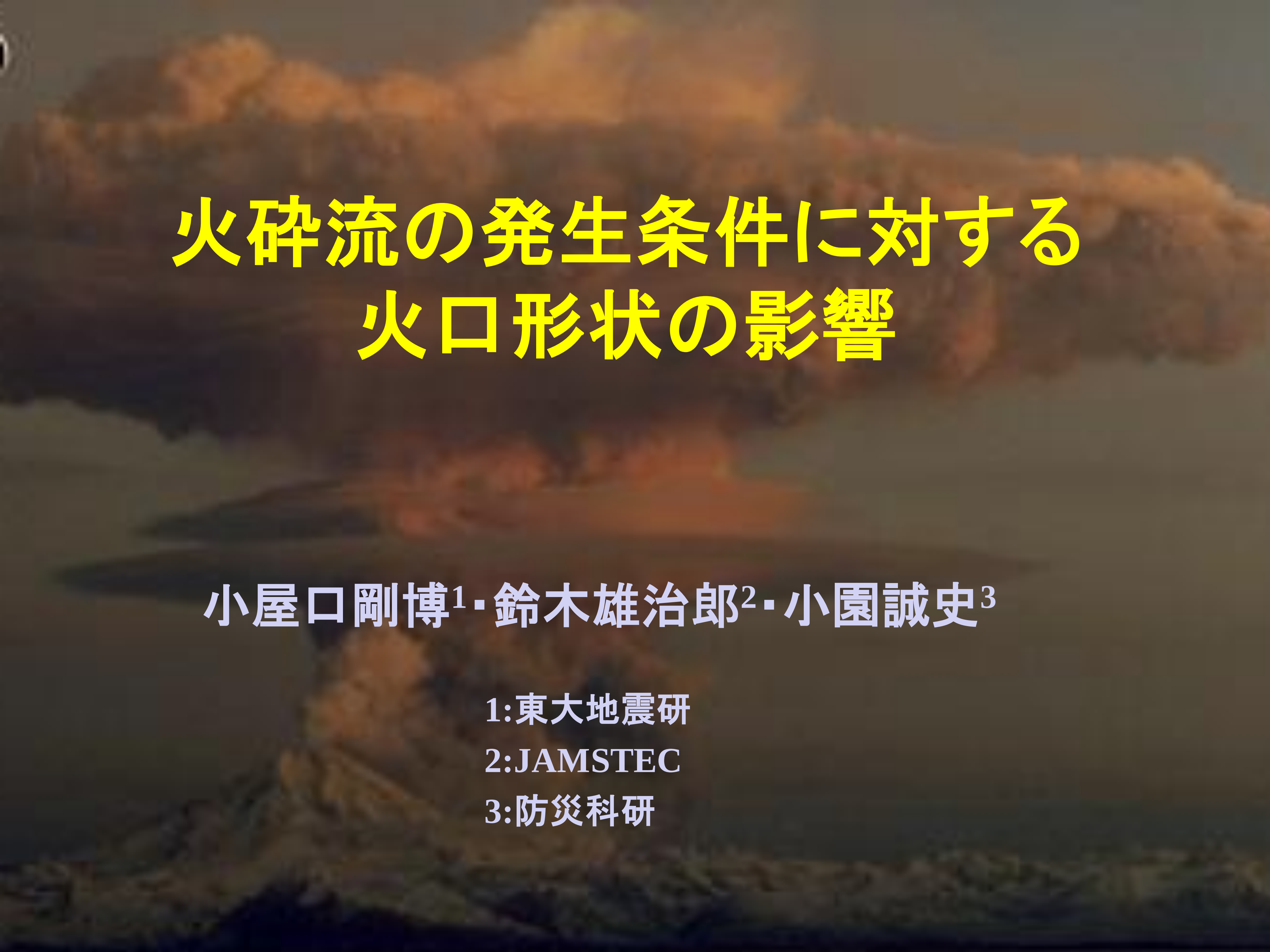

火砕流の発生条件に対する火口形状の影響

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1:東大地震研
2:JAMSTEC
3:防災科研

Column collapse condition

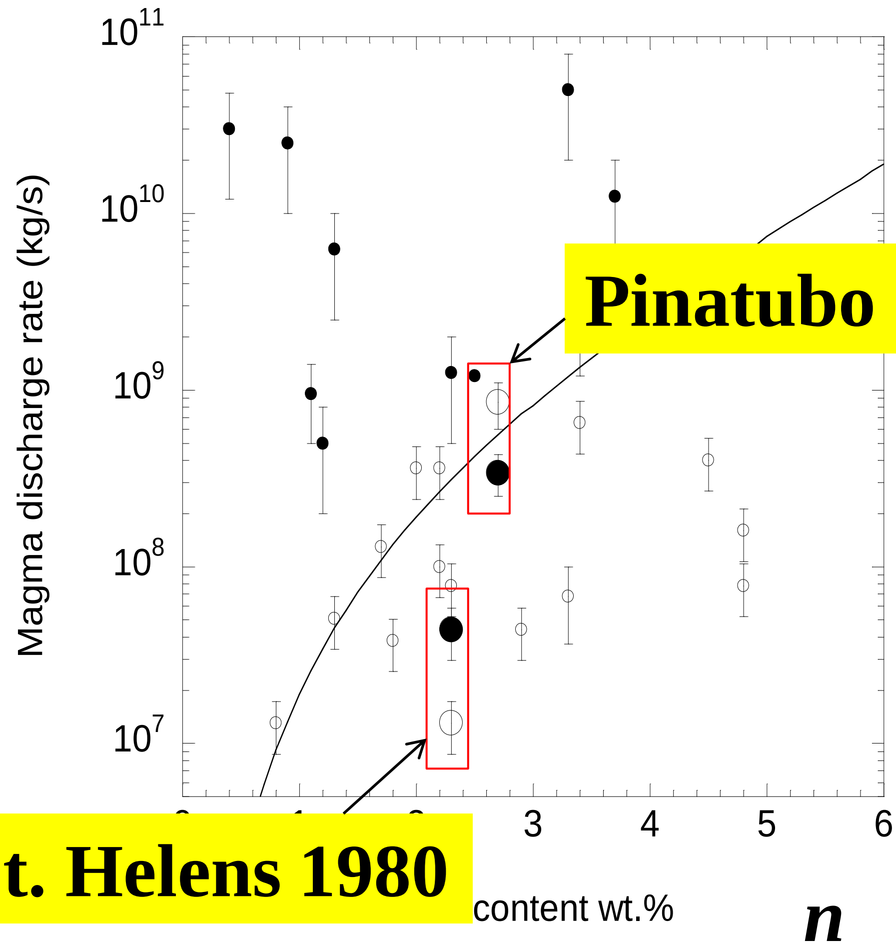
Positively or negatively buoyant

Eruption column

Example from the 1980 eruption
at Mt. St. Helens (USGS)

Pyroclastic flow

Previous model prediction based on 1-D steady eruption column model



Column collapse condition predicted
by Carazzo et al. (2008)

Pinatubo 1991

St. Helens 1980

with the assumptions

(1) A model for entrainment by Kaminski et al. (2005)

(2) $v_a \approx 138\sqrt{n}$

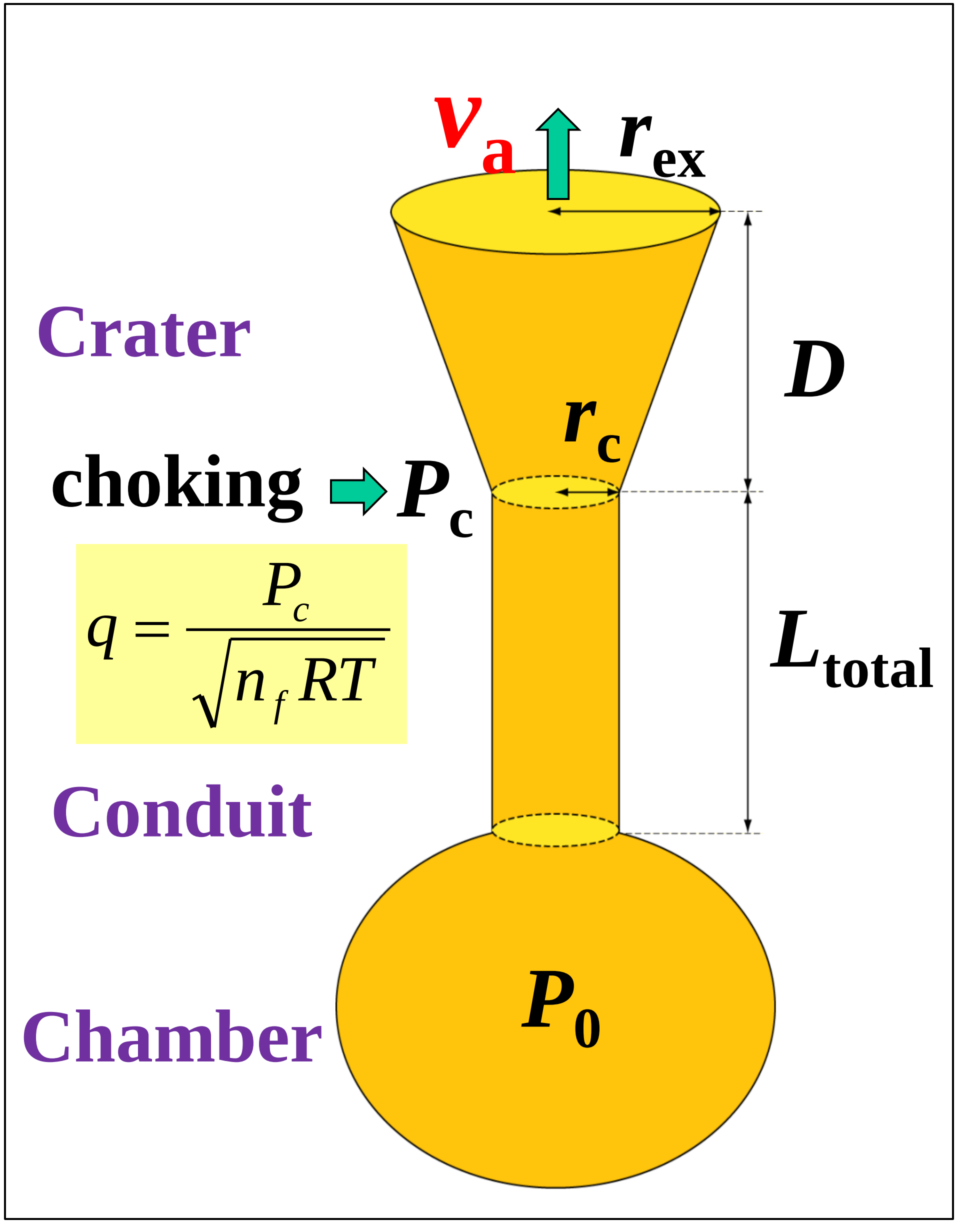
v_a: velocity at the atmospheric P just above the vent

