火道発達プロセスと噴火バリエーションに与える影響
key to understand detailed eruption process within shallow conduit by geological methods

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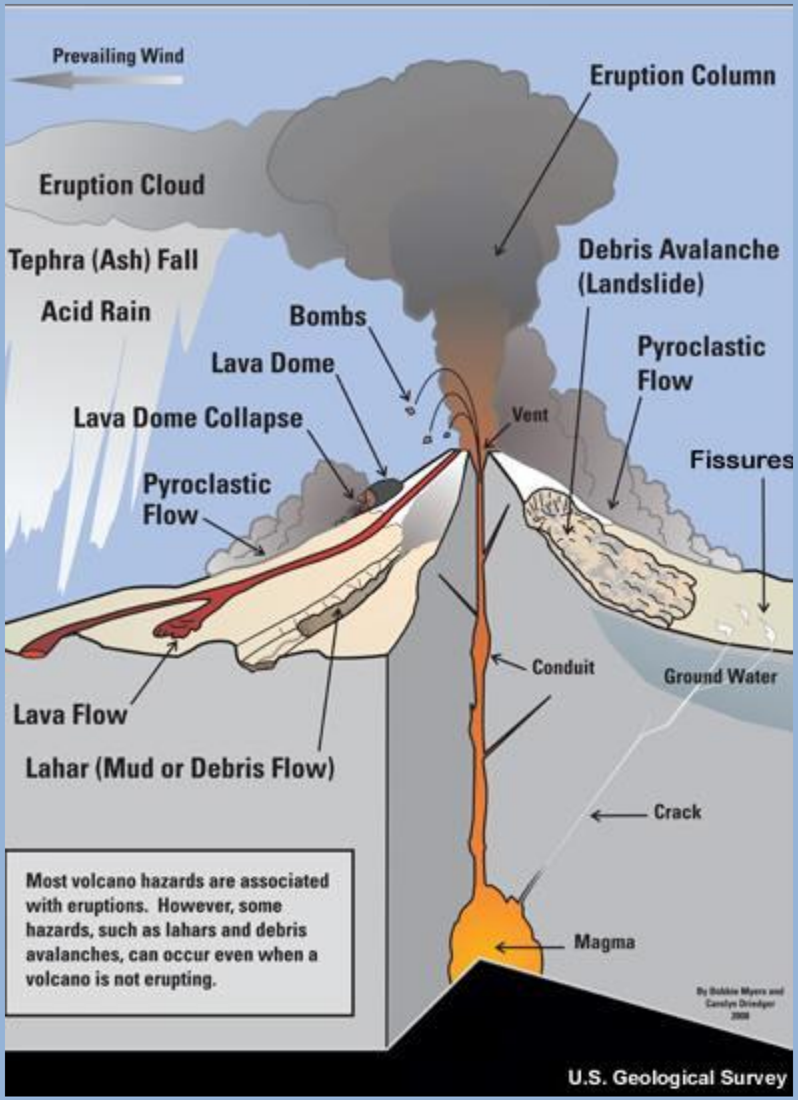
Magma plumbing system



Underground process is fundamental

because,

Magma comes from deeper part of the earth!

Relatively poor images about volcanic conduit

Invisible from the ground surface

Outcrop of feeder dike is a window for conduit system

What we should read from the feeder dike?

To combine the geophysical and geochemical observations……

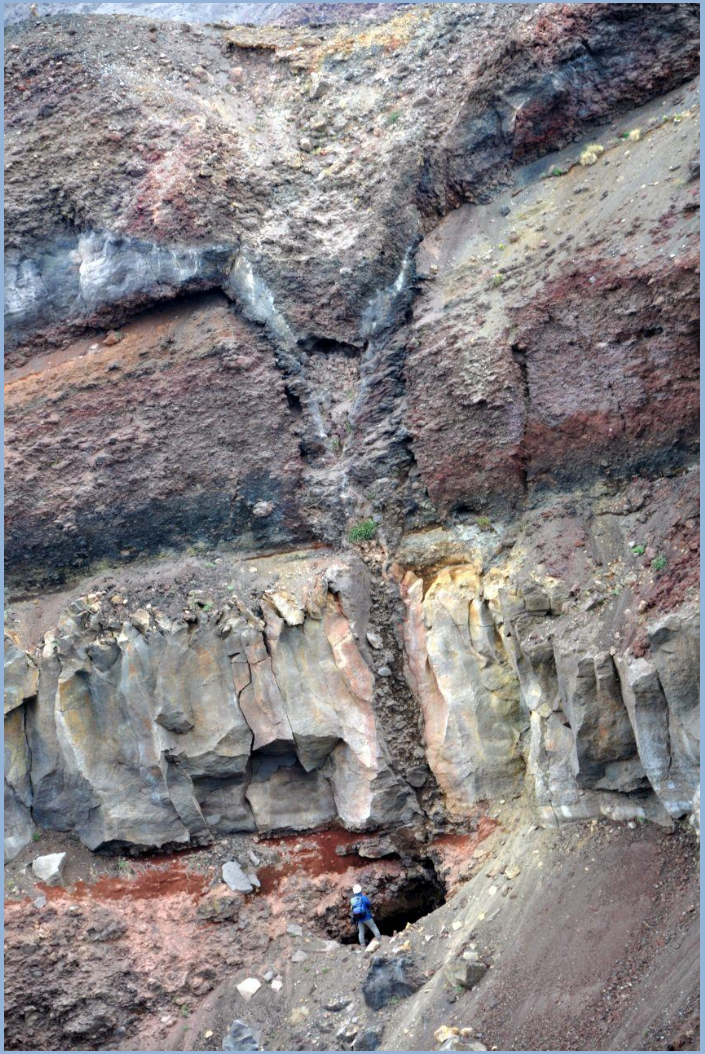
1) geometry of conduit system (meso – micro scale)

Combining with the host-rock structure

2) Sequence of the eruption and conduit development

Combining with the eruptive products on the surface

Geological Approach



Feeder dike at Etna

Poor temporal resolution

Only the final result is preserved
It is a fossil.

Limitation of depth

Only the near-surface
~100s m?

High-spatial resolution

Outcrop-scale resolution

Direct observation

Touchable !
Direct sampling !

Two Examples: basaltic stratovolcanoes

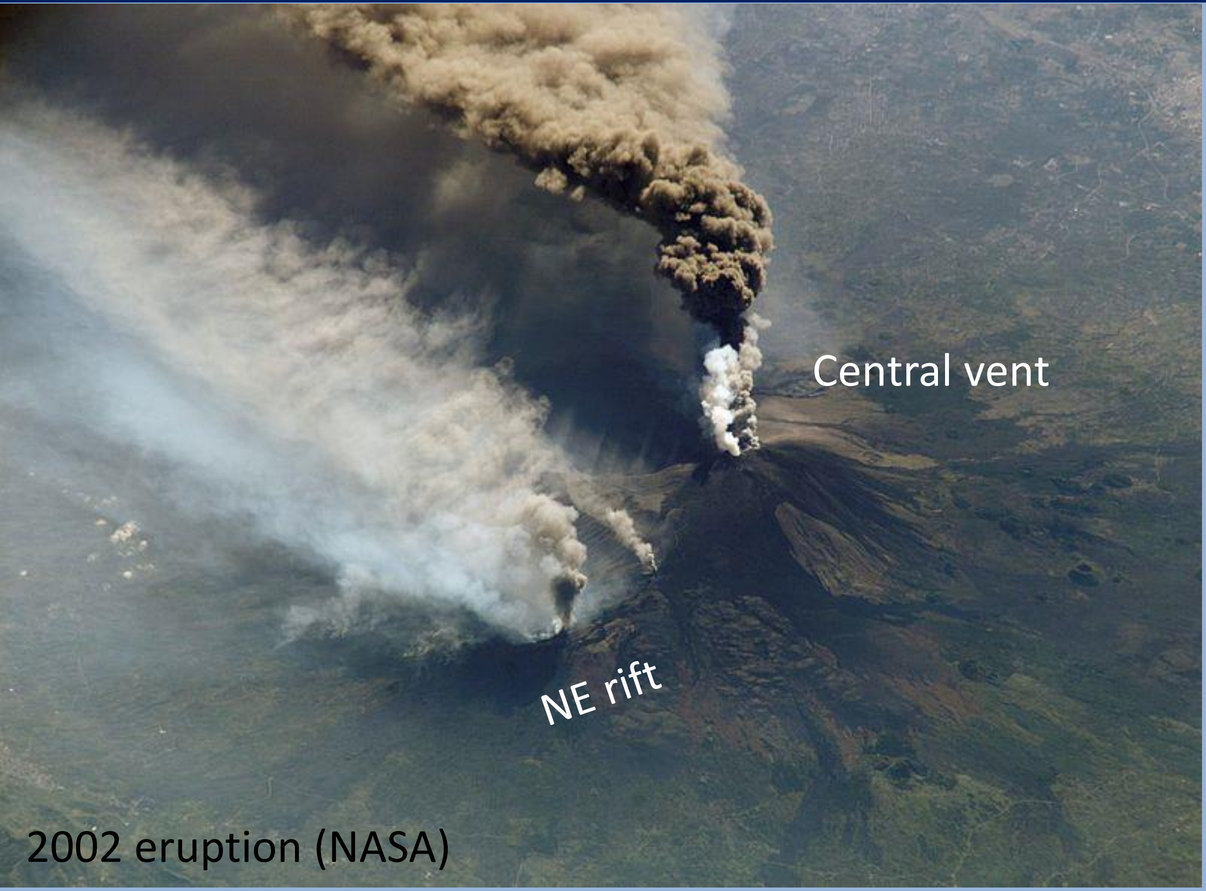
Case 1: Mt Etna, Italy

Feeder dike of a historical lateral eruption

Case 2: Miyakejima, Japan

Dike swarm with various eruption styles

Feeder dike of Etna



Lateral intrusions & eruptions in the rift zones

Our target;
The lateral eruption in 1809 AD at NE rift

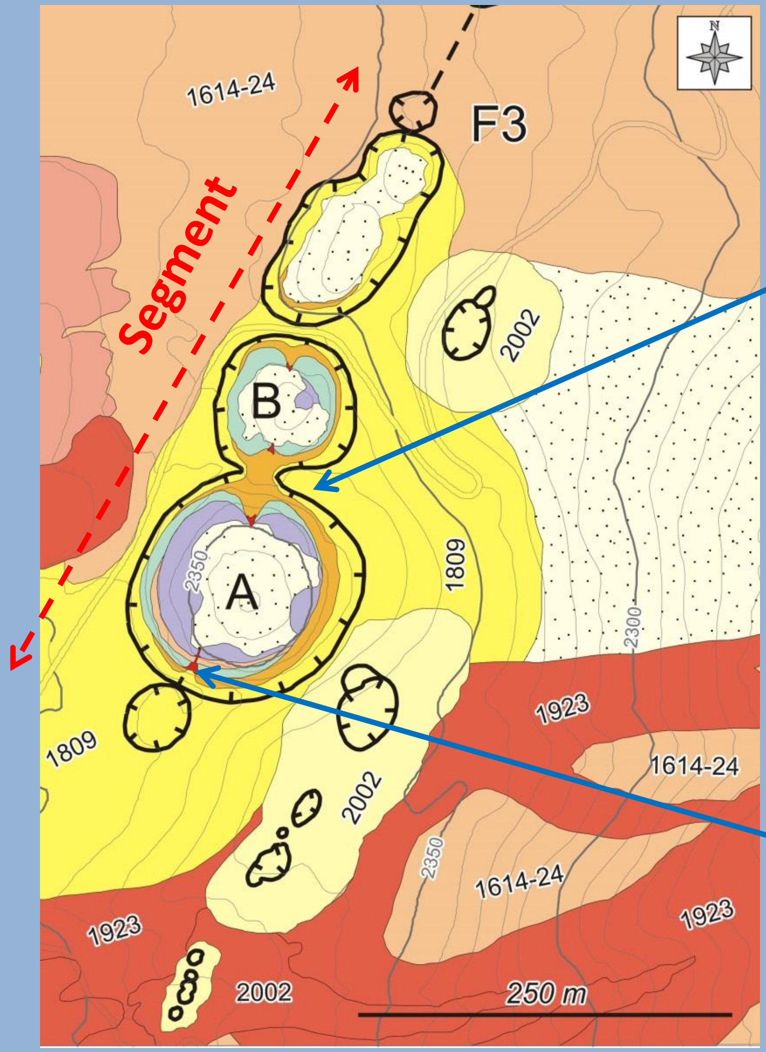
Typical lateral fissure eruption
Dike propagated from summit conduit to rift zone.

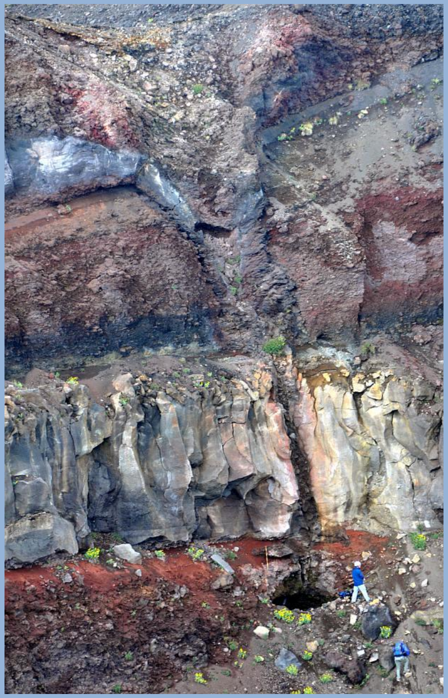
Feeder dike of the 1809 eruption

Several outcrops along an eruptive fissure

Some pit craters were formed as the progress
of the lateral eruption.
The feeder dike was cut by the pits.

