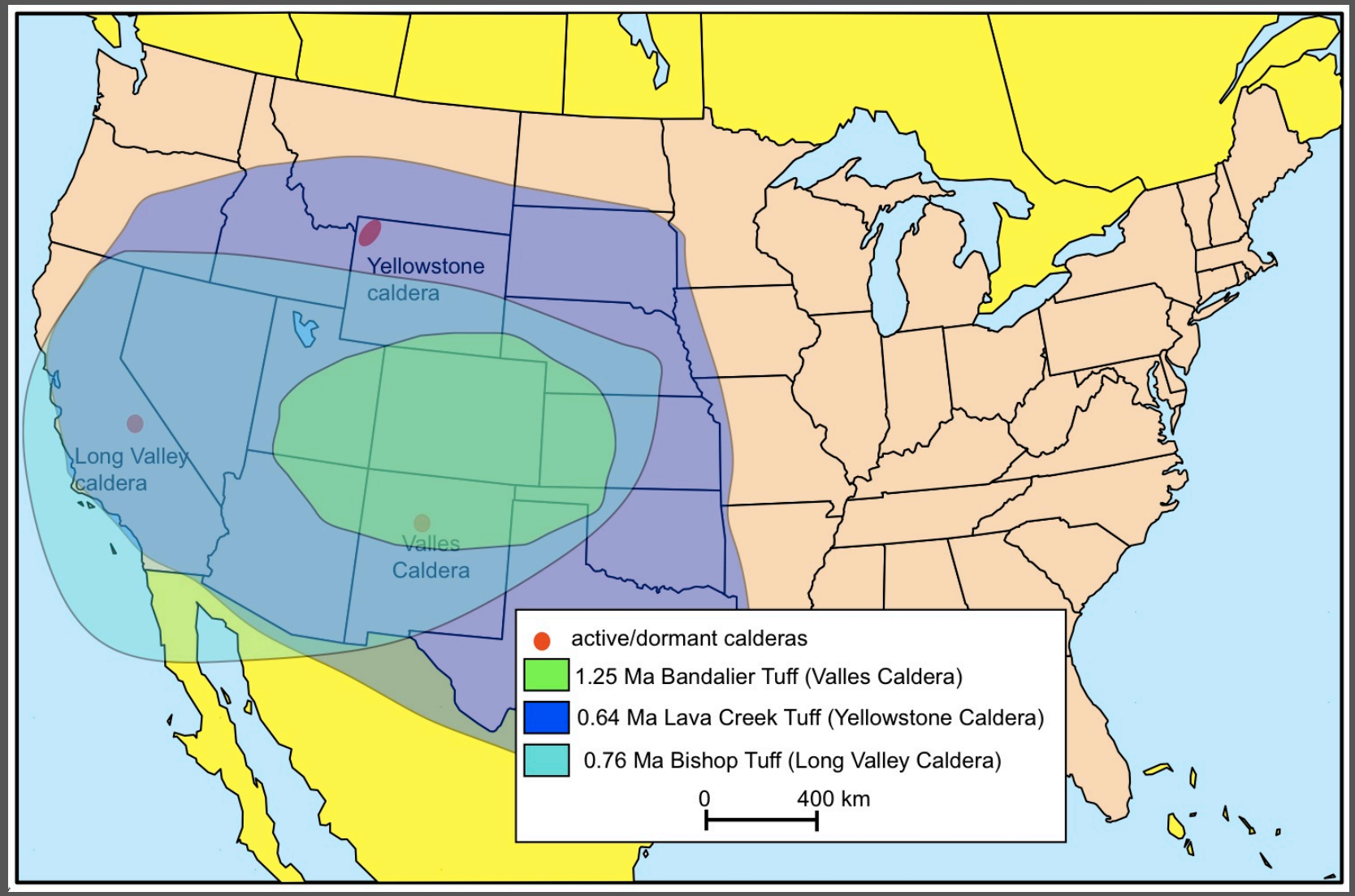
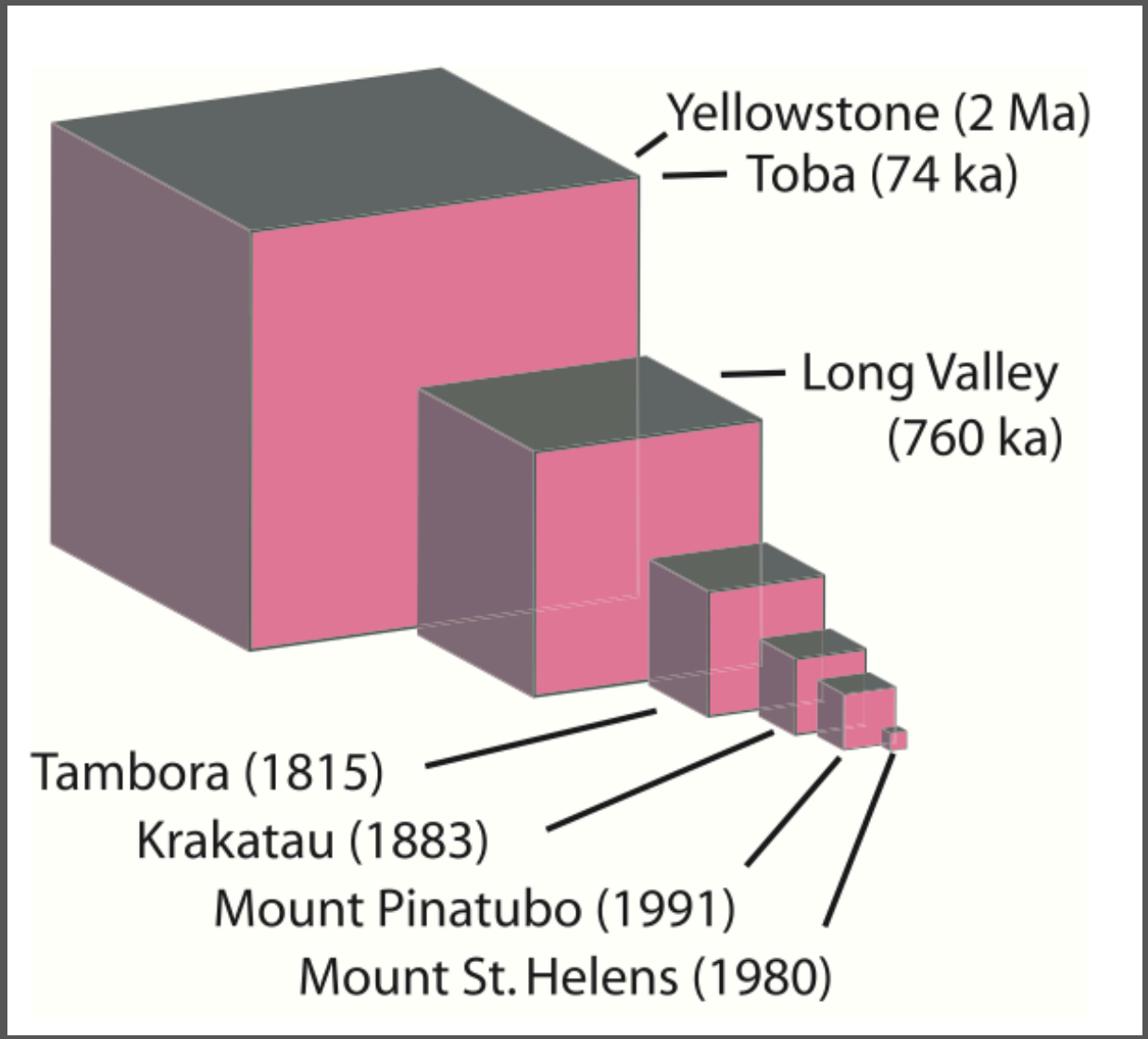
AN INTRODUCTION TO CALDERAS

Matthew Zimmerer – matthew.zimmerer@nmt.edu - Bureau 329

Caldera hazards

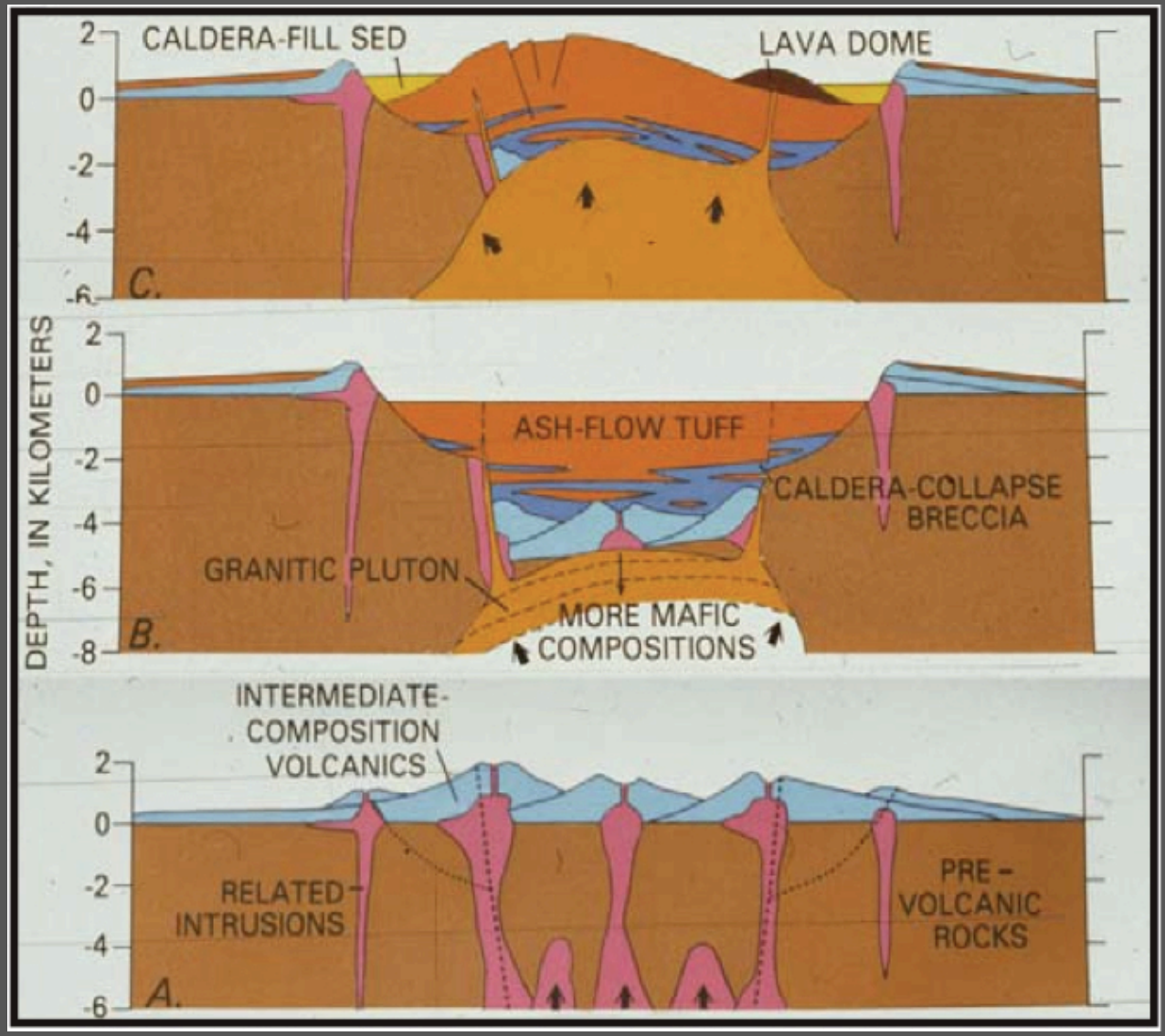


Modified from Goff, 2010


Yellowstone (2 Ma)
Toba (74 ka)
Long Valley
(760 ka)
Tambora (1815)
Krakatau (1883)
Mount Pinatubo (1991)
Mount St. Helens (1980)

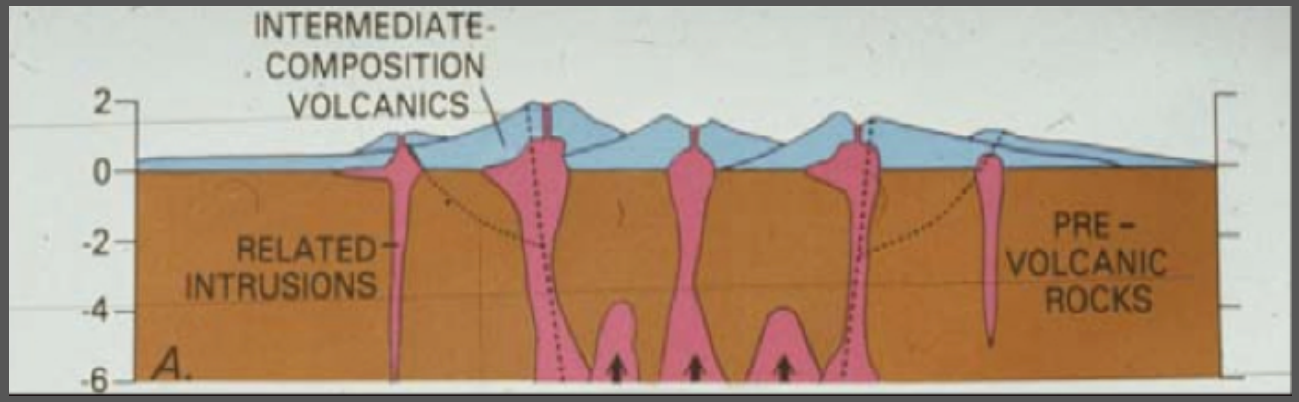
Geothermal Energy and Ore Deposits

Caldera 101

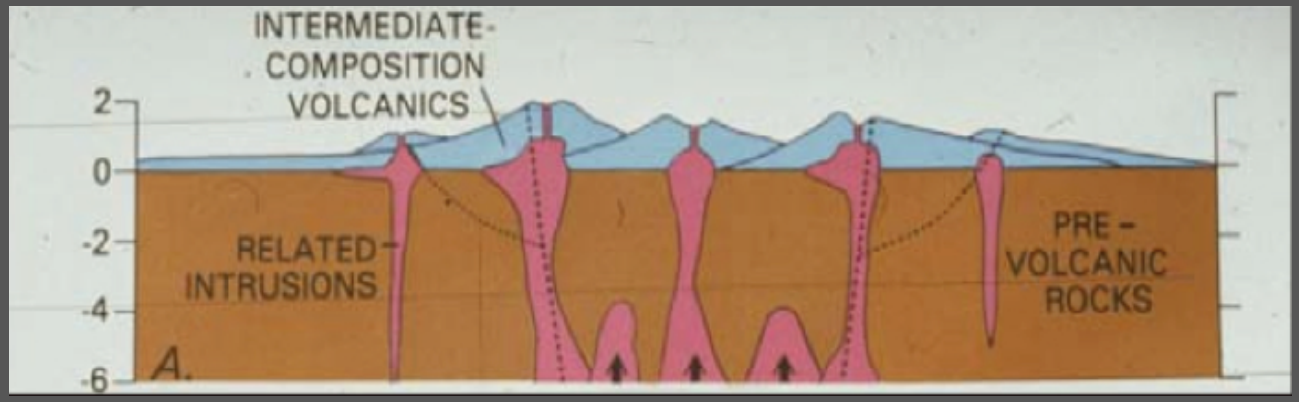


Lipman et al., 1978

Precaldera Volcanism (waxing magmatism)