Observations

● **Pyroclastic flow**

○ **Buoyant plume**

Problems to solve



$$q = \frac{P_c}{\sqrt{n_f RT}}$$

Column dynamics

Bursik and Woods (1991)
Kaminski and Jaupart (2001)
Carazzo et al. (2008)

Flow inside crater

Woods and Bower (1995)
Ogden et al. (2008) etc.

Flow in conduit

Wilson et al. (1980)
CONFLOW (2000)
Koyaguchi (2005) etc.

Entrainment hypothesis

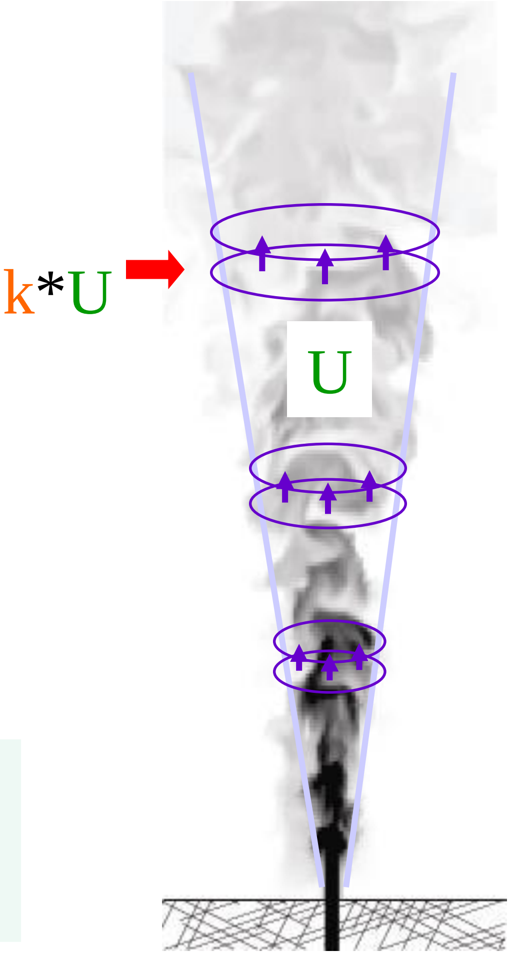
[Morton et al., 1956]

Inflow velocity = *k* * mean velocity

***k*=0.09** (e.g., Woods, 1988)

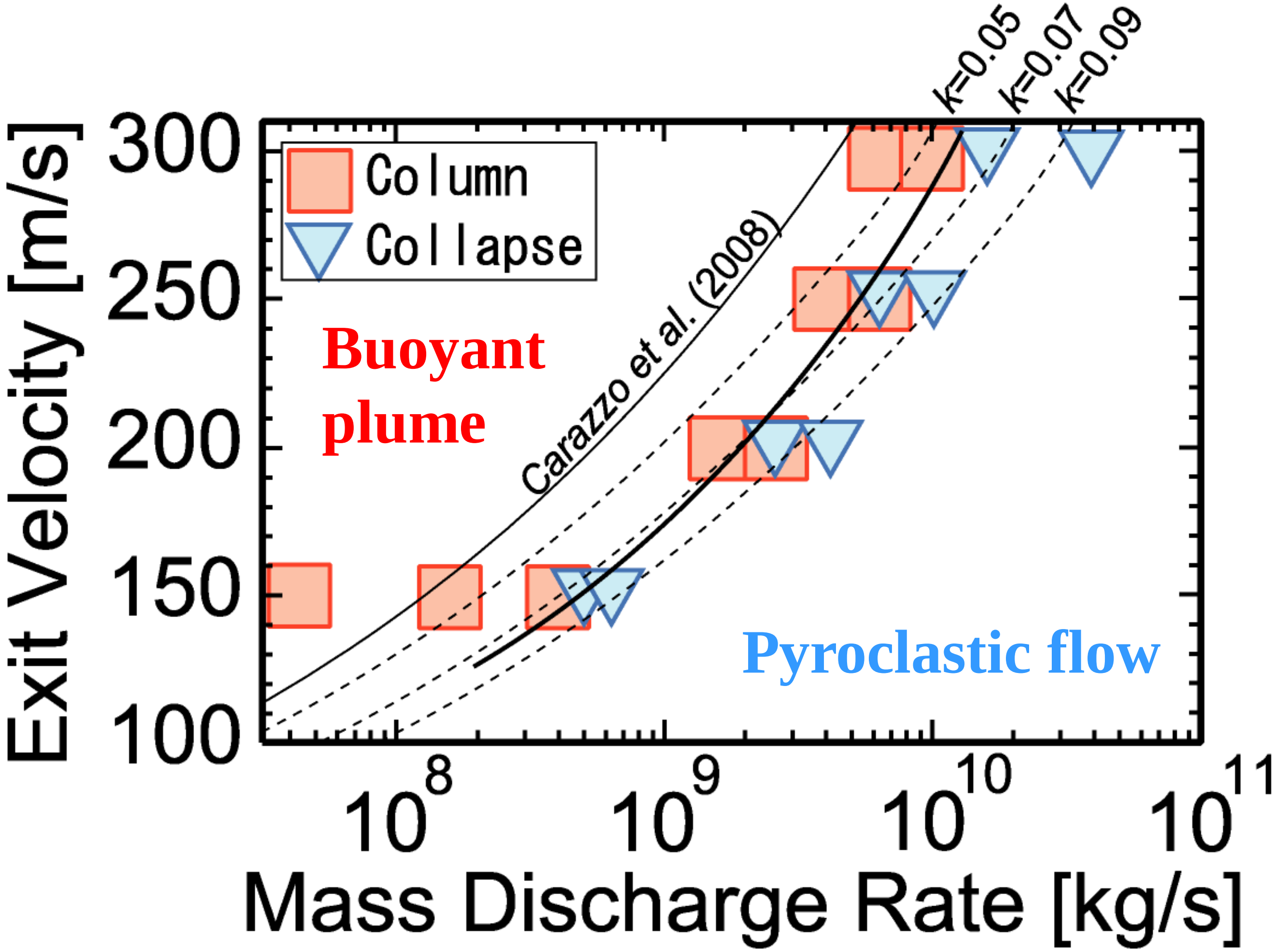
based on self-similarity of ideal steady jets or plumes

Is this applicable to non-self-similar eruption clouds?

