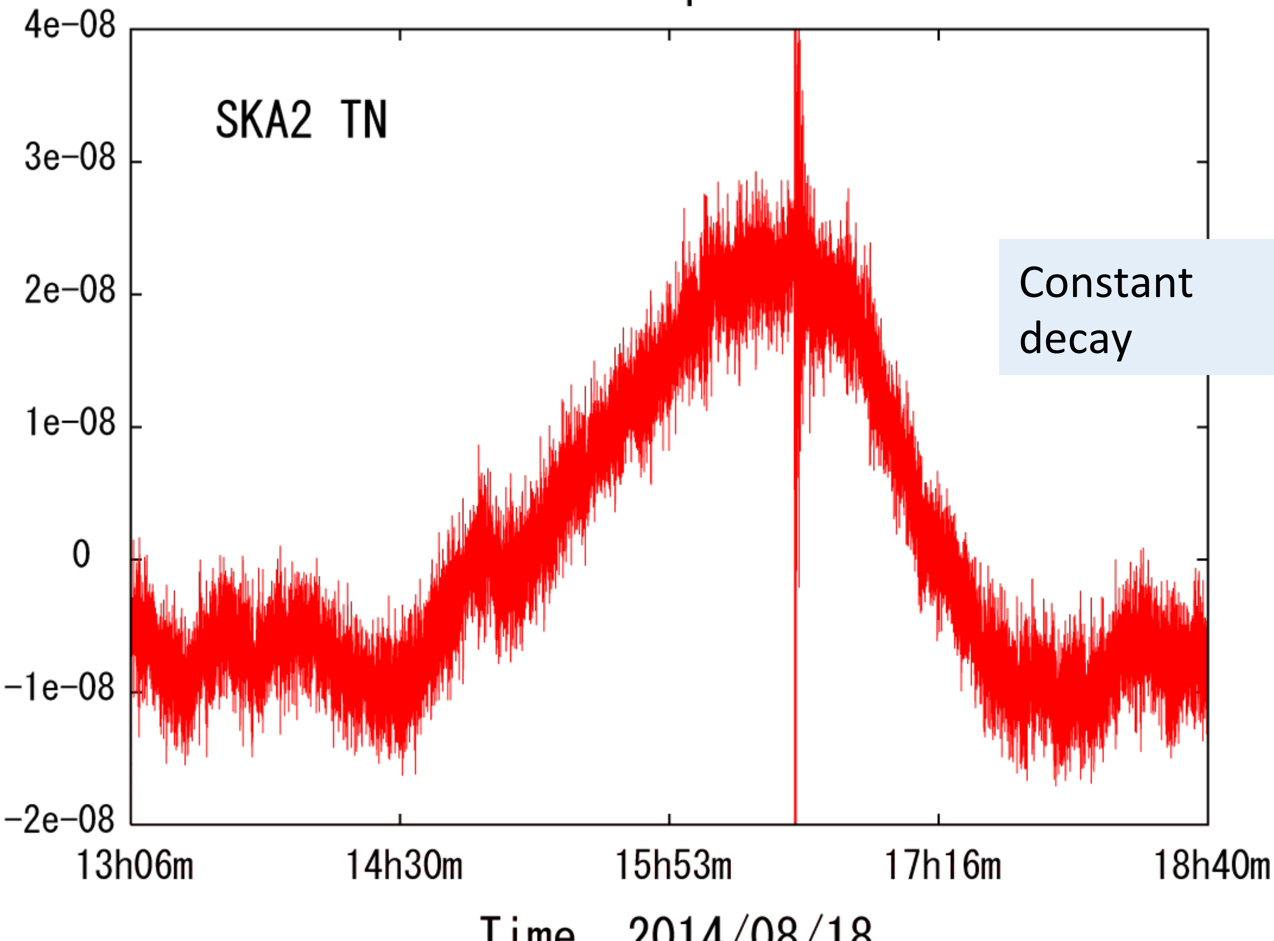
（鹿児島地方気象台（東郡元町）から撮影）

JMA



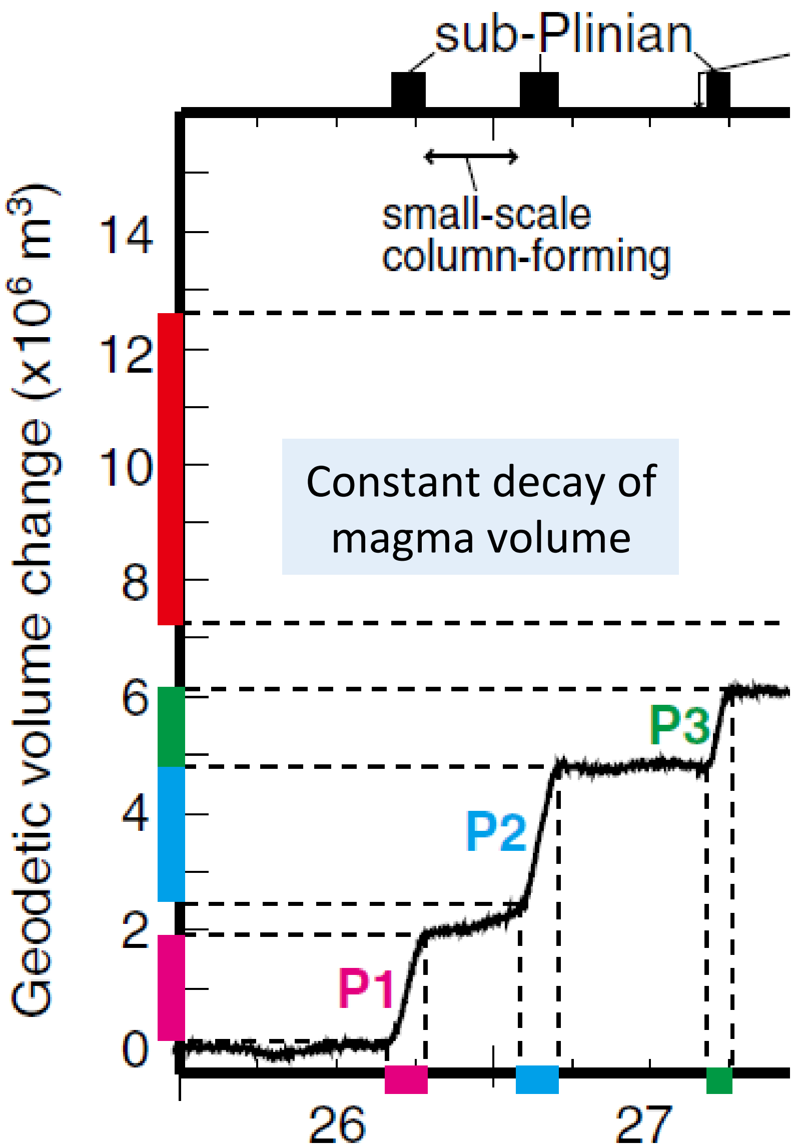
Data of the Coordinating Committee for Prediction of Volcanic Eruptions #127 (MRI, JMA, Kagoshima Univ)