Precaldera Volcanism (waxing magmatism)

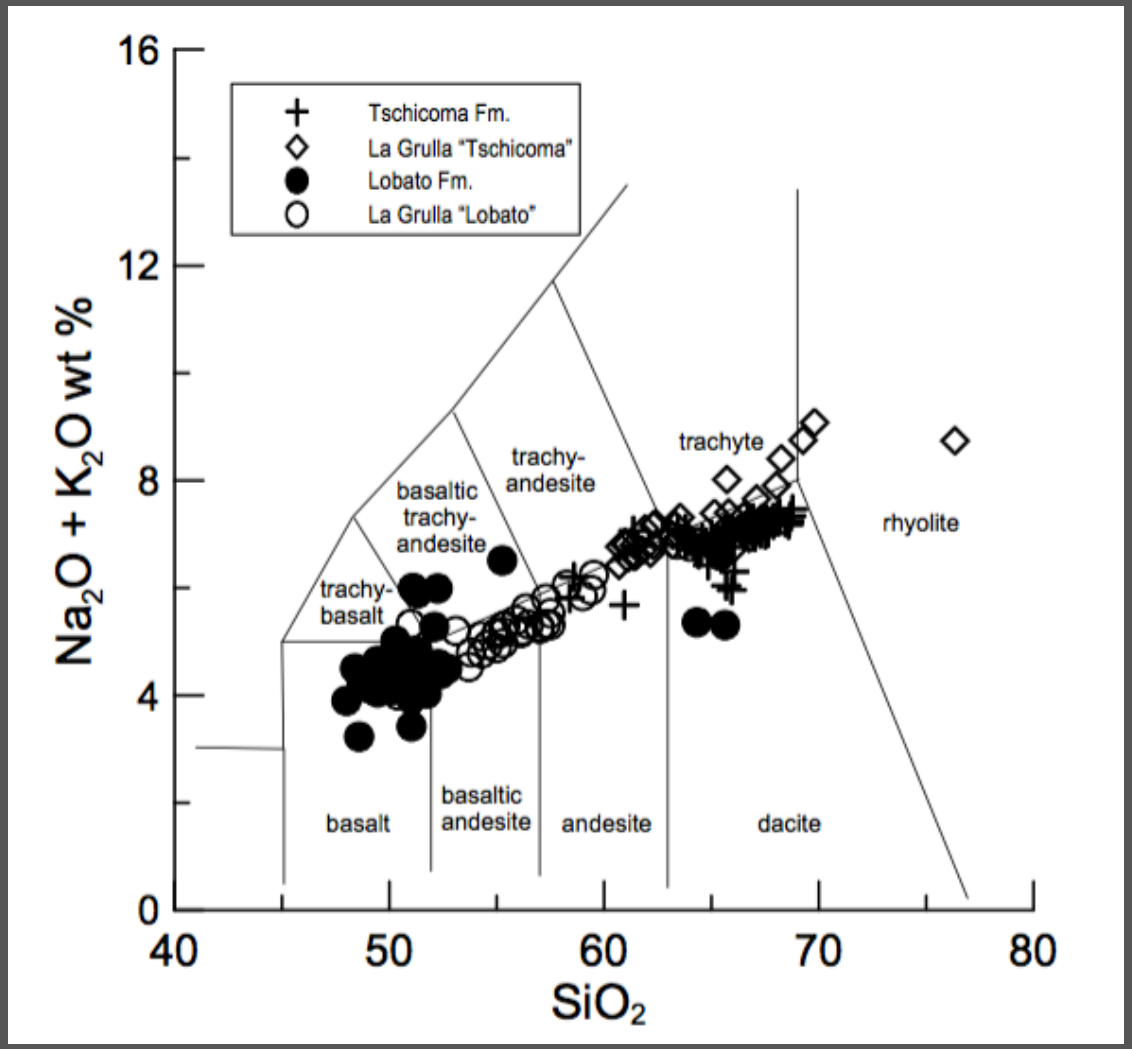


1) Numerous eruptions

2) Duration is 10^4 to greater than 10^6 yrs

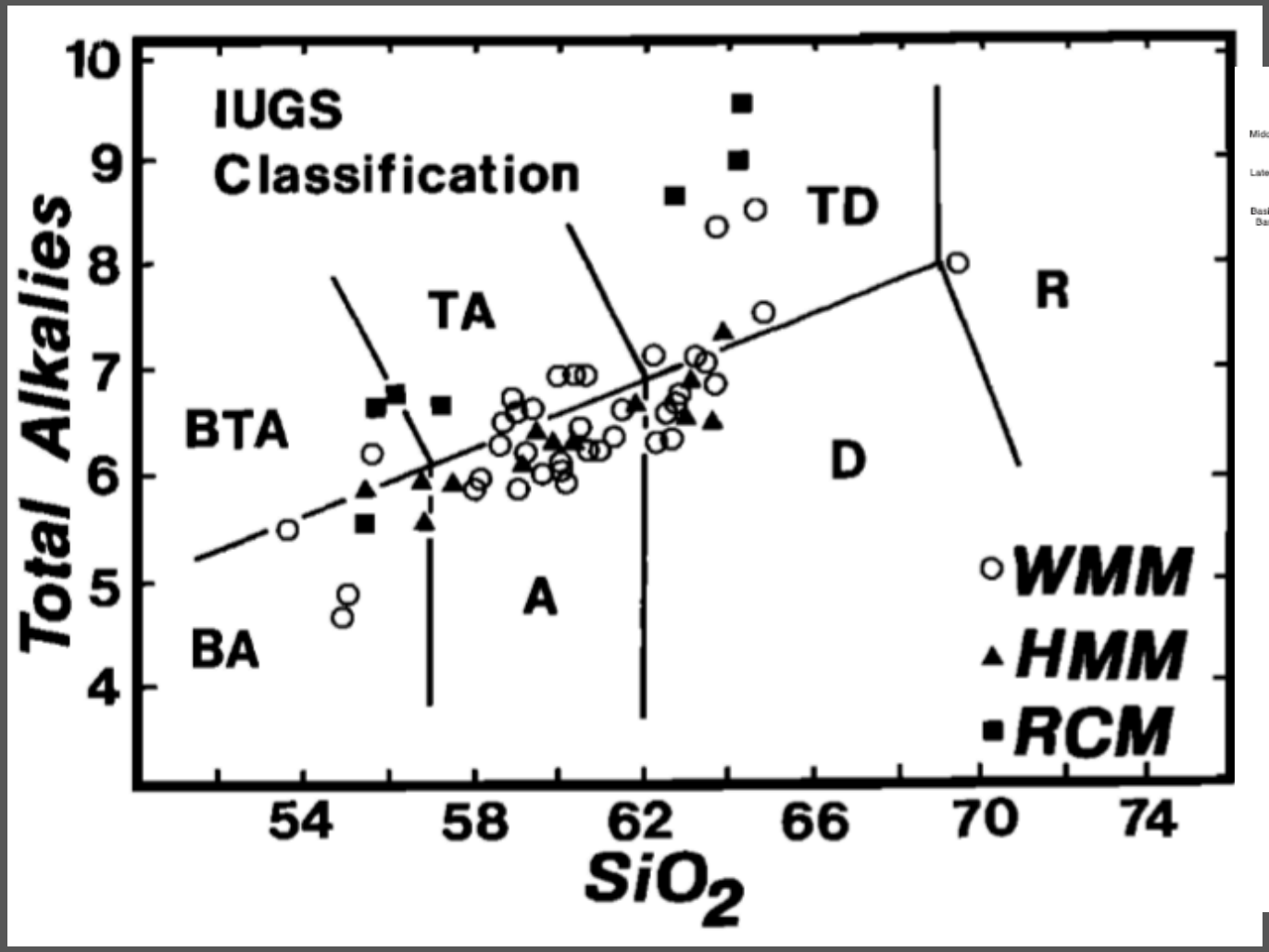
3) Compositionally diverse
(rhyolite to basalt; dominantly andesite and dacite)

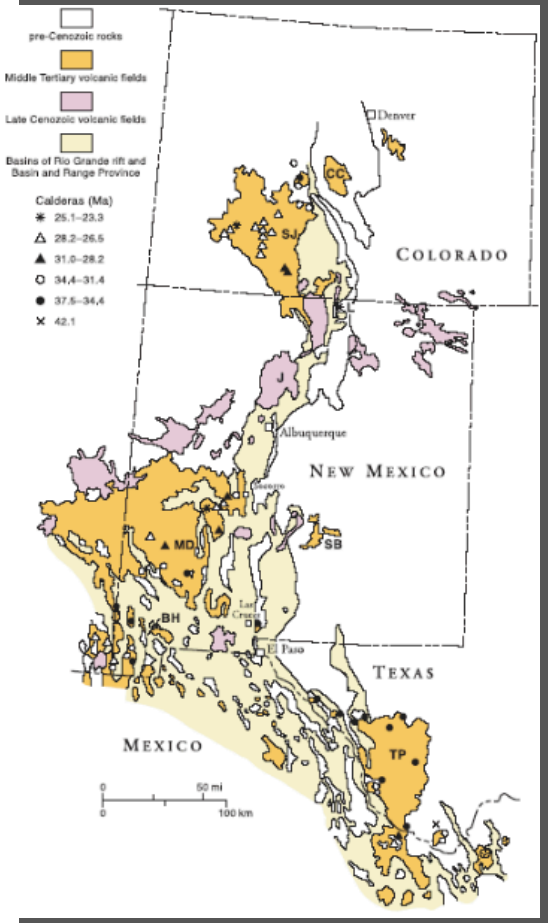
Precaldera Volcanism (waxing magmatism)



Precaldera geochemistry from Valles caldera

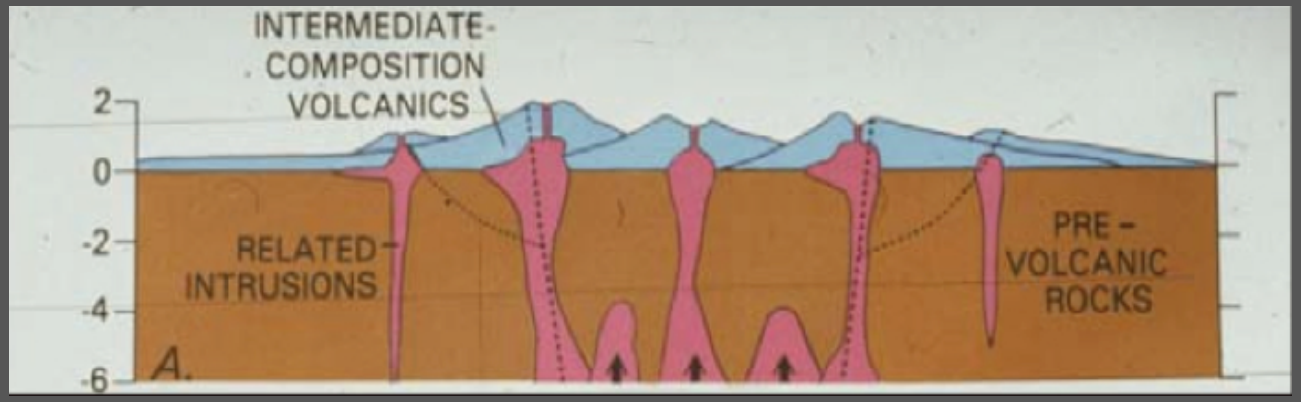
Precaldera Volcanism (waxing magmatism)





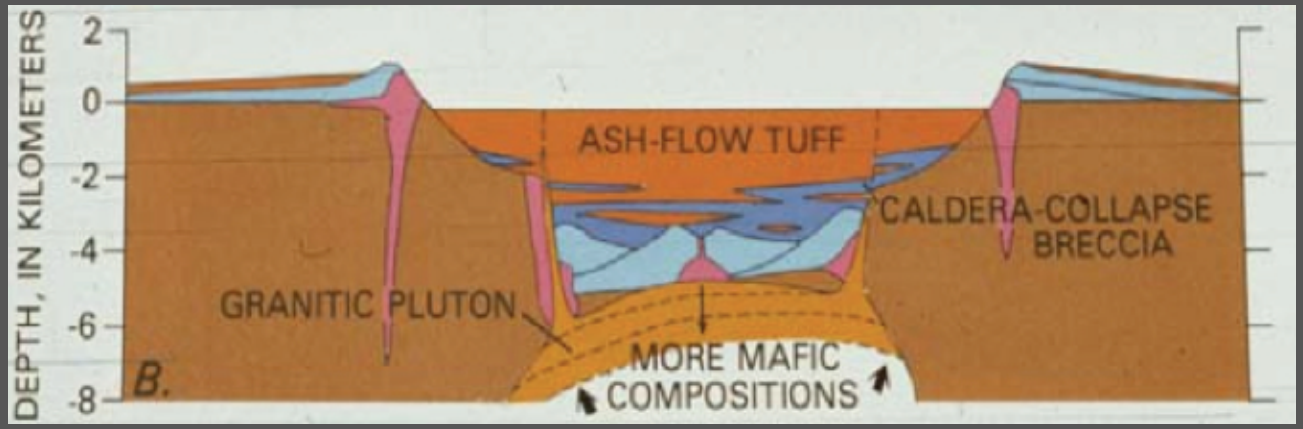
Precaldera geochemistry from San Juan VF