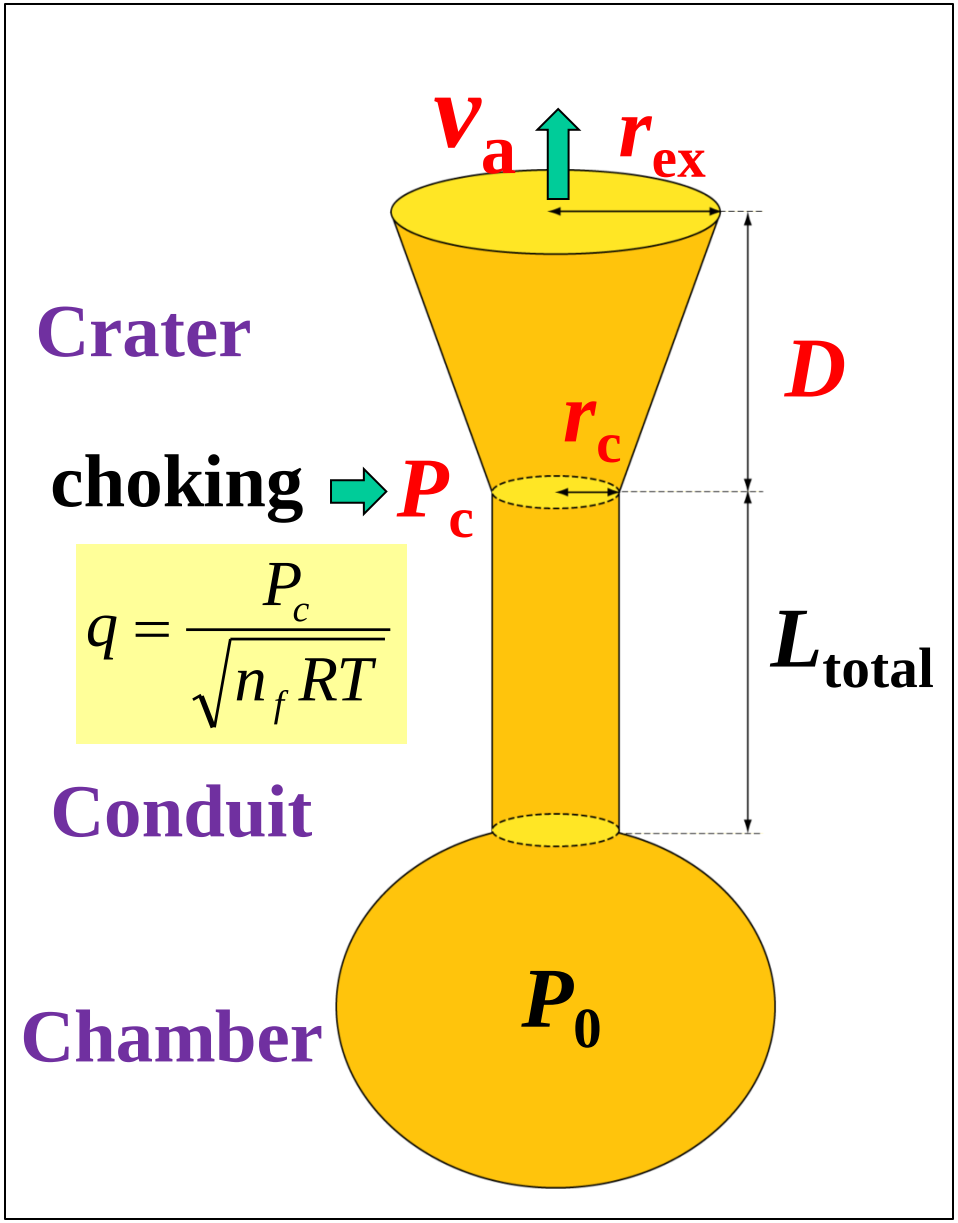


Comparison
between the 1-D and 3D models

[Suzuki et al., 2005]



Problems to solve



$$q = \frac{P_c}{\sqrt{n_f RT}}$$

Column dynamics

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Flow in conduit

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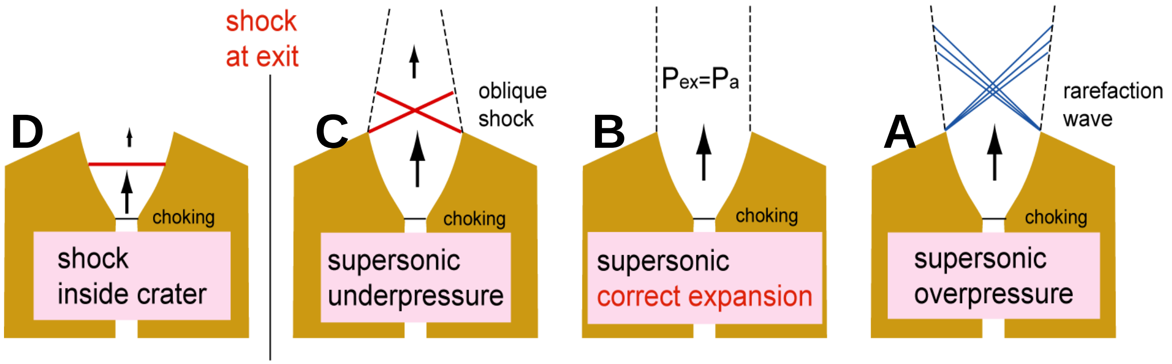
CONFLOW (2000)
Koyaguchi (2005) etc.

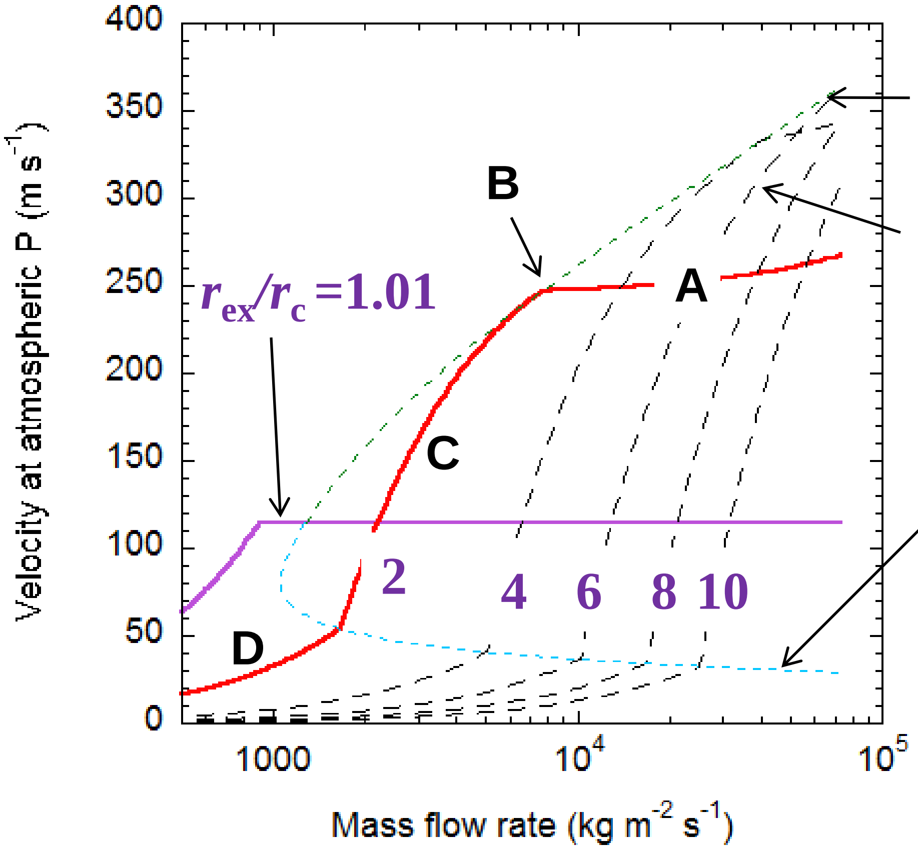
Flow inside crater

large
r_{ex}/r_c
small
MFR



small
r_{ex}/r_c
large
MFR

“v_a”



Correct expansion

Velocity change for given $r_{ex}/r_c(=2)$

Shock at exit

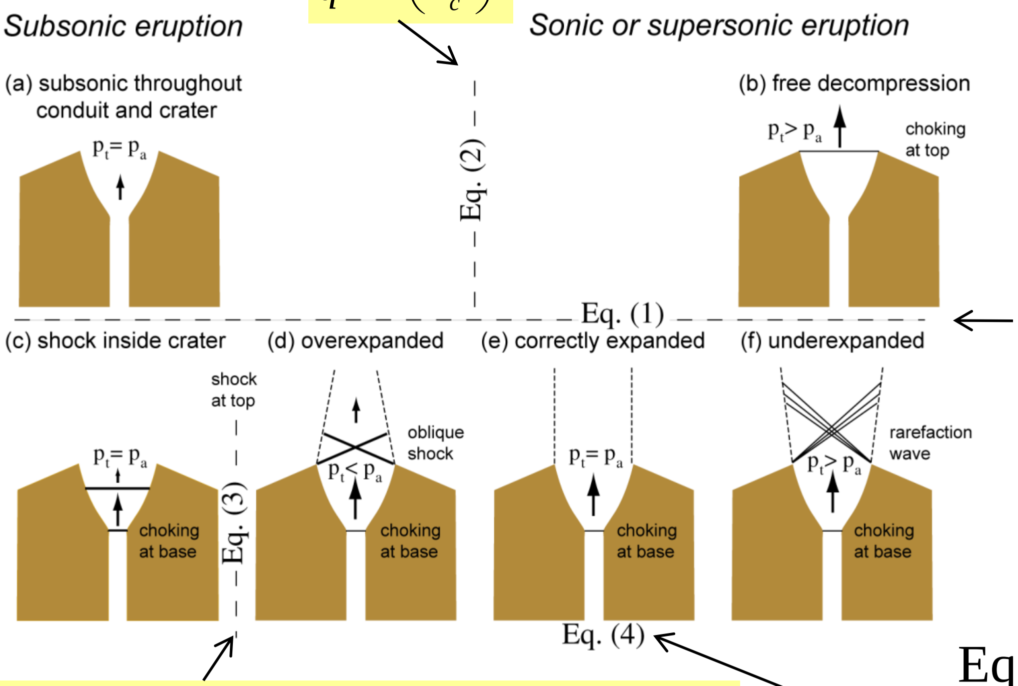
Mass flow rate (*MFR*)

$$q \equiv \rho_c v_c = \frac{P_c}{\sqrt{n_f RT}}$$

Boundaries of different flow regimes

Eq. (2)

$$\frac{q}{q^*} = \left(\frac{r_{ex}}{r_c}\right)^2$$



Eq. (1)

$$\frac{D}{l_{sc}} = \ln\left(\frac{r_{ex}}{r_c}\right)^2 + \frac{2V_L}{V_{Ga}}\frac{q}{q^*}\left\{1-\left(\frac{r_c}{r_{ex}}\right)^2\right\} + \frac{1}{2}\left(\frac{V_L}{V_{Ga}}\frac{q}{q^*}\right)^2\left\{1-\left(\frac{r_c}{r_{ex}}\right)^4\right\}$$

Eq. (3)

$$\frac{1}{2}\left(\frac{q}{q^*}\right)^2\left[\left(\frac{r_{ex}}{r_c}\right)^{-4}\left\{\frac{V_L}{V_{Ga}}+\left(\frac{q}{q^*}\right)^2\left(\frac{r_{ex}}{r_c}\right)^4\right\}^2-\left(\frac{V_L}{V_{Ga}}+\frac{q}{q^*}\right)^2\right] + \frac{V_L}{V_{Ga}}\frac{q}{q^*}\left\{\left(\frac{r_{ex}}{r_c}\right)^{-4}\frac{q}{q^*}-1\right\}+\ln\left\{\left(\frac{r_{ex}}{r_c}\right)^{-4}\frac{q}{q^*}\right\}+\frac{D}{l_{sc}}=0$$

