Caldera-forming eruptions

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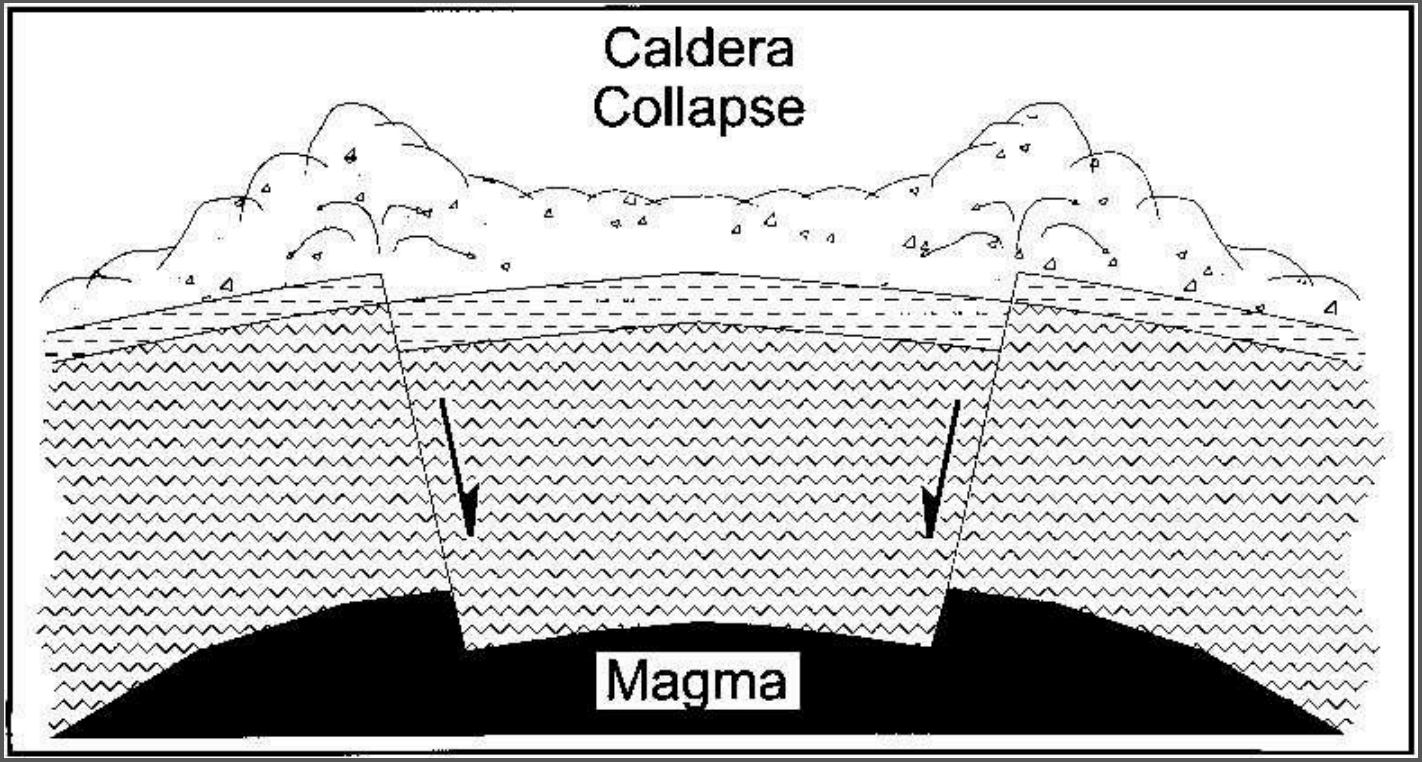

What is Magma?

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Magma: *naturally occurring, fully or partially molten rock material generated within a planetary body, consisting of melt with or without crystals and gas bubbles and containing a high enough proportion of melt to be capable of intrusion and extrusion.*

How is magma made?

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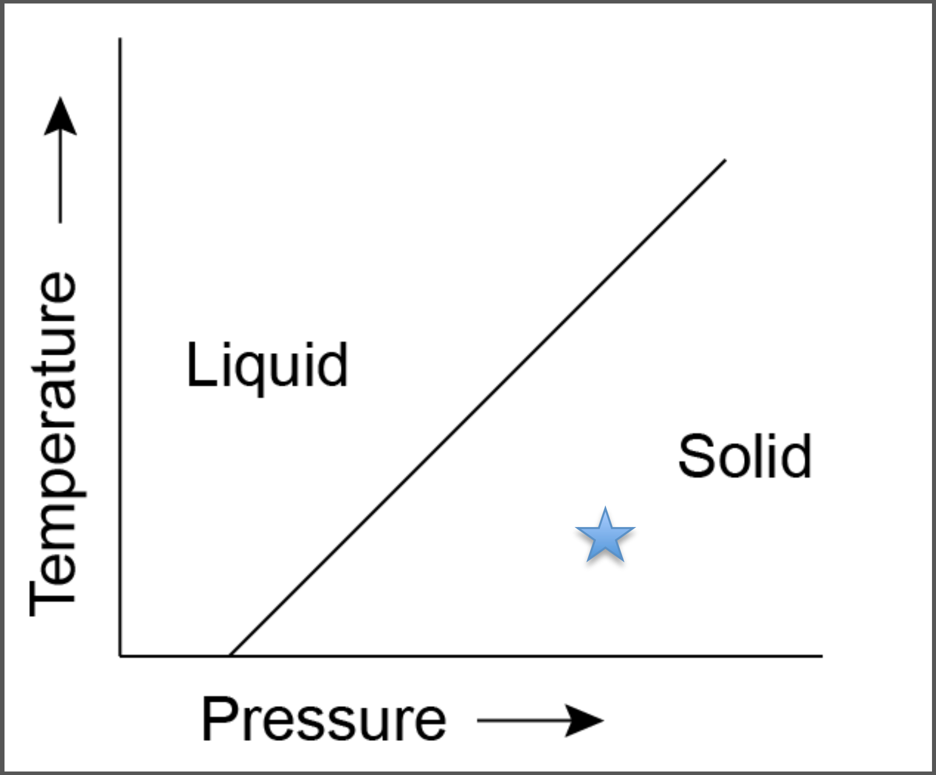
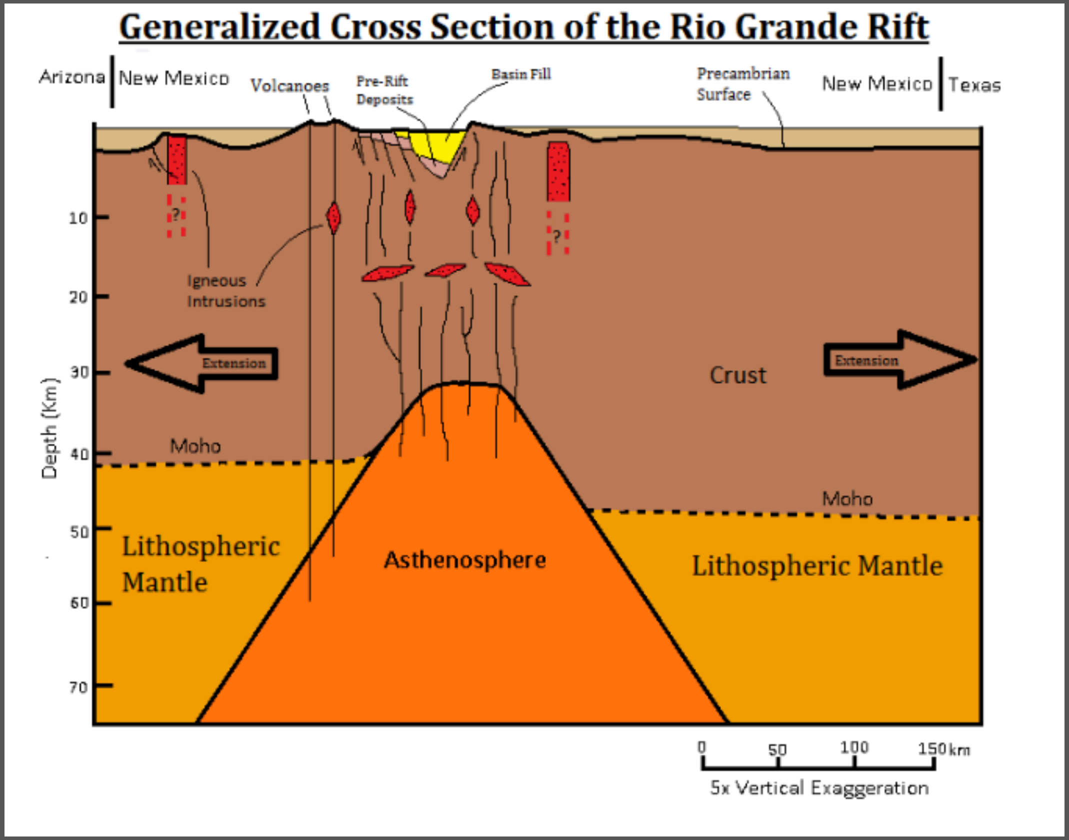
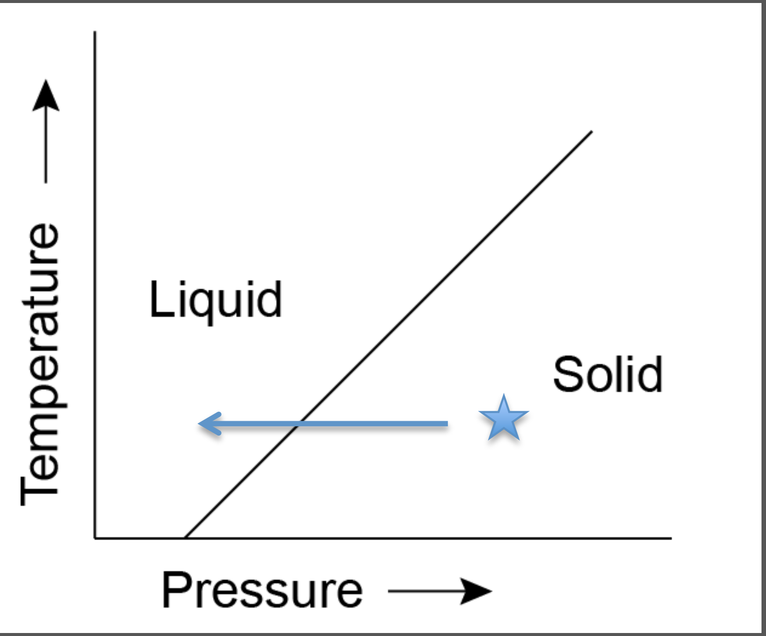


2 component phase diagram

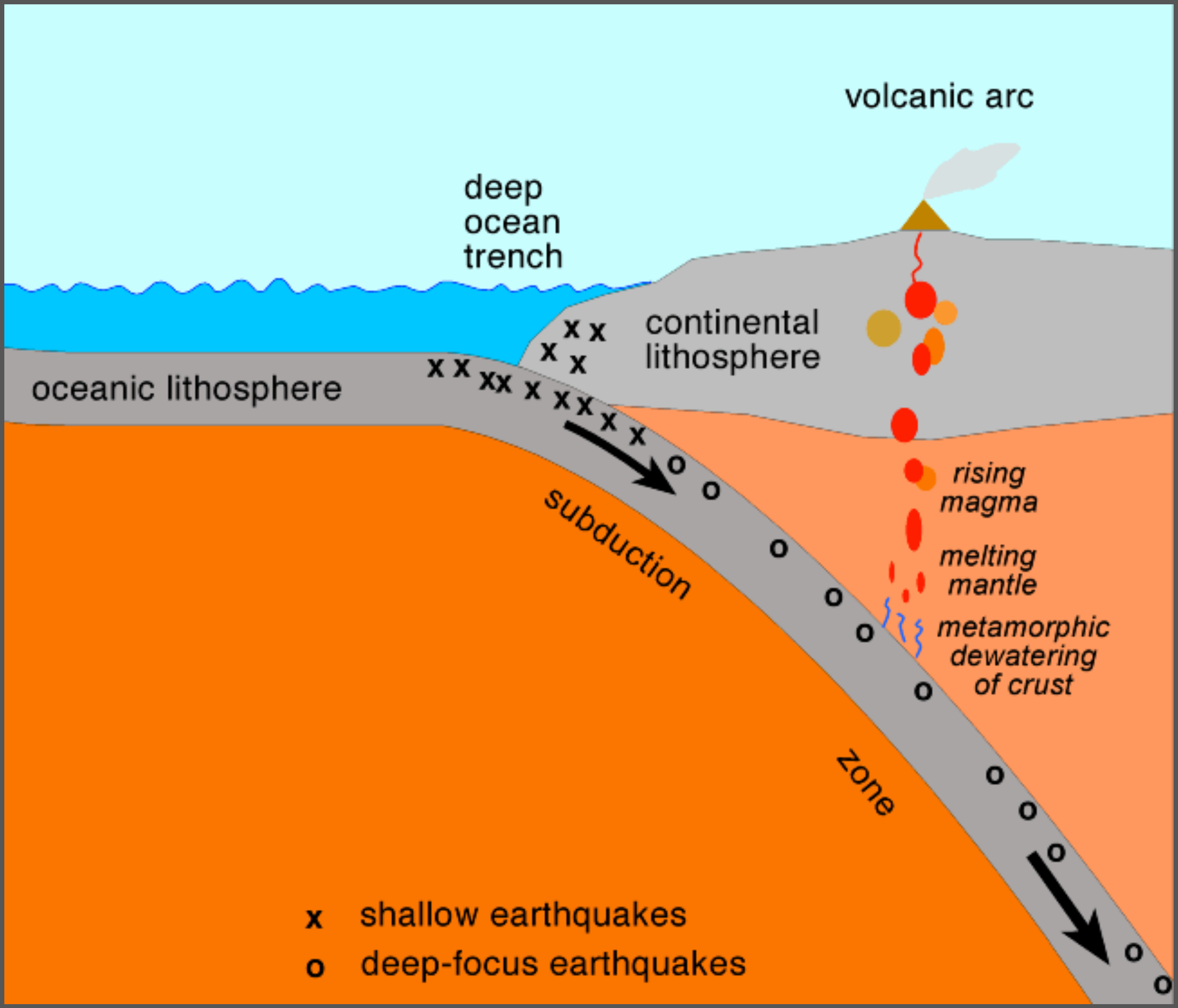
How is magma made?