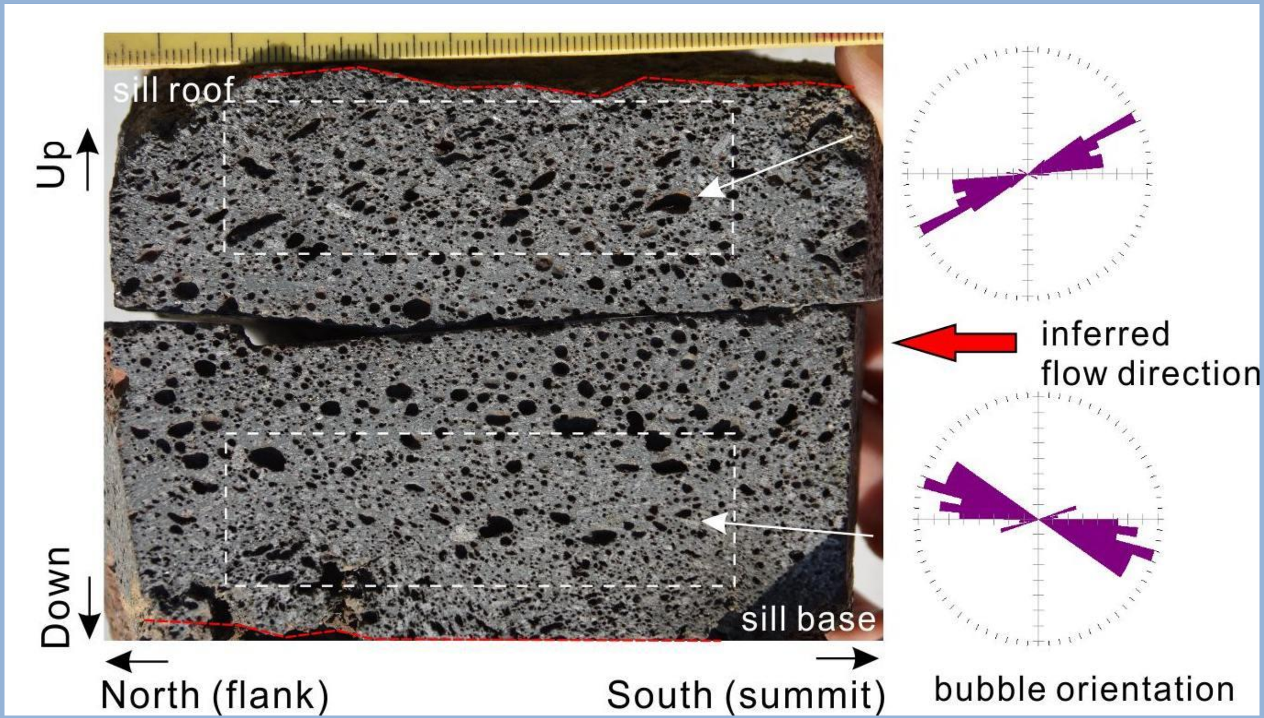
Feeder dike of the 1809 eruption





Center and edge of an eruption segment

Magmatic flow in the feeder dike

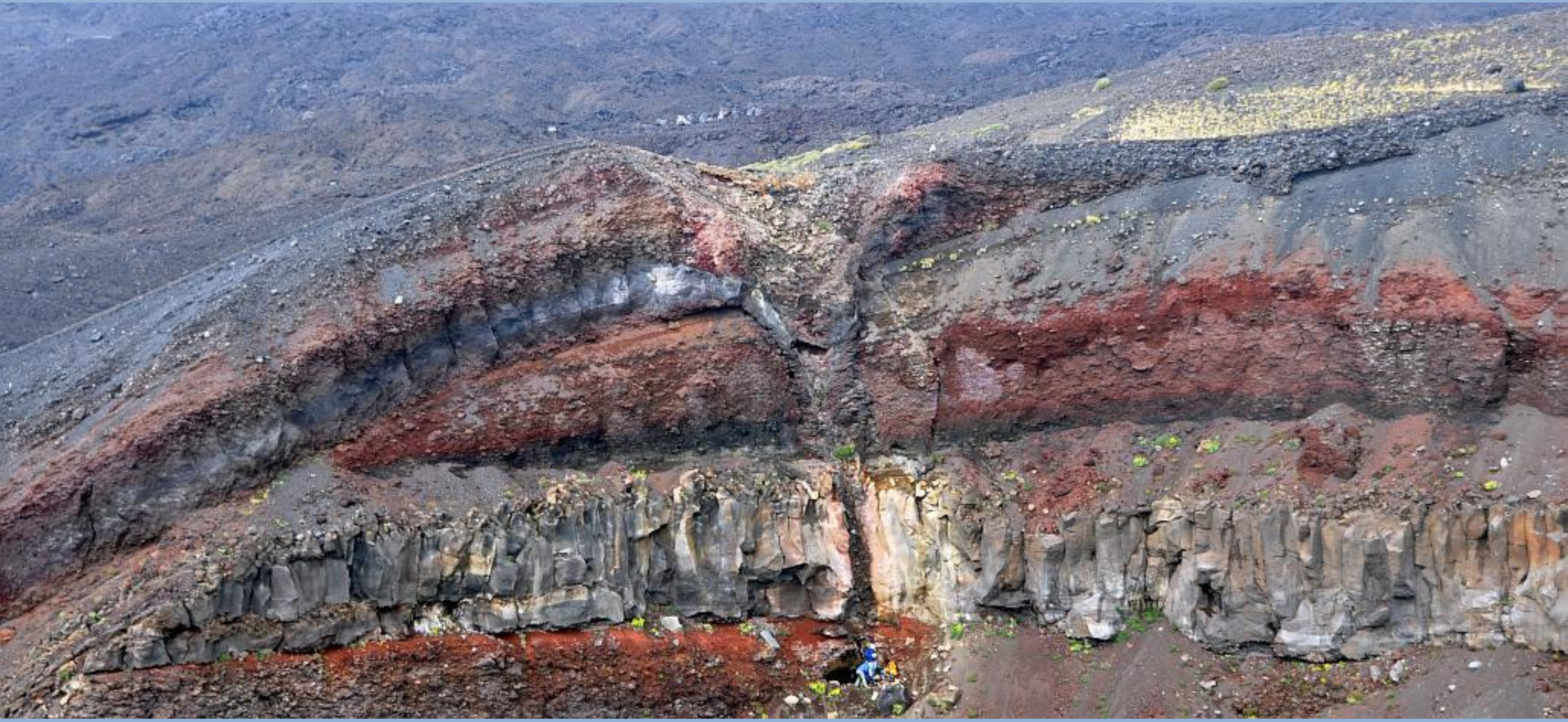


Bubble orientation indicates the flow direction in the feeder dike.

Lateral flow from the central conduit to the flank vents.

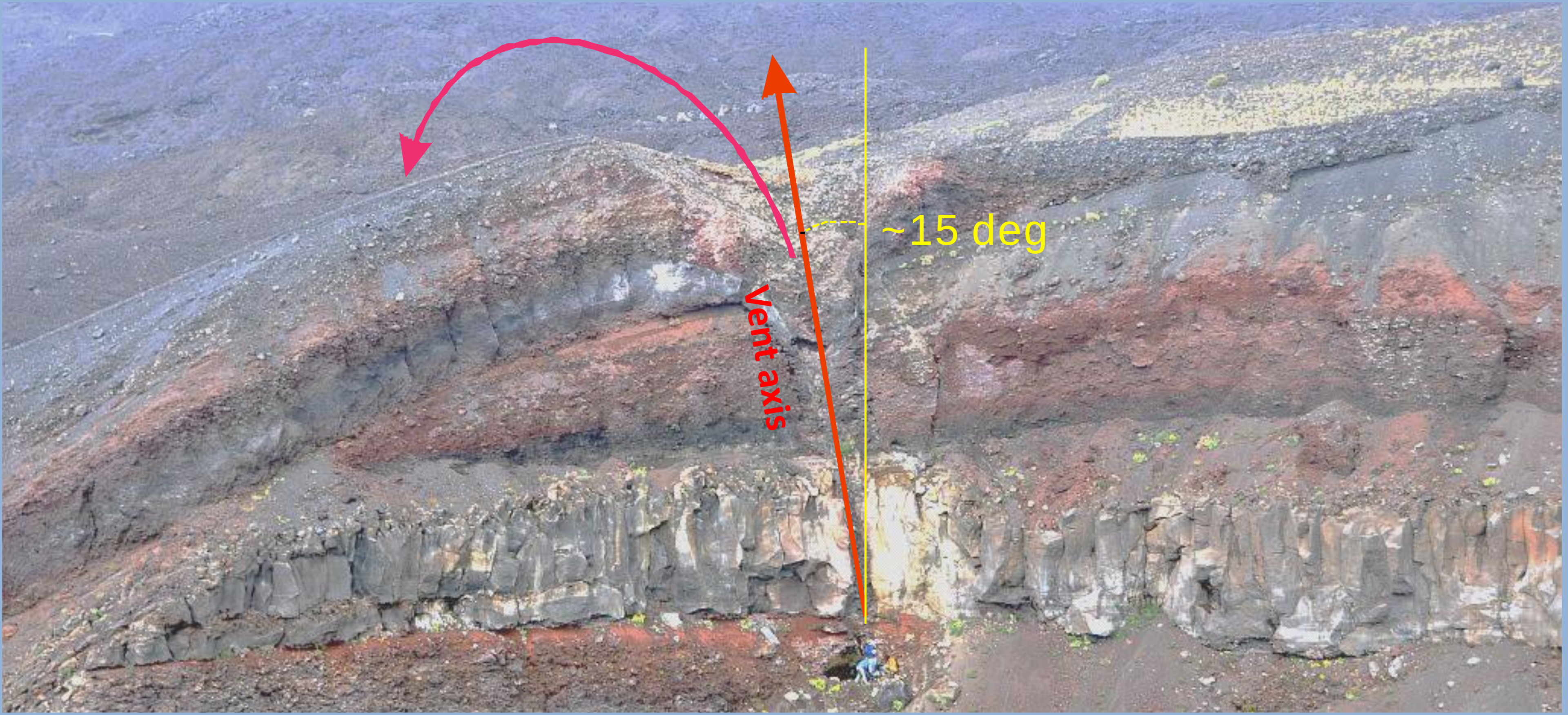
DIRECT SAMPLING!

Eruptive deposit from the feeder



Asymmetric distribution of the ballistics
Inclined vent

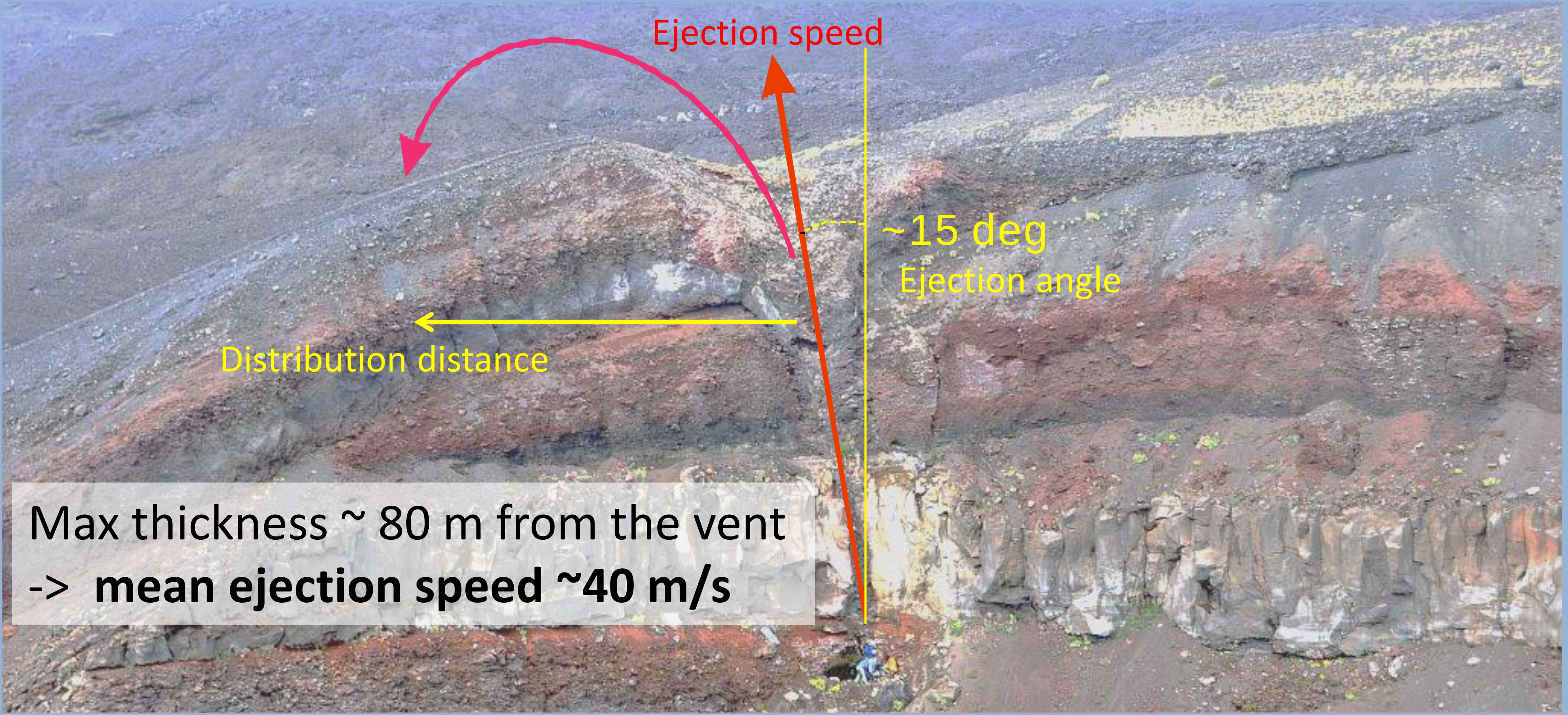
Eruptive deposit from the feeder



Asymmetric distribution of the ballistics
Inclined vent

Oblique eruption

Eruptive deposit from the feeder



Asymmetric distribution of the products
inclined vent

Oblique eruption !

Combine structure and eruptive product !

Etna feeder dike

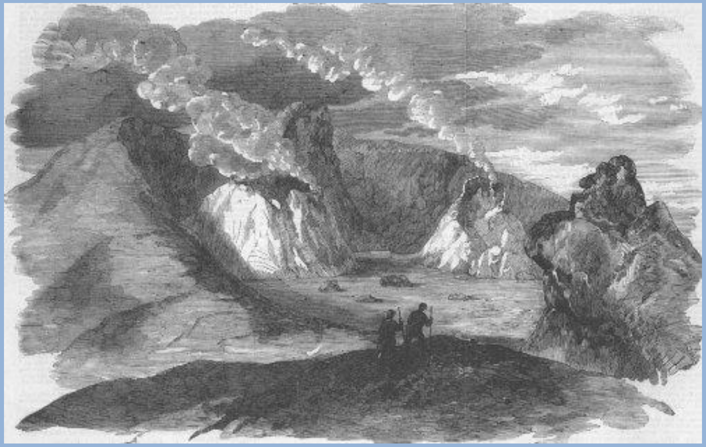
We can read from the geological evidences….

1) Flow of magma within the feeder. ------- lateral flow

2) Geometry of feeder conduit in shallow level
----- thickness, inclined angle

3) Some fundamental parameters of eruption
----- ejection speed ~40 m/s

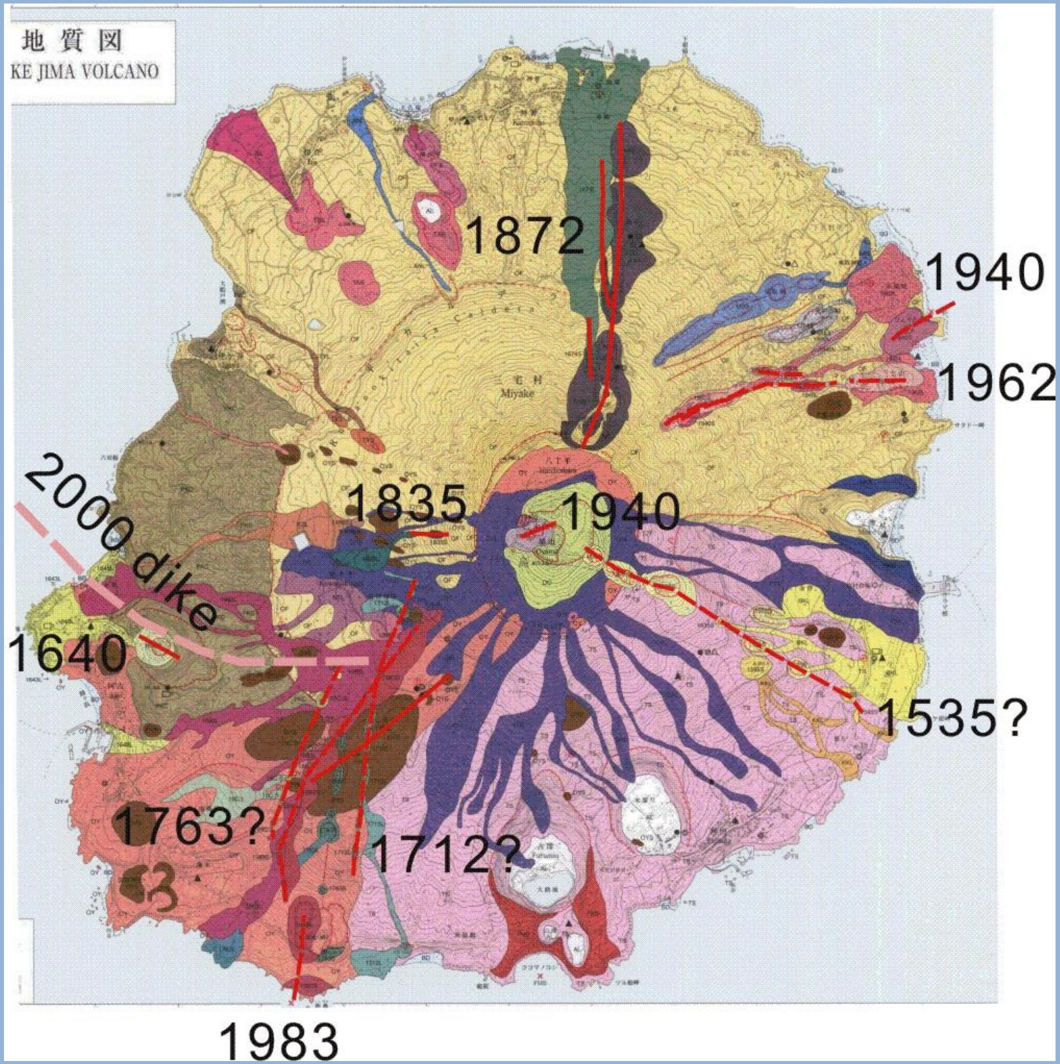
Constrain of time scale ------- difficult from geological observation only.