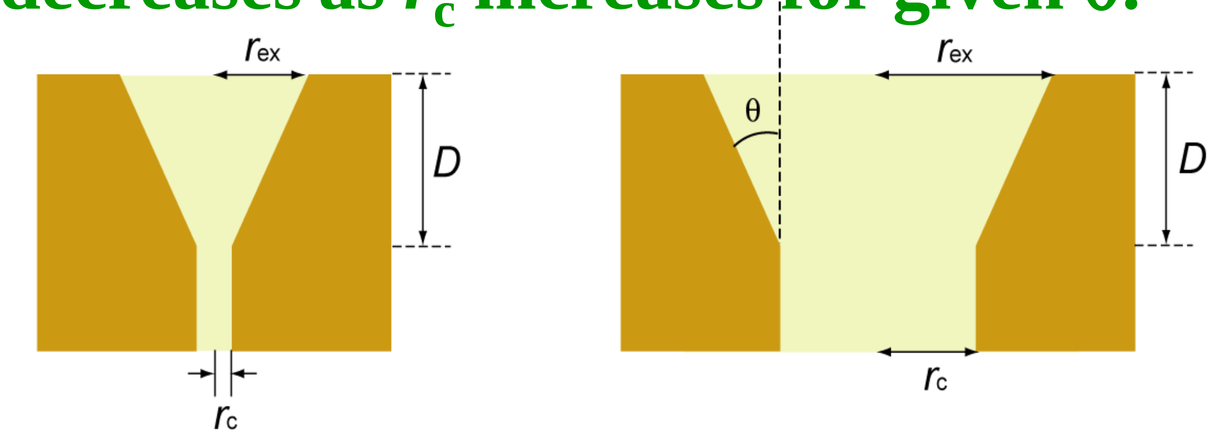
Eq. (4)

$$\frac{1}{2}\left(\frac{q}{q^*}\right)^2\left\{\left(\frac{r_{ex}}{r_c}\right)^{-4}\left(\frac{V_L}{V_{Ga}}+1\right)^2-\left(\frac{V_L}{V_{Ga}}+\frac{q}{q^*}\right)^2\right\} + \frac{V_L}{V_{Ga}}\left(1-\frac{q}{q^*}\right)-\ln\left(\frac{q}{q^*}\right)+\frac{D}{l_{sc}}=0$$

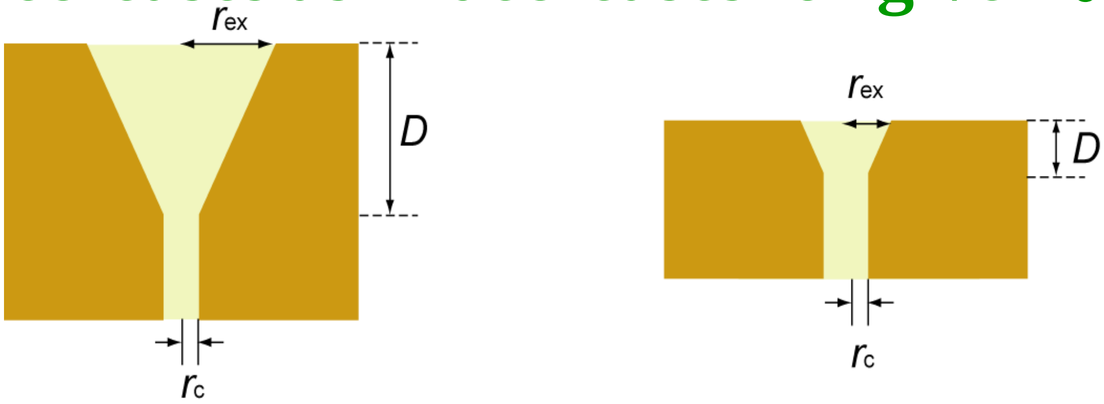
Effect of the crater shape on r_{ex}/r_c ratio

$$\frac{r_{ex}}{r_c} \approx 1 + \frac{D\tan\theta}{r_c}$$

r_{ex}/r_c decreases as r_c increases for given θ.



r_{ex}/r_c decreases as D decreases for given θ.



Flow regimes on "magma discharge rate vs r_c diagram"