Precaldera Volcanism



Tengger Caldera

Caldera Formation – peak magmatic output

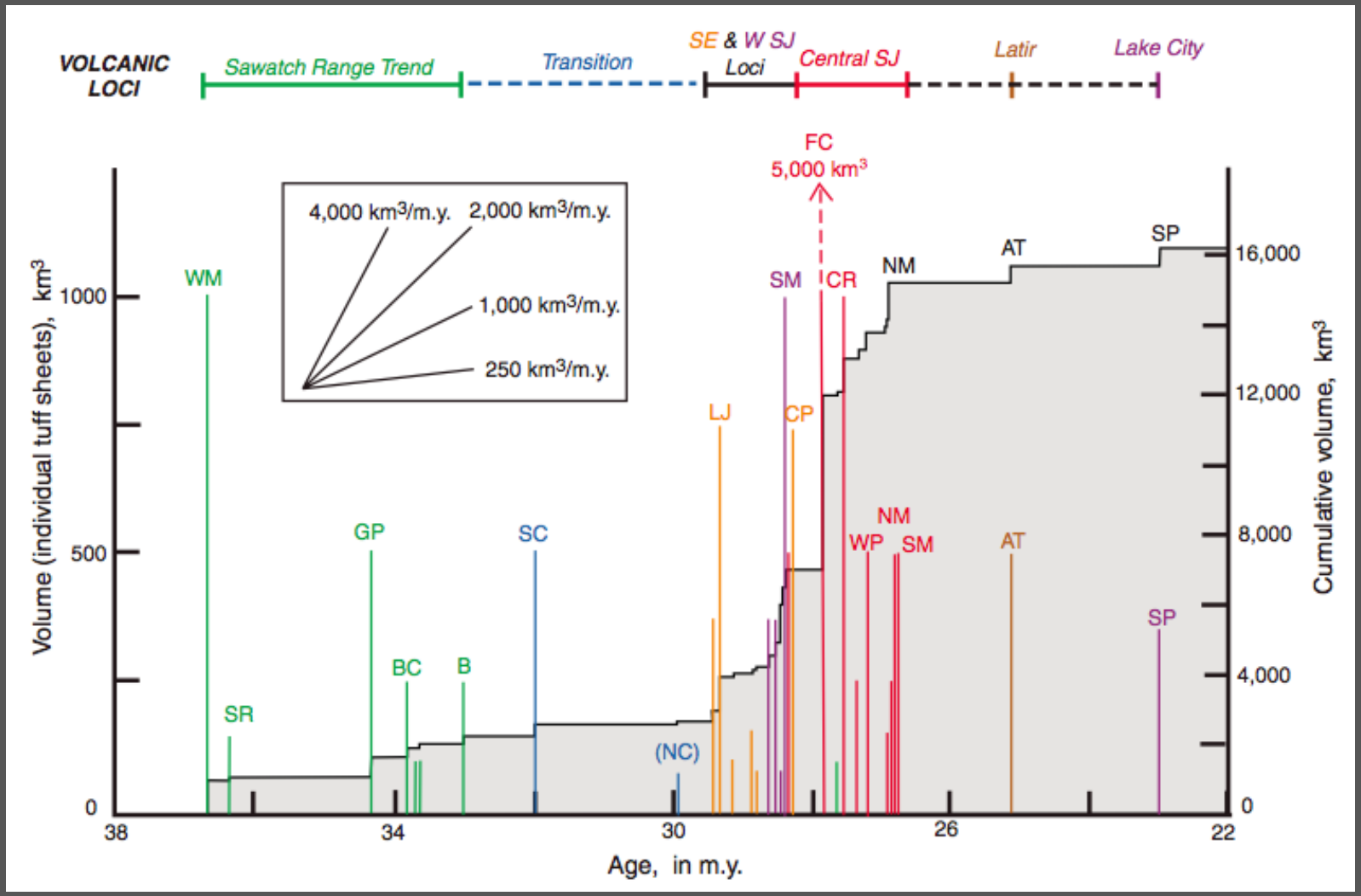


1) Eruptive duration – days to months (maybe yrs?)

2) 10s km^3 to 1000s km^3

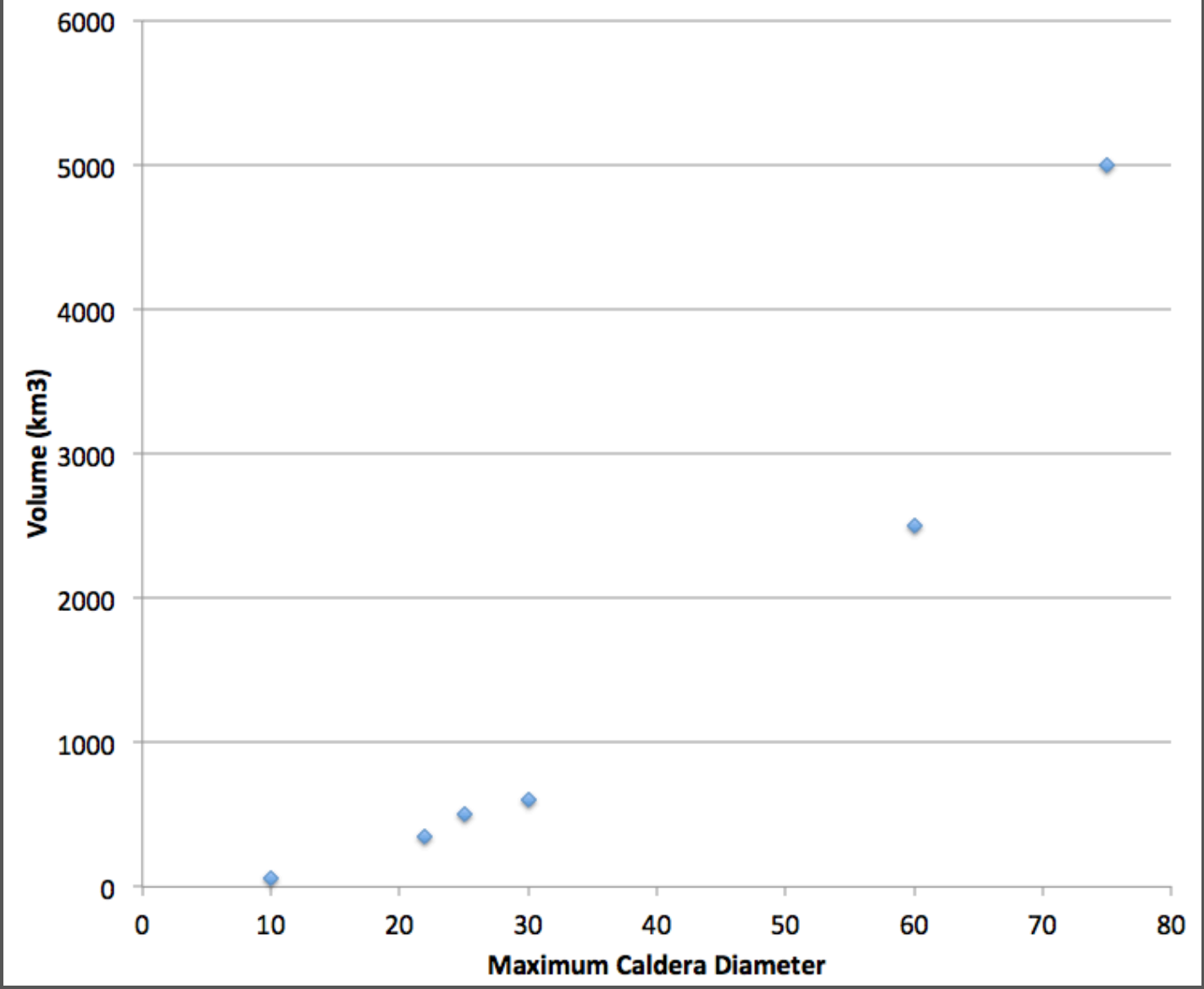
3) Rhyolite to Dacite (zoned vs. monotonous)