Decompression Melting

How is magma made?



Flux Melting Of the Mantle

Magma Differentiation

What is differentiation?

Magma Differentiation

Processes that change the composition of a magma

Magma Differentiation

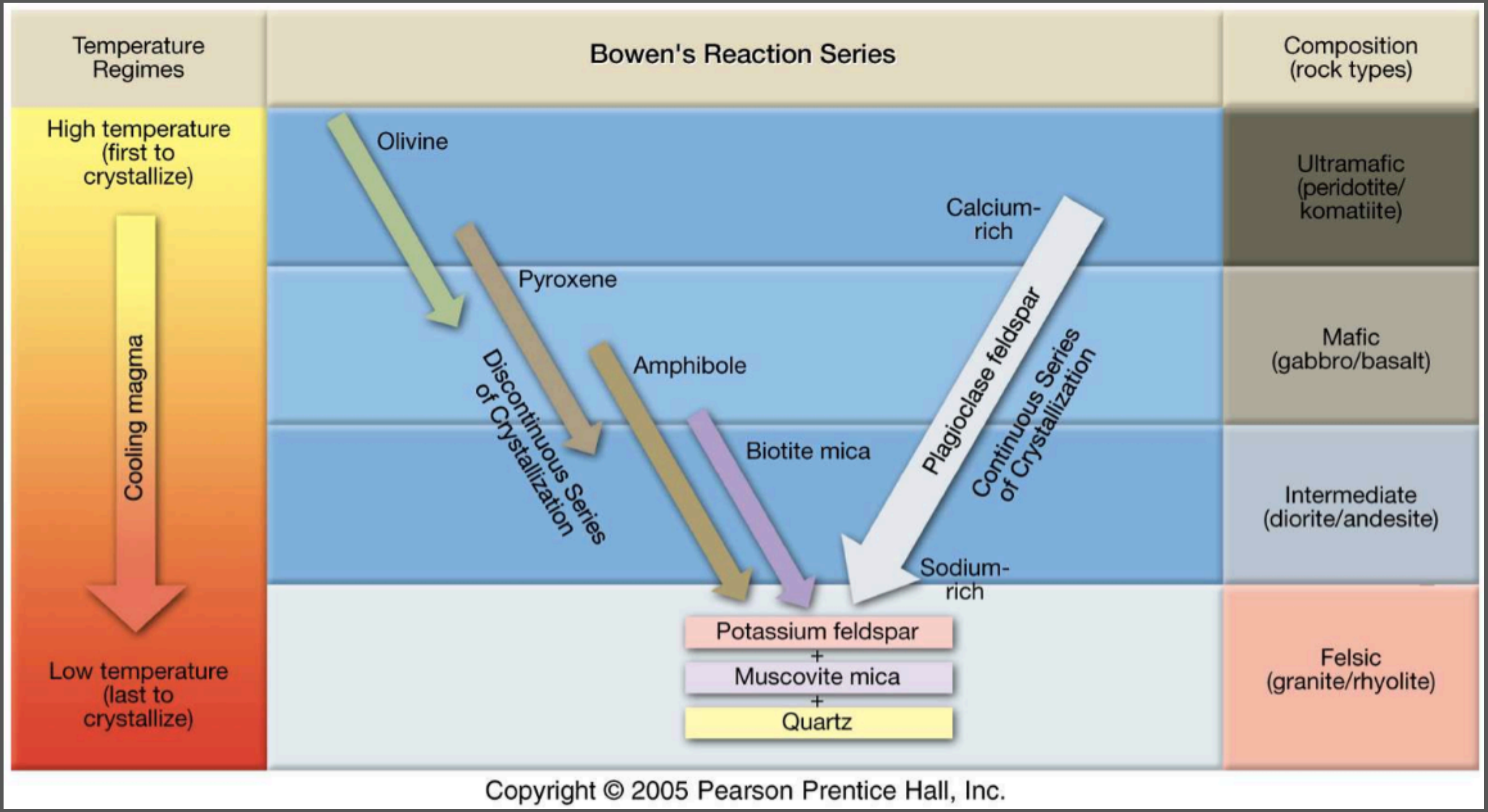
1 – Crystal Fractionation

2 – Magma Mixing

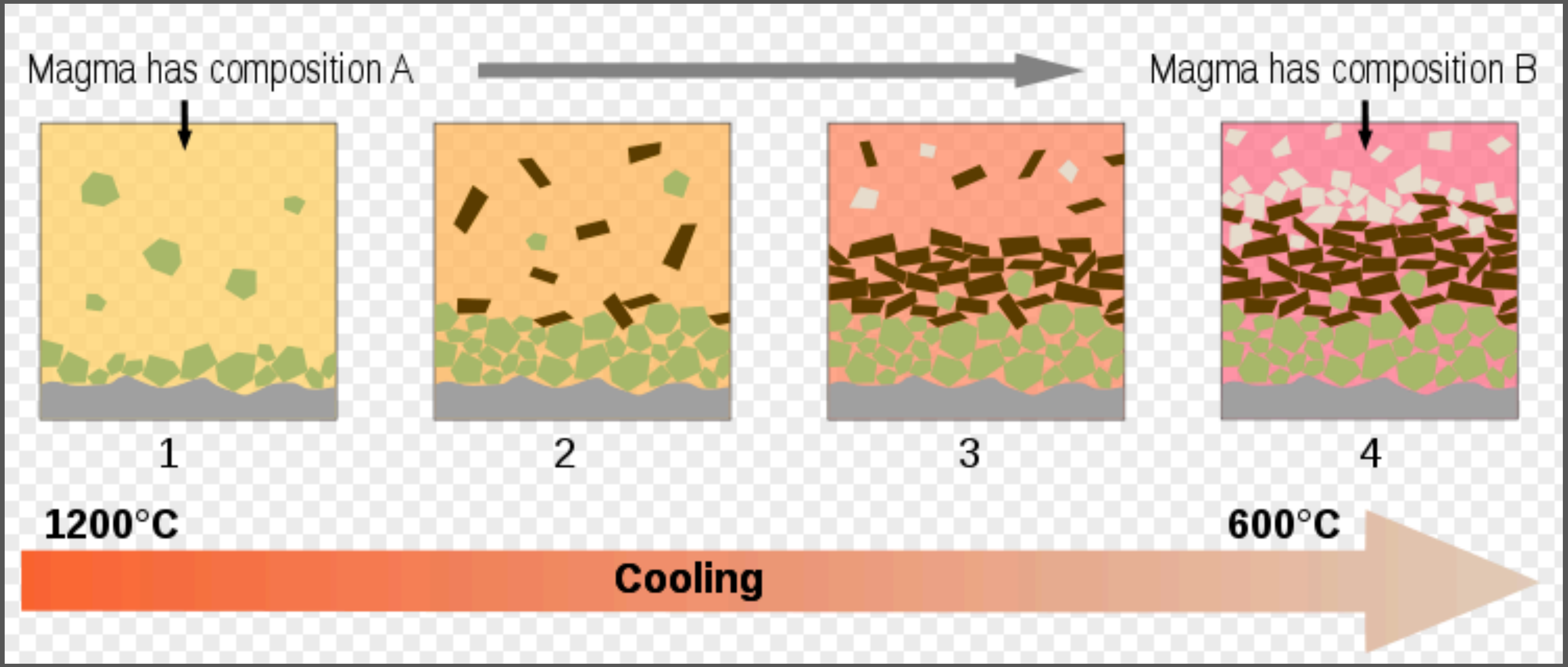
3 – Assimilation

4 – Partial Melting

Crystal Fractionation

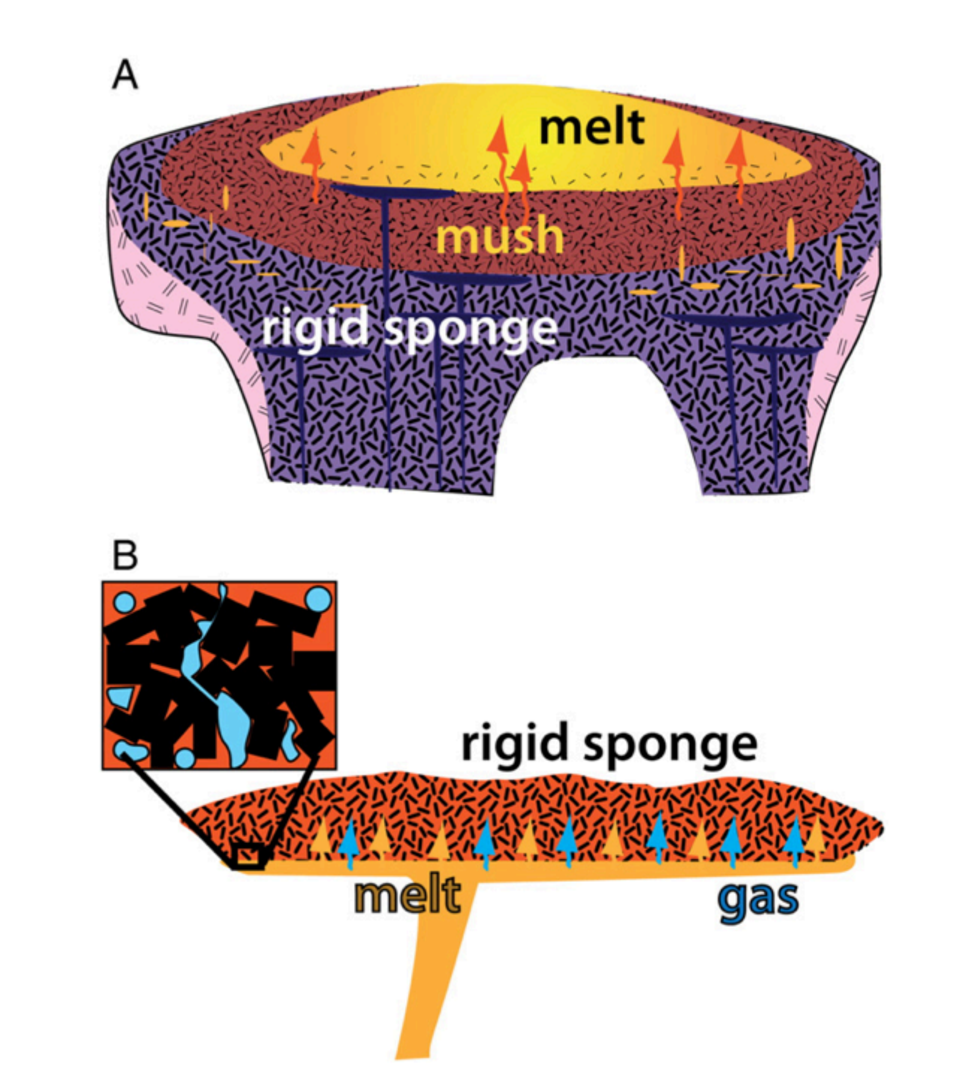


Crystal Fractionation



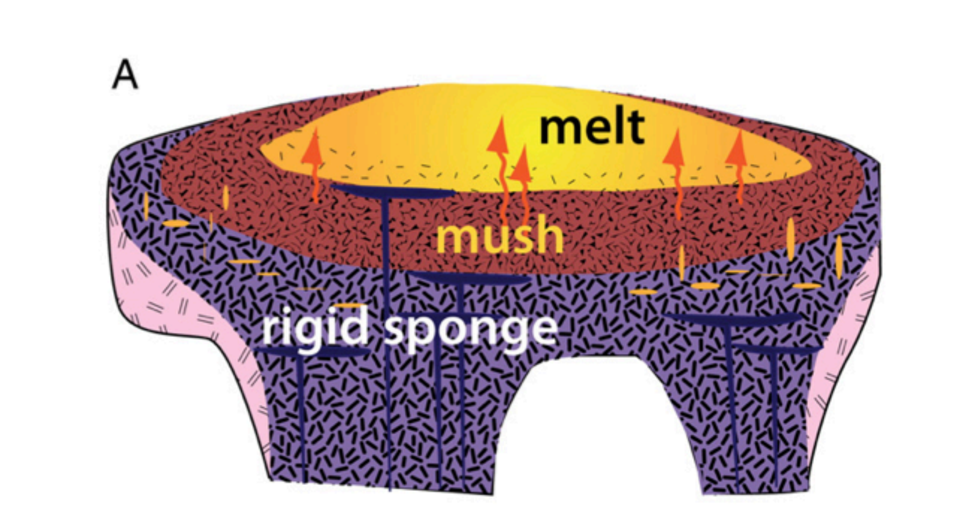
Crystal Settling – Locally important,
but probably not a large-scale mechanism
for silicic magmas