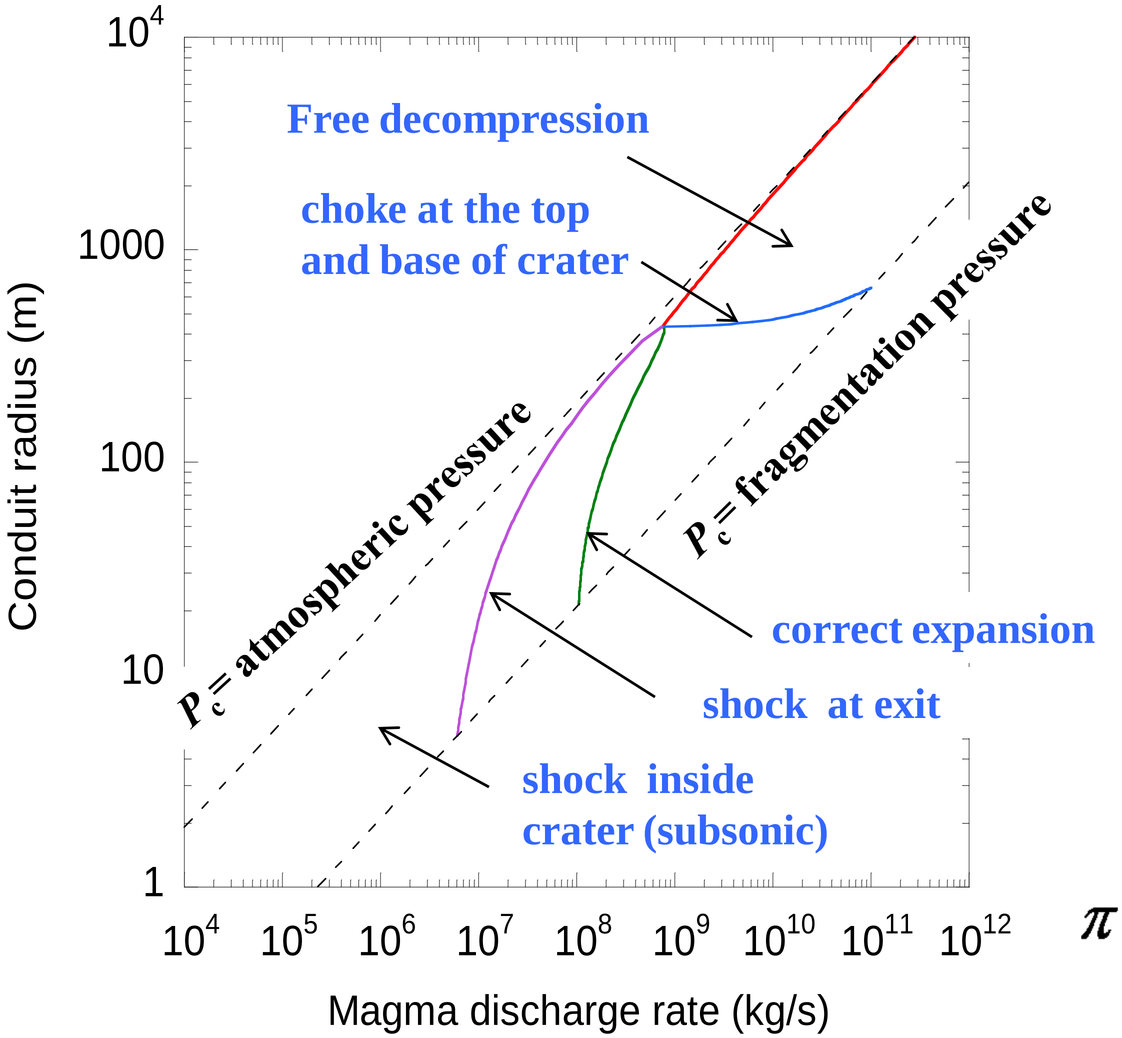
small

↑

r_{ex}/r_c

↓

large



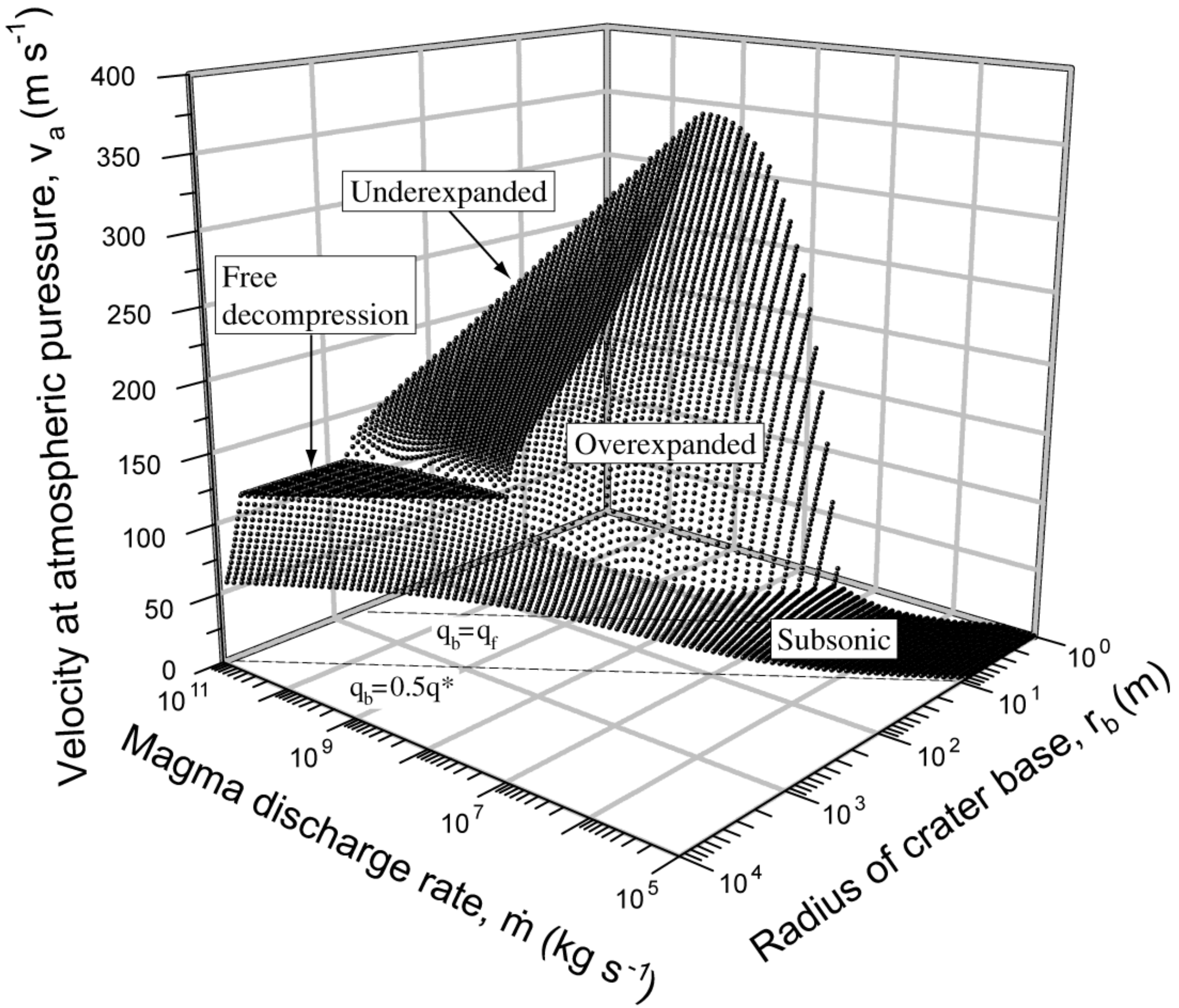
Result for
n_0=0.04
D=500 m
θ=10°

$$\pi r_c^2 q = \frac{\pi r_c^2 P_c}{\sqrt{n_f RT}}$$

Velocity at the atmospheric P (“v_a”) on “magma discharge rate vs r_c diagram”

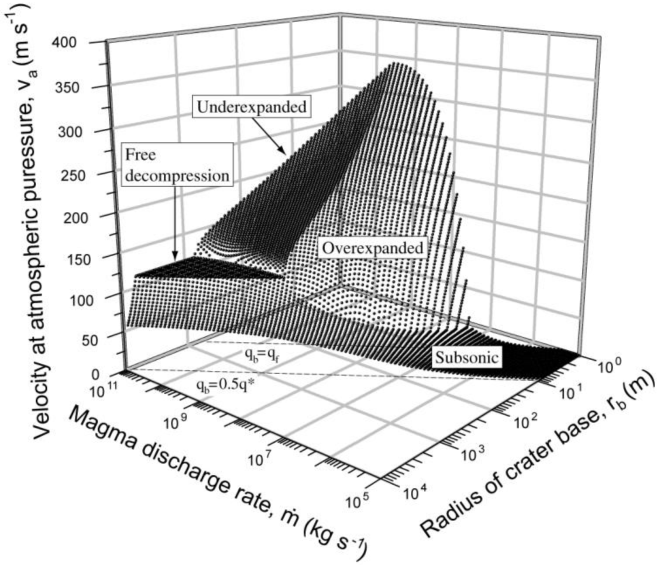
(based on Woods and Bower, 1995; Ogden et al., 2008)

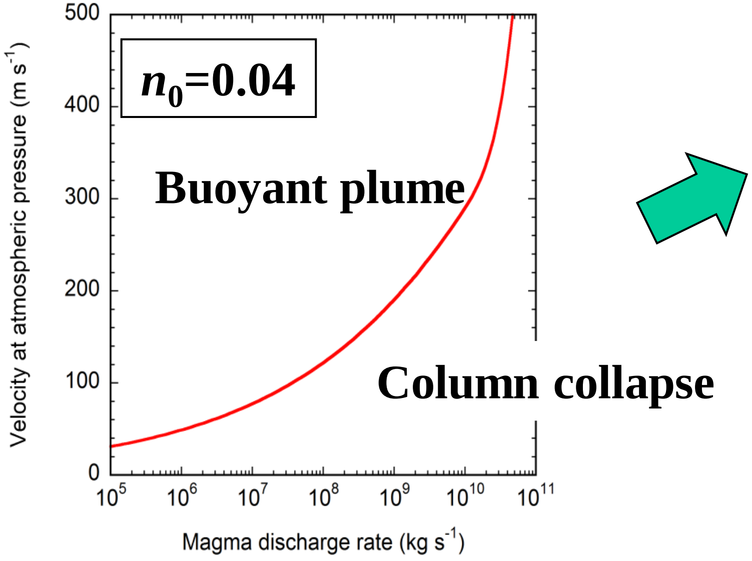
“v_a”

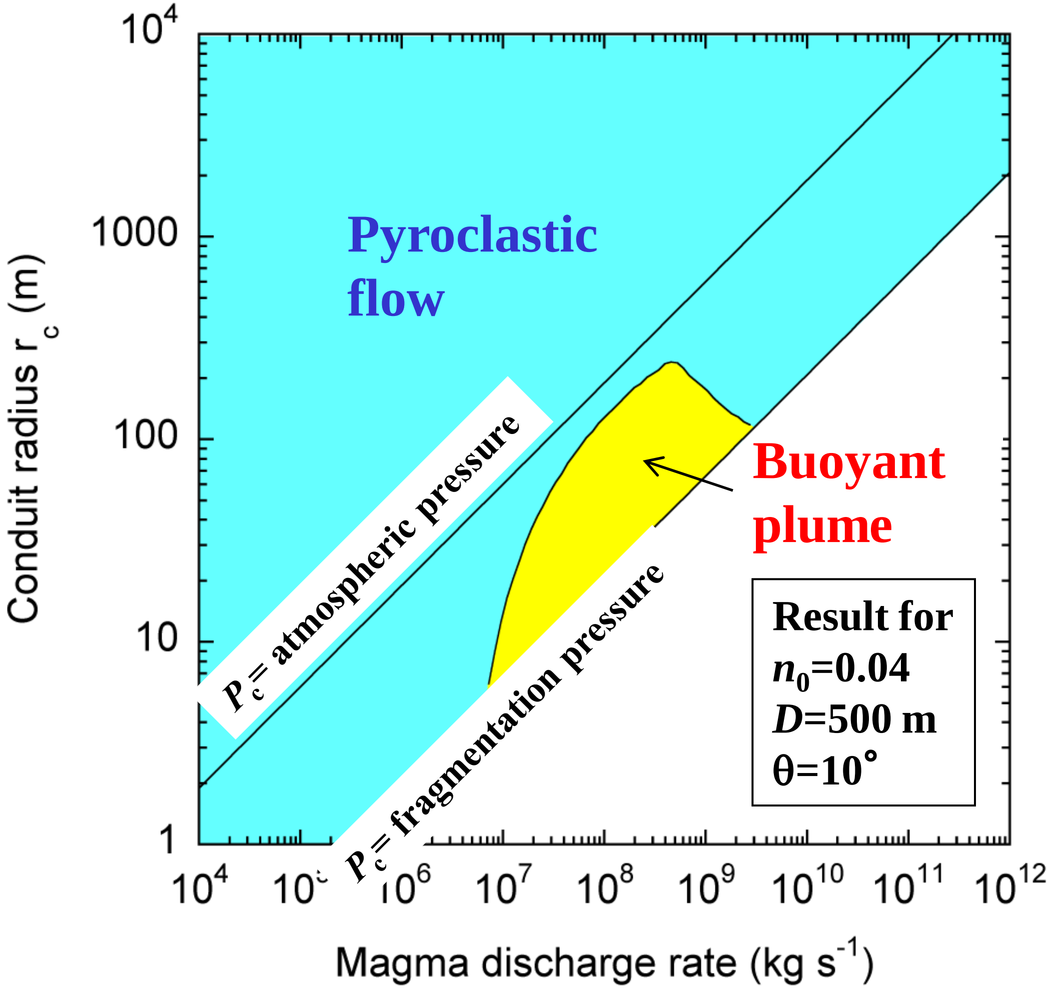


Result for
n_0=0.04
D=500 m
θ=10°

Proclastic-flow and buoyant plume regions on “magma discharge rate vs r_c diagram”