Supported by **chronological records**

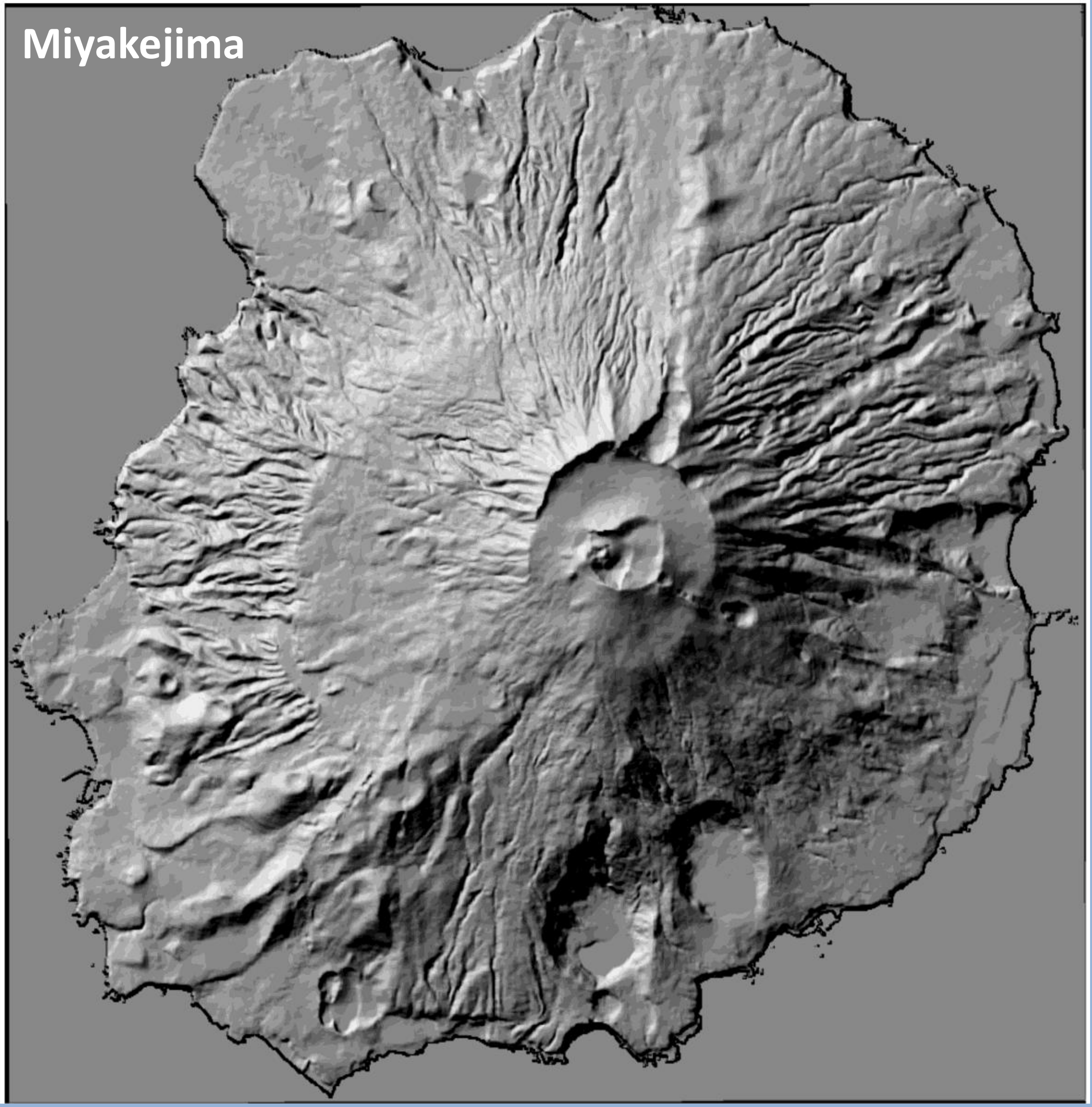
Lateral eruption: ~ day scale

Case 2: Miayekjima



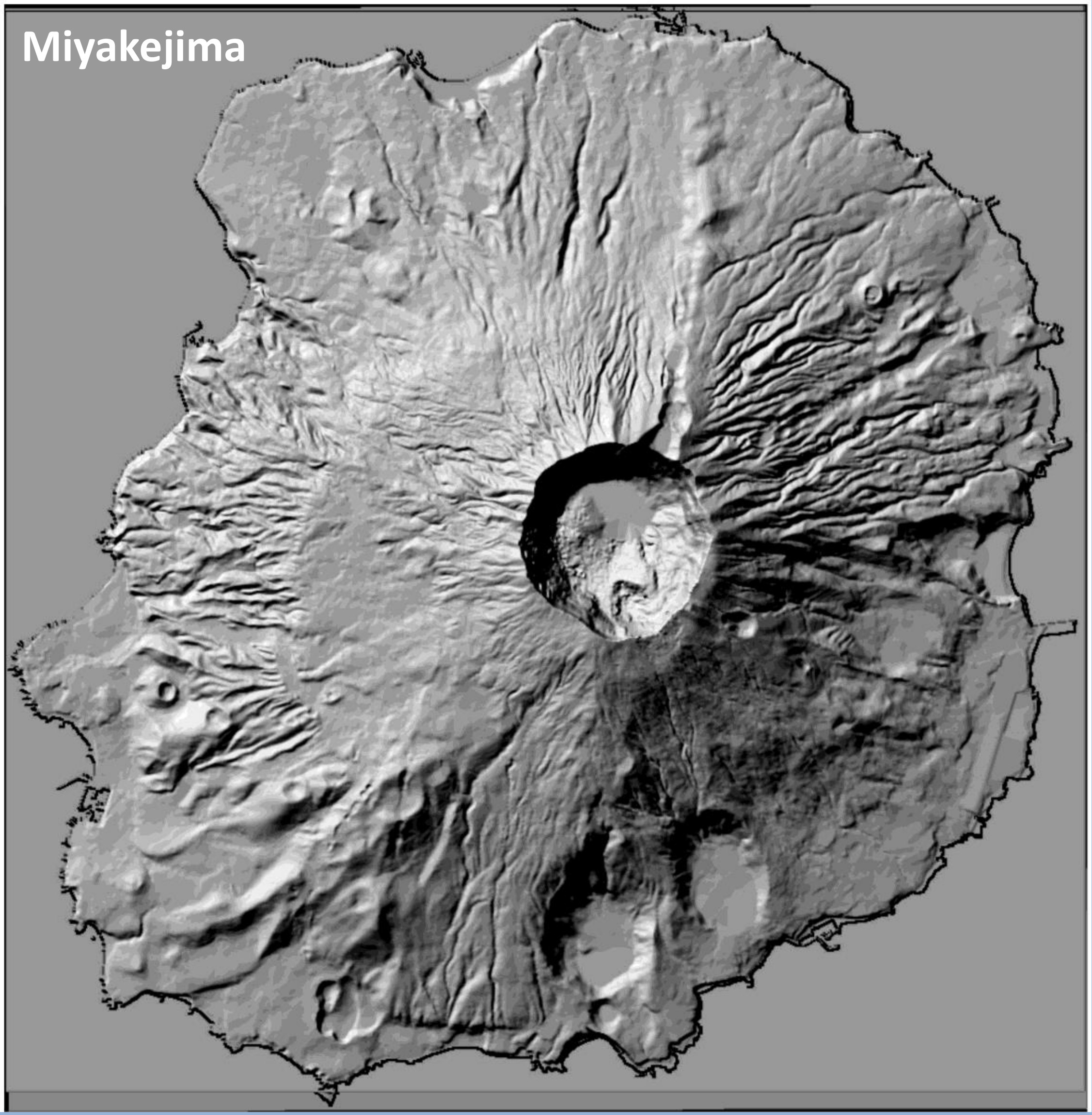
Many buried fissure vents in the volcanic edifice

Truncation of volcanic edifice



Before the caldera collapse

Truncation of volcanic edifice



After the caldera collapse in 2000

We have a good exposure of the interior of volcano.

Truncation of volcanic edifice

Cross section of the volcanic edifice
Height: 200 ~ 450 m

Cross section of feeder dikes, vents and cones

Many buried vents outcrop on the caldera wall
(> 20 feeder dikes, >200 non feeder dikes)

Trace its dike-vent structure ~150m vertically

Feeder and non-feeder dike

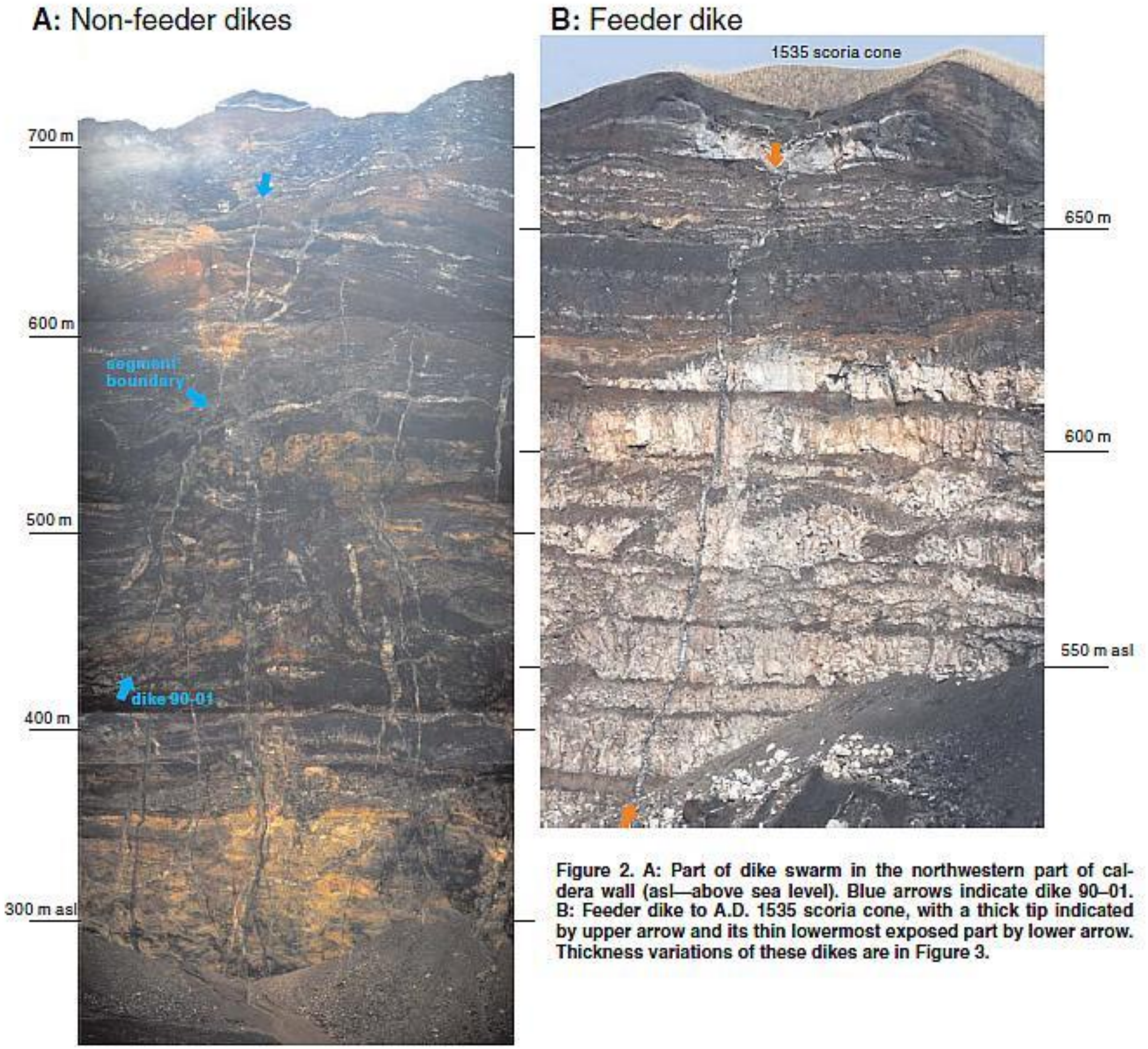


Figure 2. A: Part of dike swarm in the northwestern part of caldera wall (asl—above sea level). Blue arrows indicate dike 90–01. B: Feeder dike to A.D. 1535 scoria cone, with a thick tip indicated by upper arrow and its thin lowermost exposed part by lower arrow. Thickness variations of these dikes are in Figure 3.

Feeder and Non-Feeder dike

Geshi et al., 2010 Geology

Feeder and non-feeder dike

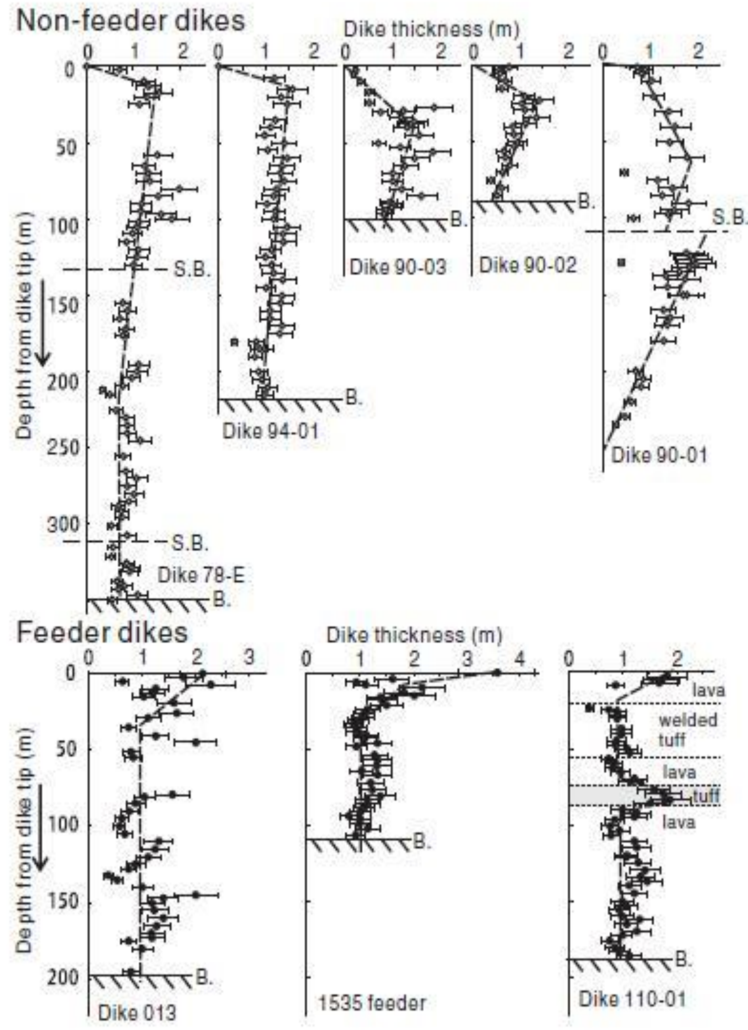
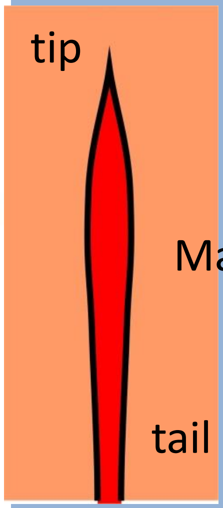
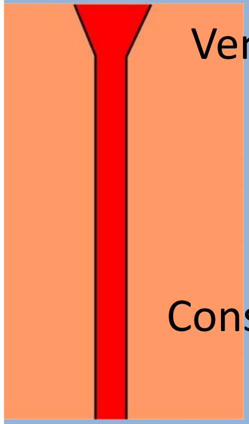