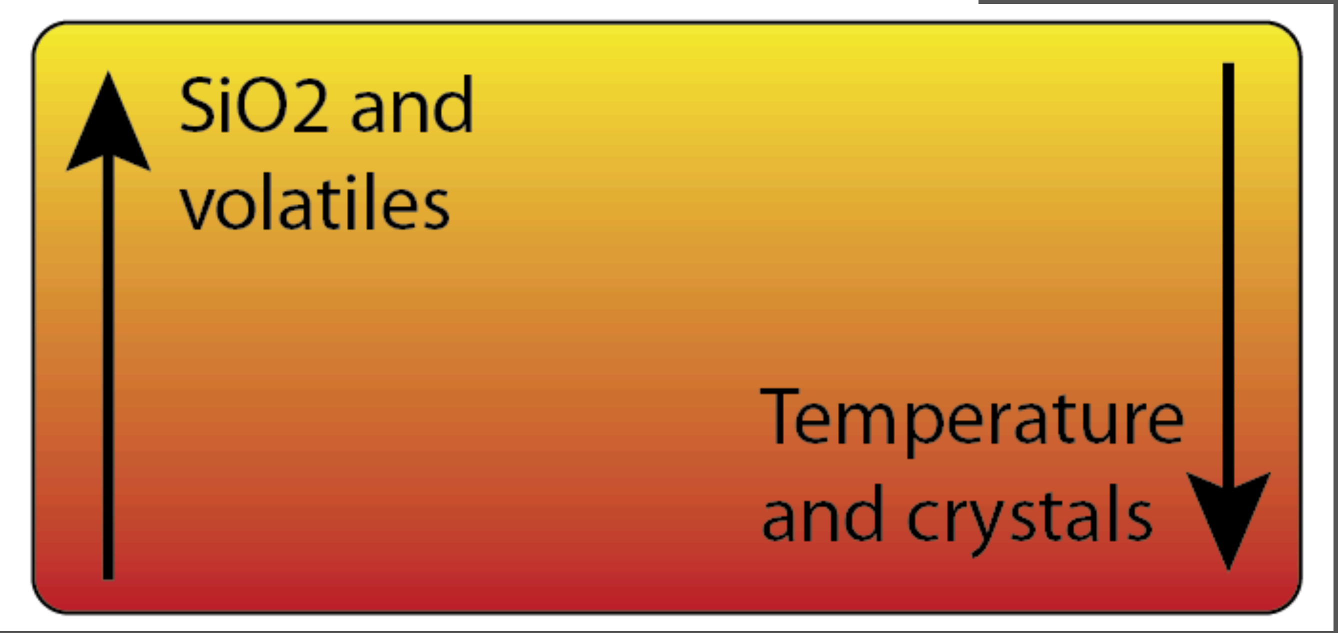
Crystal Mush Model for Fractionation



At 40-60% crystals, the crystal mush becomes "locked" and is no longer stirring

Crystal Mush Model for Fractionation





At 40-60% crystals, the crystal mush becomes “locked” and is no longer stirring

Crystal Mush Model for Fractionation

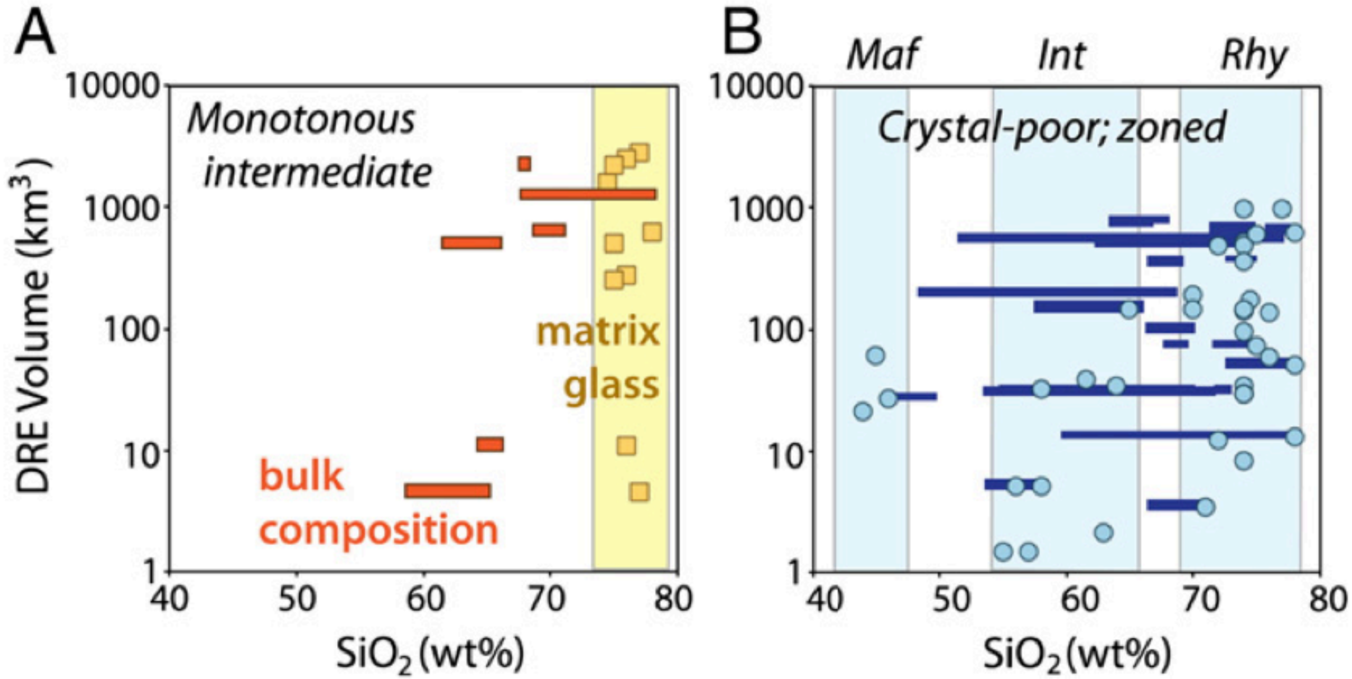


Fig. 4. Bulk rock and matrix glass compositions of CP and CR ignimbrites as a function of DRE erupted volume. (A) CR data; yellow squares show matrix glass, orange bars show bulk compositional range. (B) CP data; blue circles show matrix glass composition of earliest erupted magma, blue bars show bulk compositional range. Data sources are listed in Table S1.

Deep processes

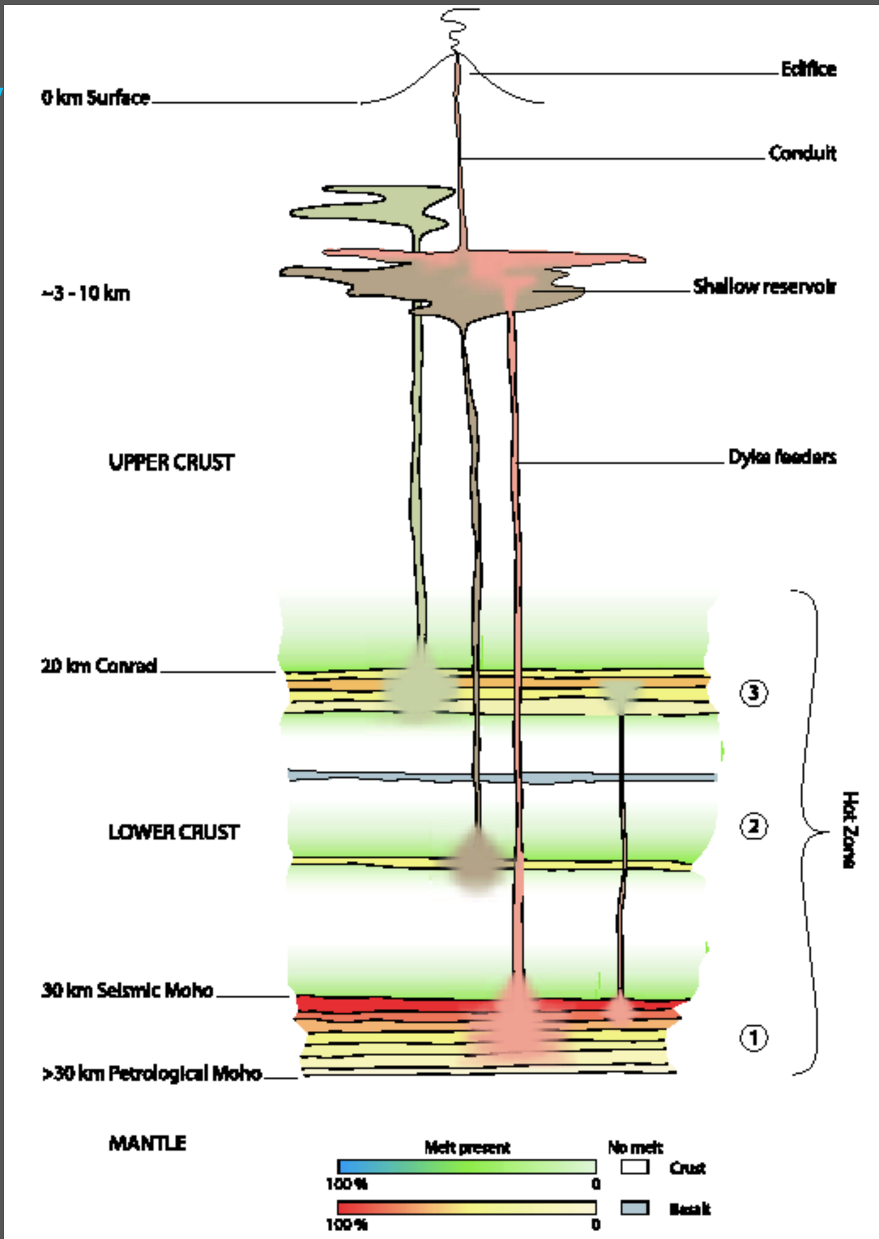
Annen et al. 2006

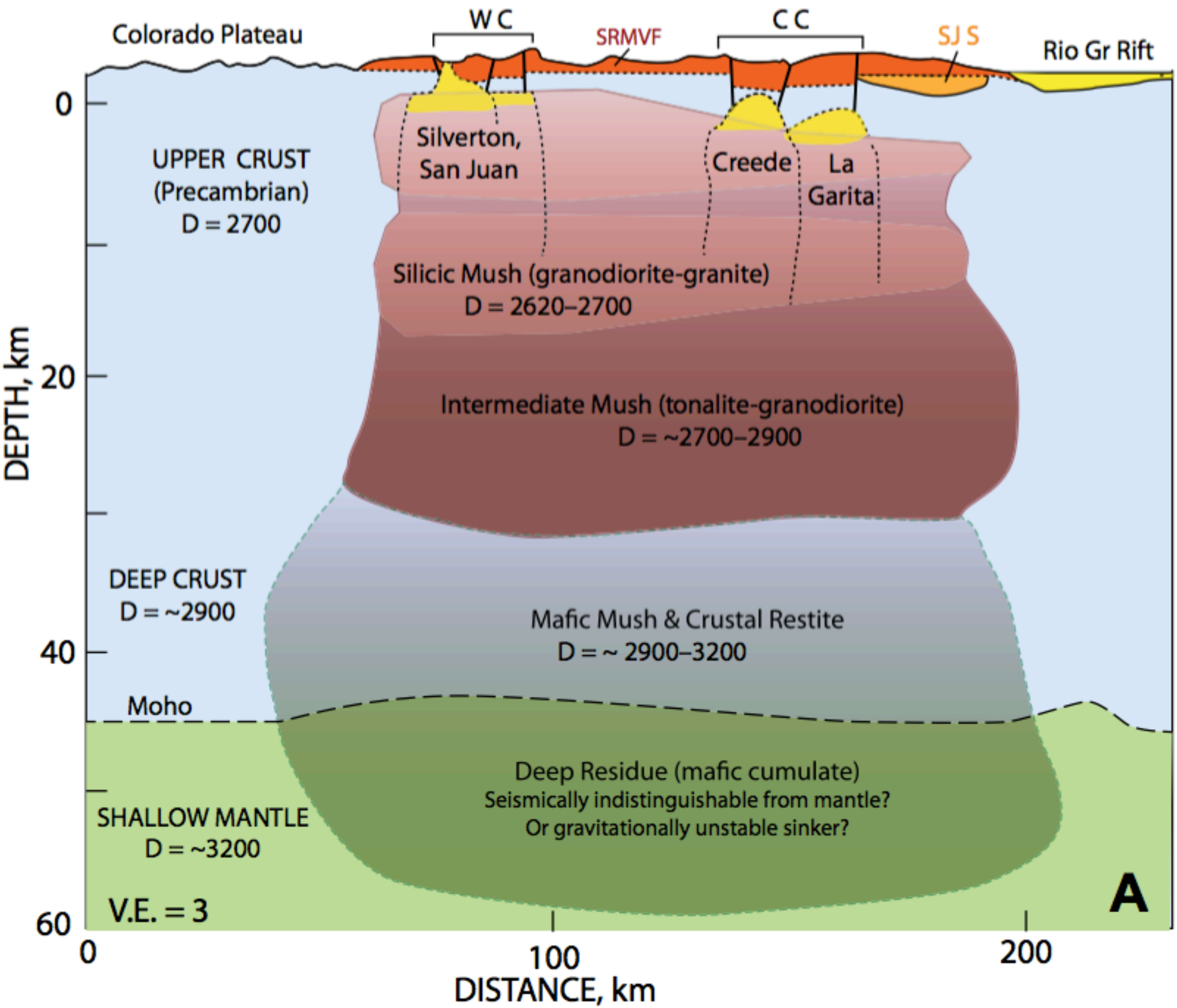
Magma differentiation processes:

- Partial melting of protolith (fertile vs. refractory) by basalt intrusions
  - H_2O-poor, high viscosity
  - Presence/absence of hydrous minerals
  - Dehydration melting
  - Peraluminous liquids produced
- Remelting of earlier intrusions by later basalt injections
- Fractional crystallization of hydrous basalt (potentially lots of H_2O, low viscosity)