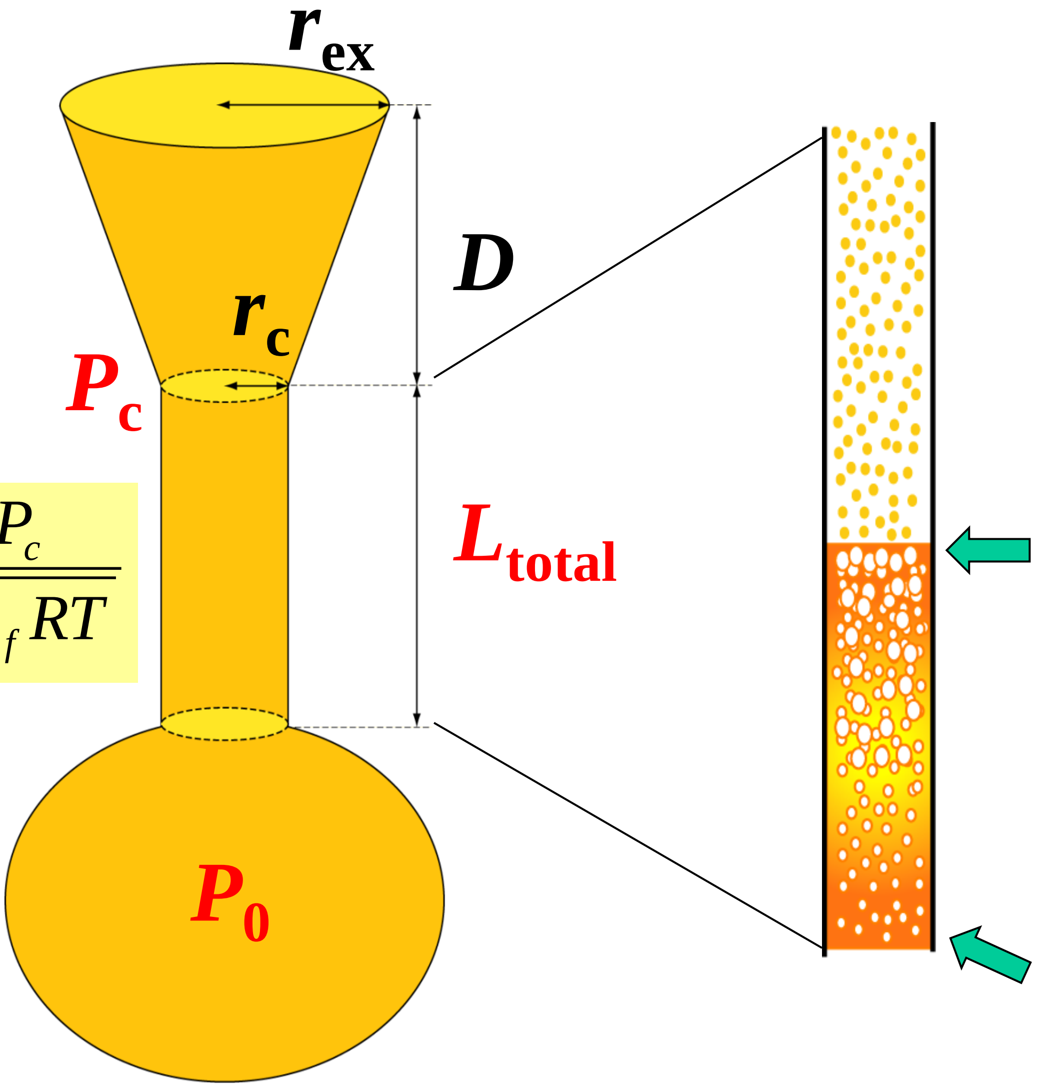






Mass flow rate through a conduit

1-D conduit flow model (e.g., Wilson et al., 1980;Koyaguchi, 2005)



$$q = \frac{P_c}{\sqrt{n_f RT}}$$

Gas-pyroclast flow

inviscid

compressible

Fragmentation surface

Bubbly flow

viscous

(compressible)

Gas exsolution

Semi-analytical solution of 1-D steady conduit flow (Koyaguchi, 2005)

small ← $$\gamma \equiv \frac{g\rho_l^2 r_c^2 \sqrt{n_f RT}}{8\eta P_f}$$ → **large**

$\gamma \ll 1$

$$\boxed{\frac{P_c}{P_f} \approx \exp\left(-\frac{gL_{total}}{n_f RT}\right)}$$

Chamber depth control

$\gamma \gg 1$

$$\boxed{\frac{P_c}{P_f} \approx \exp\left(-\frac{\Delta P}{\rho_l n_f RT}\right)}$$

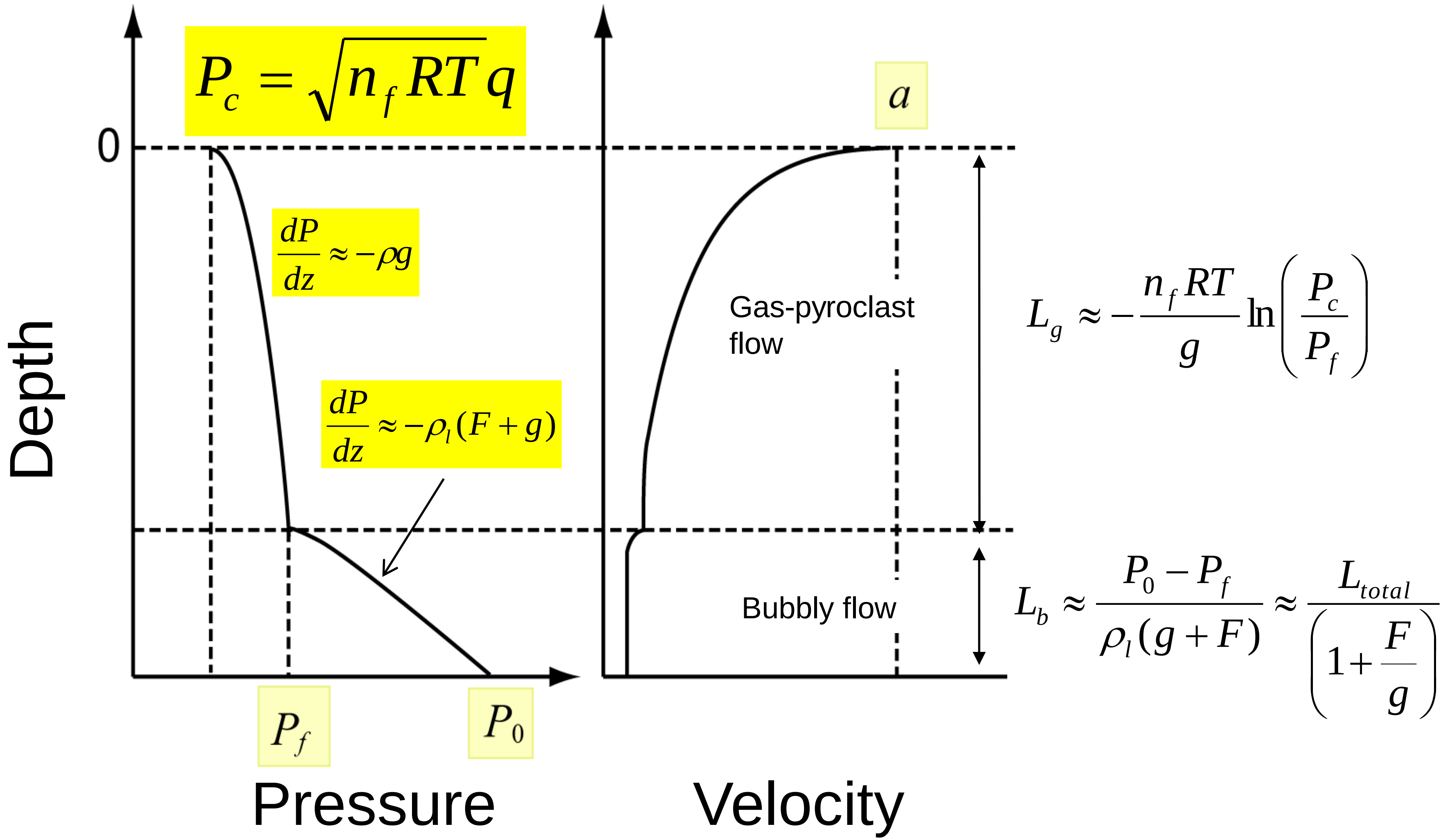
Chamber pressure control

L_{total} : chamber depth.

$\Delta P = P_{lith} - P_0$: degree of chamber under-pressure.

Semi-analytical solution of 1-D steady conduit flow (Koyaguchi, 2005)

$q = \rho v$; mass flow rate



$$P_c = \sqrt{n_f RT}\, q$$

$$\frac{dP}{dz} \approx -\rho g$$

$$\frac{dP}{dz} \approx -\rho_l (F+g)$$

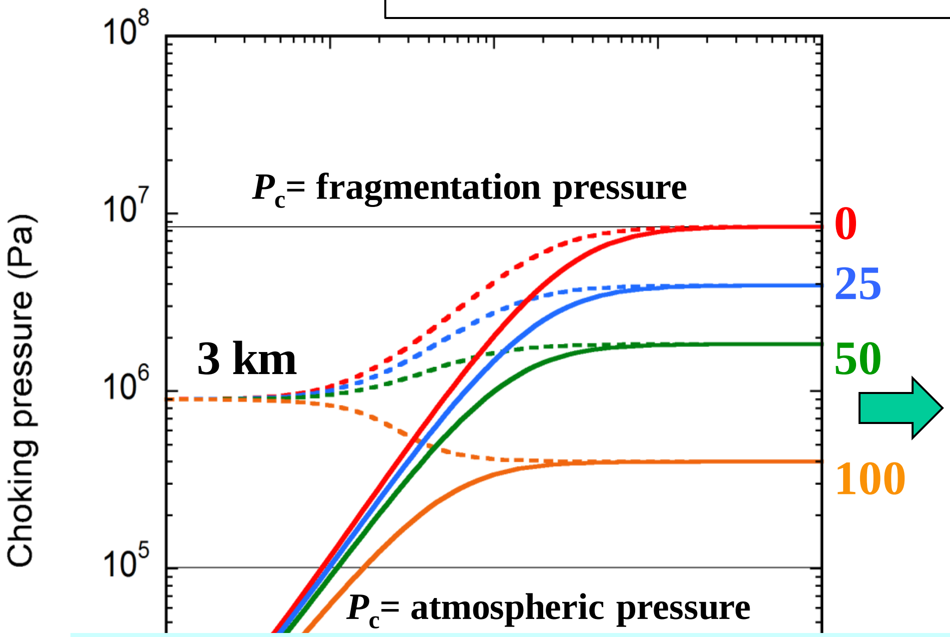
$$L_g \approx -\frac{n_f RT}{g} \ln\left(\frac{P_c}{P_f}\right)$$