Figure 3. Variation in thicknesses of representative five non-feeder and three feeder dikes. Horizontal solid lines show bottom of the





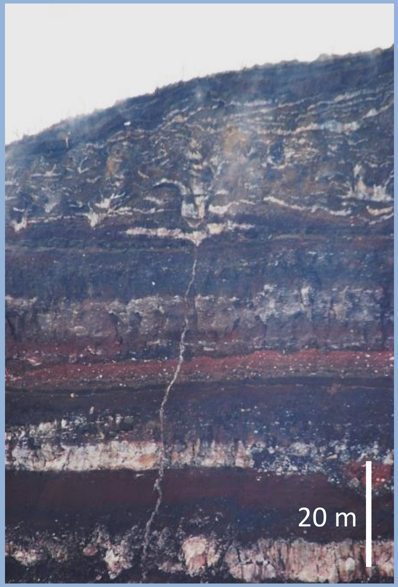
Feeder and Non-Feeder dike

Different shape

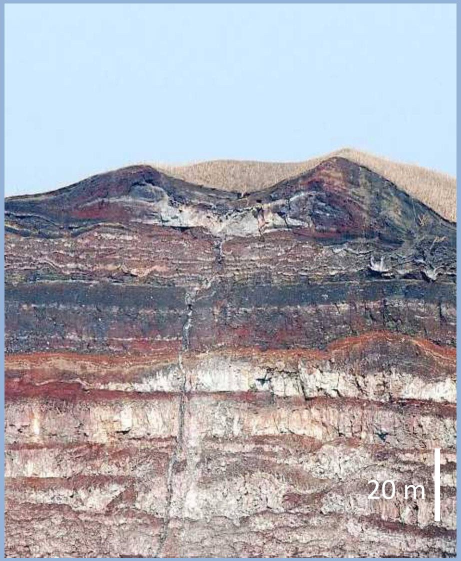
Geshi et al., 2010 Geology

Variation of the vent structure

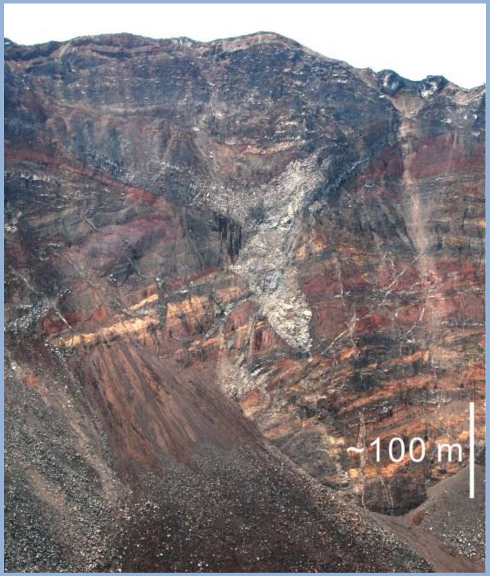
More than 20 feeder-dikes – vents structures are exposed.
The vent structures on Miyakejima can divided into three groups.



Lava flow feeder



Scoria cone feeder



Diatreme feeder

Reconstruction of eruption style 1; Lava Feeder

Feeder of the 9th century lava flow

Feeder dike connecting compound lavas.
No or very thin pyroclastic deposit.

-> Low explosivity, almost effusive

Reconstruction of eruption style 1; Lava Feeder

Feeder of the 9th century lava flow

Feeder dike connecting compound lavas.
No or very thin pyroclastic deposit.

-> Low explosivity, almost effusive

Feeder of the effusive eruption.

Reconstruction of eruption style 2; Cone Feeder

Feeder of the 1535 cone

Feeder dike connecting small and high aspect ratio scoria cone.

-> Mild explosivity

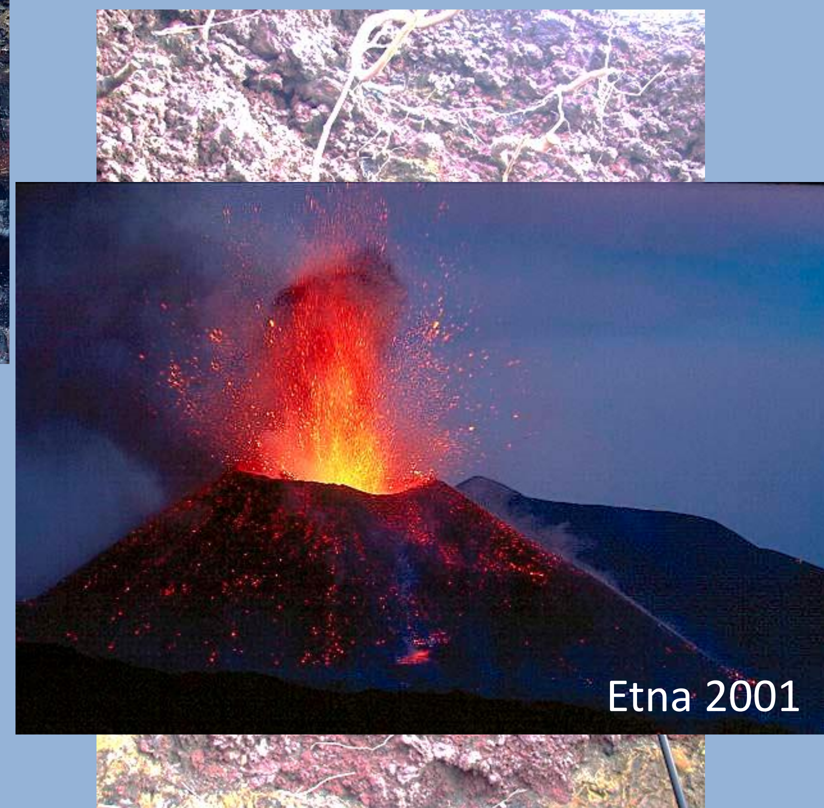
Reconstruction of eruption style 2; Cone Feeder

Feeder of the 1535 cone

Feeder dike connecting small and high aspect ratio scoria cone.

-> Mild explosivity

Feeder of
strombolian activity
Cone building



Reconstruction of eruption style 3; Diatreme Feeder

Diatreme feeder

Buried diatreme – cone system

Feeder dike connecting large and flat cone
Deep diatreme

-> High explosivity

Reconstruction of eruption style 3; Diatreme Feeder

Diatreme feeder

Buried diatreme – cone system

Feeder dike connecting large and flat cone
Deep diatreme

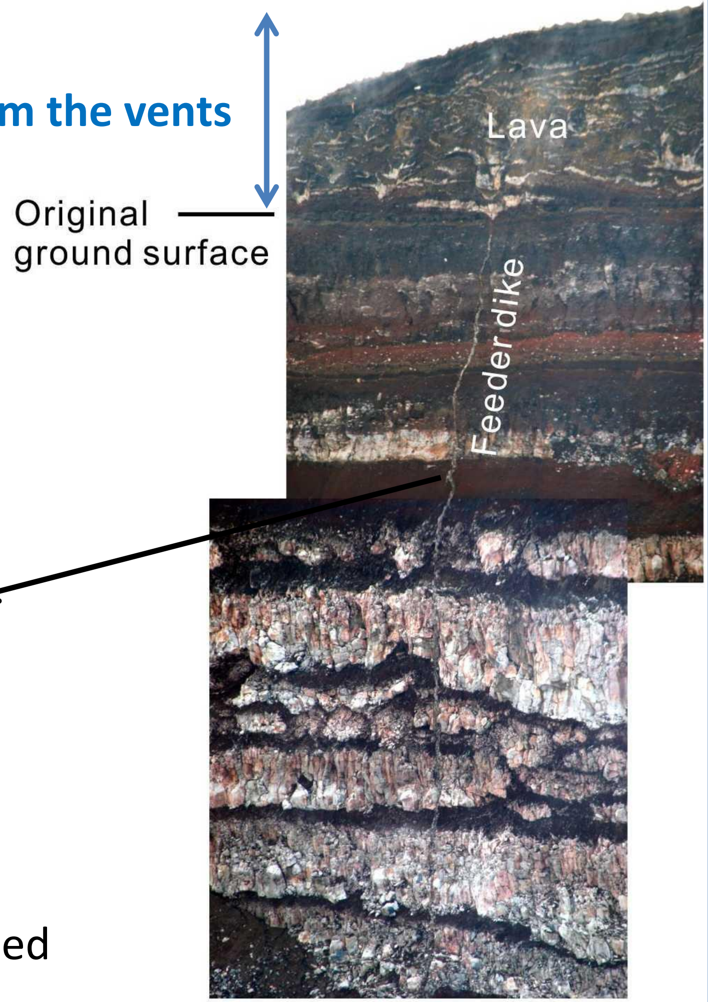
-> High explosivity

Feeder of violent Strombolian – Sub-Plinian activity

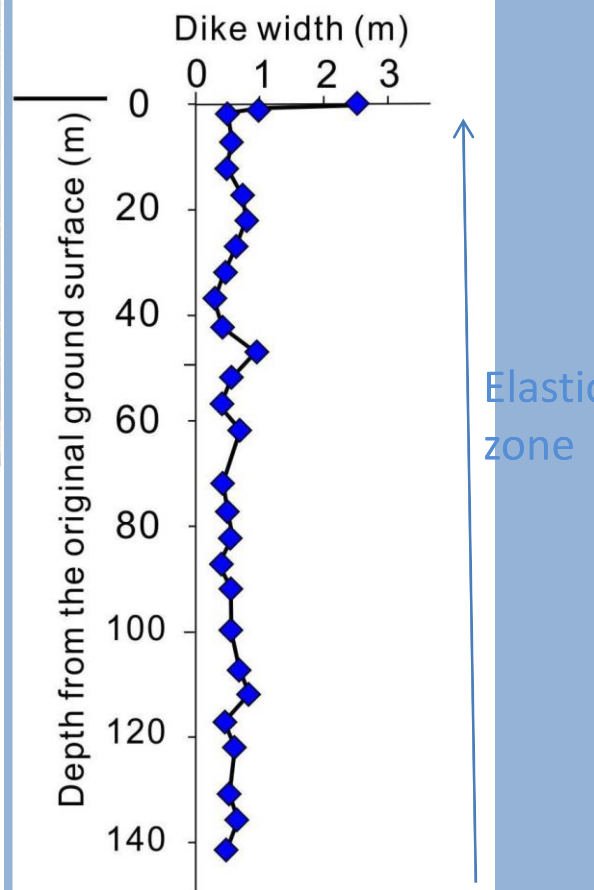
With magma-water interaction?

Vent width (1) lava feeder

"Normal" dike filled
with dense rock

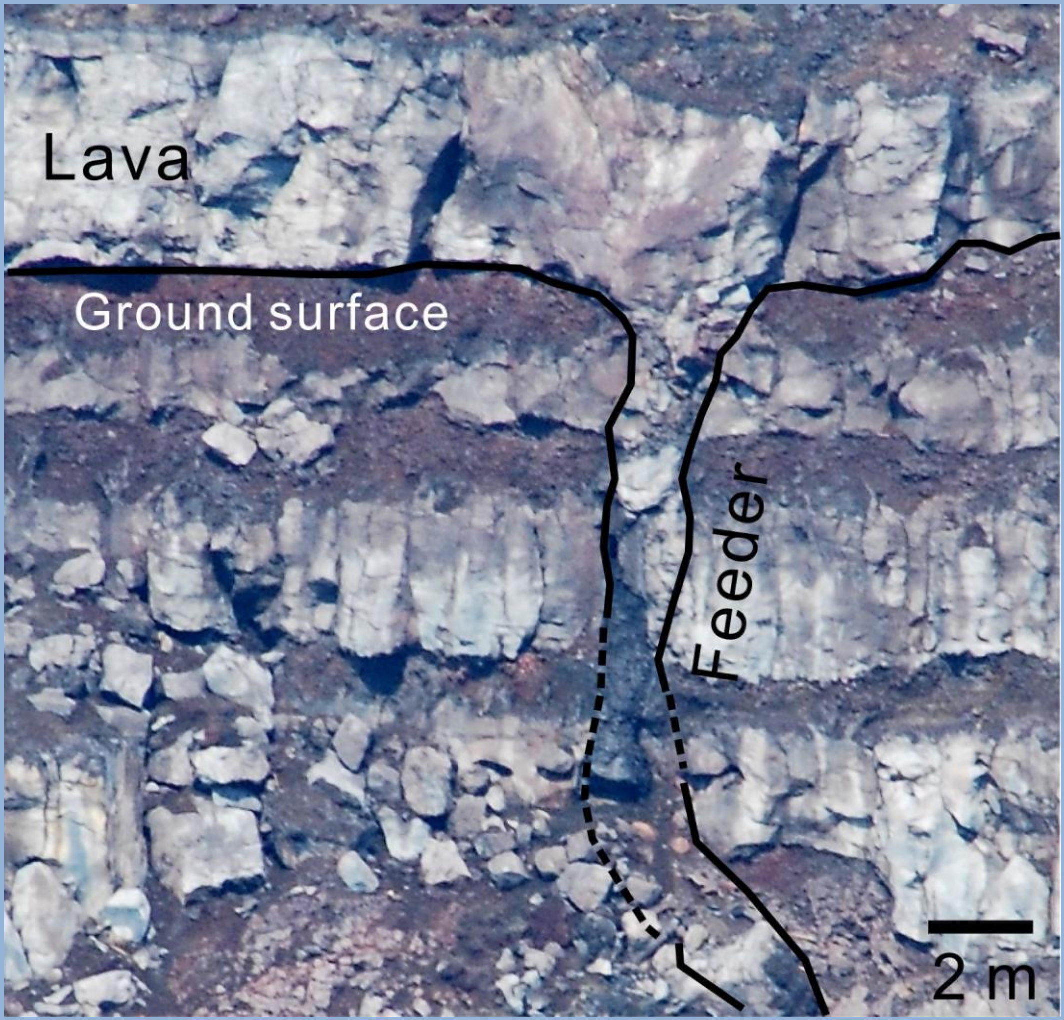


Constant thickness (elastic
opening of open fracture)



Geshi et al. 2010 Geology

Vent width (1) lava feeder

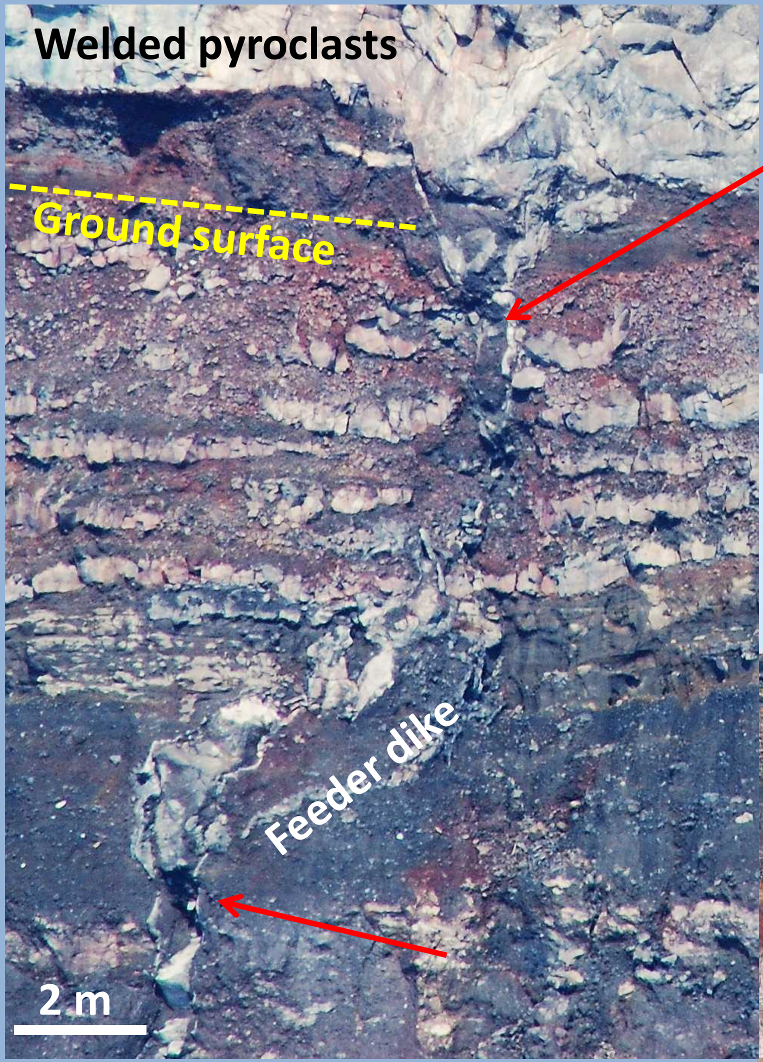


Feeder dike is filled with dense lava

No pyroclastic material in the feeder dike.