Explosion 15h31m

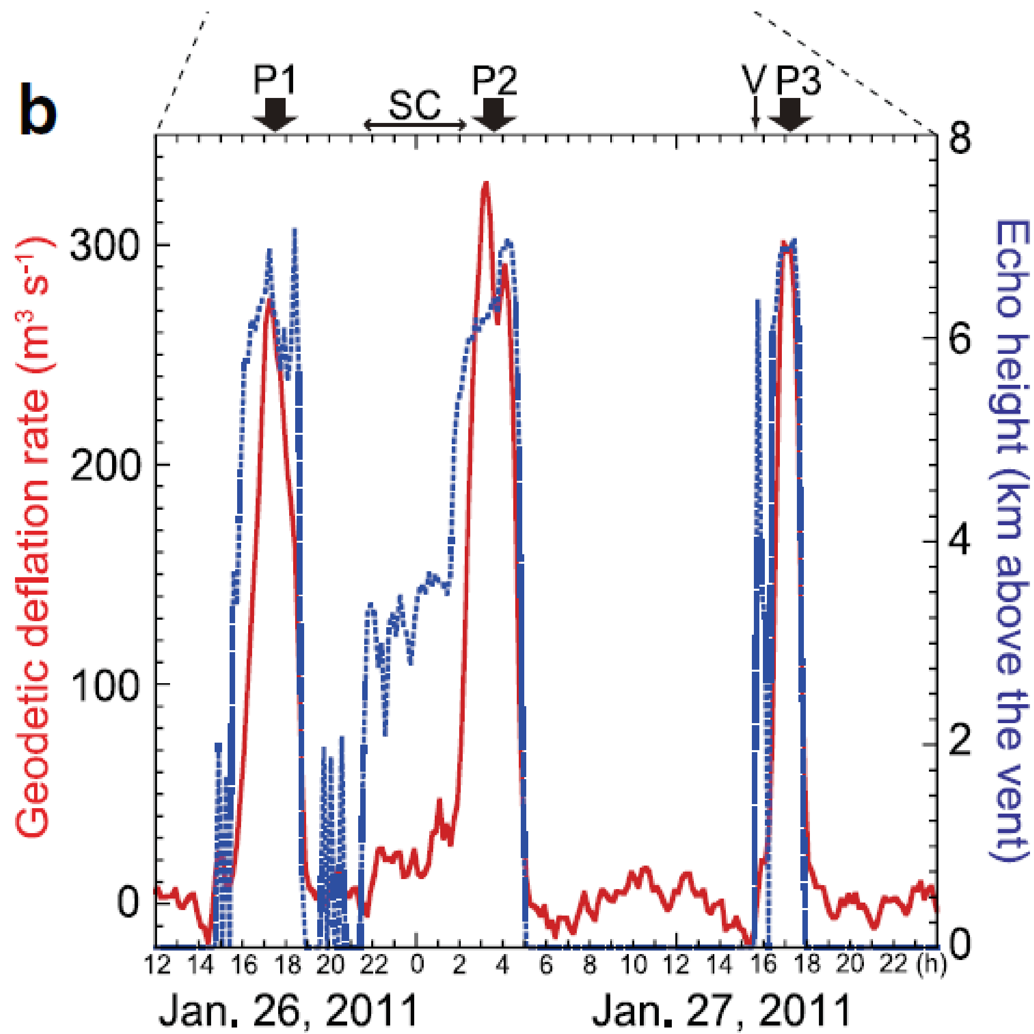


Constant decay

Shinmoe-dake Jan. 26, 2011 Sub-Plinean eruptions



Kozono et al. (2013)



Kozono et al. (2014)