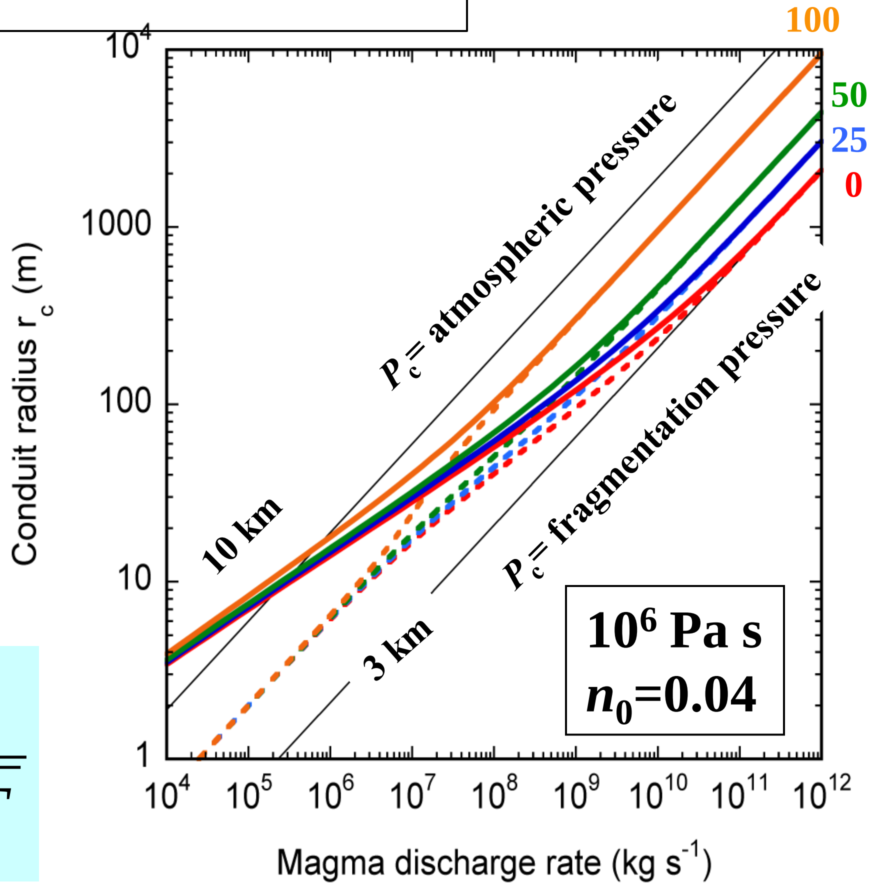
$$L_b \approx \frac{P_0 - P_f}{\rho_l (g+F)} \approx \frac{L_{total}}{\left(1+\frac{F}{g}\right)}$$

“Magma discharge rate vs r_c relationship” derived from 1-D conduit flow model

Chamber depth ----- **3 km**
—— **10 km**

Chamber under-presure **0 , 25, 50, 100 MPa**

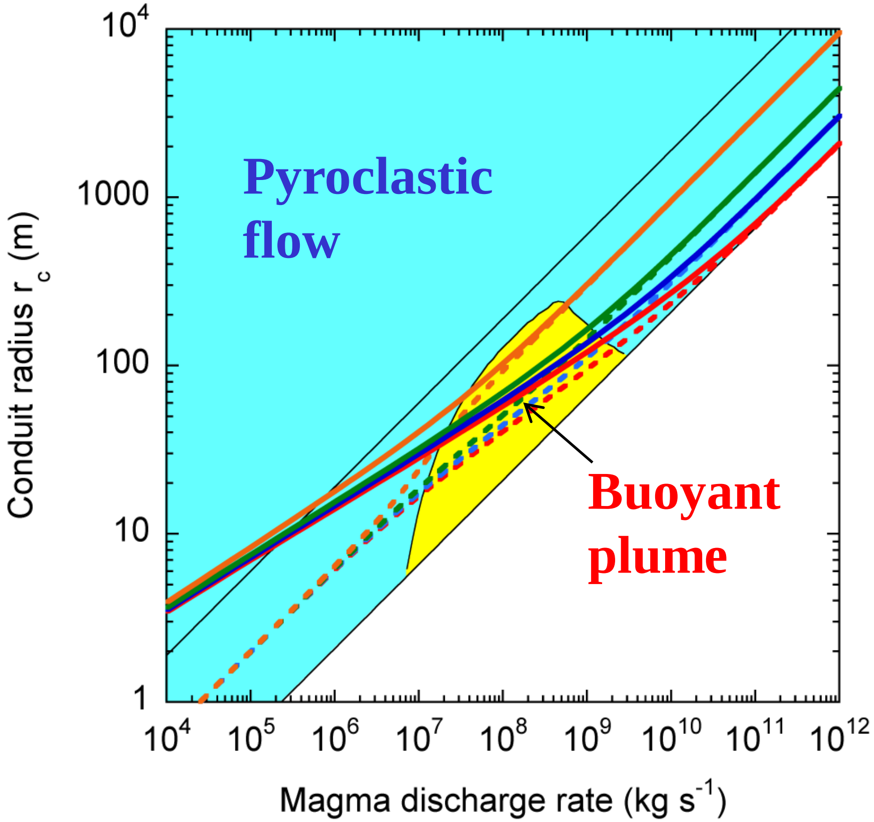




$$\text{magma discharge rate} = \frac{\pi r_c^{\,2} P_c}{\sqrt{n_f R T}}$$

Column collapse condition on "magma discharge rate vs r_c diagram"

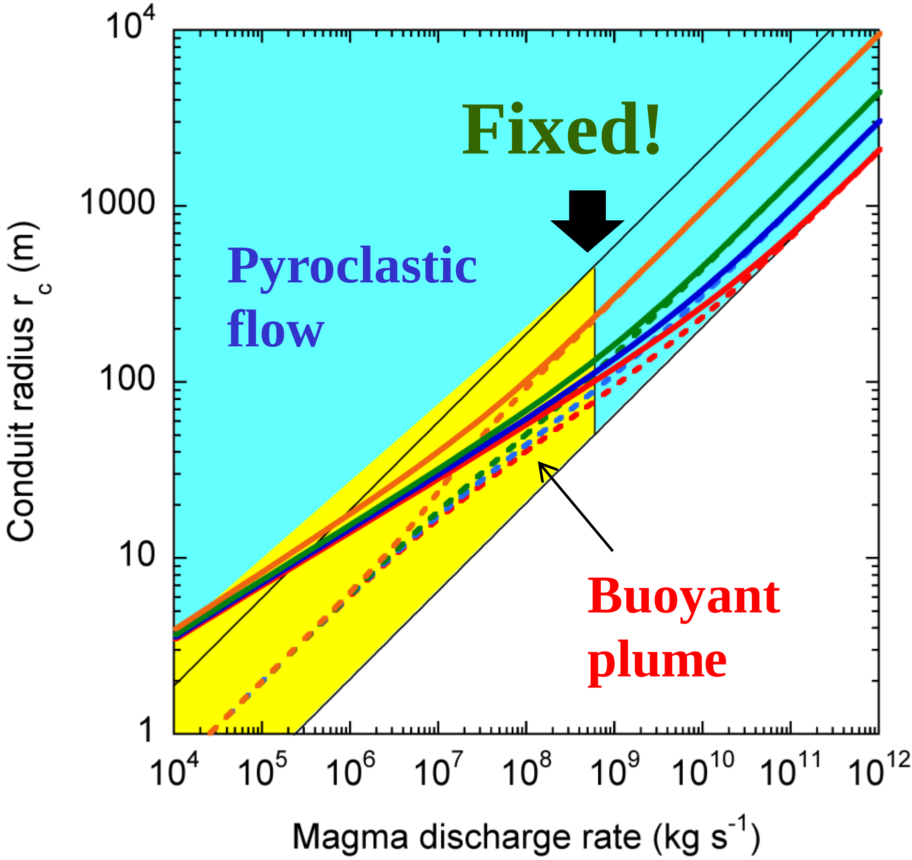
Chamber depth	------	**3 km**
	——	**10 km**
Chamber under-presure	**0 , 25, 50, 100 MPa**	



Result for
n_0=0.04
D=500 m
θ=10°

Difference from the previous study

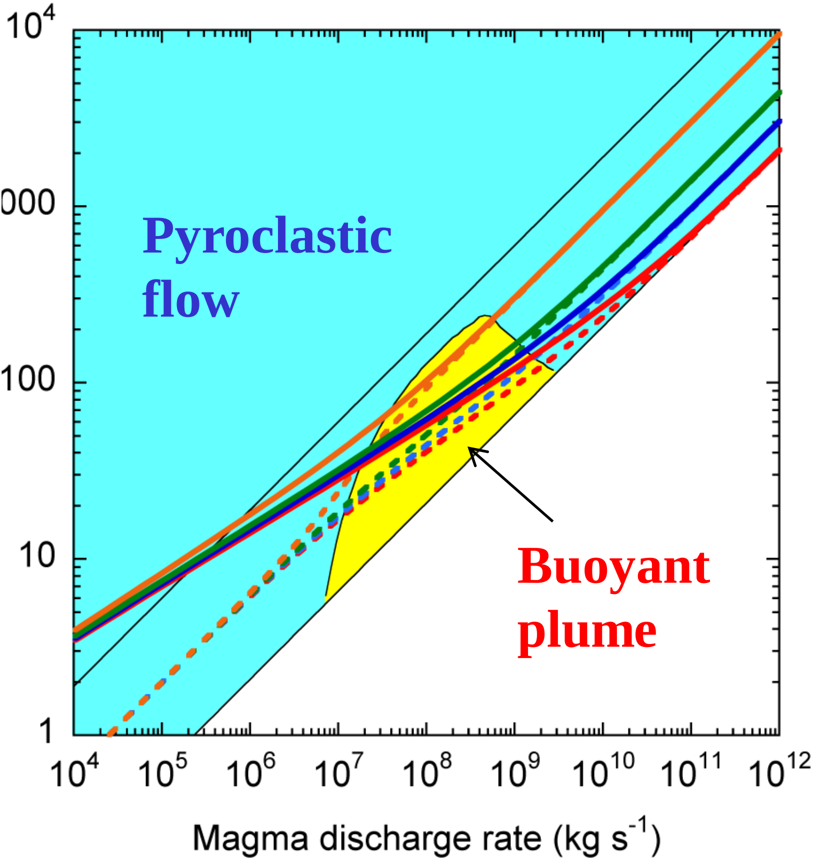
Previous study



$$v_a \approx 138\sqrt{n}$$

(e.g. Carazzo et al. 2008)