No evidence for fragmentation below ground surface

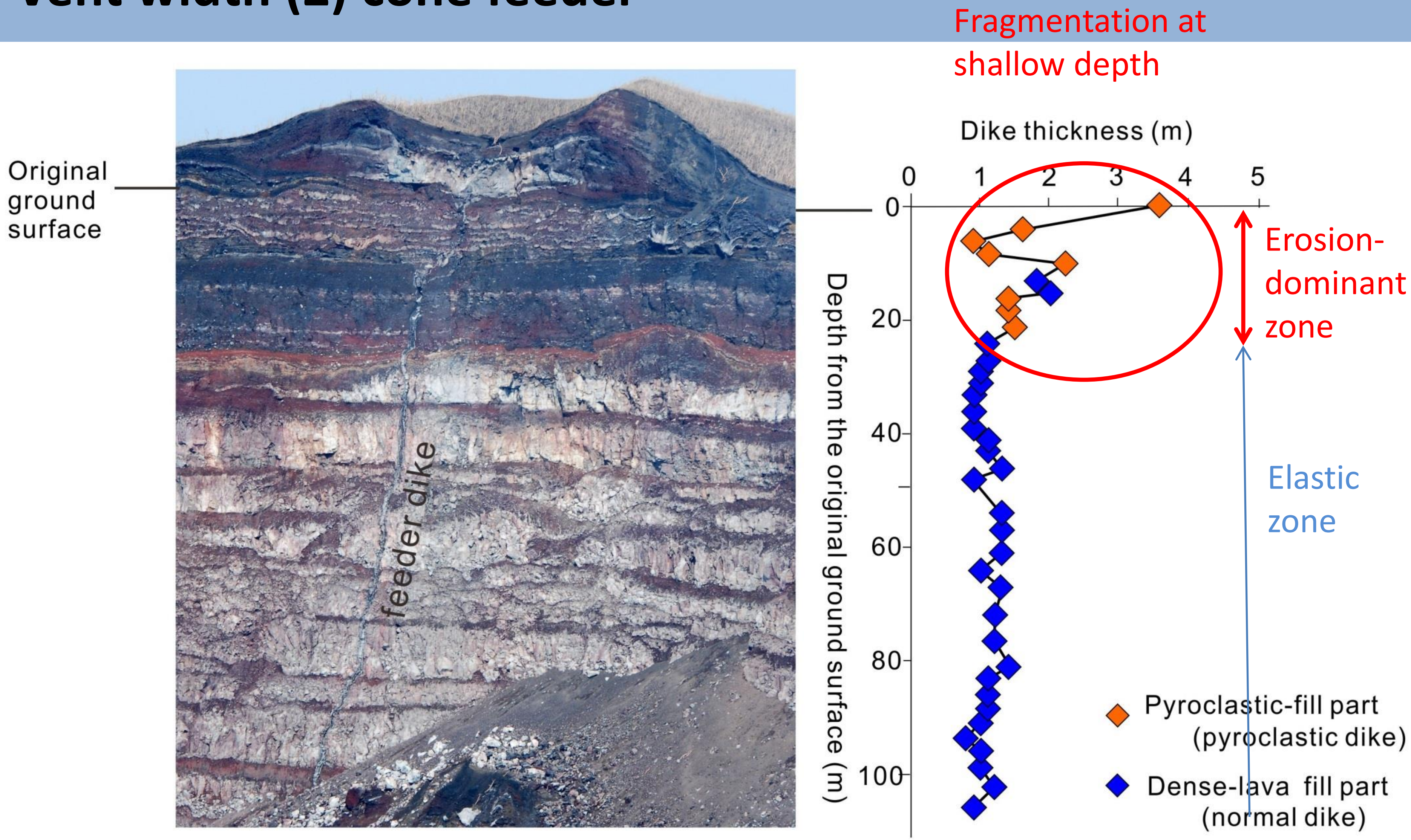
Vent width (2) cone feeder



Dike filled with pyroclastic rock

Fragmentation of magma below this depth

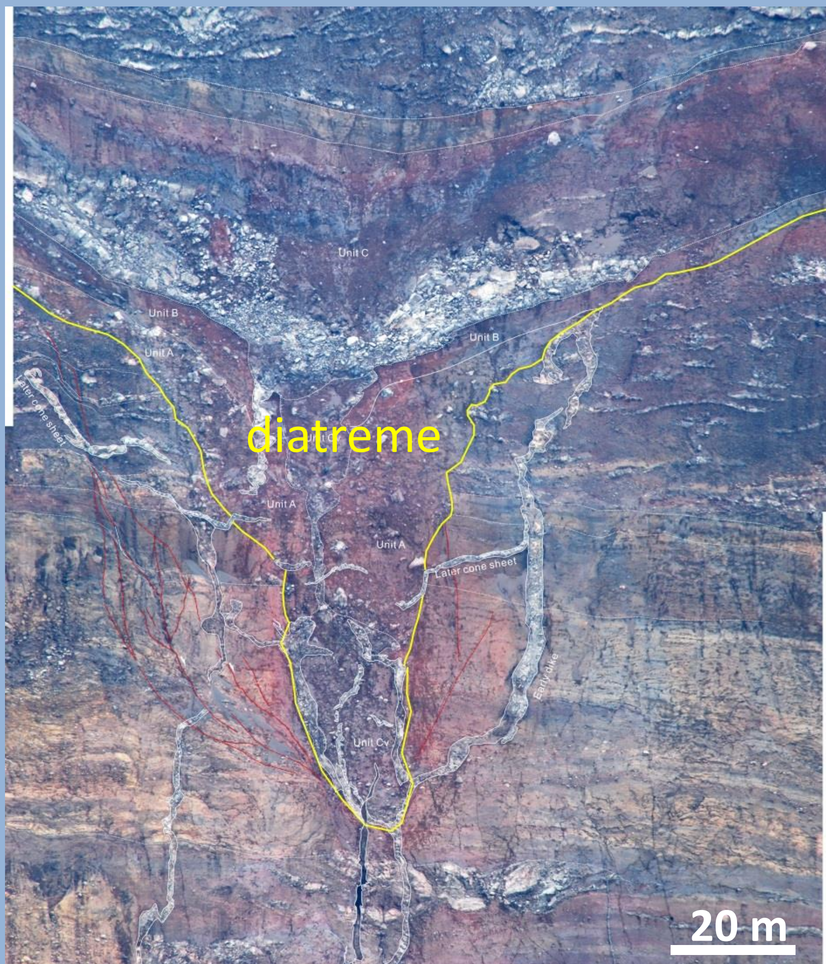
Vent width (2) cone feeder



Constant thickness (elastic opening of open fracture) of dike at deep

Geshi et al. 2010 Geology

Vent width (3) diatreme



Feeder dike

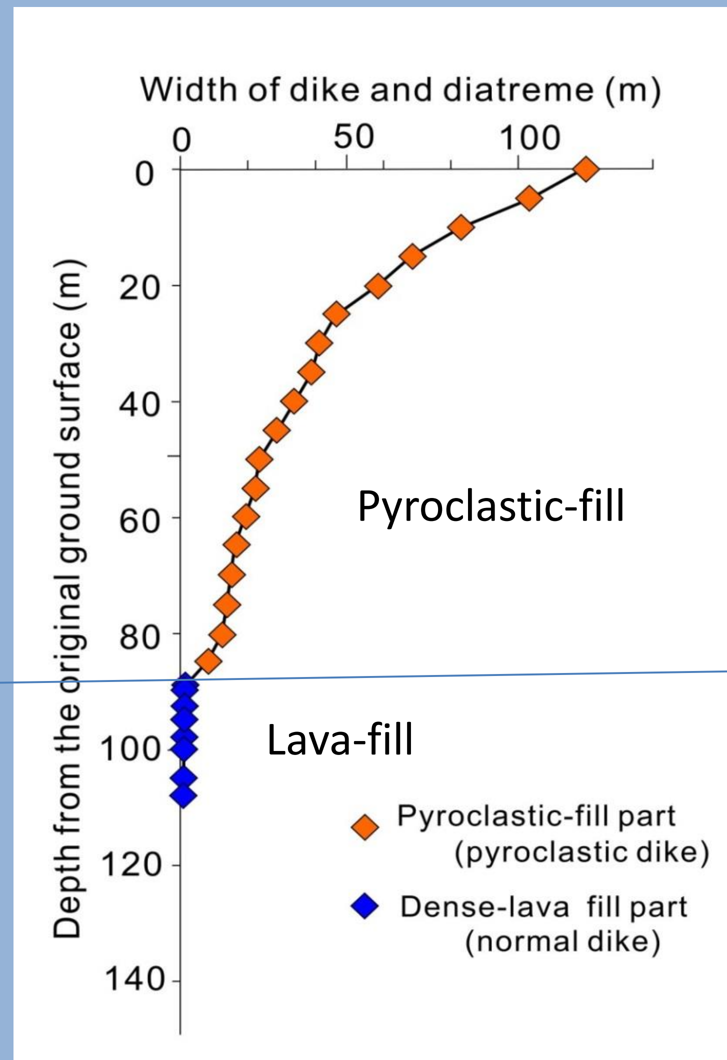
Diatreme filled with pyroclastic rock

Fragmentation of magma below this depth

Normal dike filled with dense lava

Vent width (3) diatreme

Feeder dike

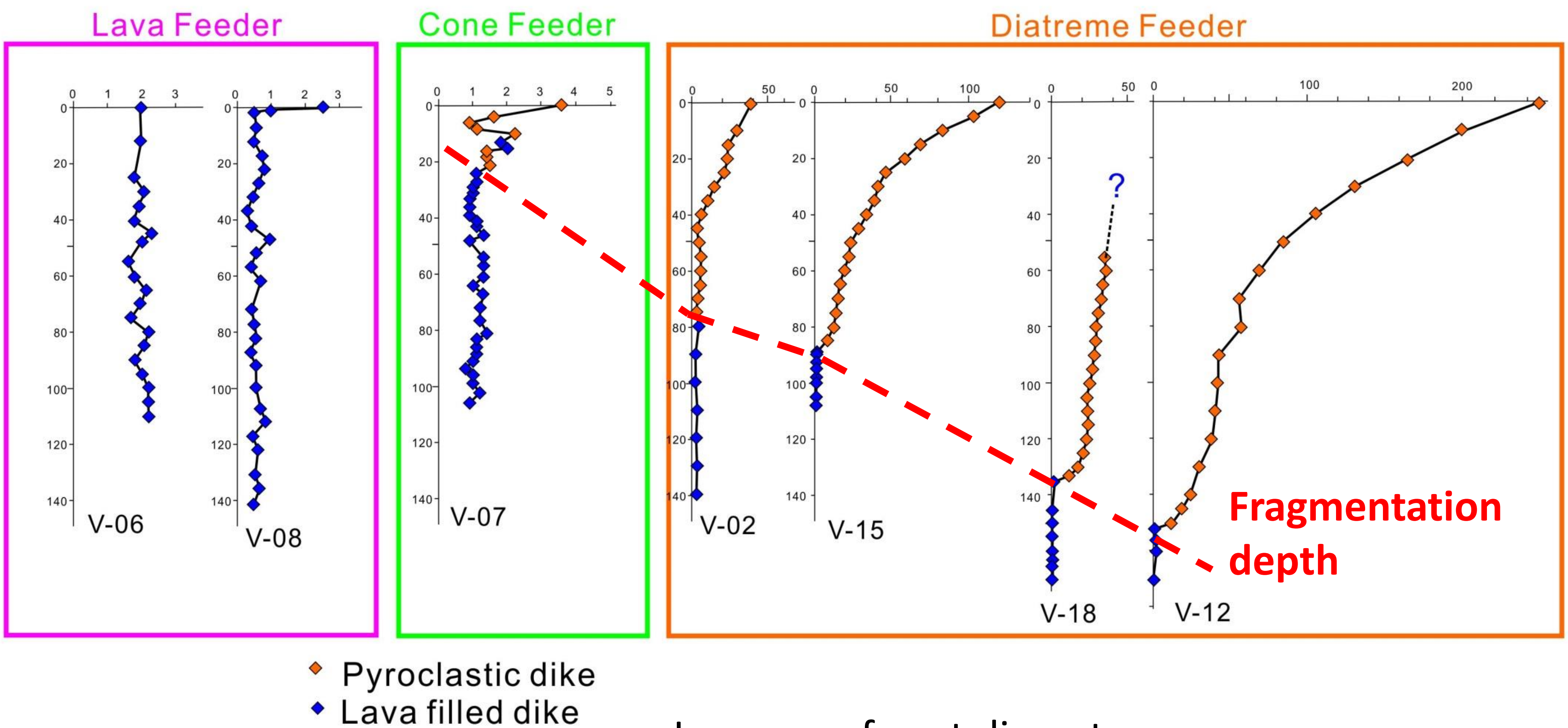


Fragmentation at deeper conduit

Erosion-dominant zone

Elastic zone

Comparison of all types



Increase of vent diameter

Explosivity large
Volume large

Geshi and Oikawa 2014 Bulletin of Volcanology

Miyakejima feeder dikes

From the dikes, we can know that….

1) **Variation of structure** reflecting the spectrum of explosivity from lava effusion to violent eruption

2) **Fragmentation depth** in the conduit is shallow for effusive eruption (~0m) and reaches >100 m for explosive activities.

3) **Erosion of the basement** (wall rock of the conduit) is dominant for explosive eruption. Erosion depth coincides with the depth of fragmentation. **Fragmentation enhances the wall erosion**.

Conclusive statements

The geological investigations of feeder dikes tell us…..

1) geometry of conduit system (meso – micro scale)

Combining with the host-rock structure

2) Sequence of the eruption and conduit development

Combining with the eruptive products on the surface

Vent opening process of the Osumi pumice fall as the precursor for caldera-forming eruption of Aira Caldera, Japan

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Our questions are;

1) How caldera-forming catastrophic eruption starts and evolves.

2) How different from the other smaller “normal” eruptions

3) Can us know the possibility of caldera collapse during precursory activity?