Volume of caldera forming ignimbrite

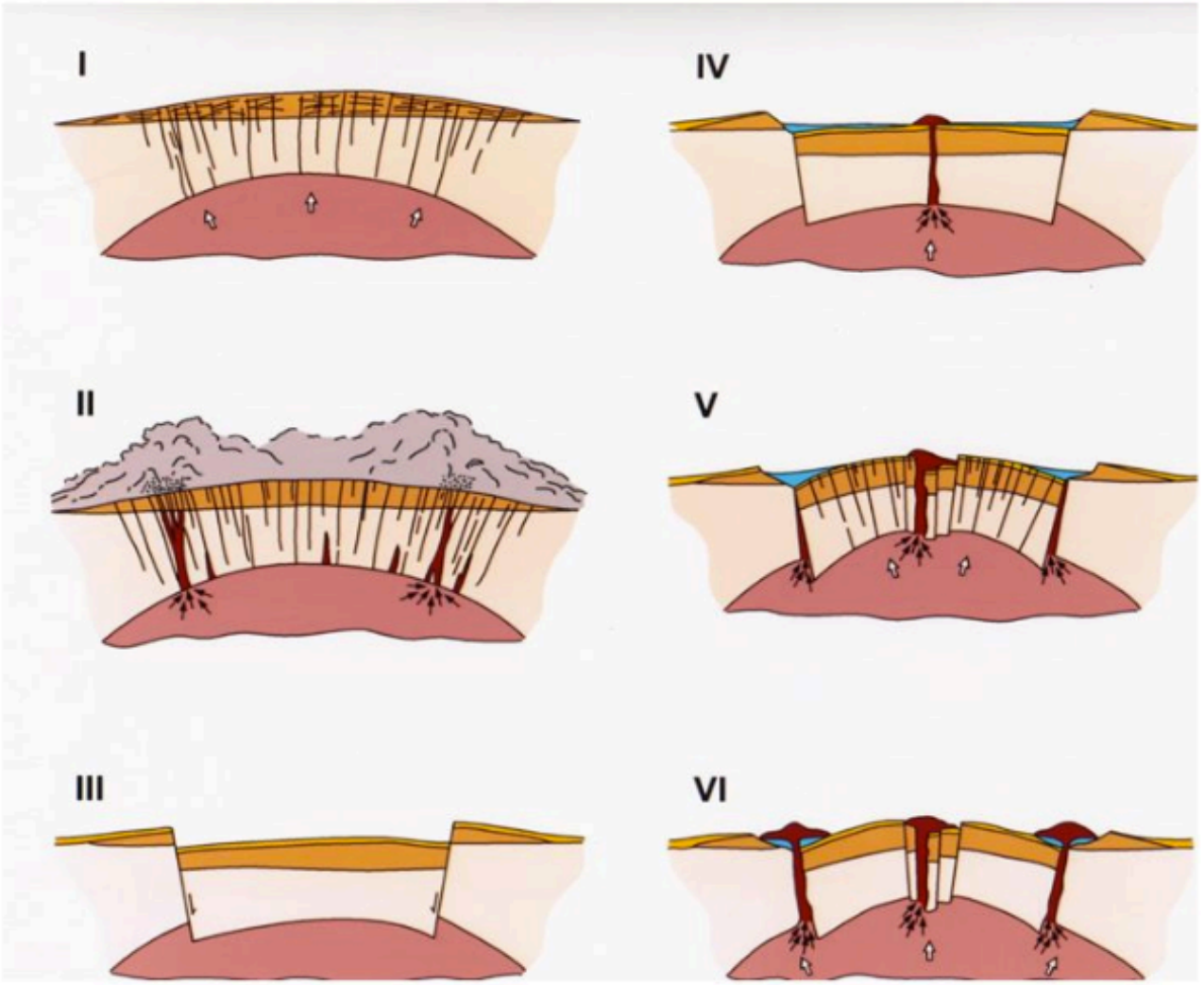


Volume range from 10s to 1000s of km^3

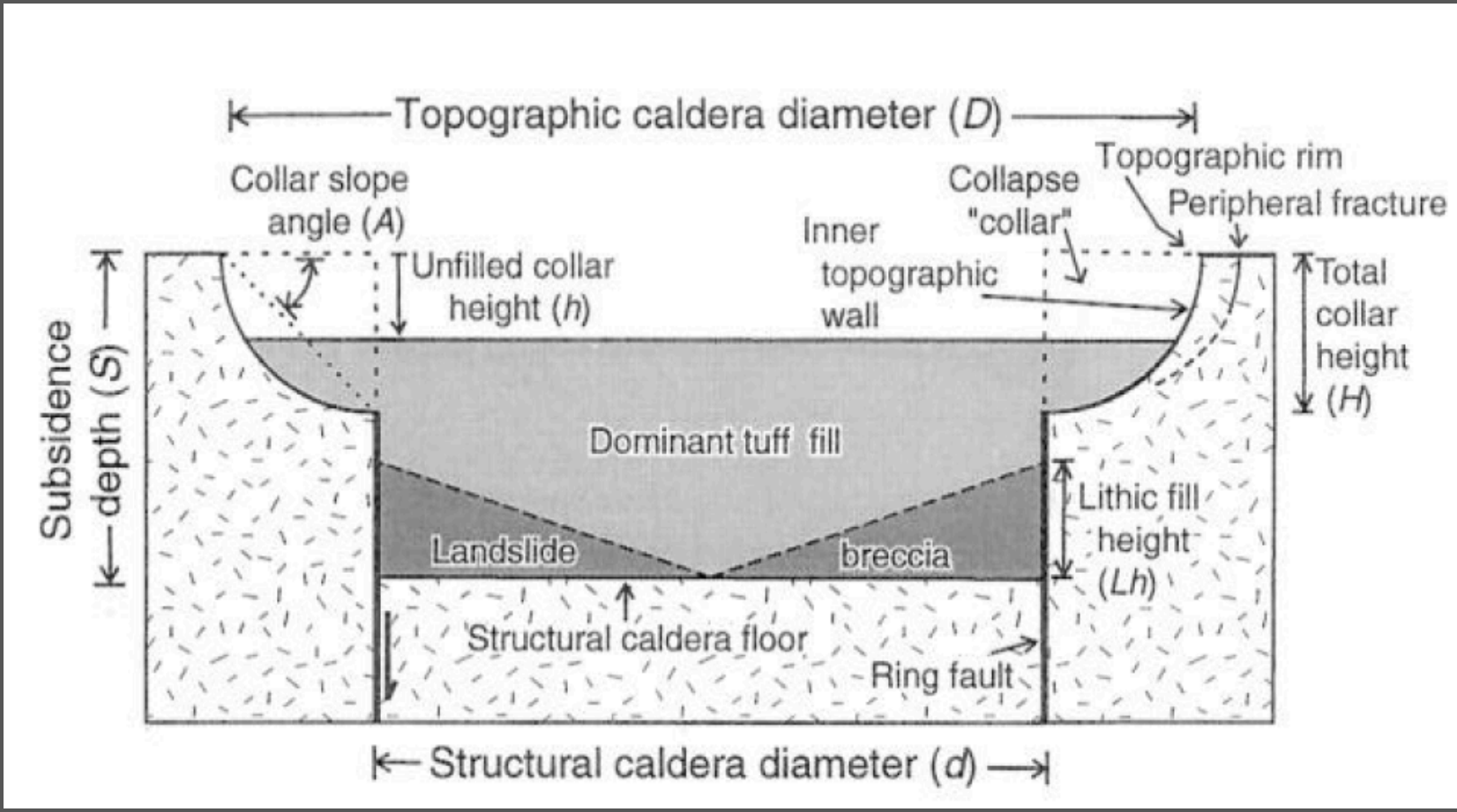
Volume erupted vs. Caldera diameter



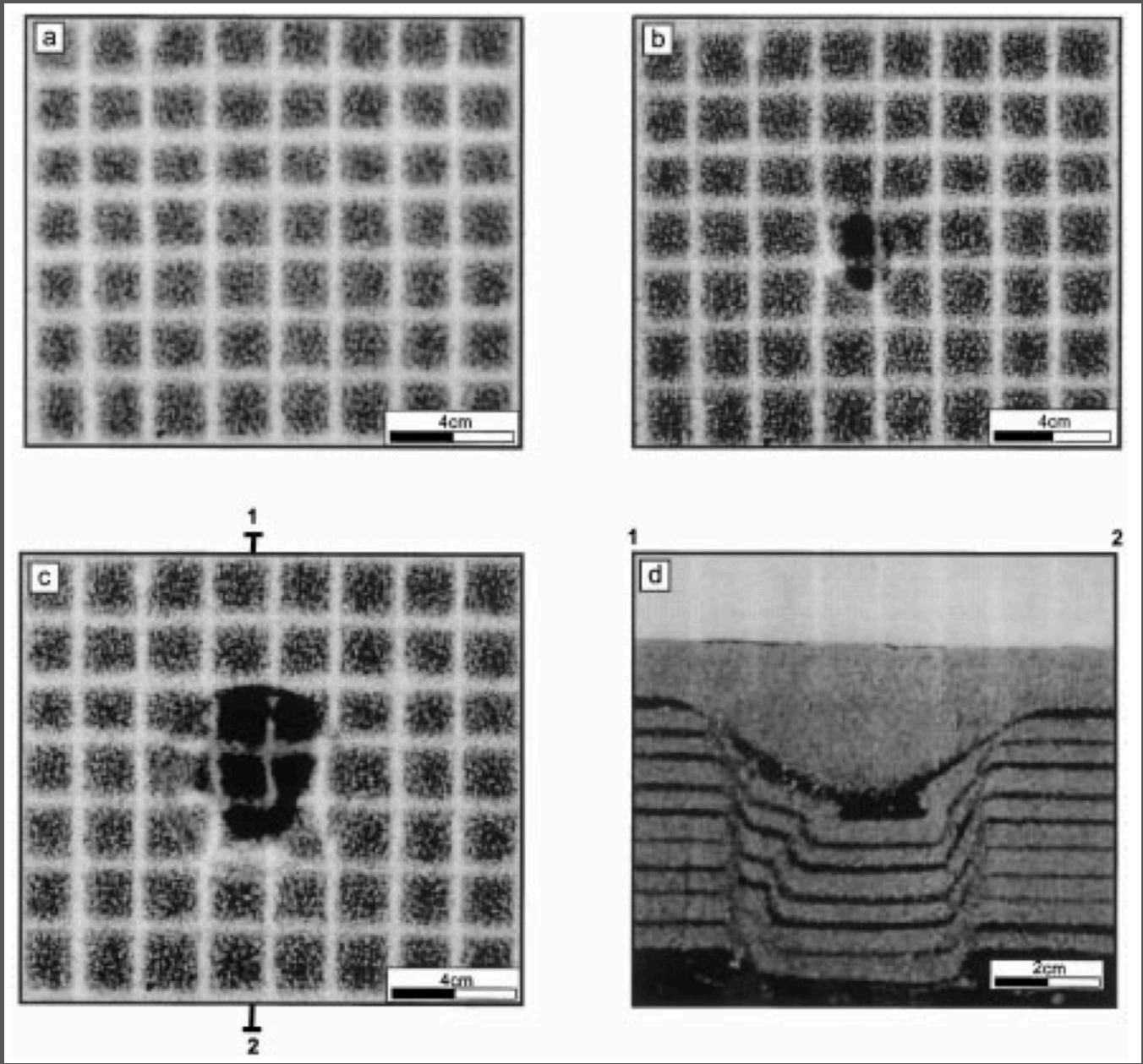
Smith and Bailey's caldera cycle



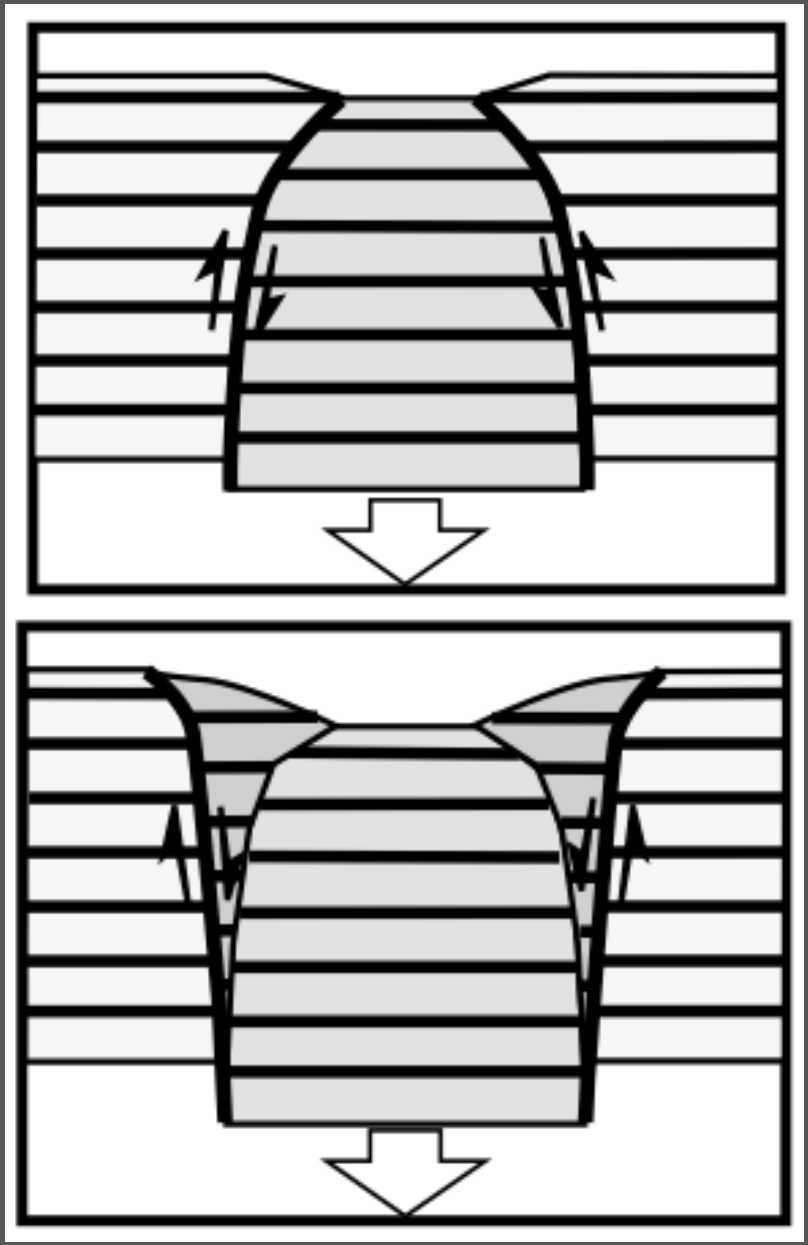
Caldera geometry



Ring Faults



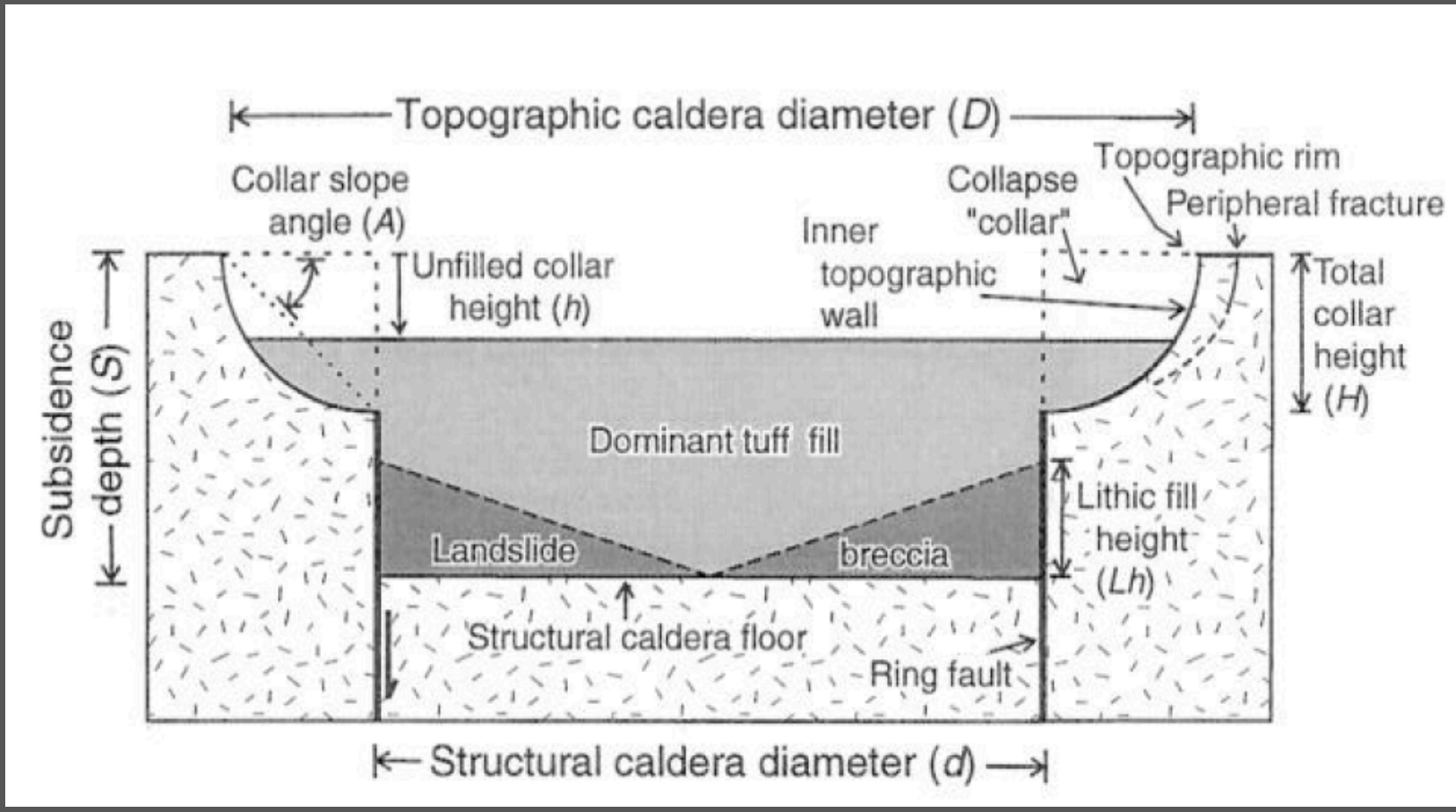
Ring Faults



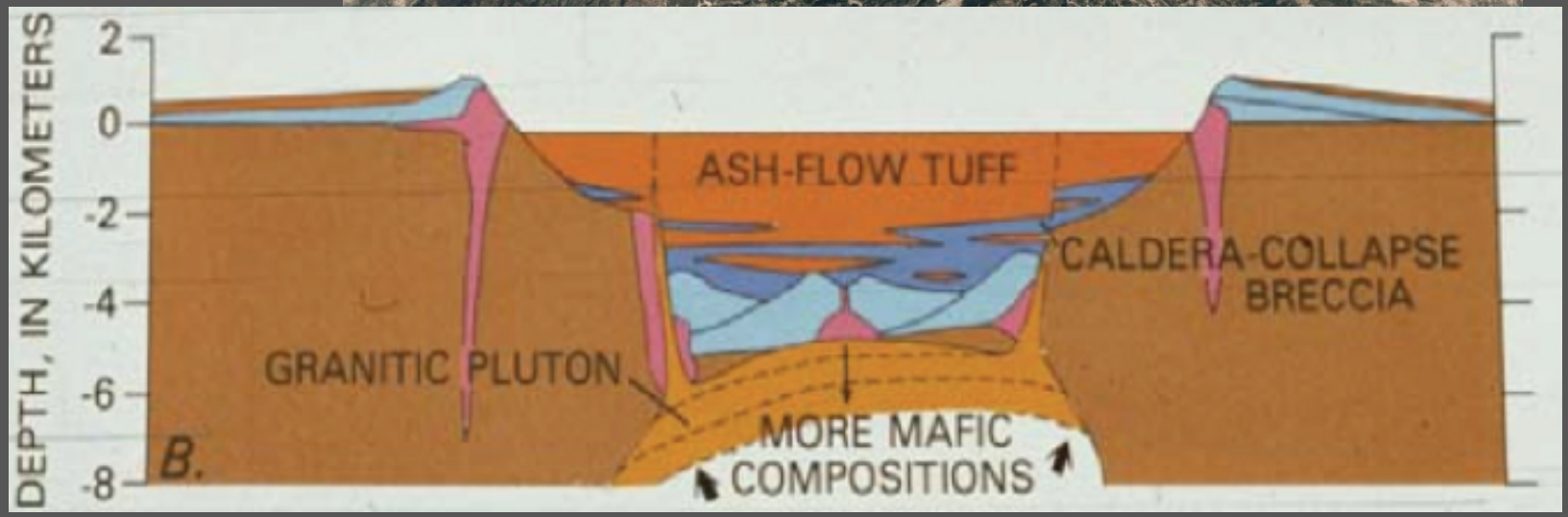
Early Stage – Reverse Faults

Late Stage – Normal Faults

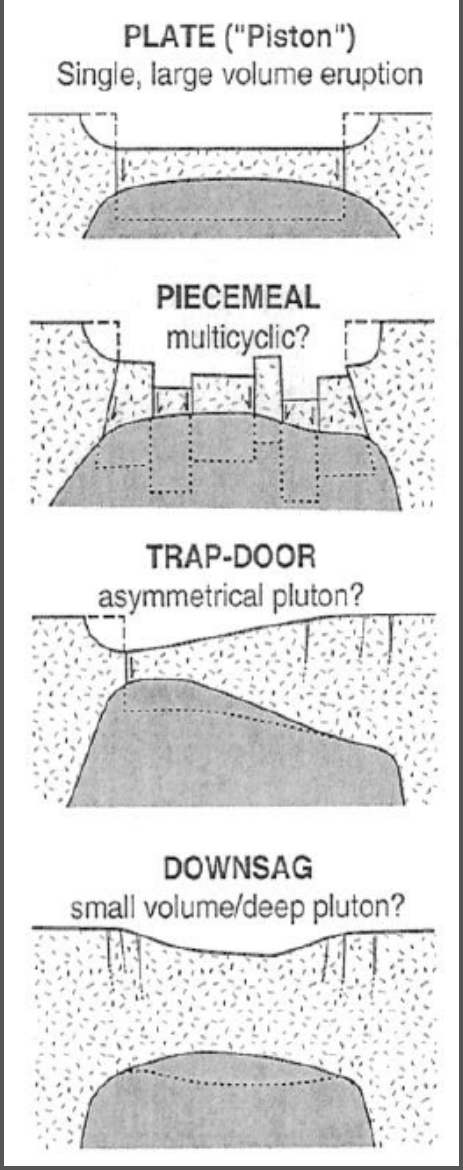
Caldera geometry



Diameter of Topographic rim > Diameter of structural margin


DEPTH, IN KILOMETERS
2
0
-2
-4
-6
-8
ASH-FLOW TUFF
CALDERA-COLLAPSE BRECCIA
GRANITIC PLUTON
MORE MAFIC COMPOSITIONS
B.