This study



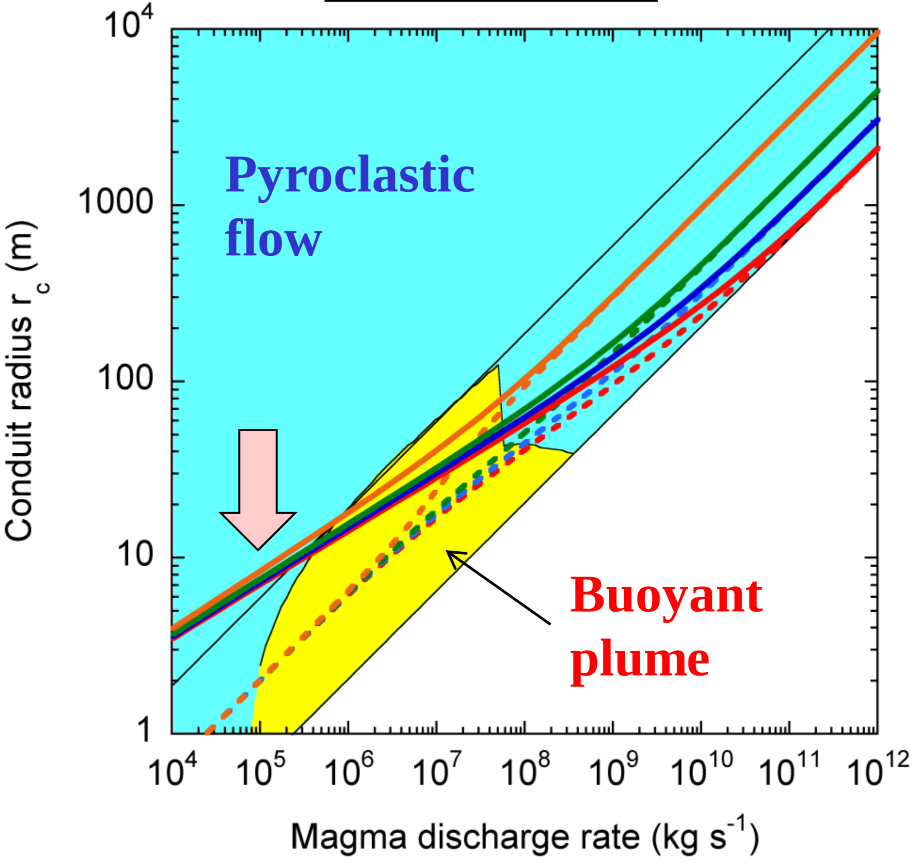
variable v_a

Dependence on crater shape

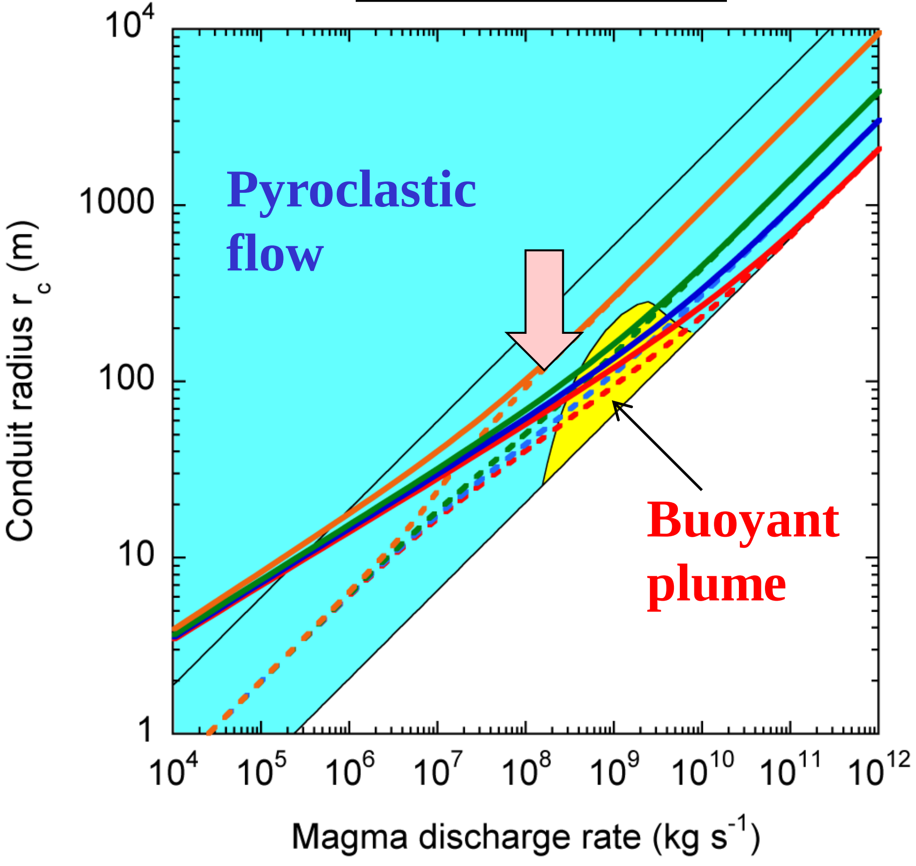
***D*=500 m**
θ=1°

$$\dot{m}_L \approx \frac{\pi P_a D^2 \tan^2 \theta}{\sqrt{n_f RT}}$$

***D*=1000 m**
θ=20°

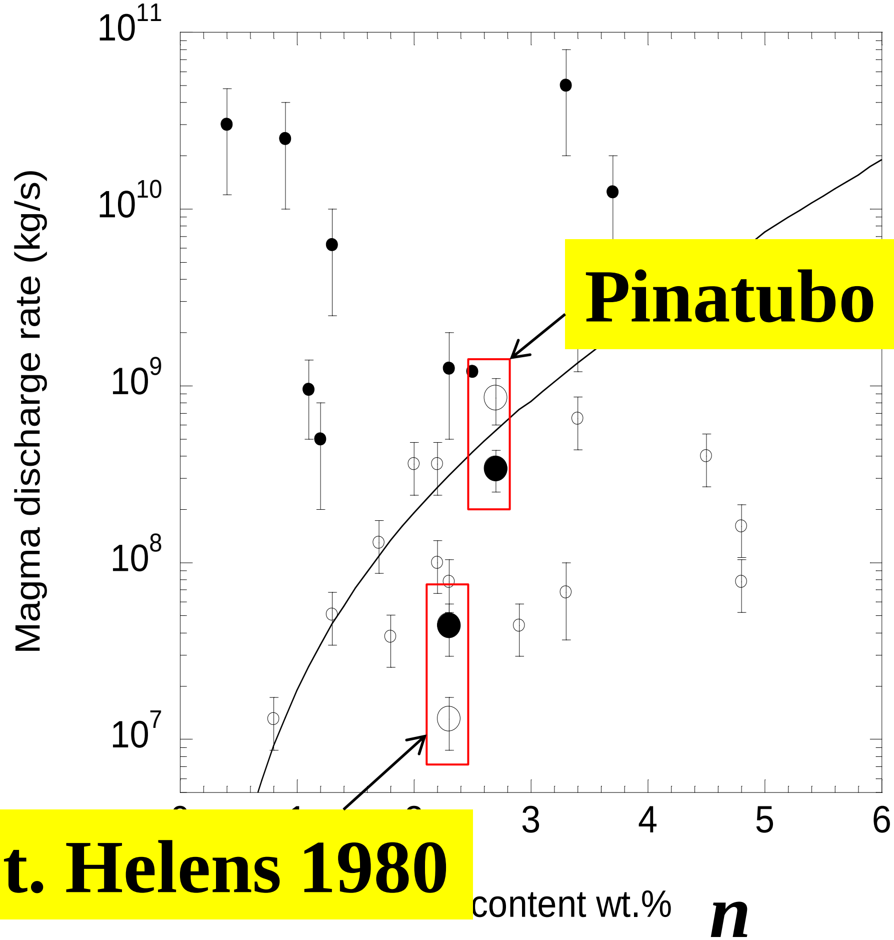


St. Helens 1980



Pinatubo 1991

Observations and previous prediction



Column collapse condition predicted
by Carazzo et al. (2008)

Pinatubo 1991

St. Helens 1980

n

Observations

● **Pyroclastic flow**

○ **Buoyant plume**

Conclusions and future direction

- The column collapse condition of depends on entrainment coefficient, crater shape, and magma chamber pressure.

- The entrainment coefficient may be approximated by

  k=0.04〜0.07 near the exit
  k=0.10〜0.15 far from the exit.

- The effects of crater shape and magma chamber pressure on the column collapse condition can be systematically analyzed using the magma discharge rate vs r_c diagram.

- In order to confirm the present conclusions, 3-D simulations of eruption cloud are in progress, particularly focusing on more quantitative evaluation of the effects of compressible flow inside and just above the crater.