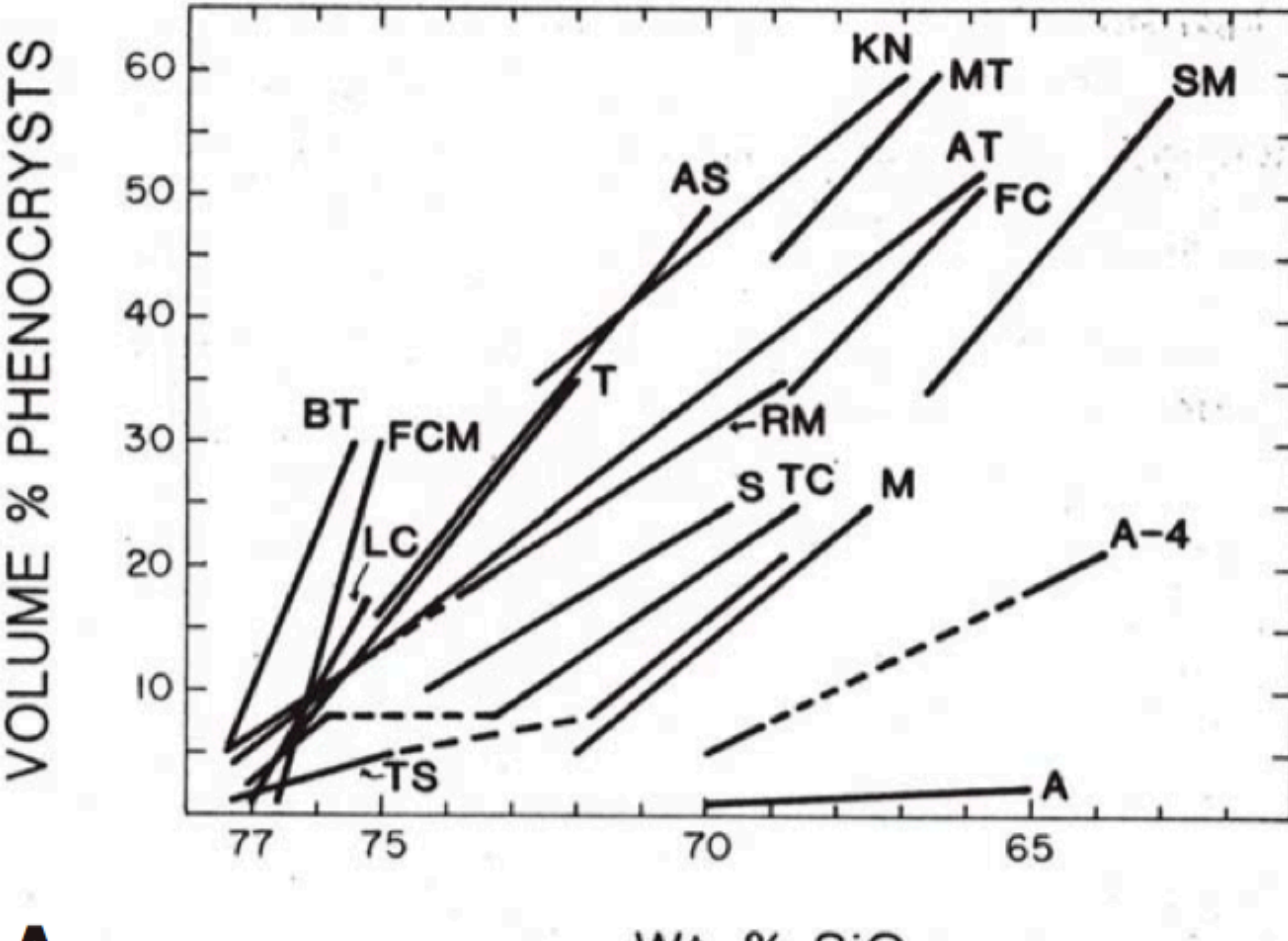
Think about:

- Combinations of the above
- Differences in physical properties and rheology of the liquids produced
- Chemical and isotopic signatures



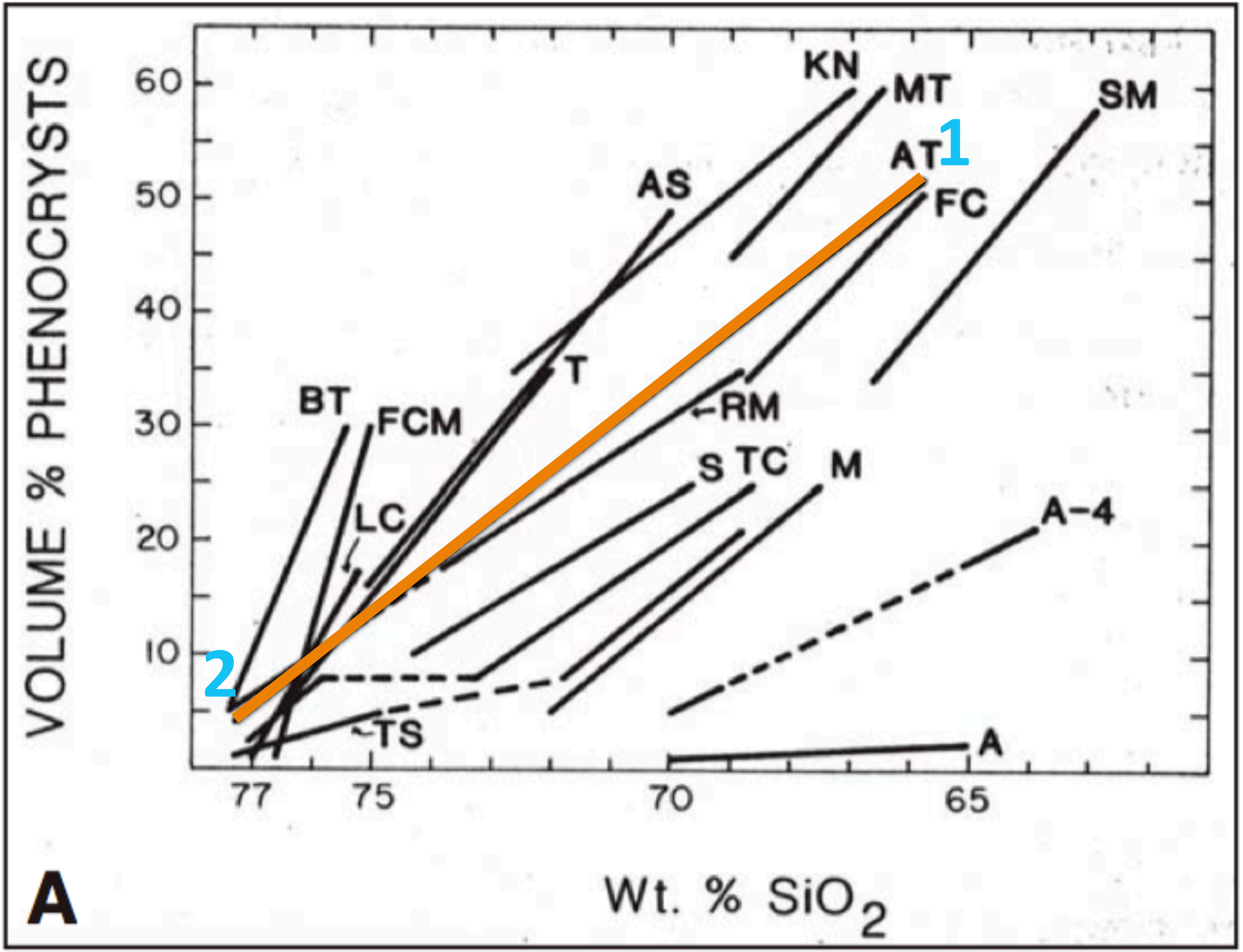


Colorado Plateau
W C
SRMVF
C C
SJ S
Rio Gr Rift
Silverton, San Juan
Creede
La Garita
UPPER CRUST (Precambrian) D = 2700
Silicic Mush (granodiorite-granite) D = 2620–2700
Intermediate Mush (tonalite-granodiorite) D = ~2700–2900
DEEP CRUST D = ~2900
Mafic Mush & Crustal Restite D = ~ 2900–3200
Moho
Deep Residue (mafic cumulate)
Seismically indistinguishable from mantle?
Or gravitationally unstable sinker?
SHALLOW MANTLE D = ~3200
V.E. = 3
A
DEPTH, km
0
20
40
60
DISTANCE, km
0
100
200

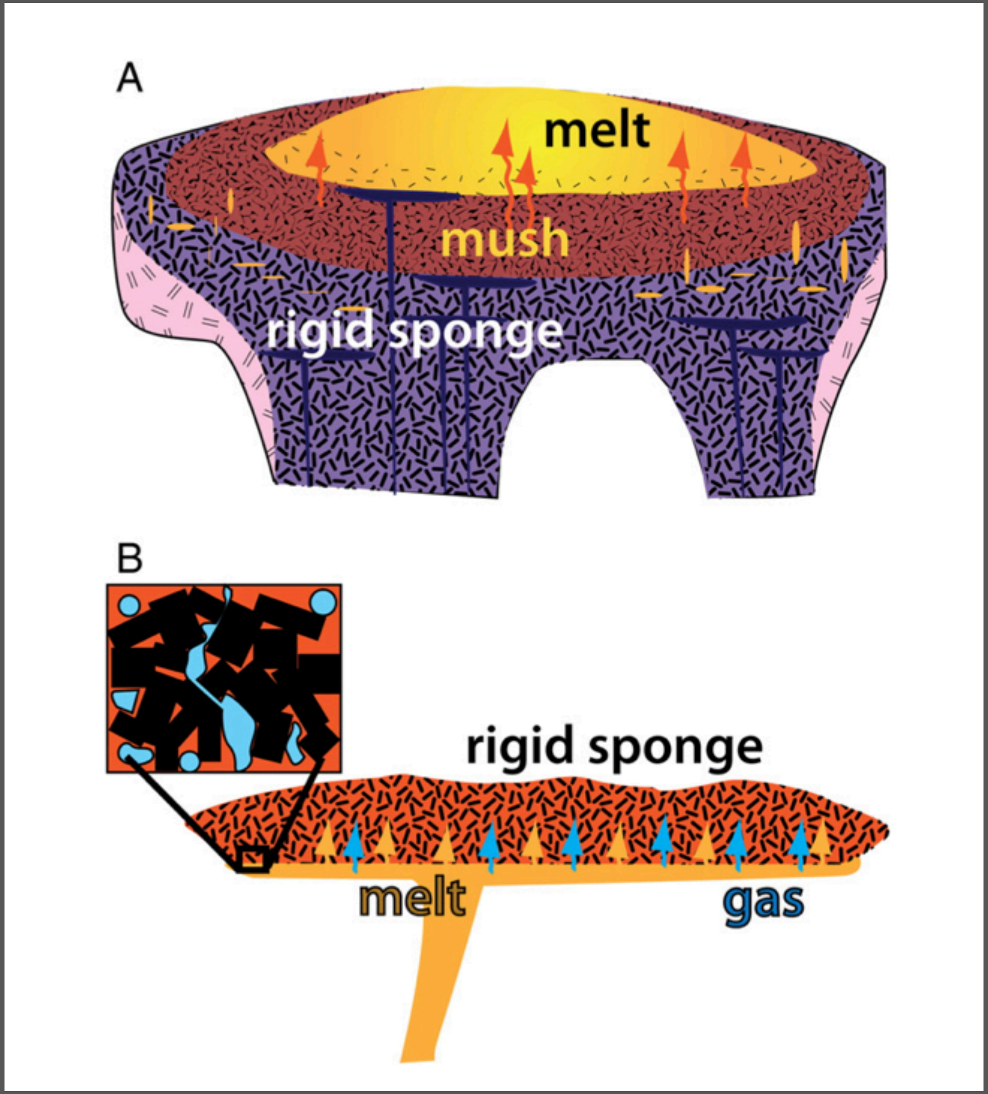


VOLUME % PHENOCRYSTS
60
50
40
30
20
10
77
75
70
65
Wt. % SiO2
KN
MT
SM
AT
AS
FC
T
BT
FCM
RM
S
TC
M
LC
A-4
TS
A

A



VOLUME % PHENOCRYSTS
60
50
40
30
20
10
77
75
70
65
Wt. % SiO2
KN
MT
SM
AT
1
FC
AS
T
RM
BT
FCM
S
TC
M
LC
A-4
2
TS
A


A
melt
mush
rigid sponge
B
rigid sponge
melt
gas

Crater Lake caldera – Magma zonation

Late Erupted - Dacite

Early Erupted - Rhyolite

Why did the eruption stop?