Collapse Styles



Different collapse styles a function of:

1) Roof geometry of caldera-forming magma chamber

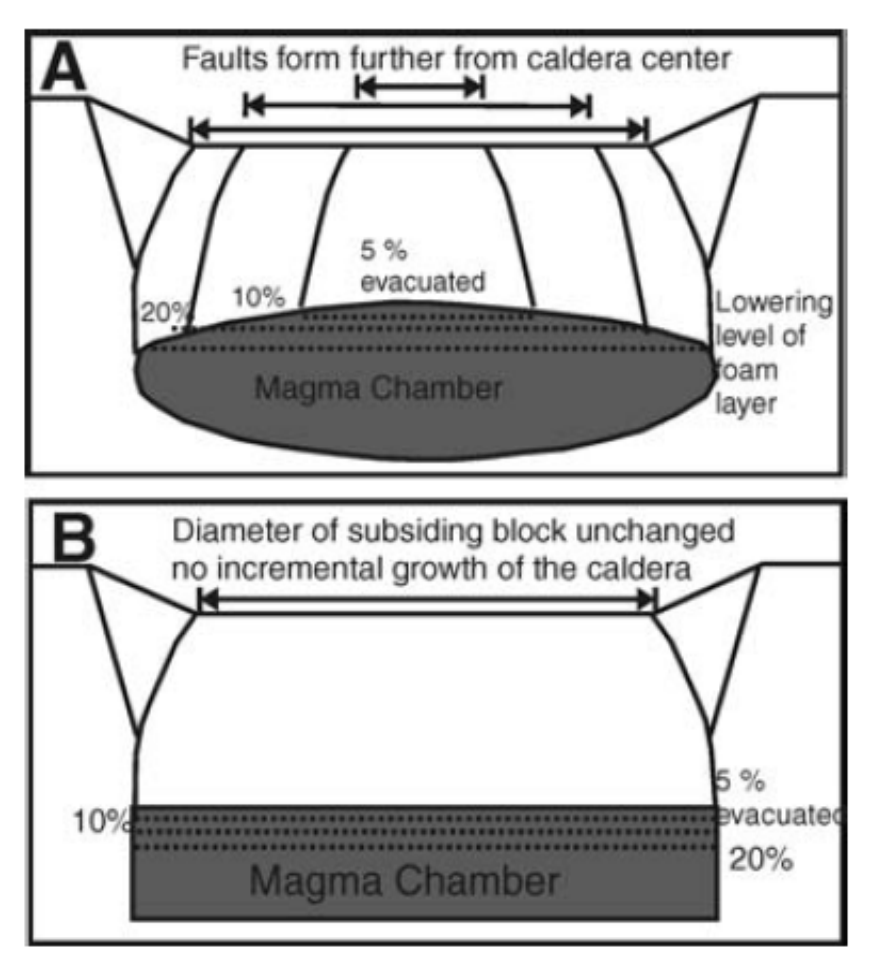
2) Depth of magma chamber

3) Timing of collapse during caldera-forming eruption

4) Number of caldera cycles

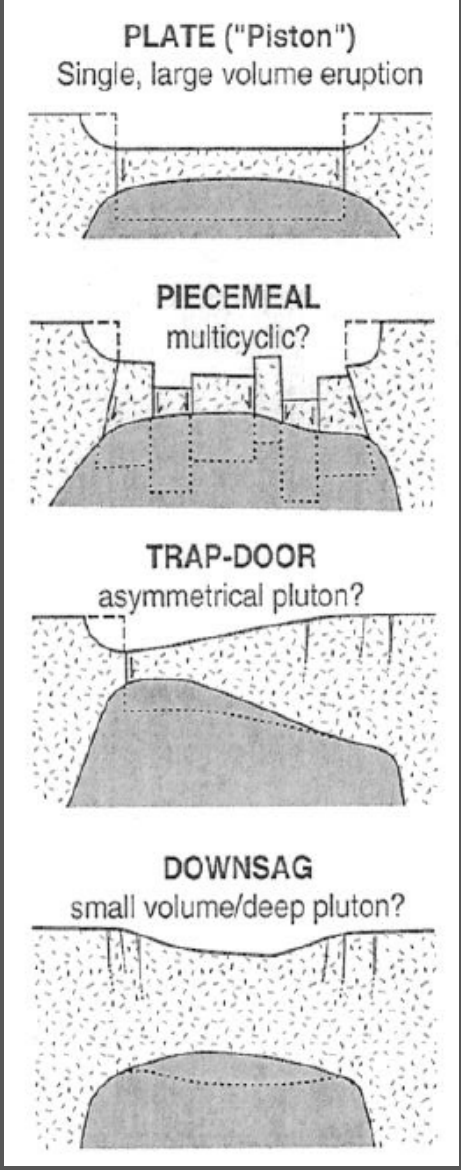
5) Tectonics and Lithologic controls

Influence of chamber shape



From Roche et al 2000, Kennedy et al 2004, GSA Bull

Collapse Styles



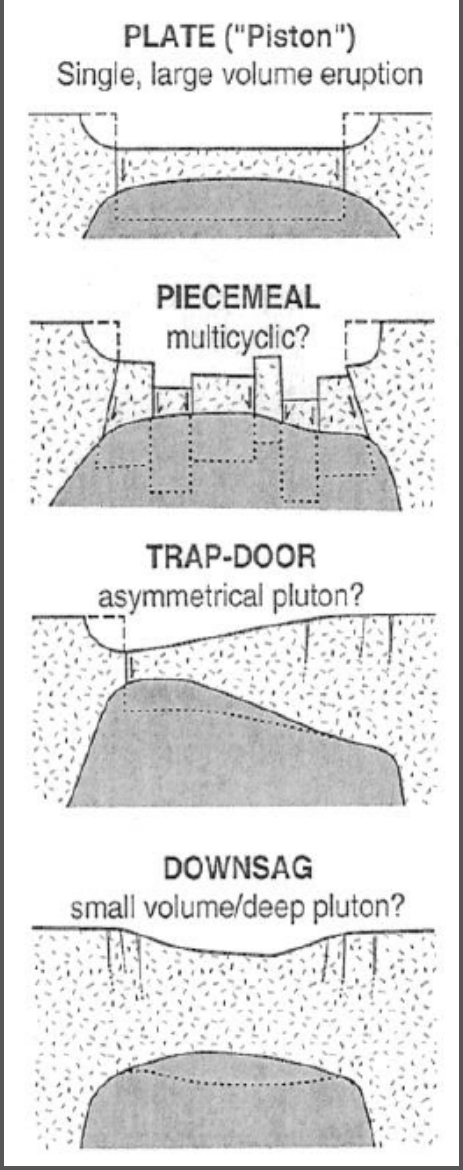
Plate

1) Oversimplified

2) A single, ring fault

3) Near uniform thickness of intracaldera tuff

Collapse Styles



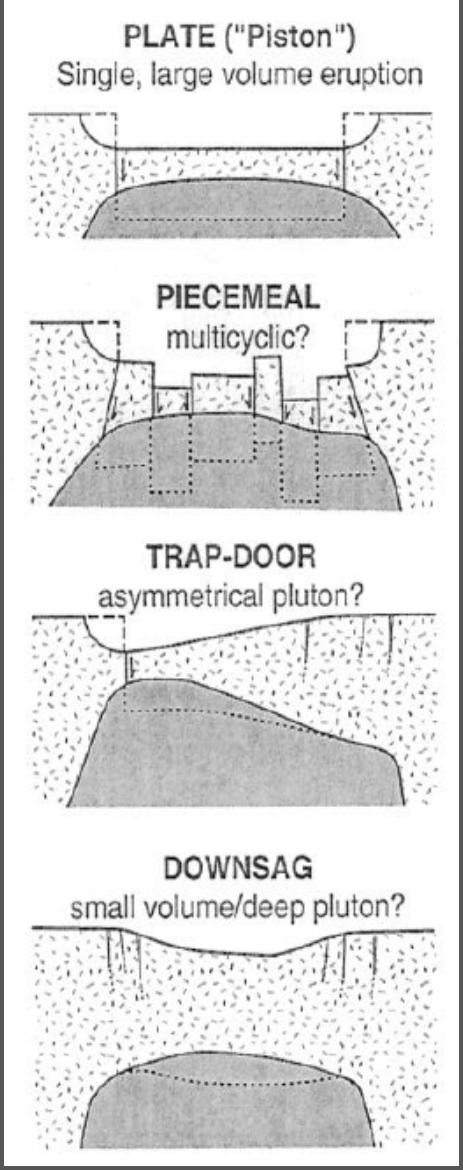
Piecemeal

1) Most realistic?