A magma eruption model

Gas bubble growth in magma chamber
Choking condition at the conduit exit

$$Q = dV/dt = const.$$

$$dp = -k\, dV/V_0$$

$$1/\rho(p) = n(p)/\rho_g(p) + (1 - n(p))/\rho_l$$

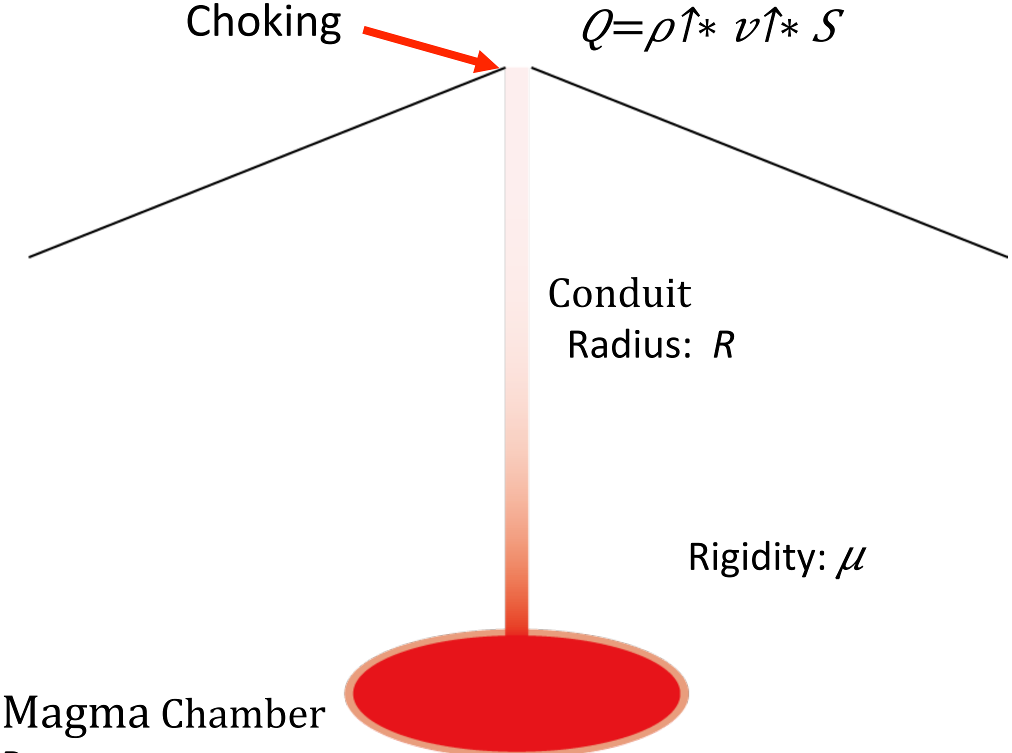
$$n(p) = (n_0 - s\sqrt{p})/(1 - s\sqrt{p})$$

mass ratio of gas

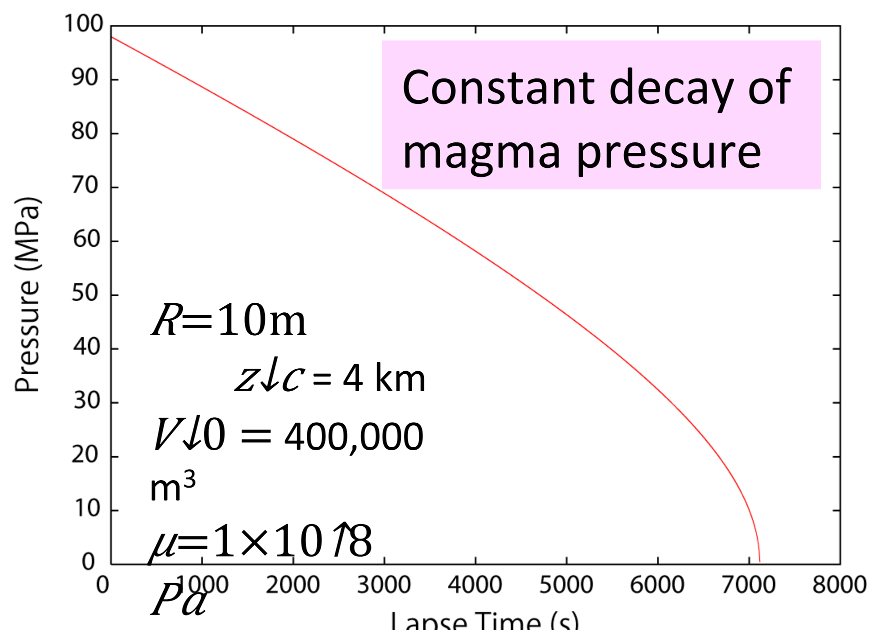
$s\sqrt{p}$: concentration
$s \sim 4\times10^{-6}\ Pa^{-1/2}$

Constant eruption rate

$Q = \rho^* v^* S$



Magma Chamber
Pressure : p
Depth : z_c
Concentration : $n_0 = s\sqrt{p}$



Summary

1. Volcanic pressure sources exponentially decay with time for small eruptions (Ontake 2014, Shinmoe 2010, Sakurajima vulcanian). The exponential decays are matched with the predictions from magma pseudo gas approximation model.

2. Contrary, large magmatic eruptions indicate constant decays of pressure of the sources (Plinean of Shinmoe, 2011, Sakurajima).Magma eruption model with chocking condition can explain the constant decays.

3. Exponential decay and constant decay can be also examined from detailed observation and analyses of volcanic ash monitoring.