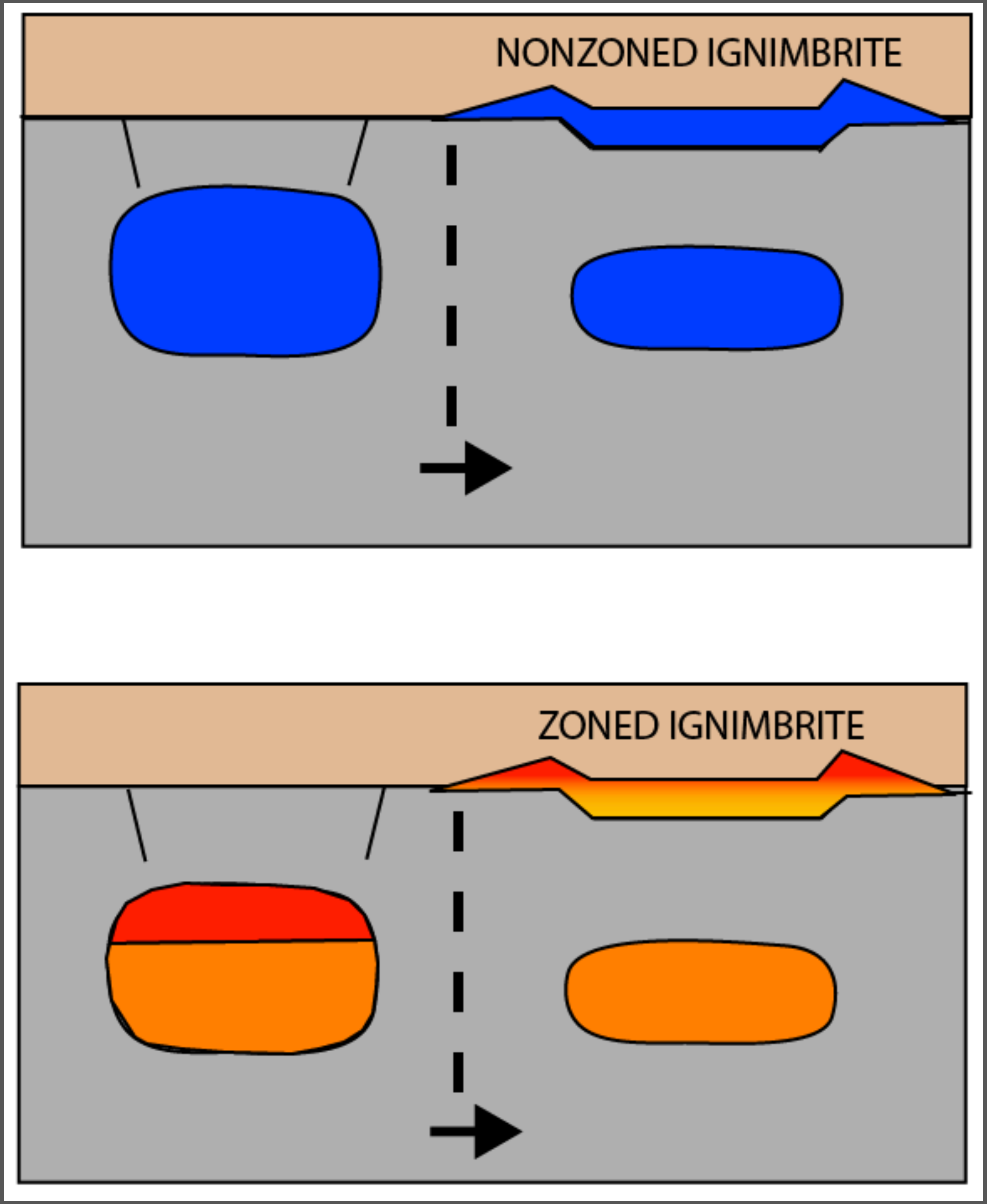
Crater Lake caldera – Magma zonation

Early Erupted - Rhyolite

---------Change in viscosity & crystal content----------

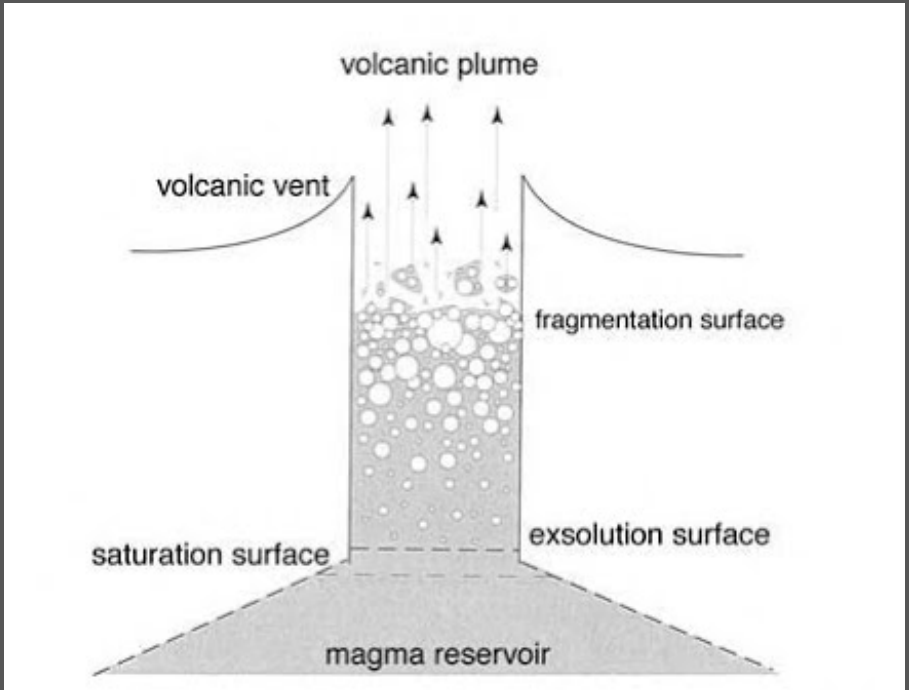
Late Erupted - Dacite

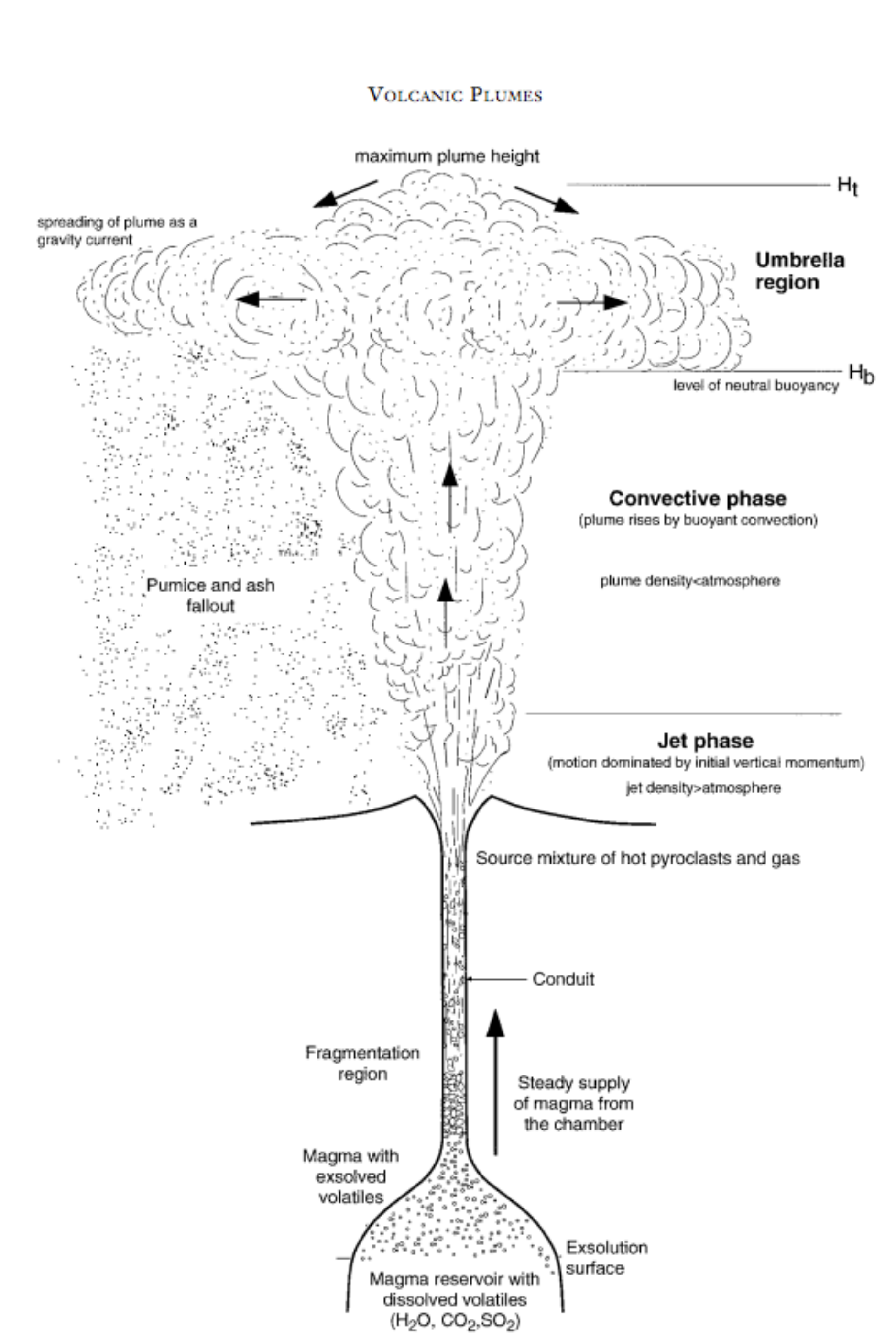
Why did the eruption stop?



Lipman et al., 1978

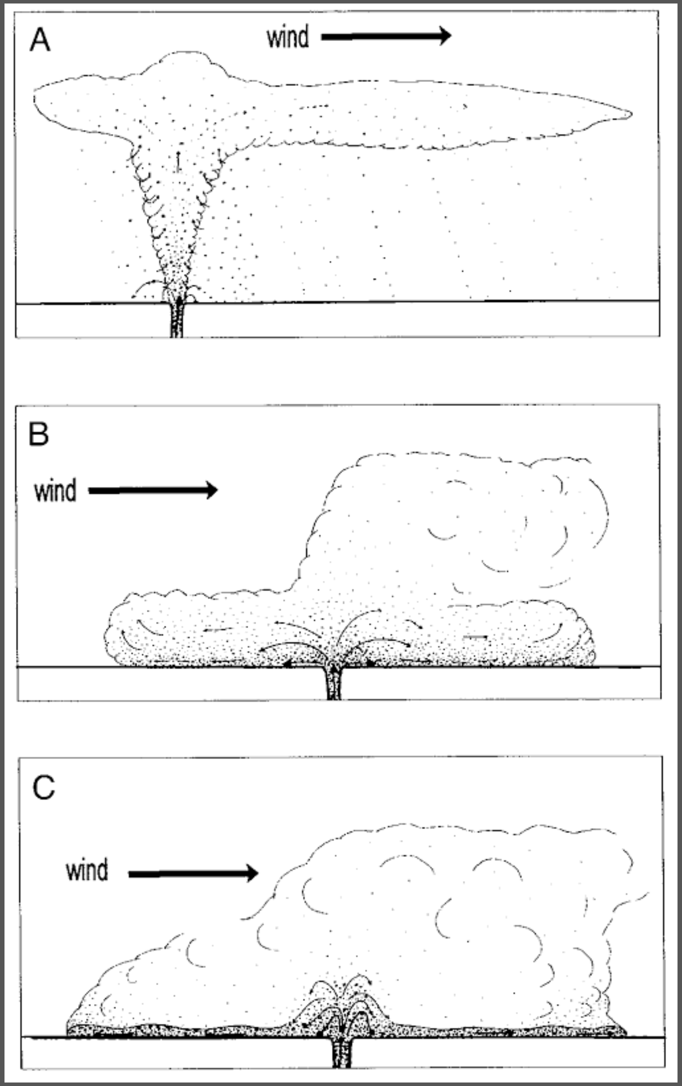
Components and emplacement of caldera-forming eruptions





Components in eruptive plume?