2) Multiple structural faults with variable Offsets

3) Dramatic lateral variation in fill thickness

Collapse Styles



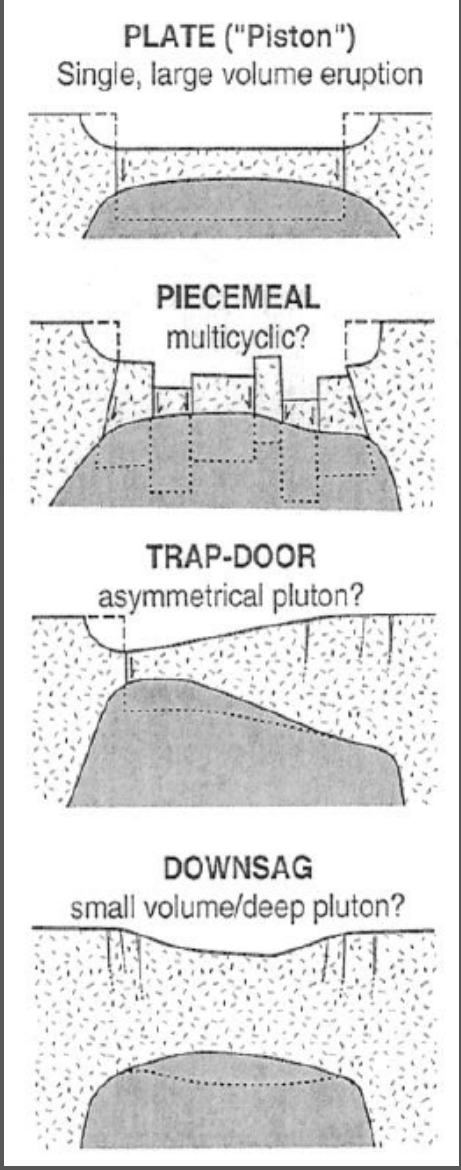
Trap-door

1) Somewhat rare

2) Incomplete formation of ring fault

3) Wedge-shaped geometry of intracaldera fill

Collapse Styles



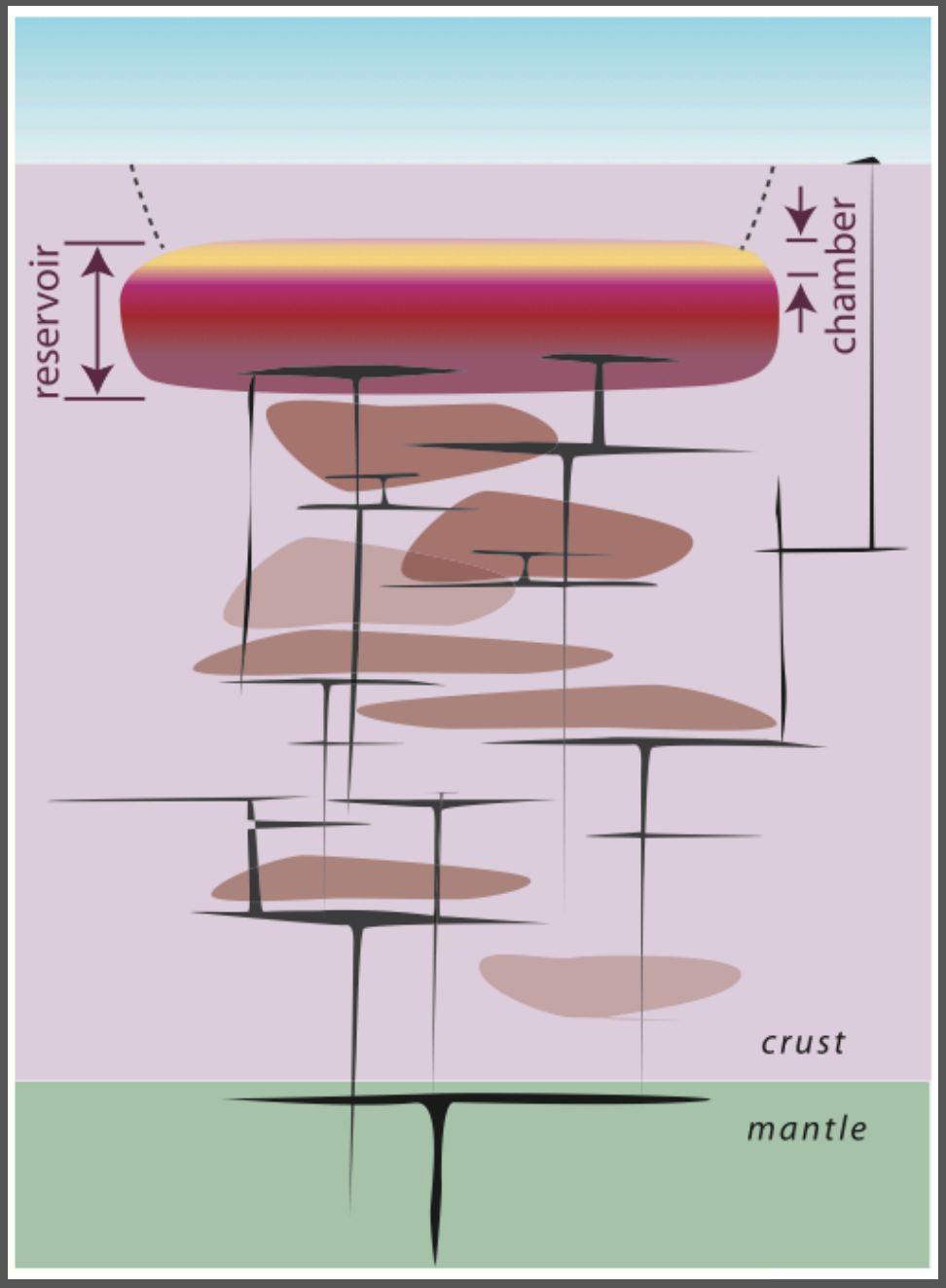
Downsag

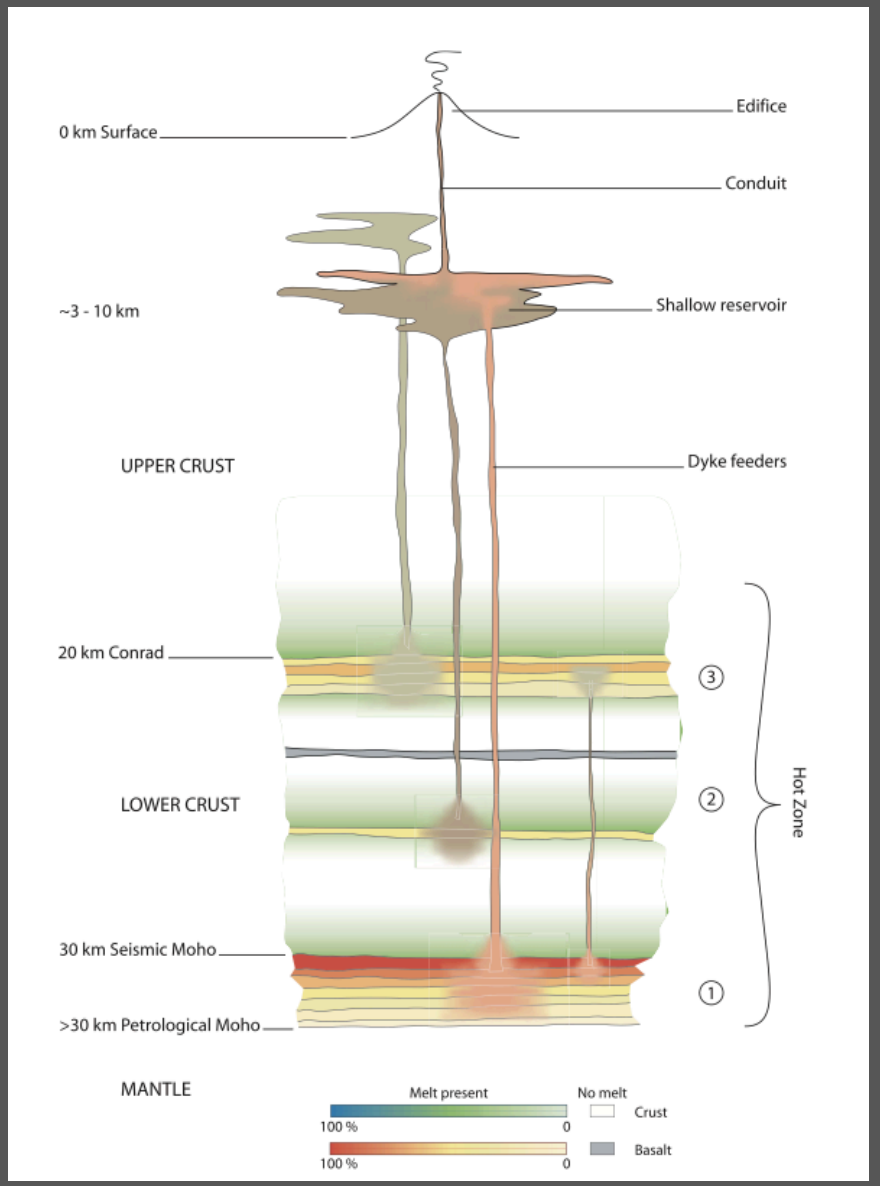
1) Somewhat rare for large eruptions; More common in smaller summit calderas

2) Ring faults do not intersect surface

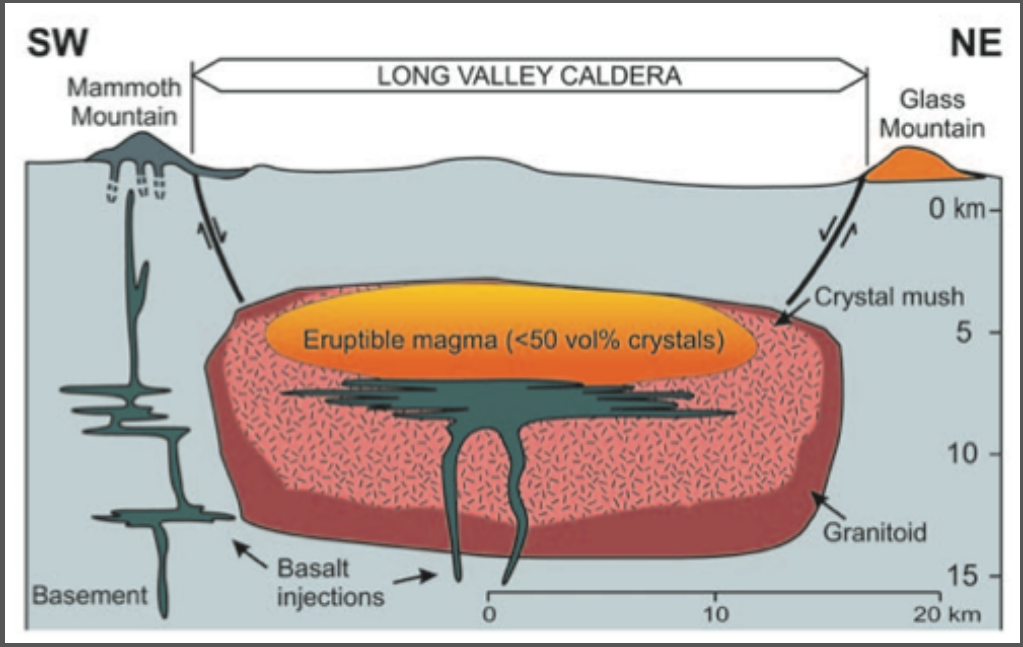
3) Lens-shaped geometry of intracaldera fill

Magmatic plumbing Beneath calderas…

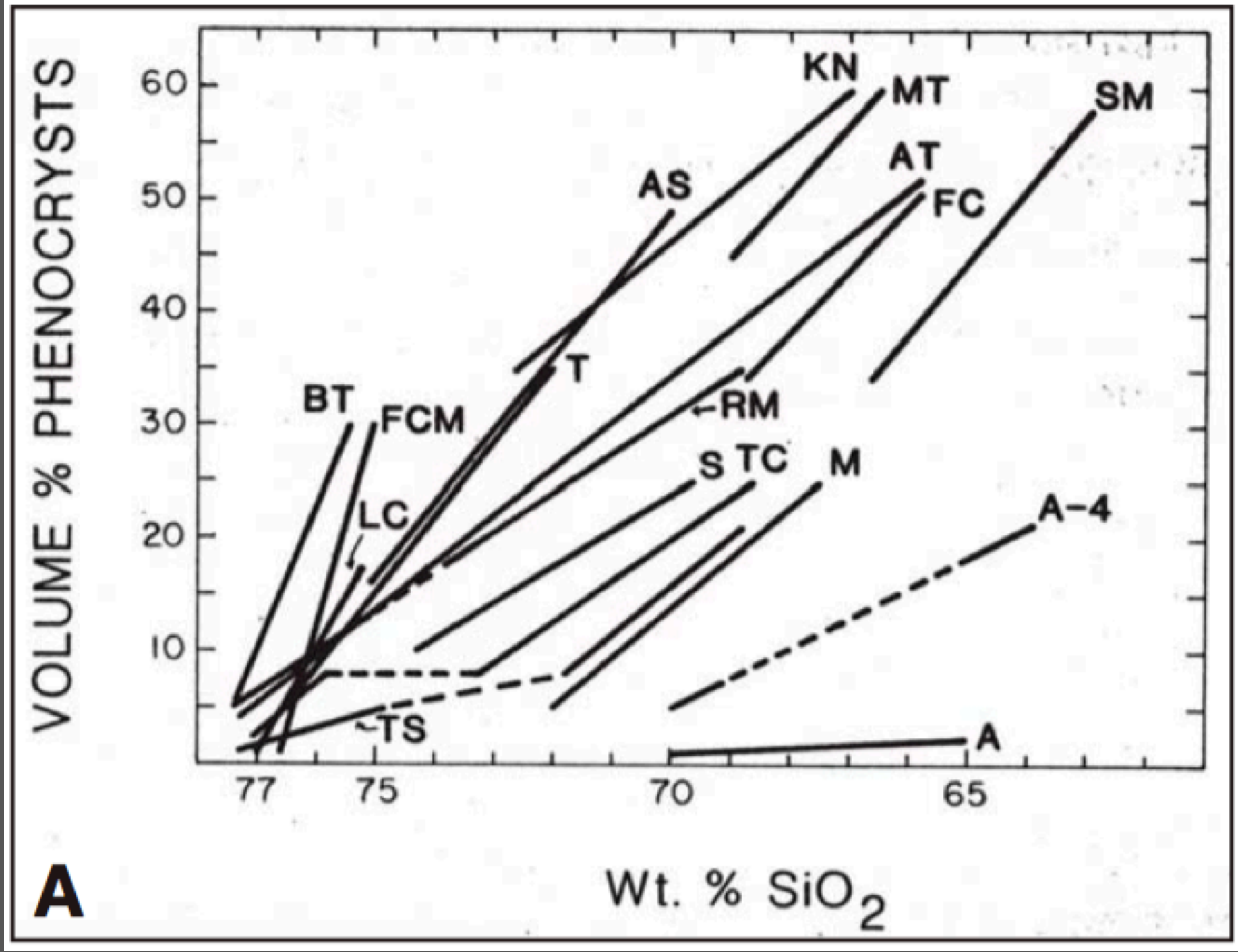




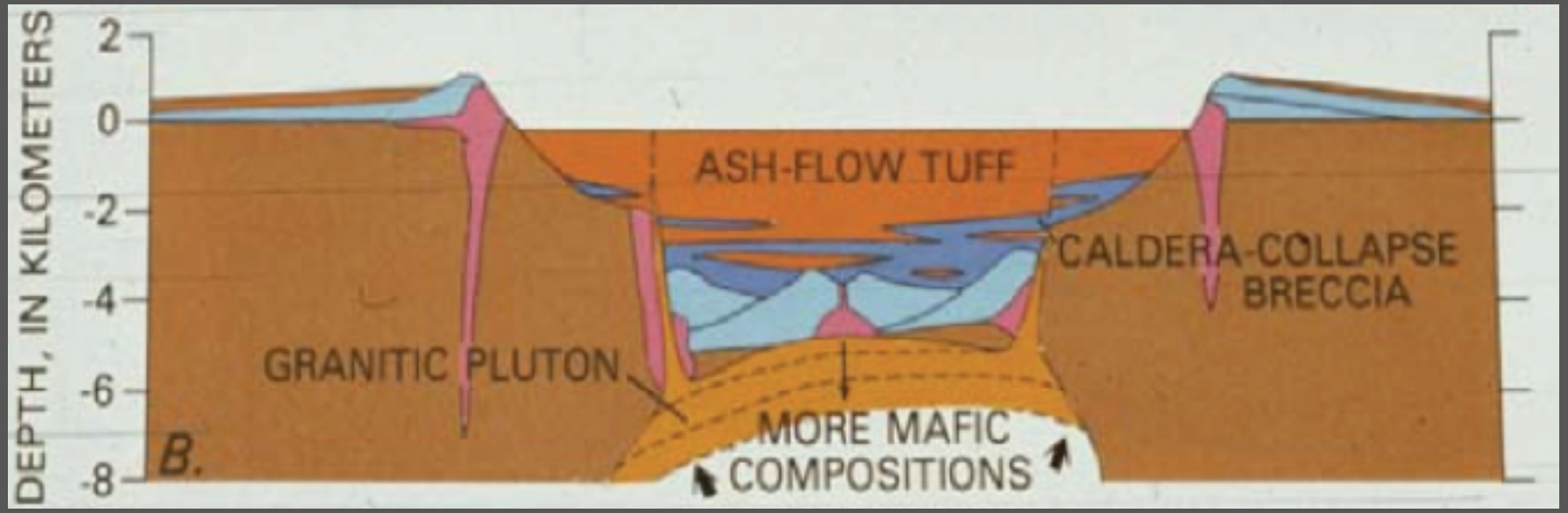
Magmatic plumbing
Beneath calderas…



Not a simple, completely molten magma body


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

Intracaldera Tuff vs. Outflow Tuff



Intracaldera Tuff vs. Outflow Tuff

1-5 km thick deposit

> 1 km of Intracaldera Tuff w/ no base exposed

Intracaldera Tuff vs. Outflow Tuff

> 1 km intacaldera tuff with no base exposed

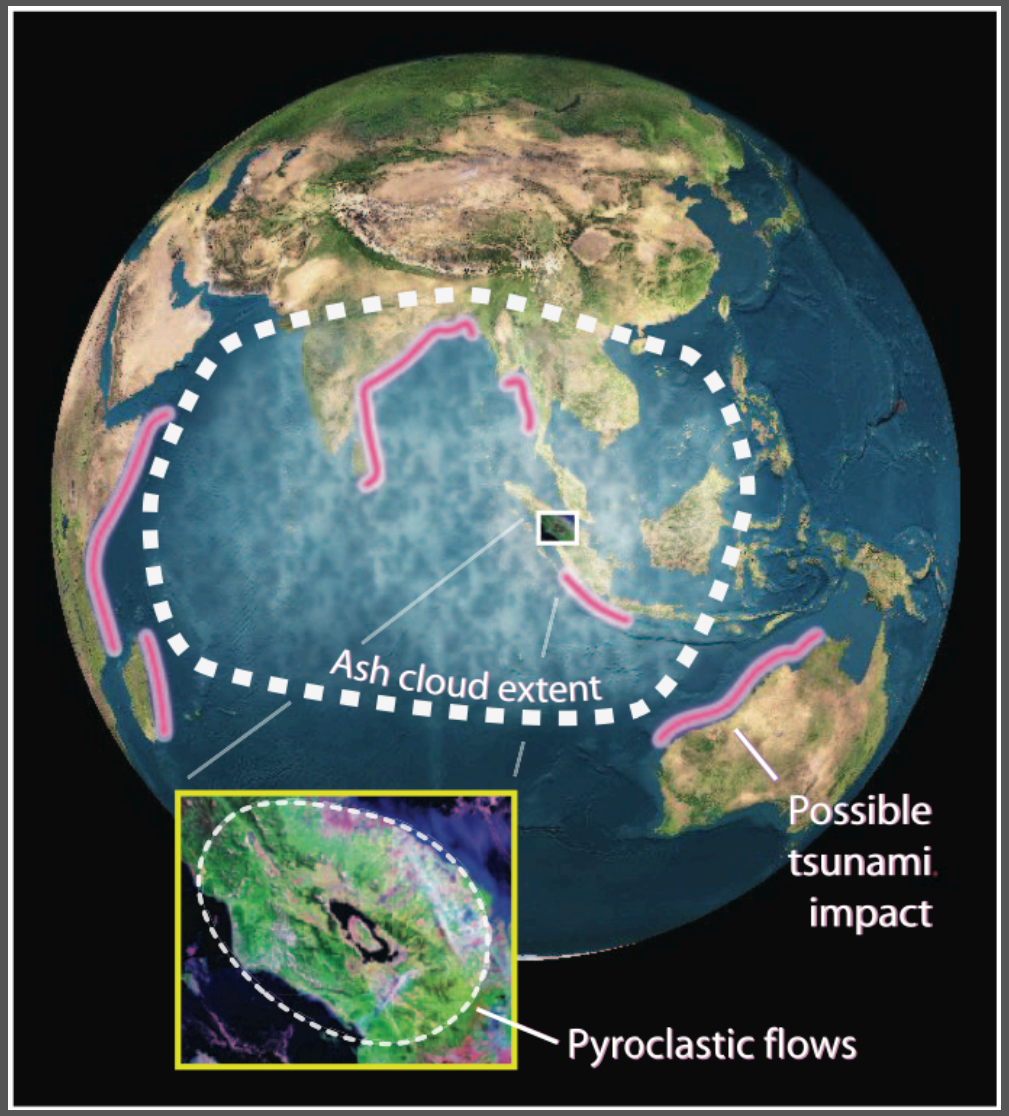
Intracaldera Tuff vs. **Outflow Tuff**

Proximal Outflow Deposit

Intracaldera Tuff vs. **Outflow Tuff**

Ignimbrite Sheet

Outflow Tuff vs. Ash-Fall deposits



Toba Caldera
75 ka

Postcaldera Volcanism

Postcaldera Volcanism (waning magmatism)