4. Eruption with exponential decays may enable us to predict the duration time of eruption and roughly estimate the volume of ejecta if we can precisely monitor the ground deformation. But, eruptions with constant discharge rate may suddenly stop, which makes the prediction difficult.

Temporal change of eruption column is a key to understand

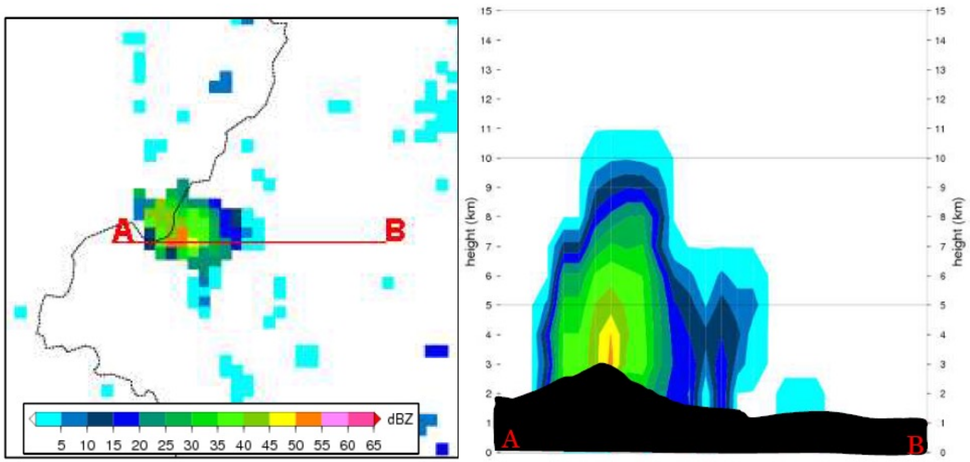


図３：2014 年 9 月 27 日 12 時 20 分における反射強度 CAPPI（3km）と断面図