Pyroclastic Deposits

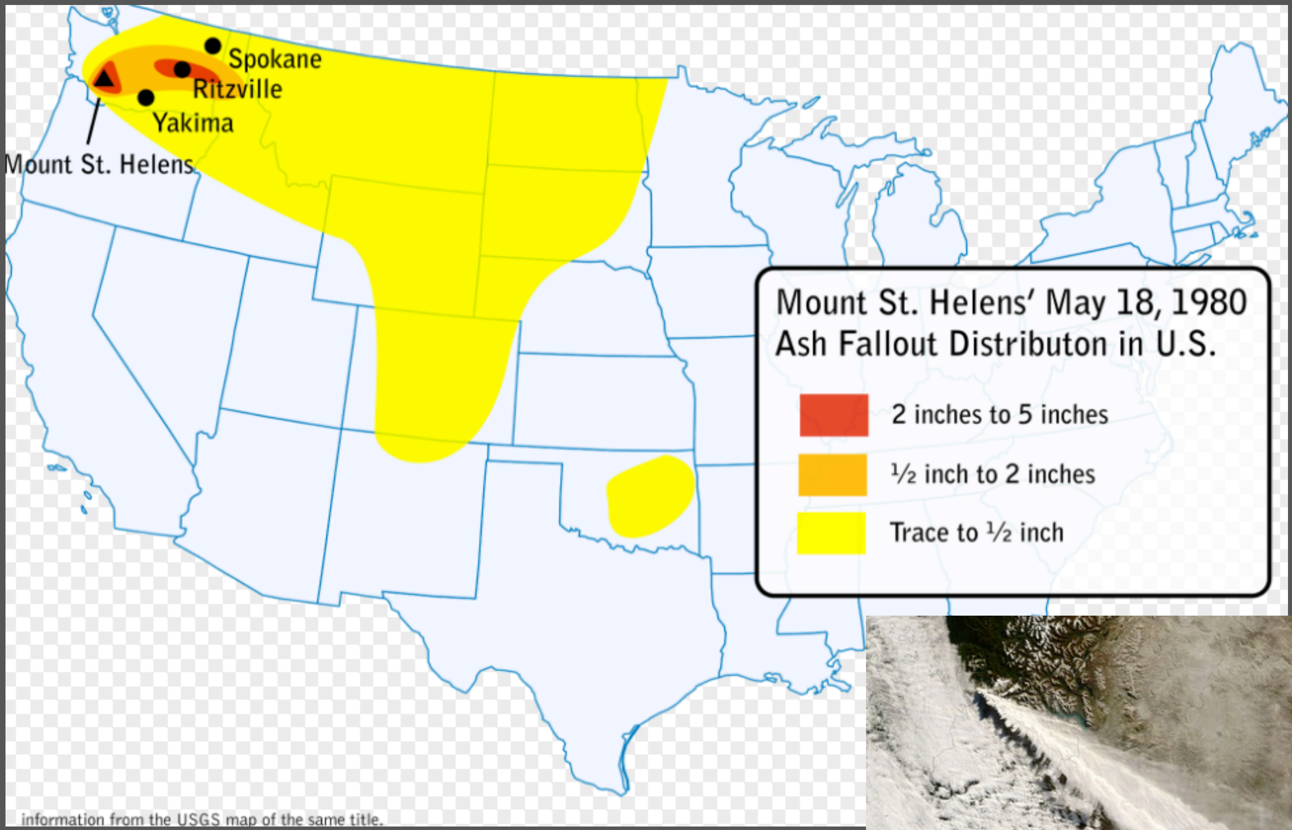


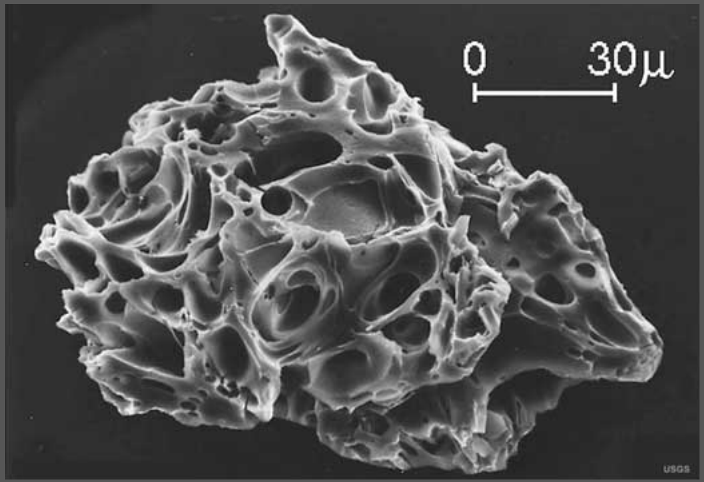
Fall Deposits

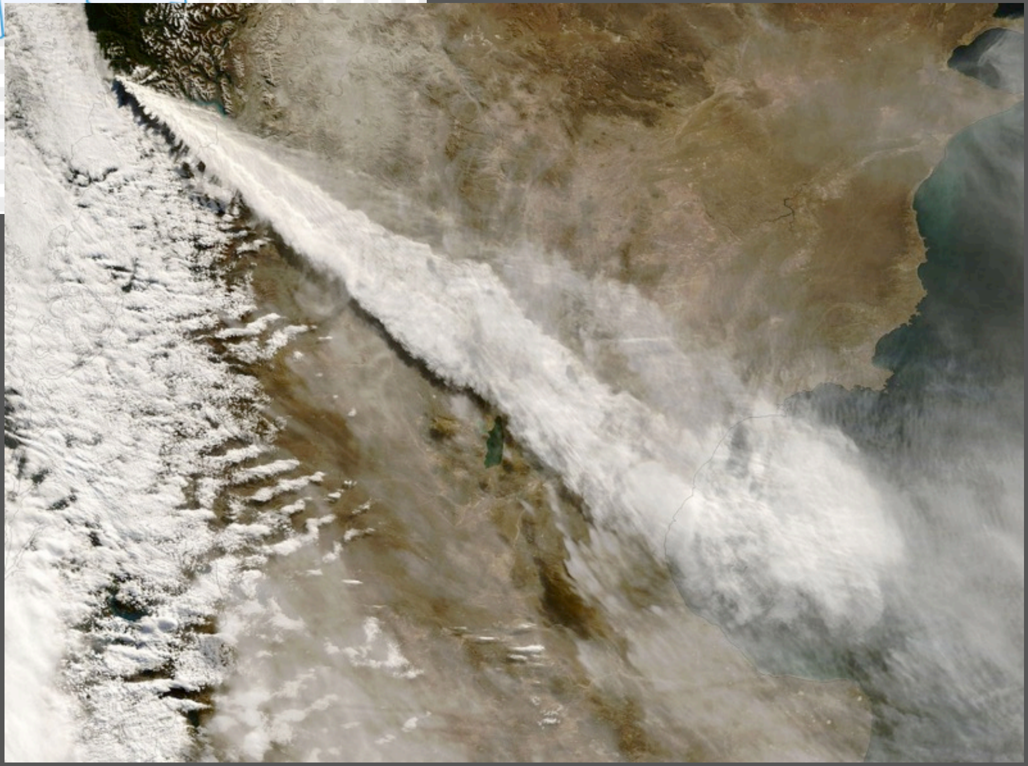
Surge Deposits

Flow Deposits

Fall Deposits







Fall Deposits

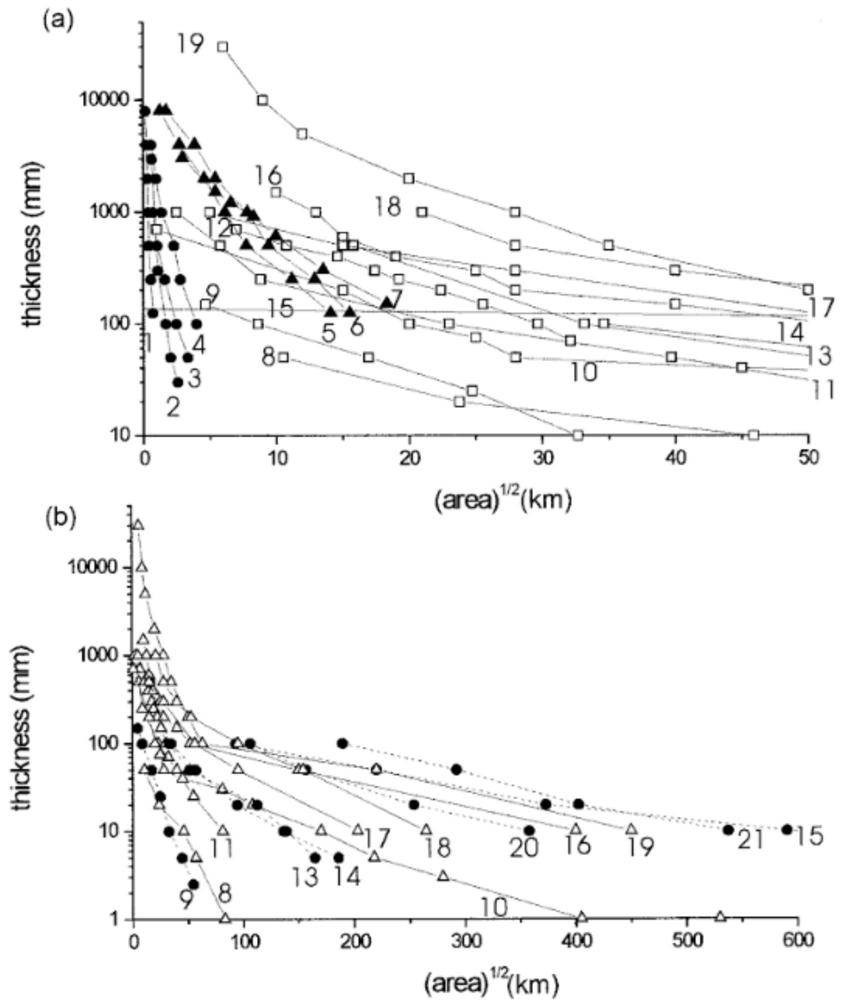


FIGURE 3 Plots of ln T versus $\sqrt{A}$. (a) Plot of proximal thinning relationships for representative hawaiian/strombolian (solid circles), subplinian (solid triangles), and plinian/phreatoplinian (open squares) tephras. (b) Similar plot at expanded scale for the plinian (open triangles; solid line) and phreatoplinian (solid circles; dashed line) units.

Fall Deposits

Fall Deposits

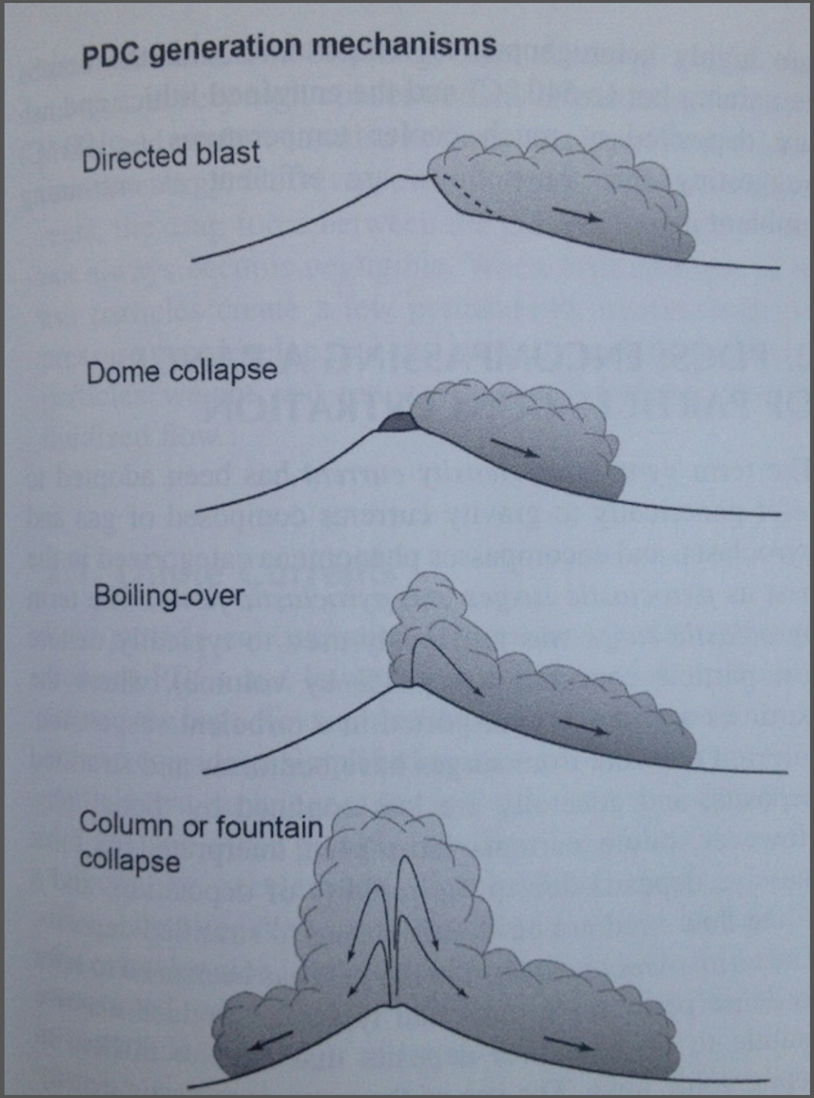
Fall Deposits

1 – Mantle topography
(just like snow)

2 – Individual deposits are well sorted

3 – Graded beds
(changing in wind direction, eruption intensity)

Plume Collapse and Pyroclastic Density Currents (PDCs)



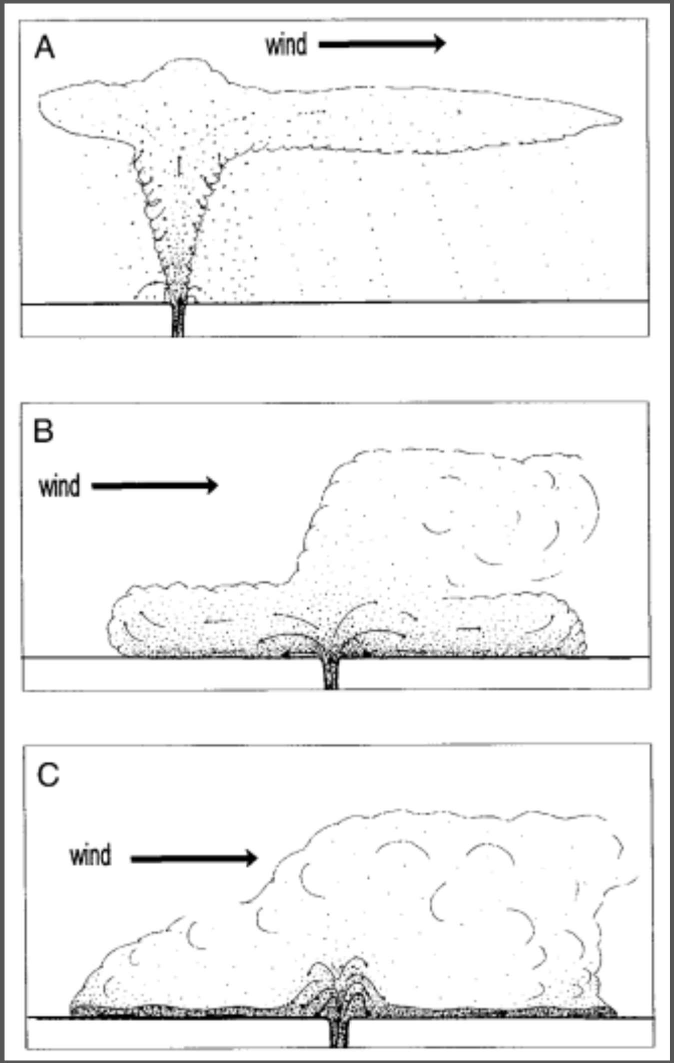
Small volume – postcaldera domes

Small volume – postcaldera domes

Low eruption rate

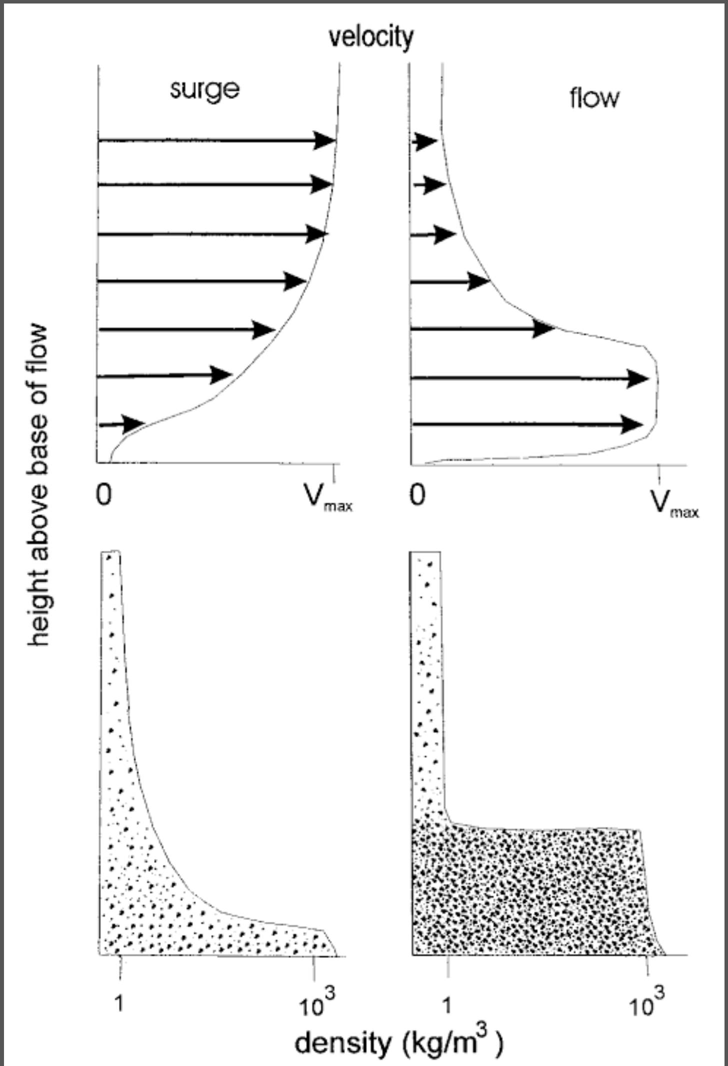
Most relevant to large calderas

Pyroclastic Density Currents (Surge and Flow)



surge

flow



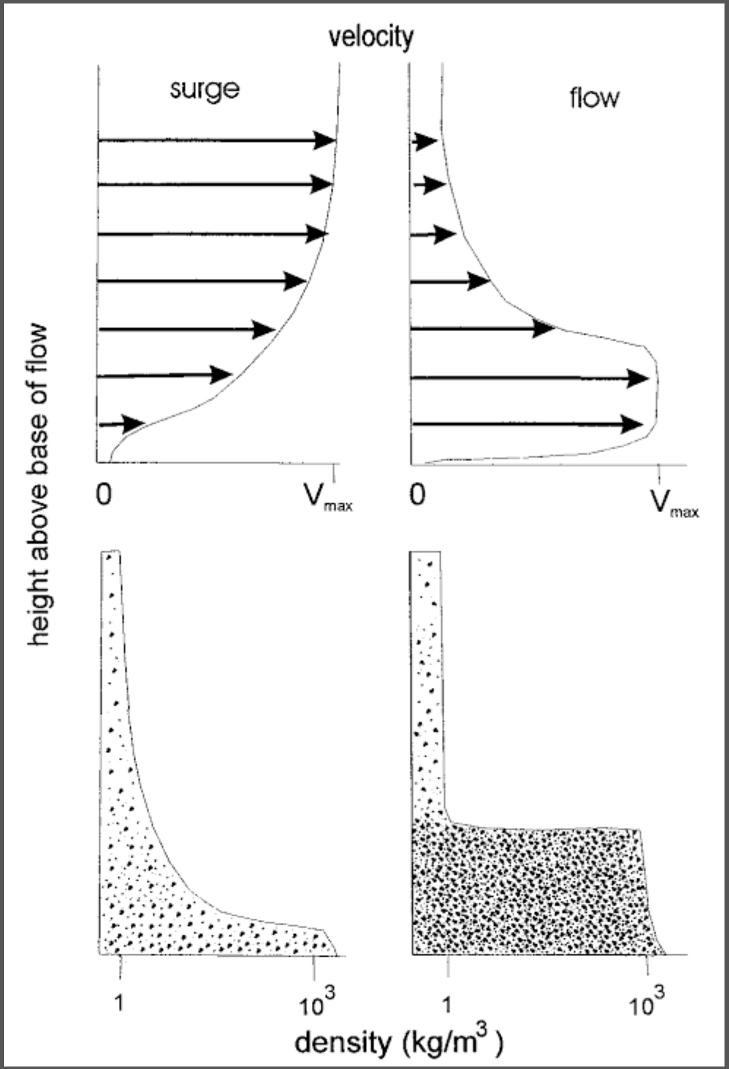
Pyroclastic Density Currents (Surge and Flow)