1) Numerous eruptions, compositionally diverse, during extended period (10^4 to > 10^6 yrs)

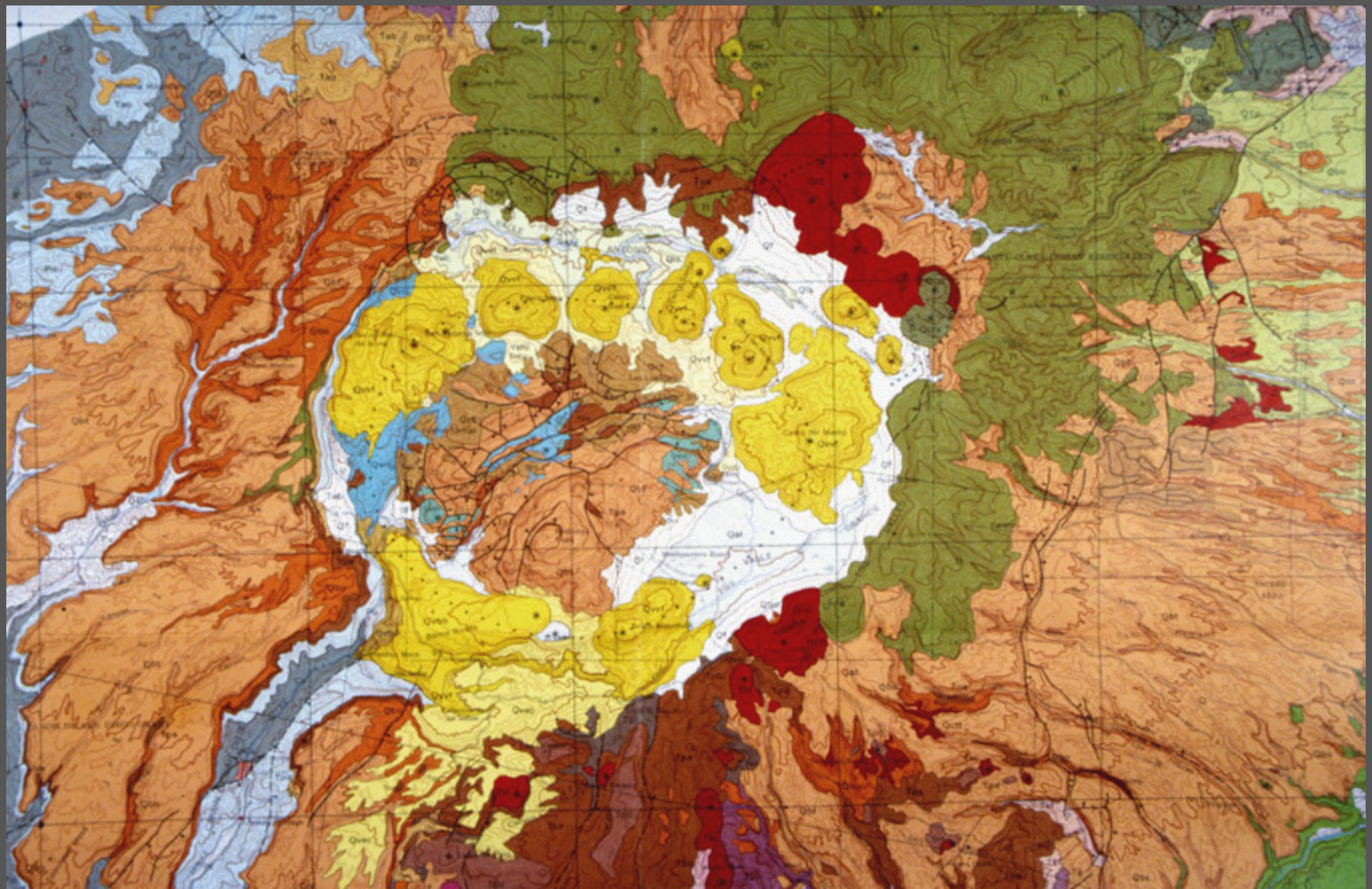
2) Caldera lake

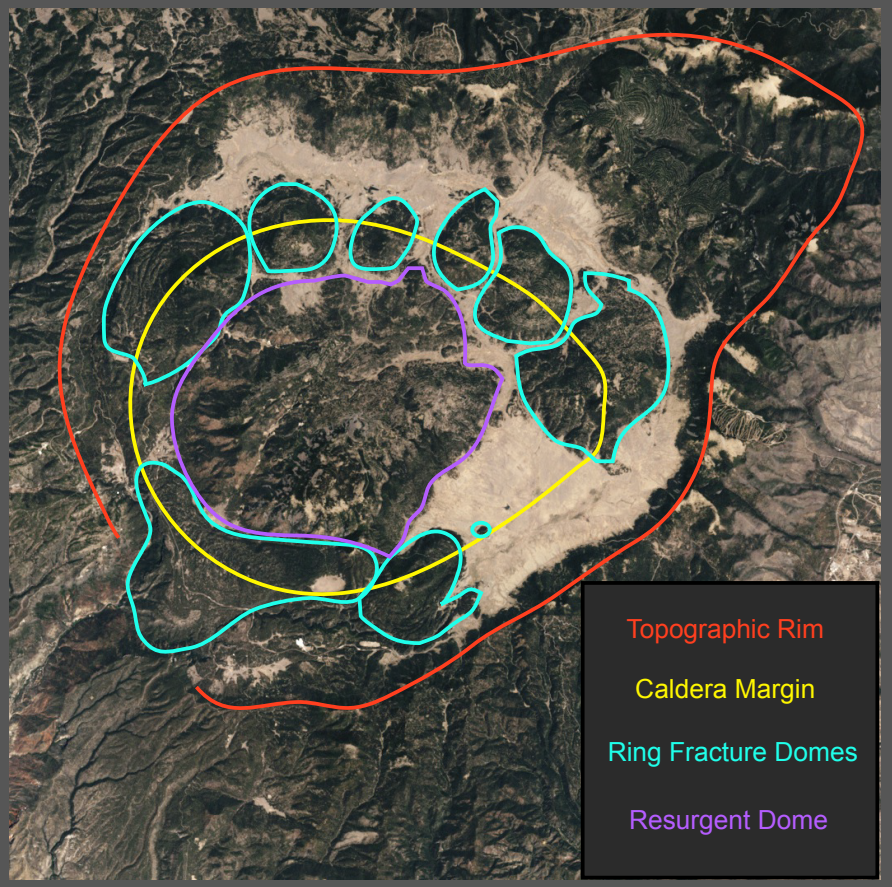
3) Formation of resurgent dome

4) Extensive mineralization

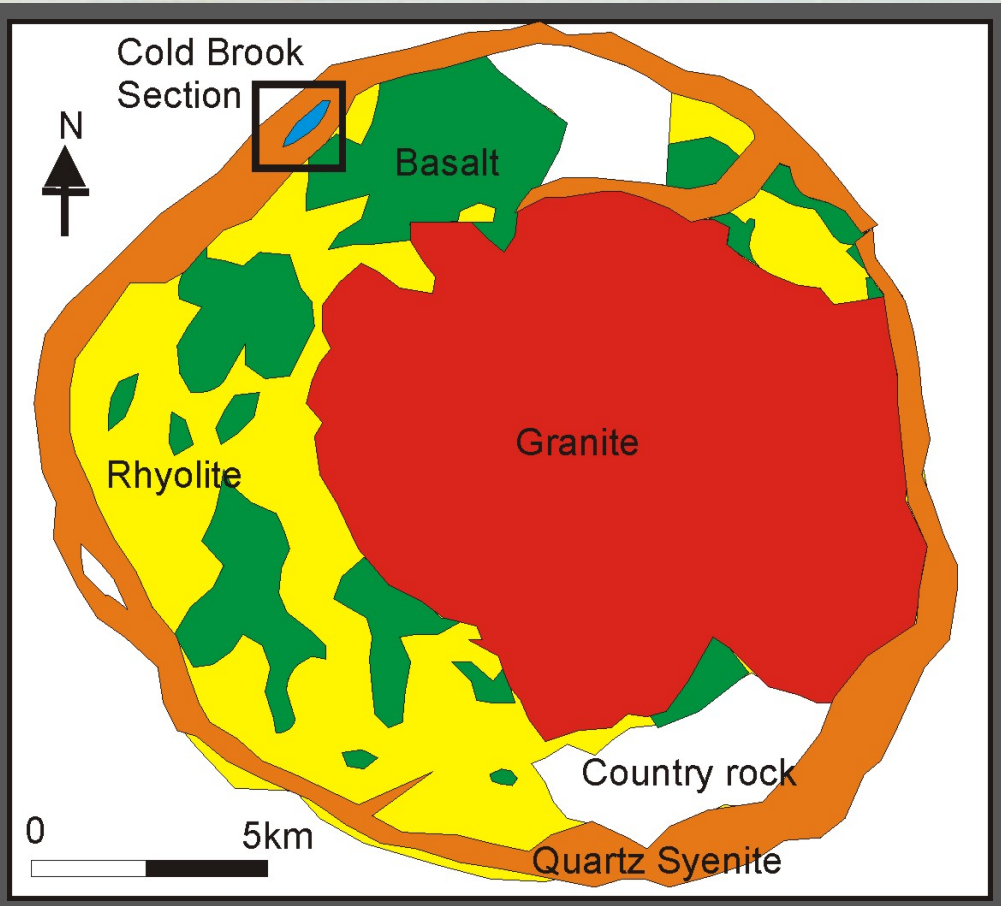
5) Large volume of magma emplaced as plutons/intrusion