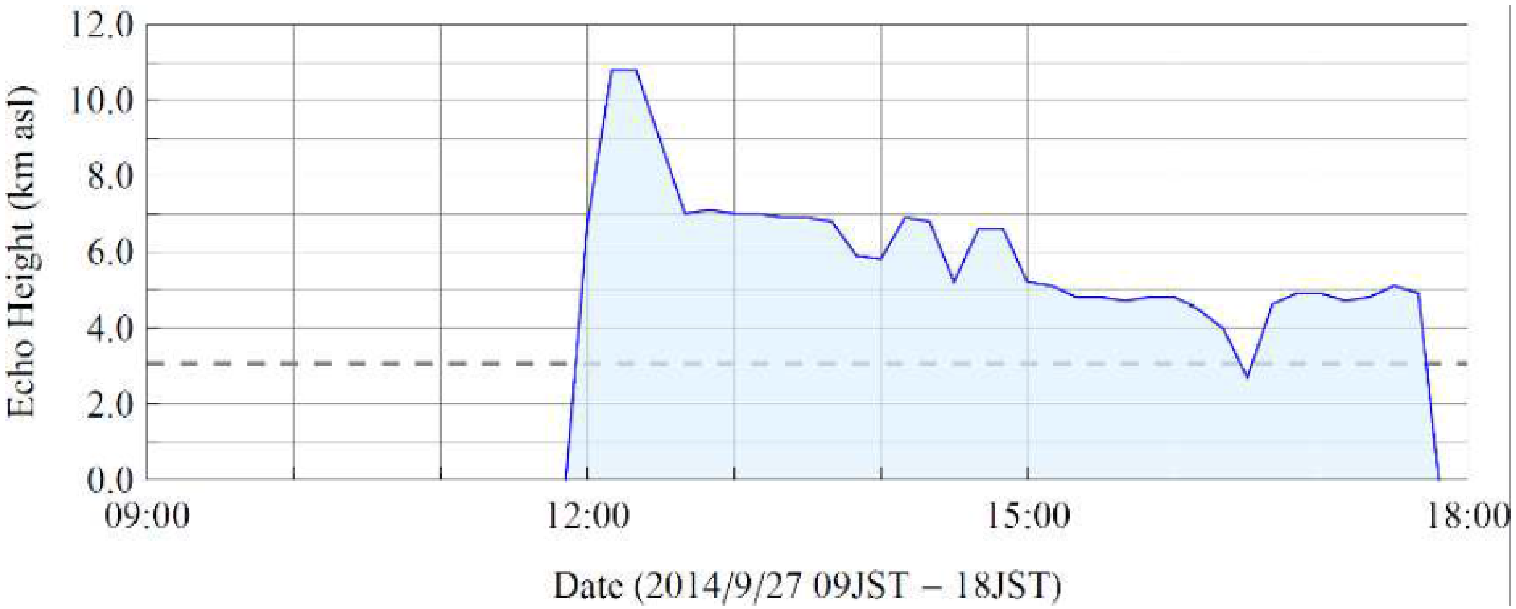


図４：2014 年 9 月 27 日 9 時から 18 時における御嶽山付近のエコー頂（合成）高度
（点線は剣ヶ峰の高度 3,067m）

Report of Extended Board of the Coordinating Committee for Prediction of Volcanic Eruptions. 2014/09/28

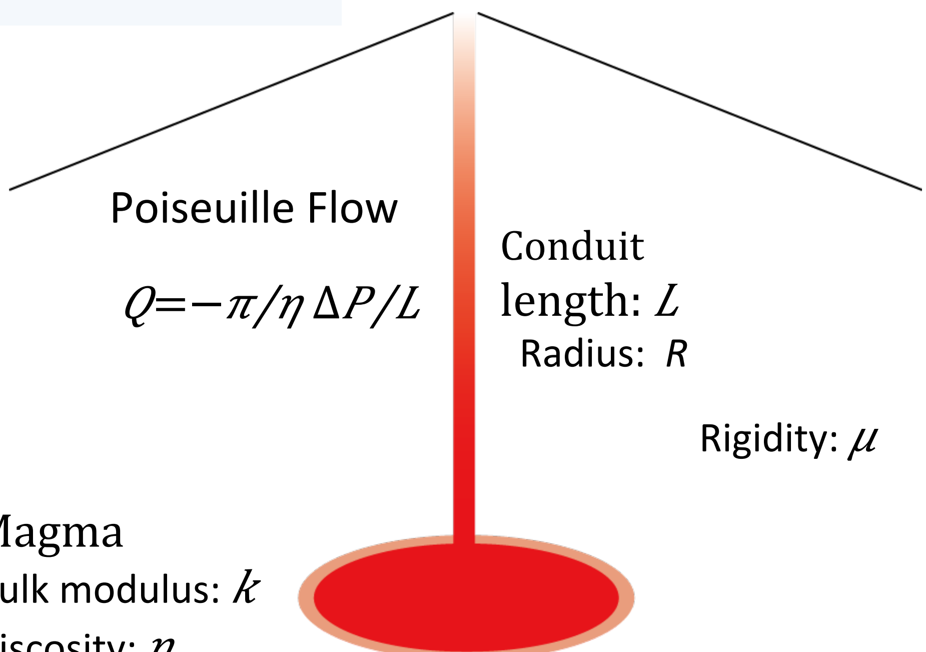
Magma pressure driven model

Grímsvötn Volcano, Iceland

Explosive Eruption of basaltic magma in May 2011

$Q = Q_0 \exp(-t/\tau)$
$P = \Delta P \exp(-t/\tau)$

Hreinsdóttir et al. (2014)