SURGE

- Dilute (gas >> particles)
- Turbulent Flow
- Small-volume

FLOW

- Concentrated (solids >> fluid)
- ~Laminar Flow
- Large-volume



Pyroclastic Surges

Cross-bedding

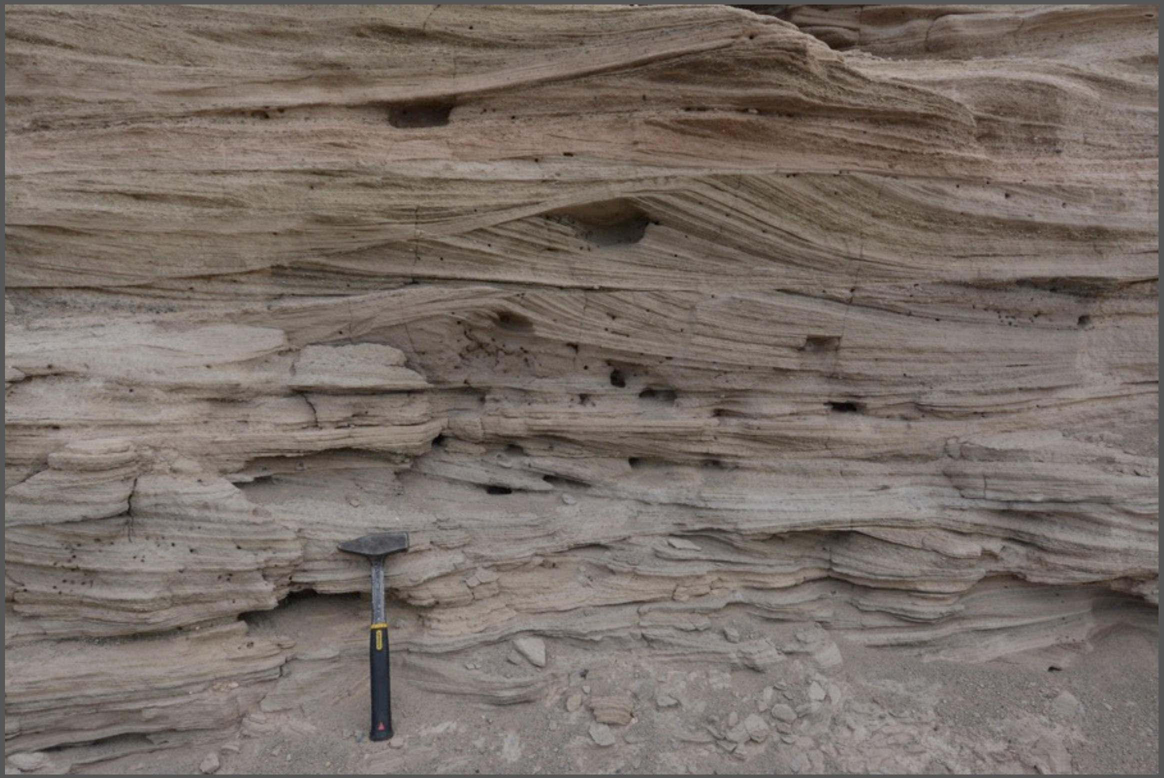
Dunes

Well to moderately sorted
(less than fall; more than flow)

Some grain size variation
(few fines and coarse material)

Thin to thick beds
(< 10 cm to several m)

Volumetrically Minor



Pyroclastic Surges

Pyroclastic flows (ignimbrite)

Pyroclastic flows (ignimbrite)

Bedded to Massive

Poorly sorted

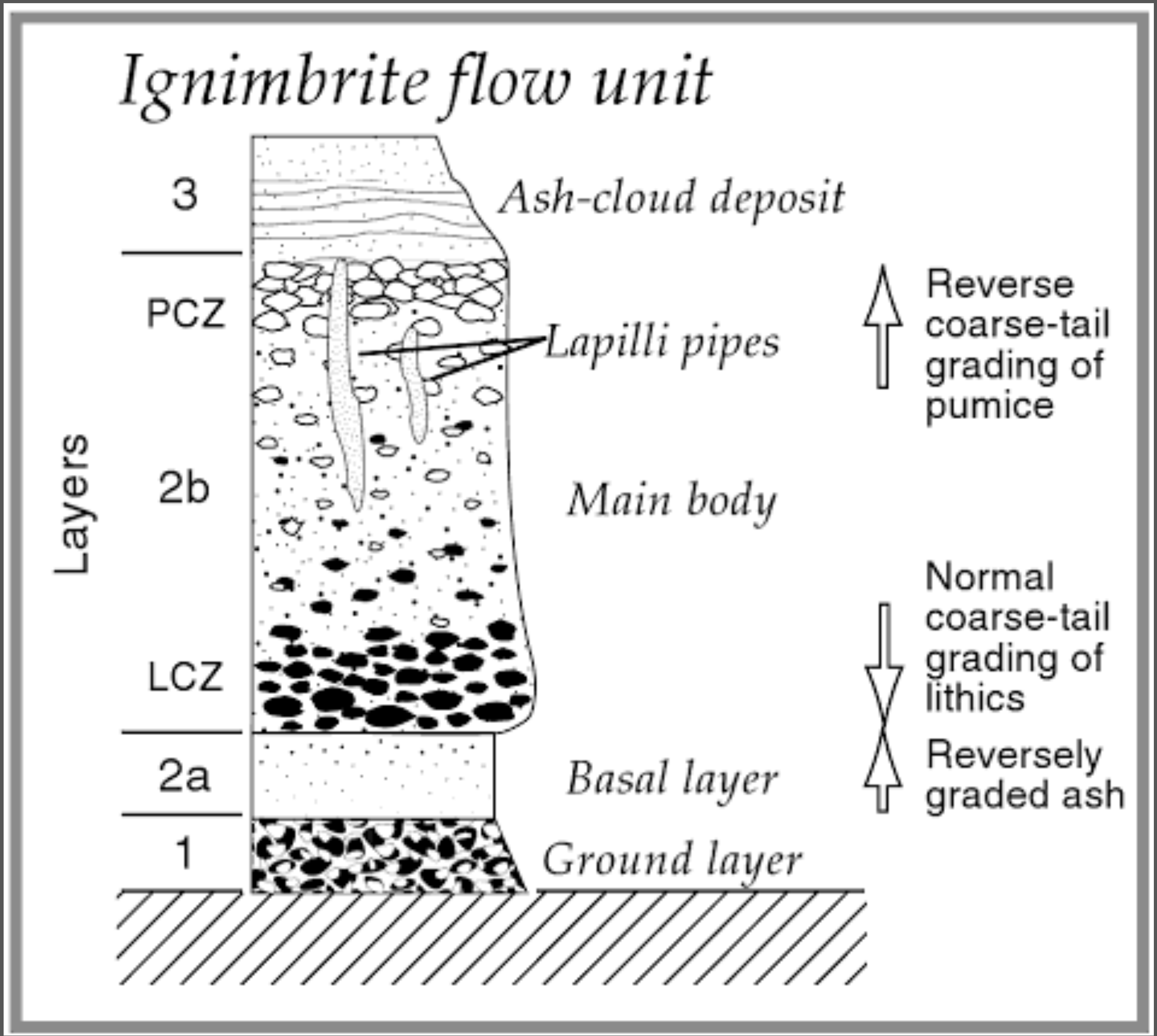
Graded

Large grain size distribution
(< 1 mm as to >>1 m blocks)

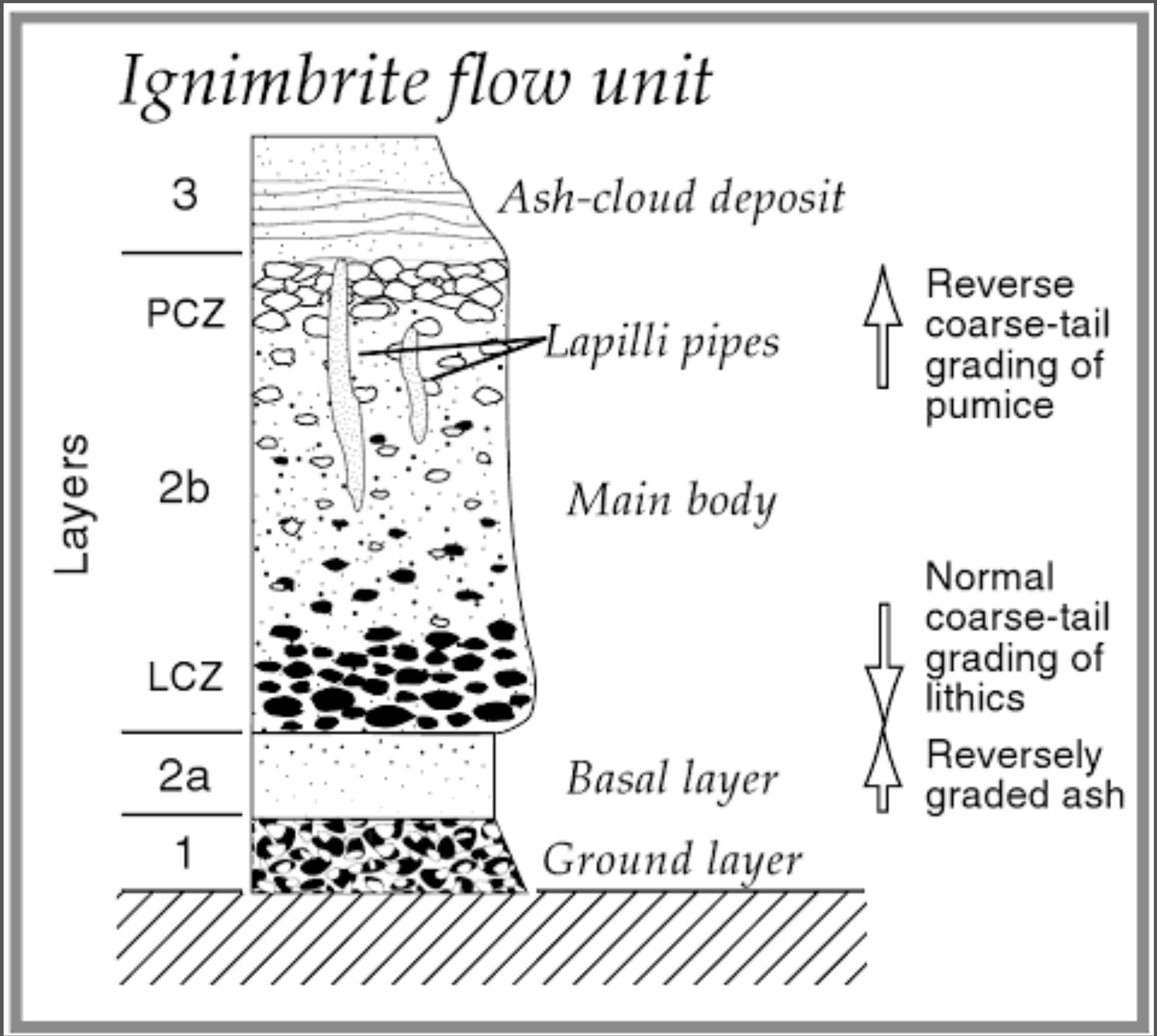
Emplaced into topographic lows
“flows follows lows”