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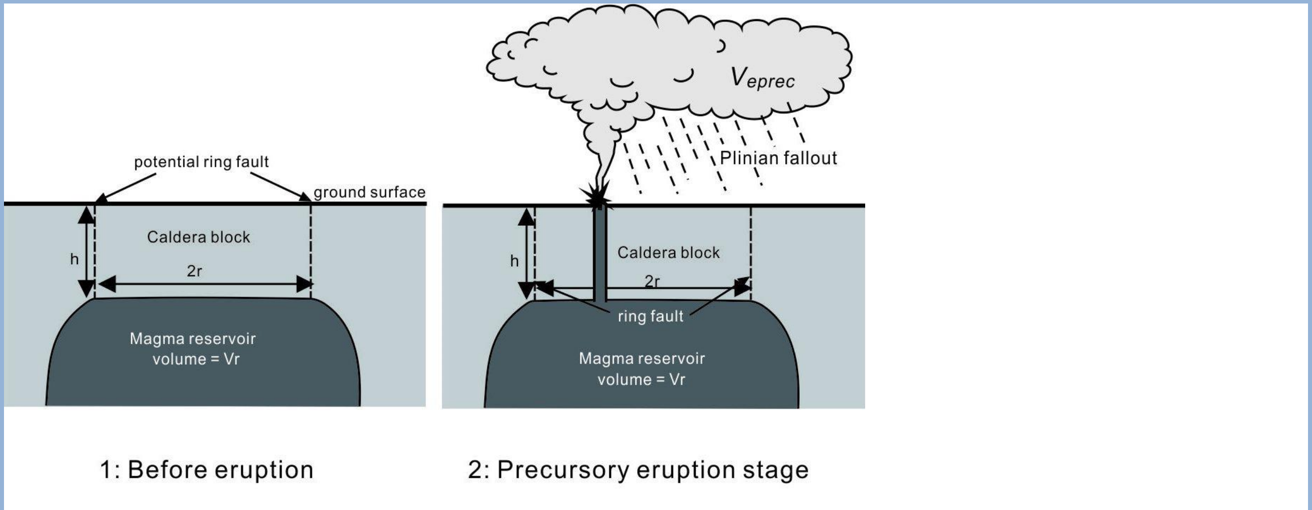
Our questions are; Our answers are:

1) How caldera-forming catastrophic eruption starts and evolves.
➔ Open and enlarge the conduit to maintain the high magma flux

2) How different from the other smaller “normal” eruptions
➔ Increasing of mass flux, extraordinary high flux

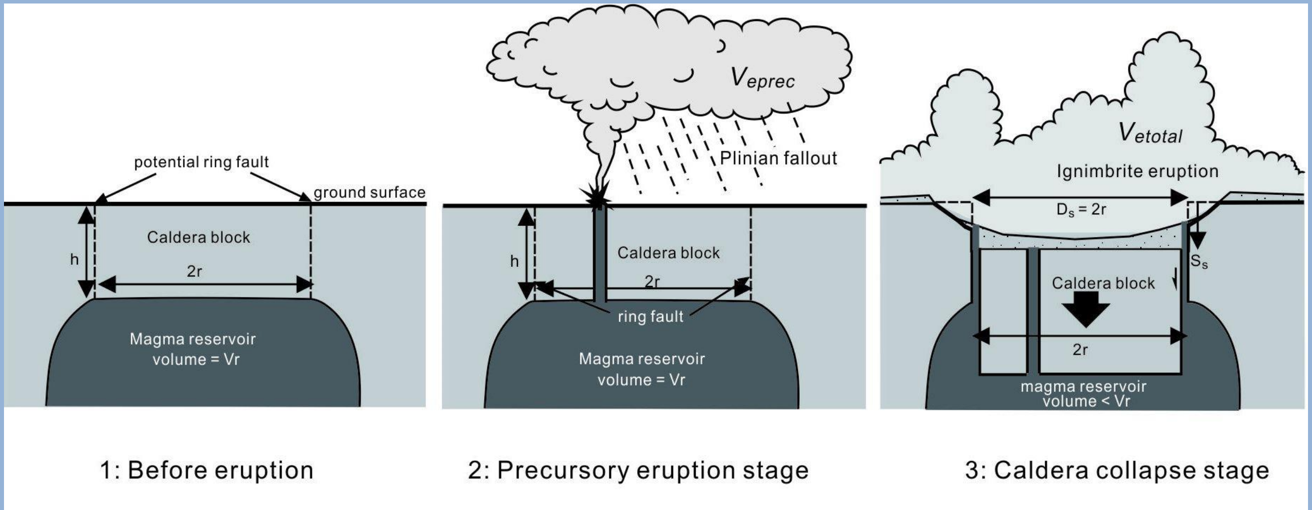
3) Can us know the possibility of caldera collapse during precursory activity?
➔ Probably YES, but only few days prior to the catastrophe.

Sequence of caldera-forming eruption



Decompression of magma chamber by precursory eruption ➡ Activation of Caldera border fault

Sequence of caldera-forming eruption

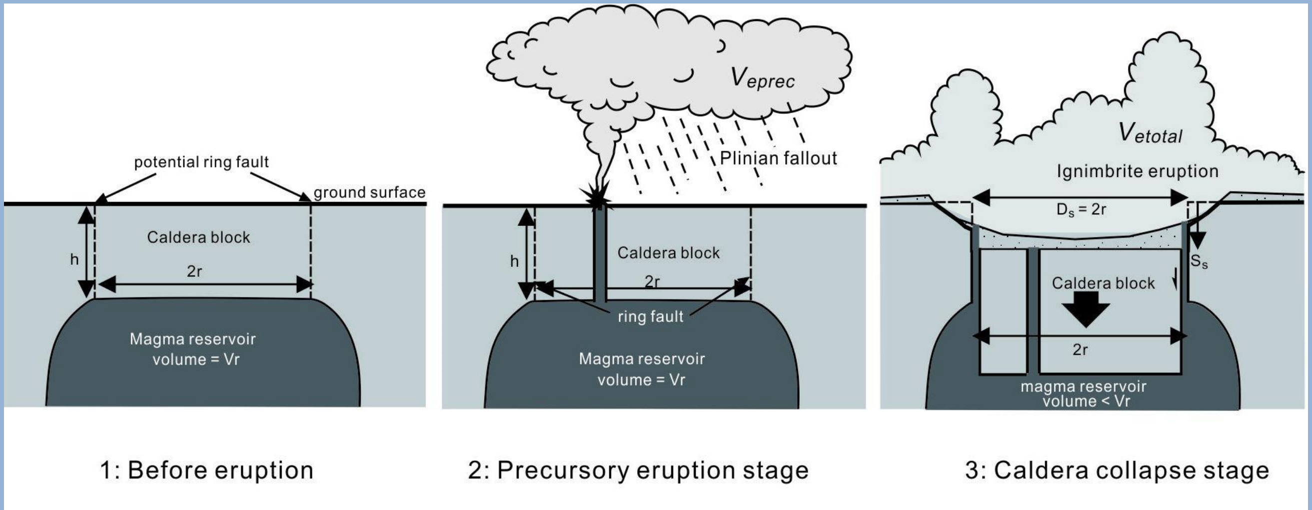


Decompression
of magma chamber
by precursory eruption

Activation of
Caldera border
fault

Onset of collapse
Ignimbrite eruption

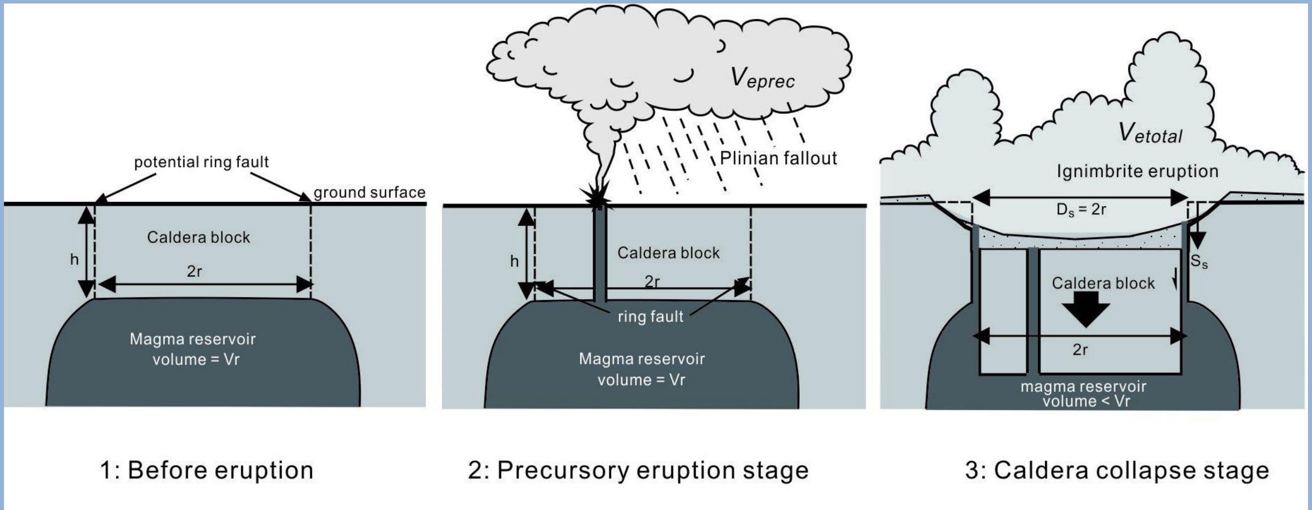
Sequence of caldera-forming eruption



Decompression of magma chamber by precursory eruption → Activation of Caldera border fault → Onset of collapse Ignimbrite eruption

↘ Caldera border Fault is not activate

Sequence of caldera-forming eruption



Decompression
of magma chamber
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Activation of
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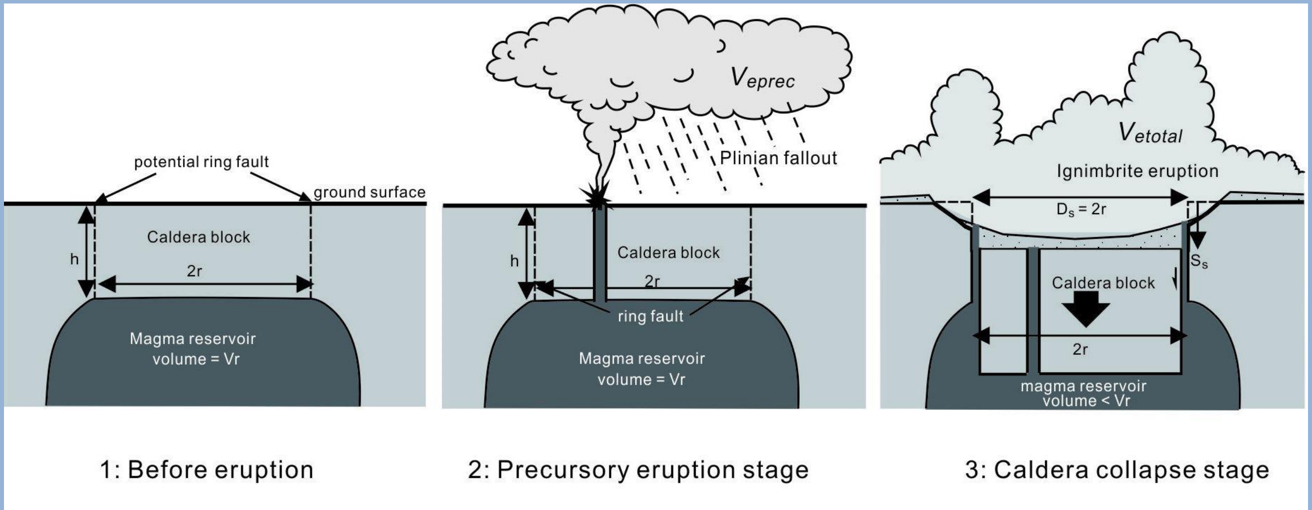
fault

Onset of collapse
Ignimbrite eruption

Caldera border
Fault is not
activate

No collapse
Eruption stops

Sequence of caldera-forming eruption



Decompression
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by precursory eruption

Activation of
Caldera border
fault

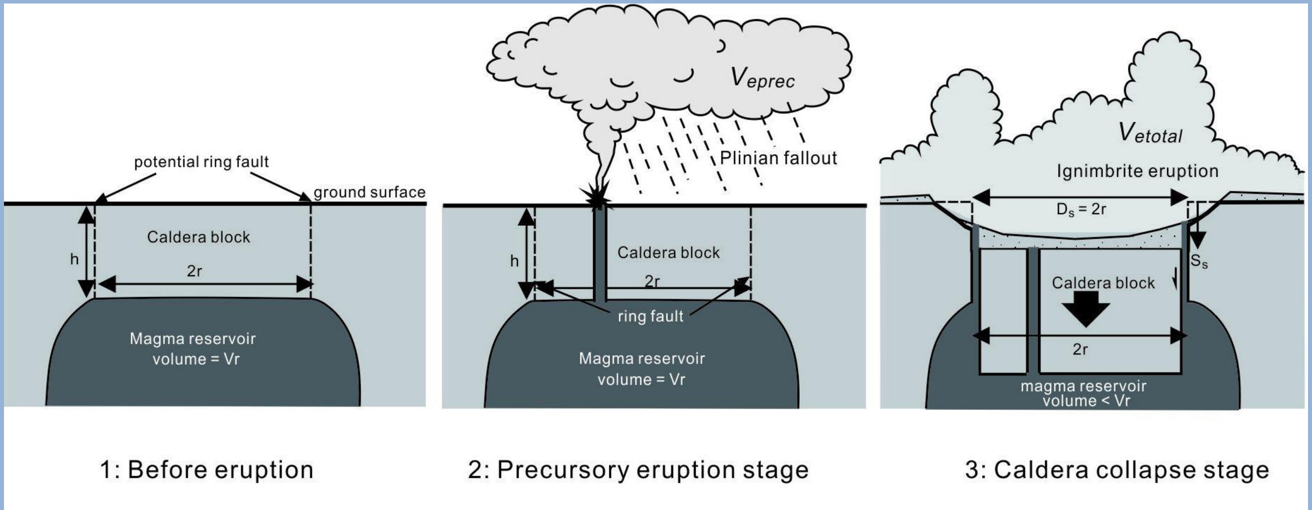
Onset of collapse
Ignimbrite eruption

Key Process of
caldera-forming eruption

Caldera border
Fault is not
activate

No collapse
Eruption stops

Field Example



Let’s Go Field and Examine !

Field Example

Aira Caldera (~29,000 BP) in Japan

Formed by an eruption VEI~8.

Kagoshima, Last IAVCEI site

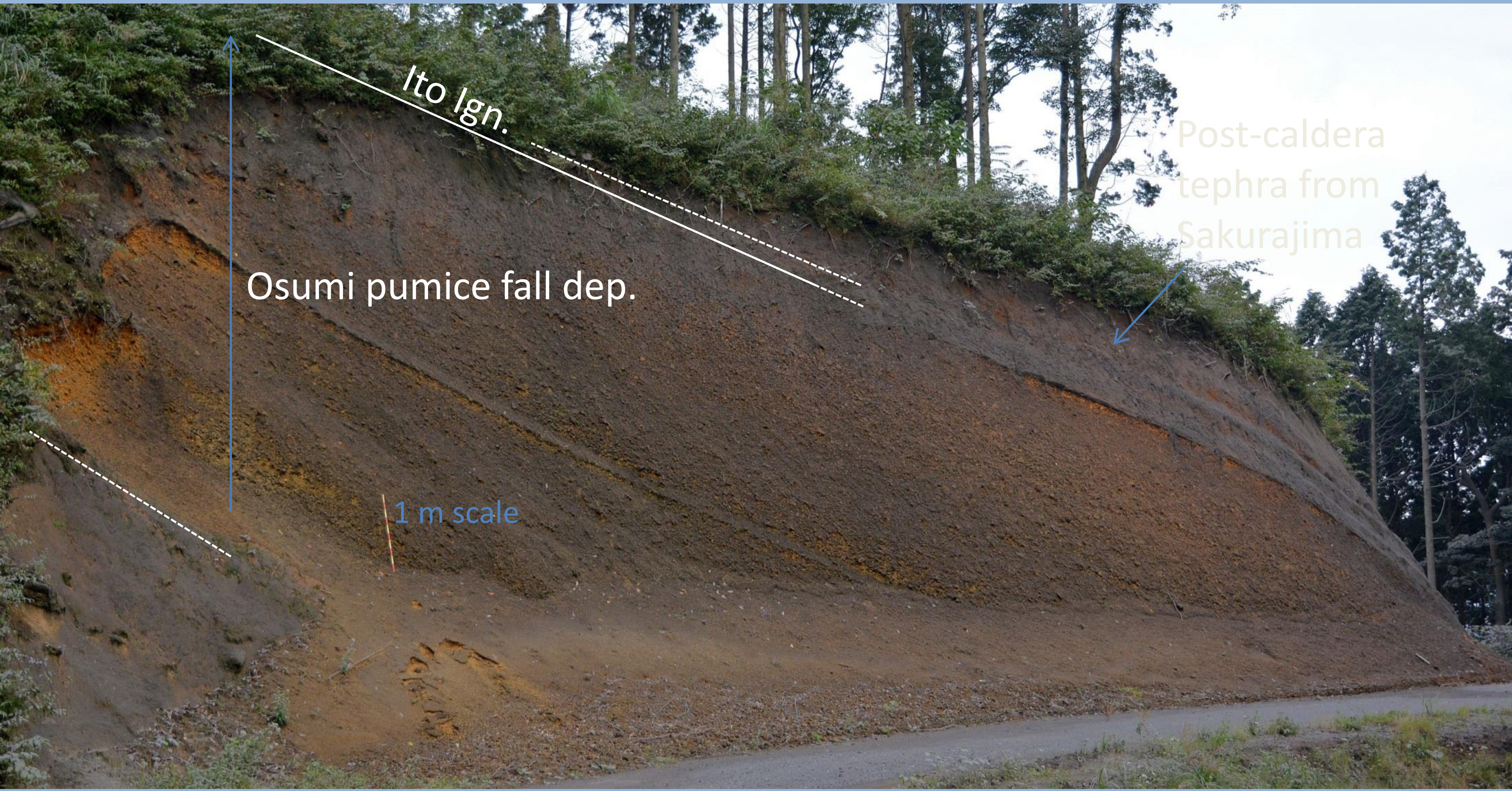
Osumi Pumice Fall: basal pumice fall of the Ito Ignimbrite

Total bulk volume ~100 km^3 (~ 40 km^3 DRE)
Maximum thickness >15 m

Ito ignimbrite: climax product of 29 ka eruption
total ~350 km^3 DRE

One of the largest plinian eruptions within late Pleistocene to Holocene in Japan

Outcrop of Osumi pumice fall



~15 km from the vent
Thickness in this outcrop is ~9m.