Poiseuille Flow

$Q = -\pi/\eta \, \Delta P/L$

Conduit length: L

Radius: R

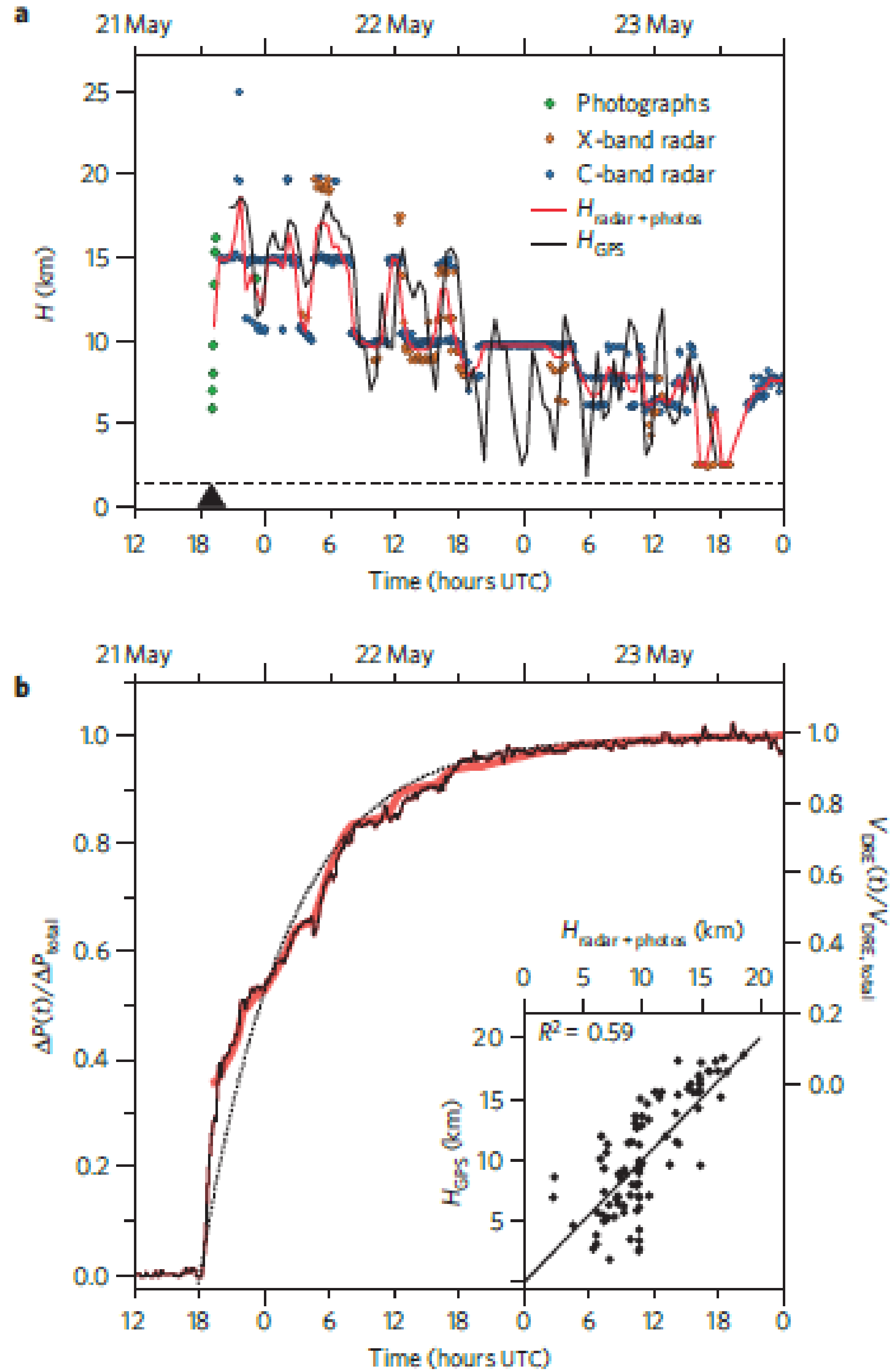
Rigidity: μ

Magma

Bulk modulus: k

Viscosity: η

Pressure Increse: $\Delta P Q = dV/dt = -\pi(1/\mu + 3/4k)$
$a^3 \, d\Delta P/dt$



Data during eruptions

- **Eruption column** (Rader observation)

- **Eruption tremor** (seismic observation)
  - VEI and maximum amplitude (McNutt, 1994)
  - Temporal changes（McNutt & Nishimura, 2008）
  - Eruption volume and tremor amplitude at Sakurajima (Iguchi, 2012)

Unknown and complex mechanism of eruption tremor !

- **Volcano deformation**
  (Geodetic observation)
  - Measurement of moment

Vulcanian eruptions at Sakurajima
  Exponential decay
Iguchi (2012, Bull. Dis. Prev. Res. Inst. Kyoto Univ.)

Few reports !