GSA
CM
IN

Ignimbrite Stratigraphy



Ignimbrite Stratigraphy



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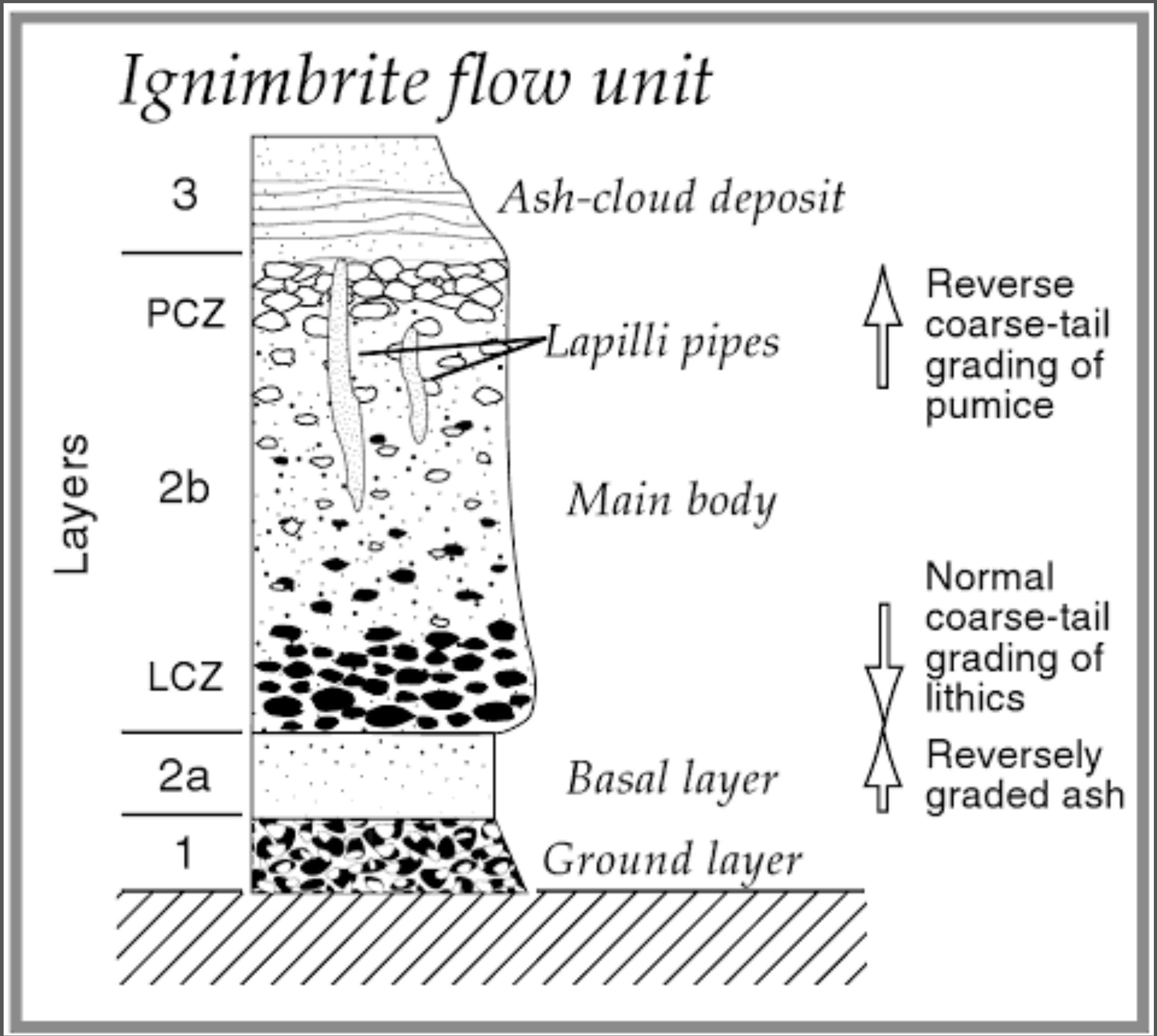
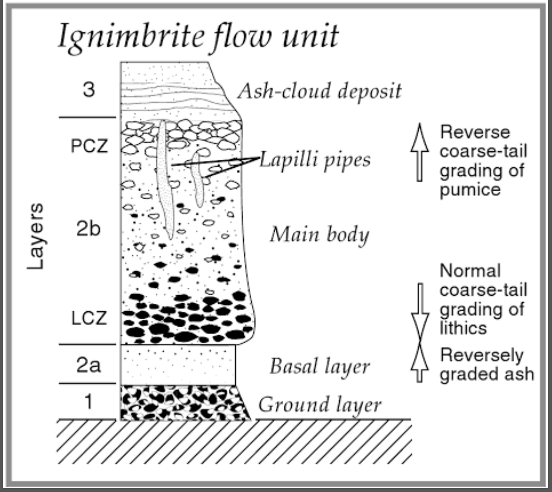


Layer 2b –

Graded
(lithics on sink
and pumice floats)

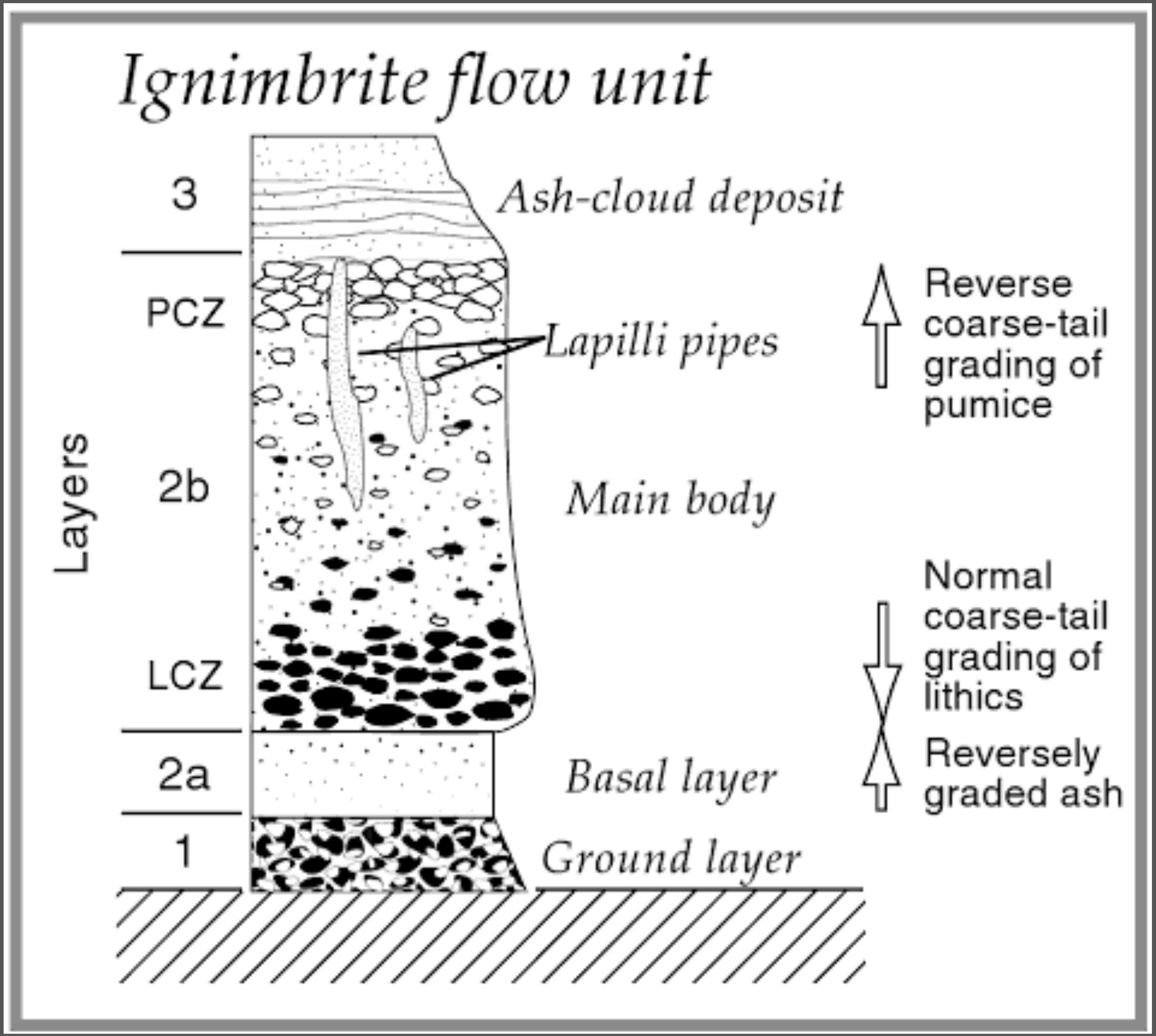
Ignimbrite Stratigraphy



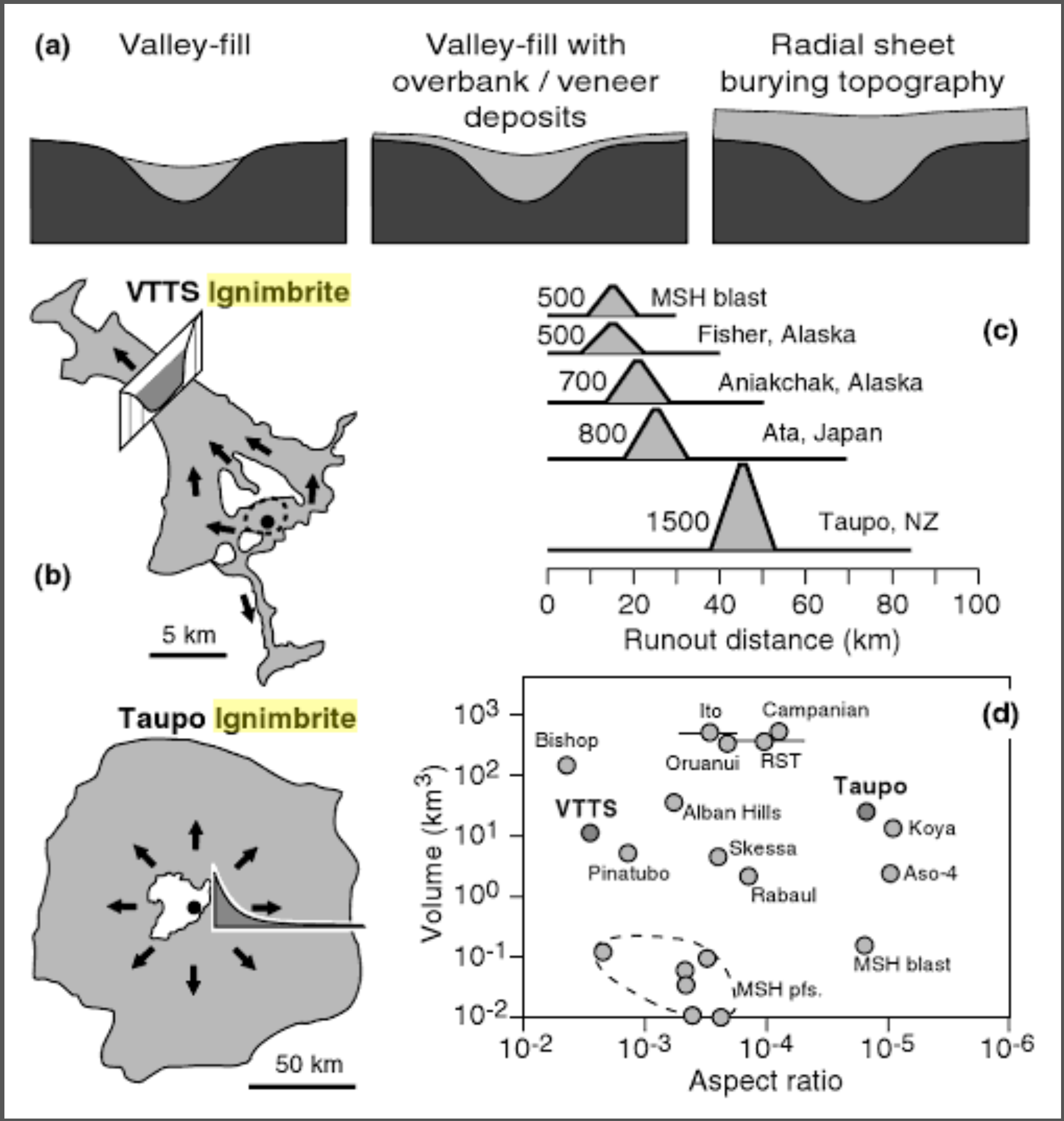
Lithics “sink”

Pumice “floats”

Ignimbrite Stratigraphy



Ignimbrite Distribution



Welding of Ignimbrites

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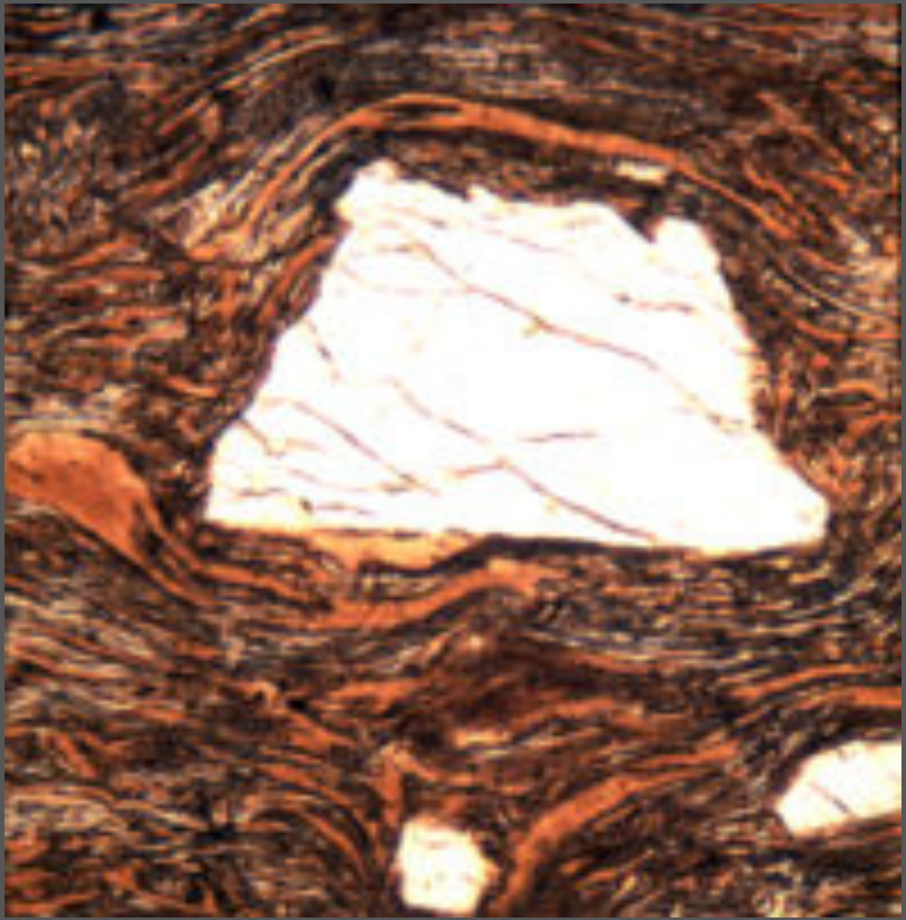

Rheomorphic flow of ignimbrite

Ductile flow after emplacement

Welding and Devitrication Zones within Ignimbrites