Fall Unit

Ito Ignimbrite

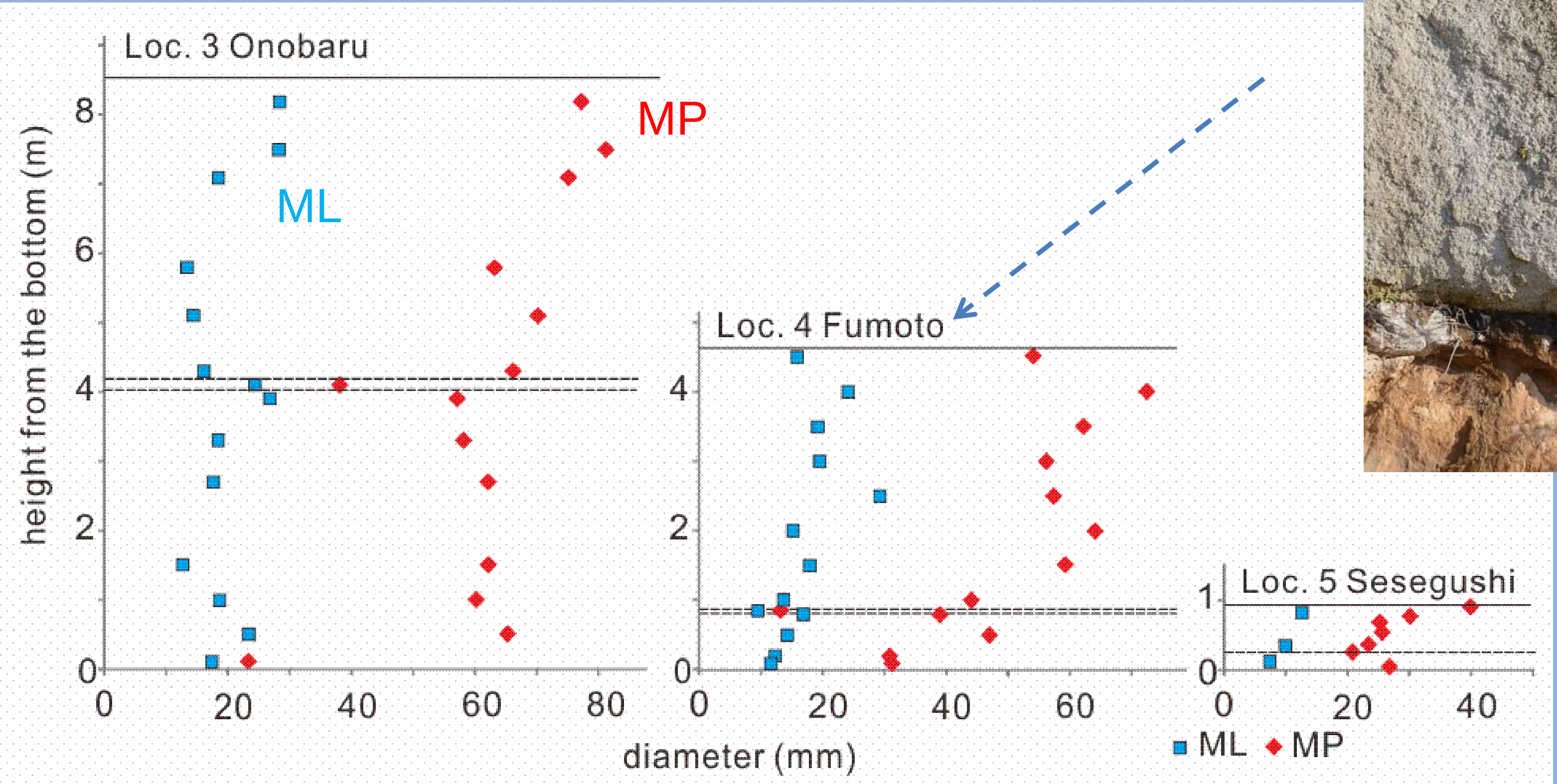
Unit 2

Unit 1

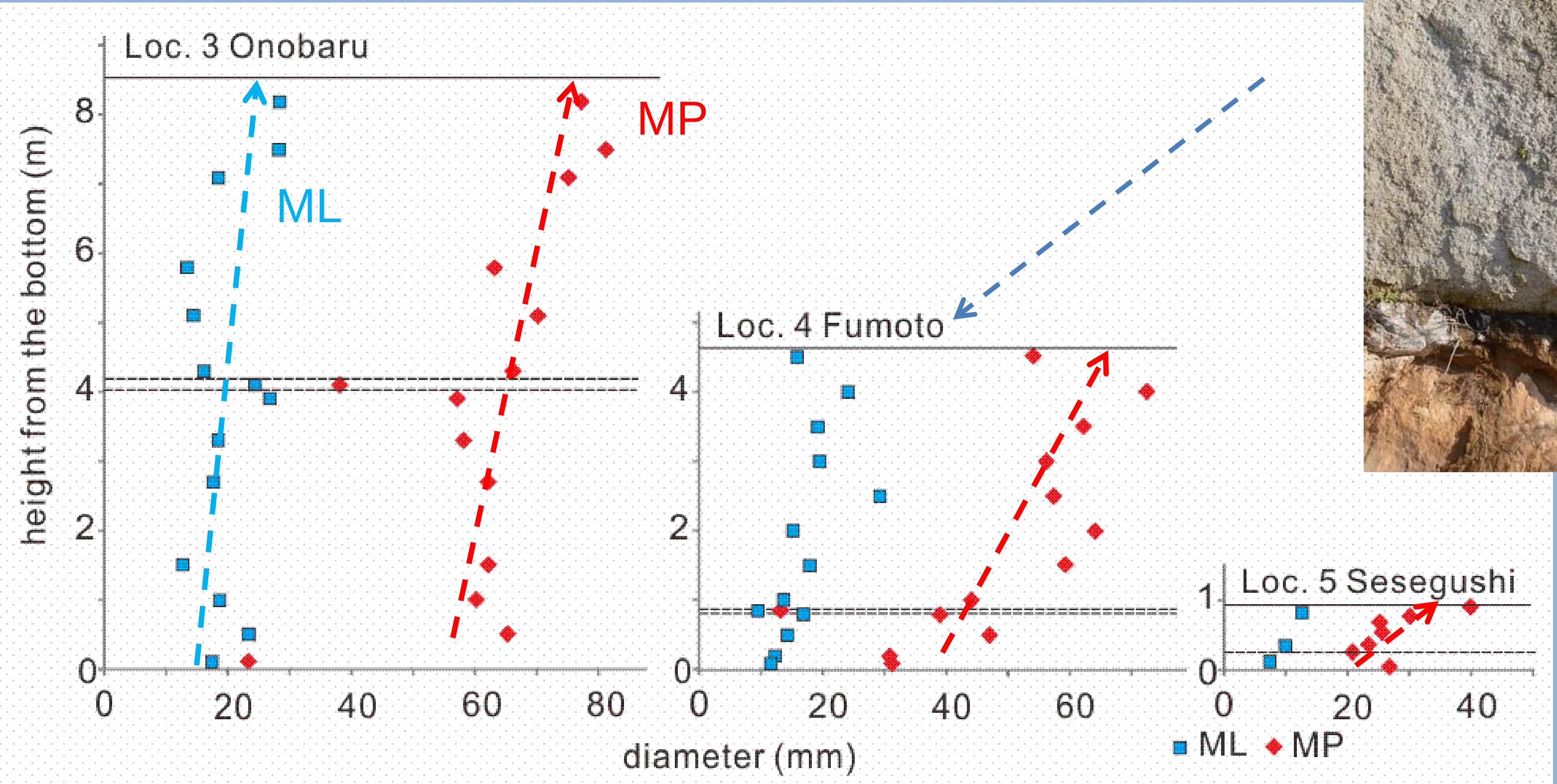
～30 km downwind

~15 km downwind

Grain-size grading

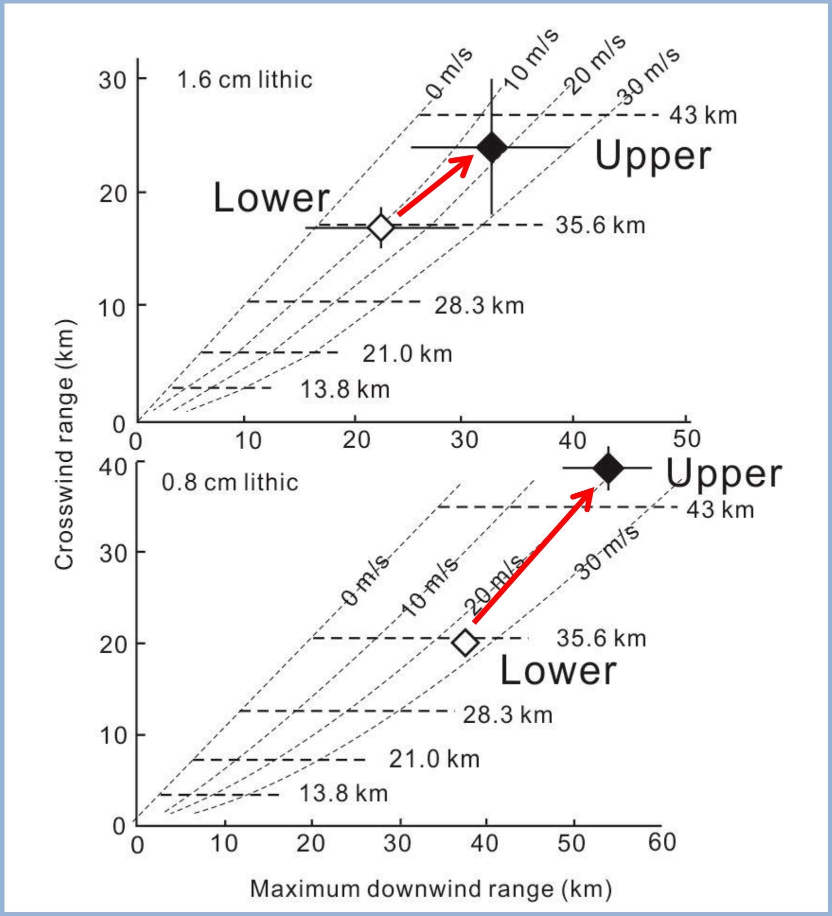


Grain-size grading



Everywhere upward-coarsening

Increase of mass flux



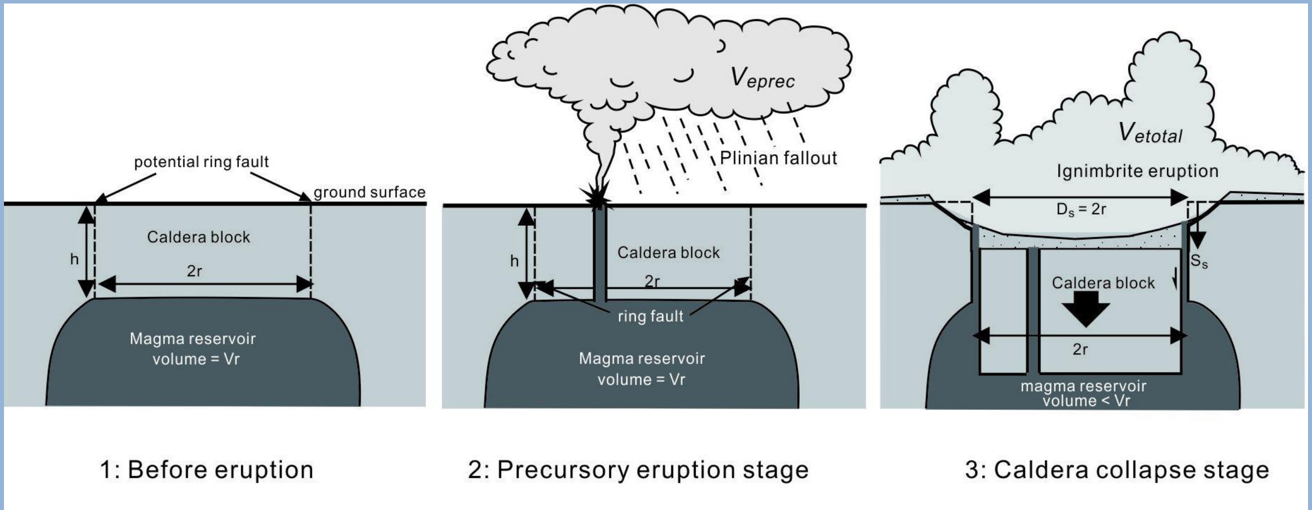
Carey & Sparks 1986 diagram

Upward-coarsening
= increase of magma flux

Column height increased from ~35 km to ~43 km

Mass flux; up to >10^8 kgs^{-1}

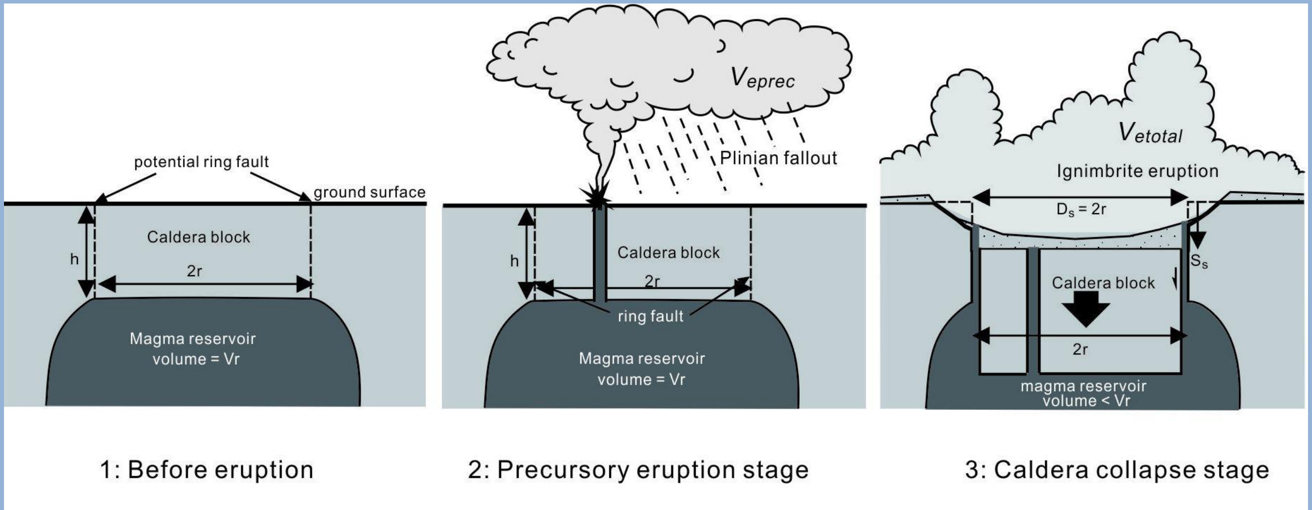
Decompression of magma chamber



Pressure gradient between magma chamber and surface decreases to caldera collapse

Pressure gradient decreases but flux increases. Why?

Decompression of magma chamber



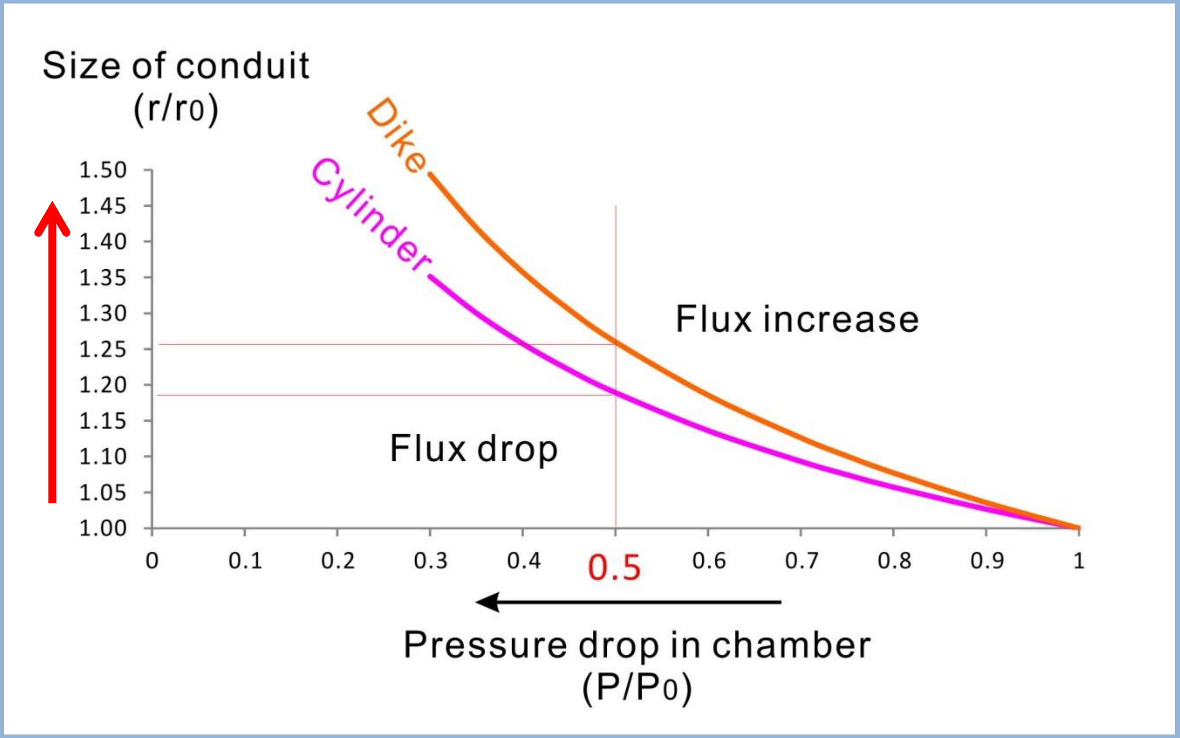
Pressure gradient between magma chamber and surface decreases to caldera collapse

Pressure gradient decreases but flux increases. Why?

Conduit enlarge

Magma flux and conduit size

In the case of Hagen-Poiseuille flow in a cylindrical conduit, flow flux correlates lineally with the pressure gradient and power 4 of the radius of conduit in a cylindrical conduit,
or
cube of the width of conduit in a dike conduit



Magma flux and conduit size

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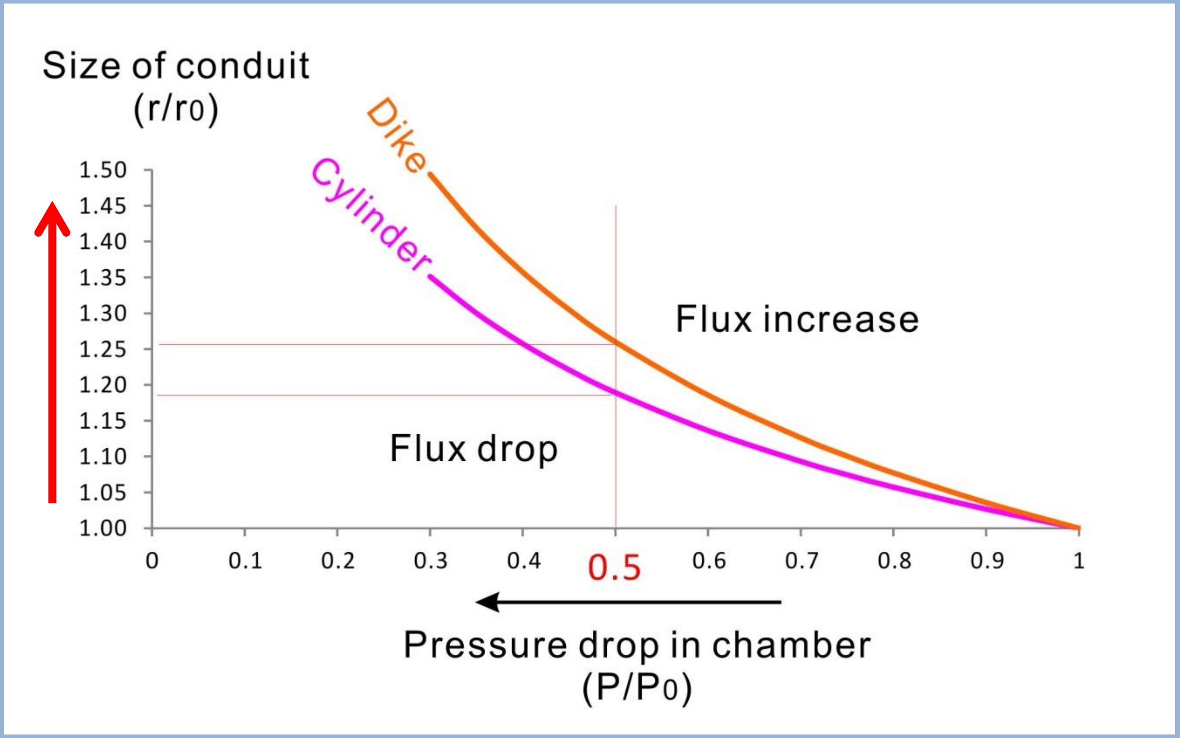
Radius of conduit should be widen ~20 % to maintain the flow flux with the drop of source pressure to half.



Lithic fragments (xenolith) in Osumi pumice fall

Lithic content
2-10%   locally >20%
Average ~5 % in volume

~5 km^3 of conduit wall were eroded

Lithic fragments (xenolith) in Osumi pumice fall

Shale

Basement rock

Welded tuff

Andesitic
lava

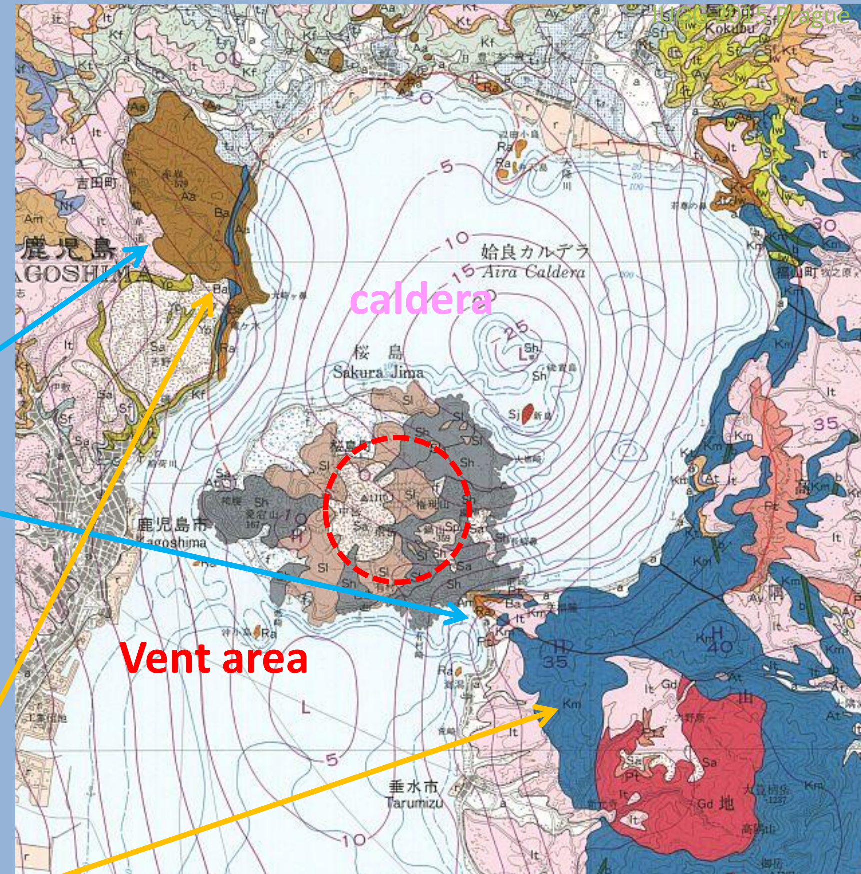
Metamorphic rock

Basement rock
(deep, not exposed)

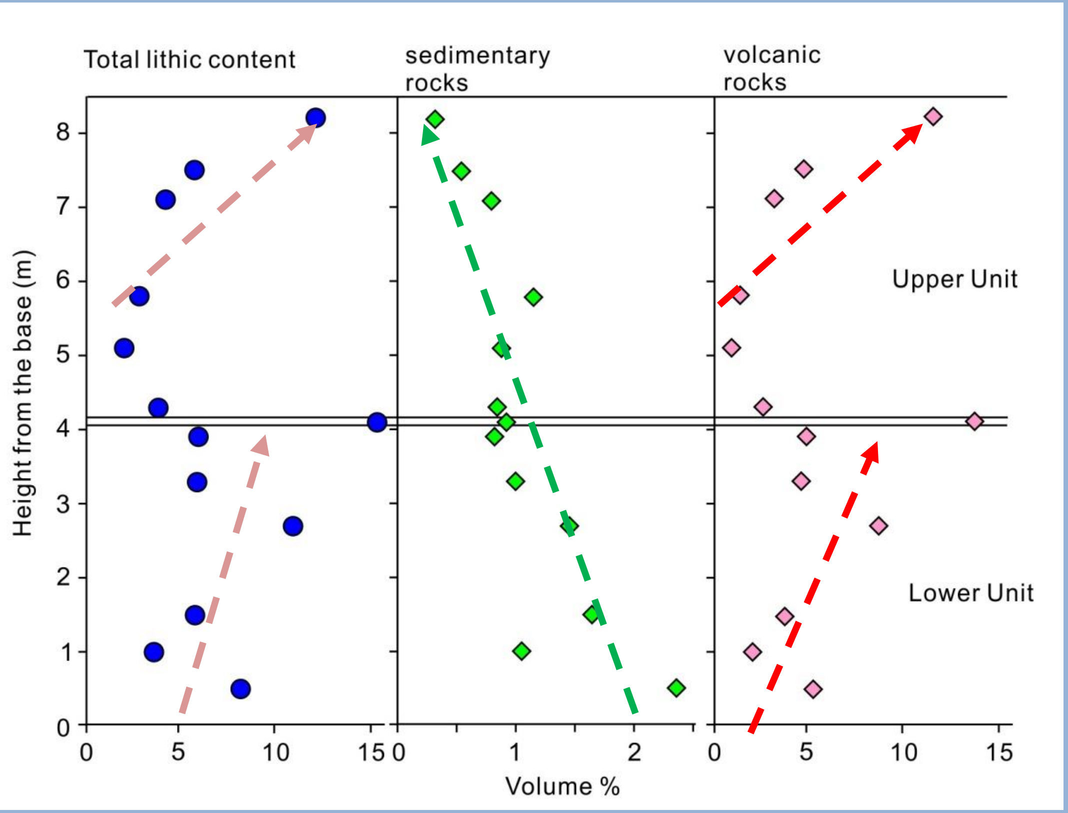
Where did they come?

Quaternary volcanic rock

Paleogene Sedimentary basement rock

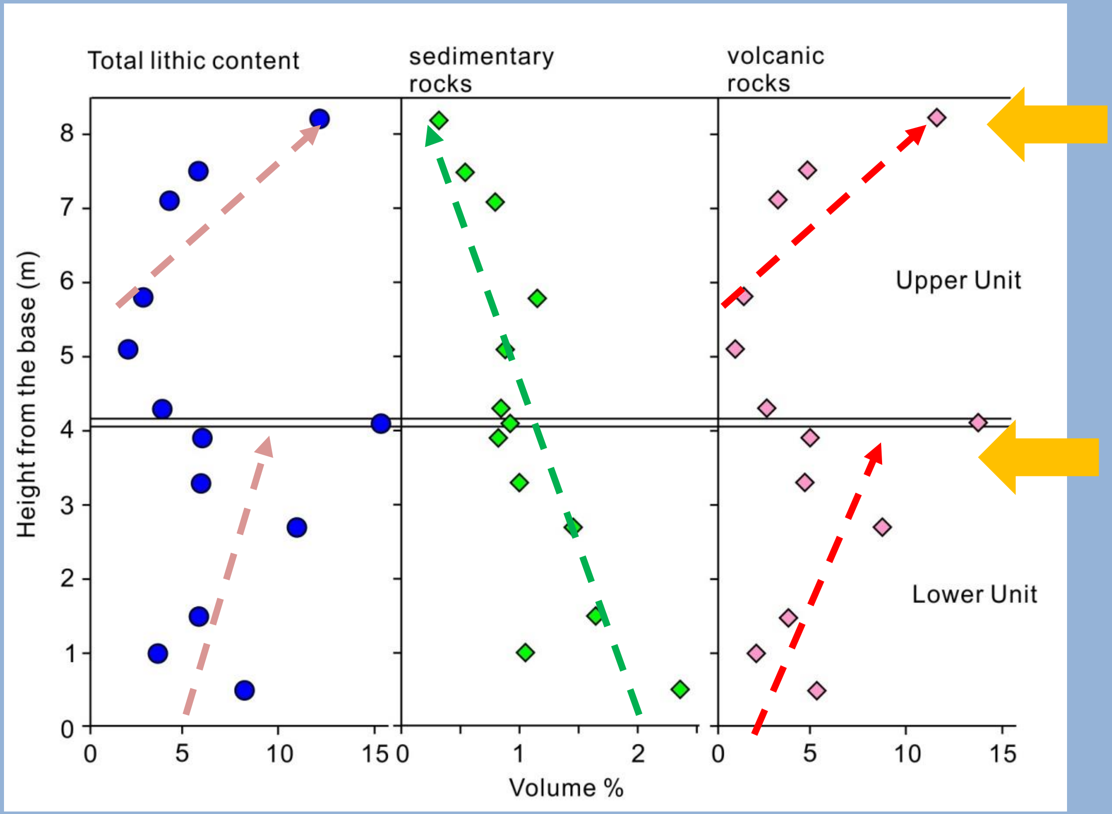


Change of xenolith component



Lateral enlargement of the vent？

Change of xenolith component



Peak of lithic content

Only volcanic rock from shallow conduit

Vent collapse?

Lateral enlargement of the vent？

Conduit enlargement

*Voluminous xenolith fragments in Osumi pumice fall deposit shows the effective erosion of conduit wall during the eruption.

*Widening of eruptive conduit allows the high flux rate during the decreasing of pressure gradient in the conduit.

*Maintain of high flux results the withdrawal of voluminous magma from the chamber to induce caldera collapse and results the eruption of massive ignimbrite sheet (Ito ignimbrite).

Conclusions

*Conduit erosion is a key process to caldera-forming eruption

*High magma flux plinian eruption, with voluminous xenolith fragments can be a sigh for caldera collapse.

*We can detect the onset of caldera collapse by monitoring the eruption flux and xenolith component
(but probably too late to escape...)