Valles – circular moat rhyolite pattern




Topographic Rim
Caldera Margin
Ring Fracture Domes
Resurgent Dome

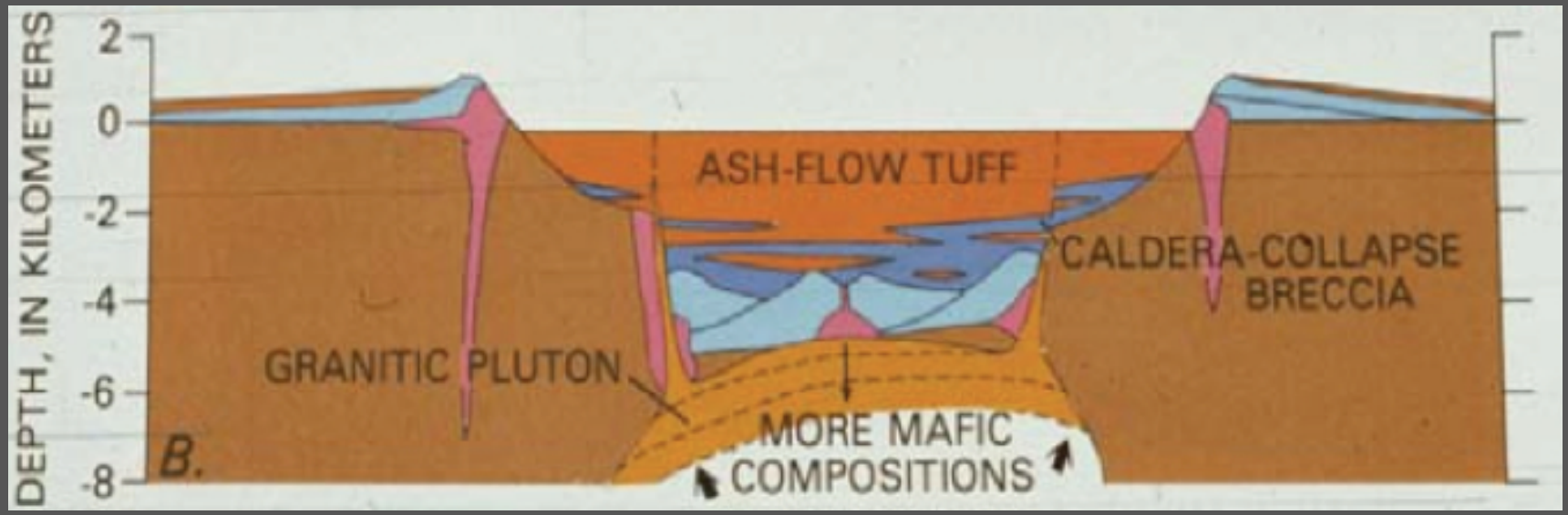
Ossipee ring complex



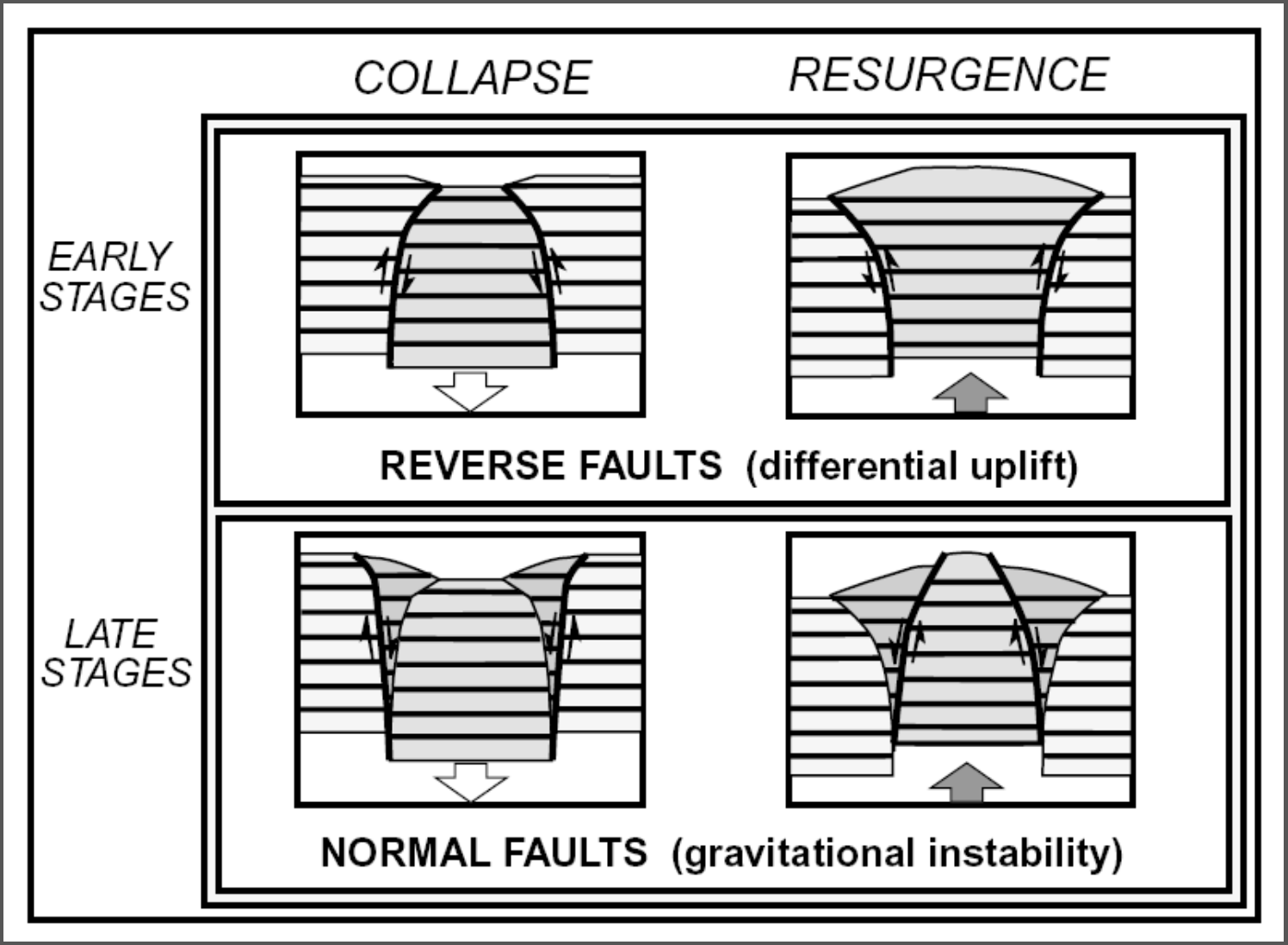
Caldera Lakes

Caldera Lakes

Resurgent domes

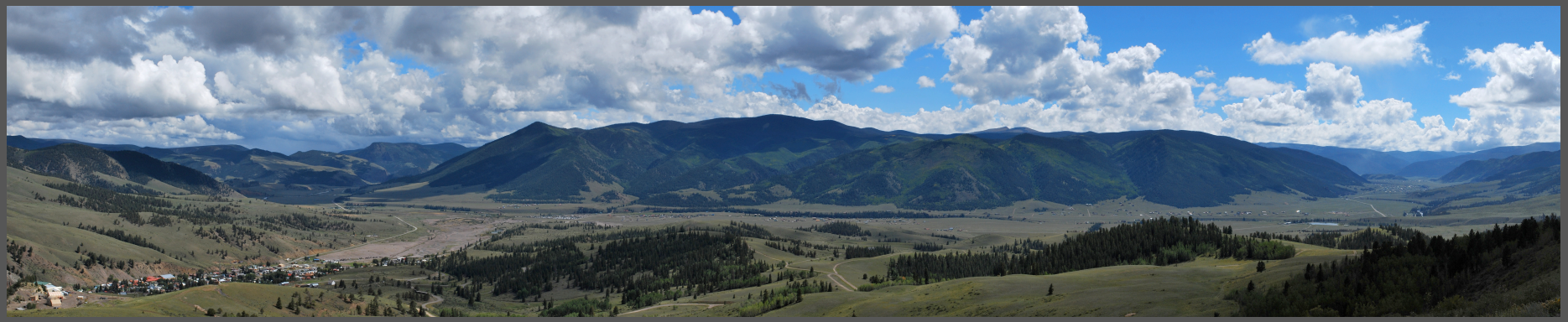


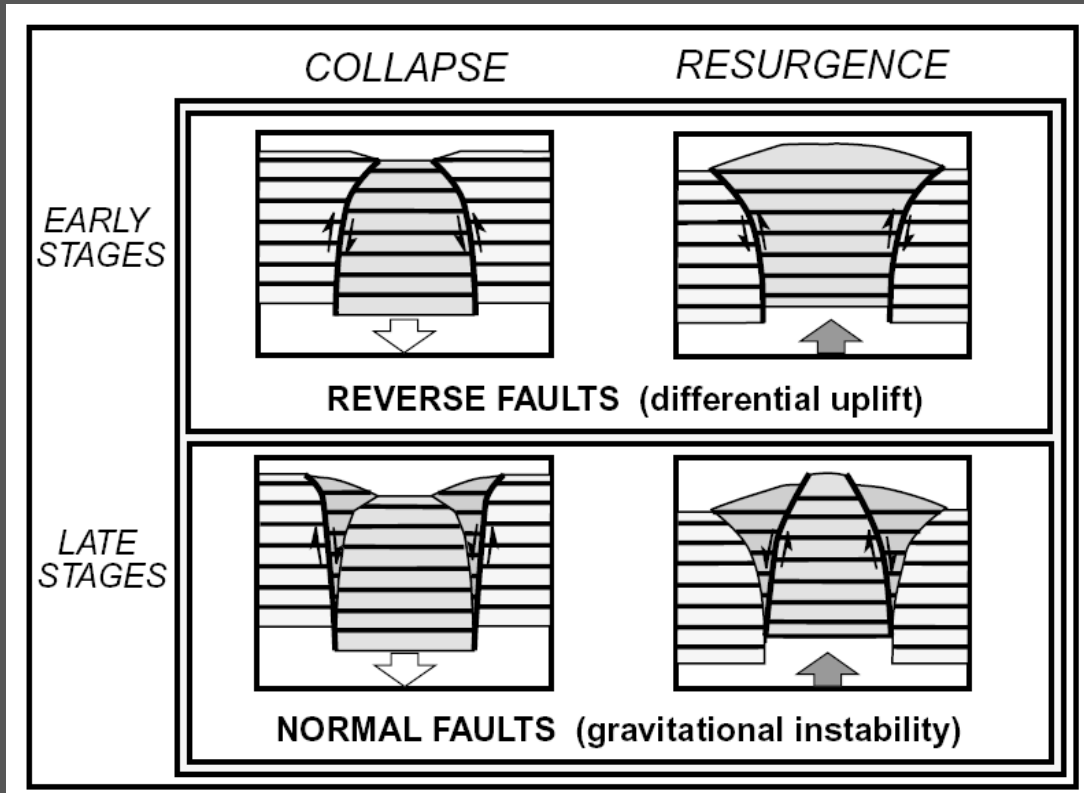
Faulting during collapse and resurgence



Acocella et al 2001

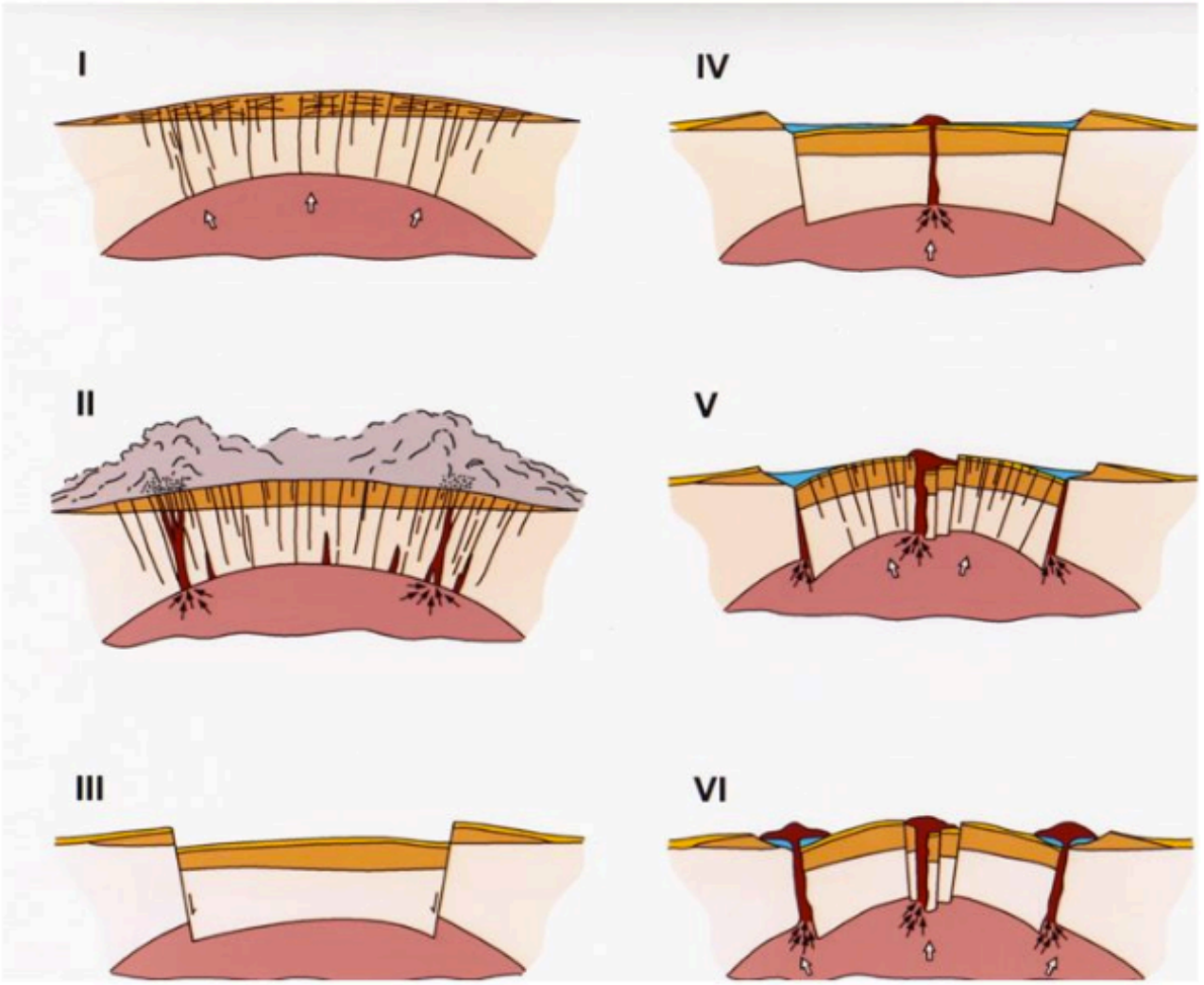
Resurgent domes





26.9 Ma Creede Caldera
SW Colorado

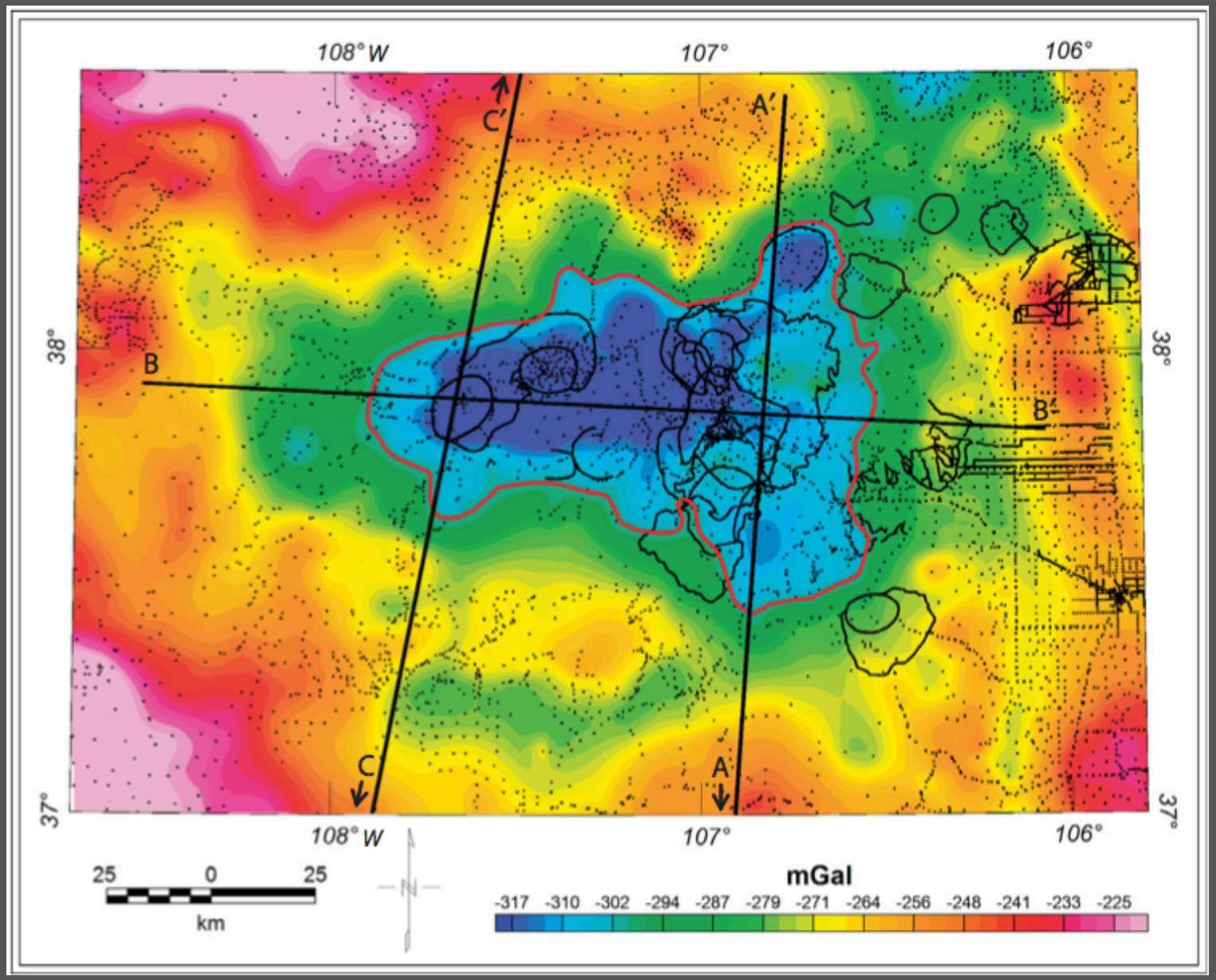
Smith and Bailey's caldera cycle



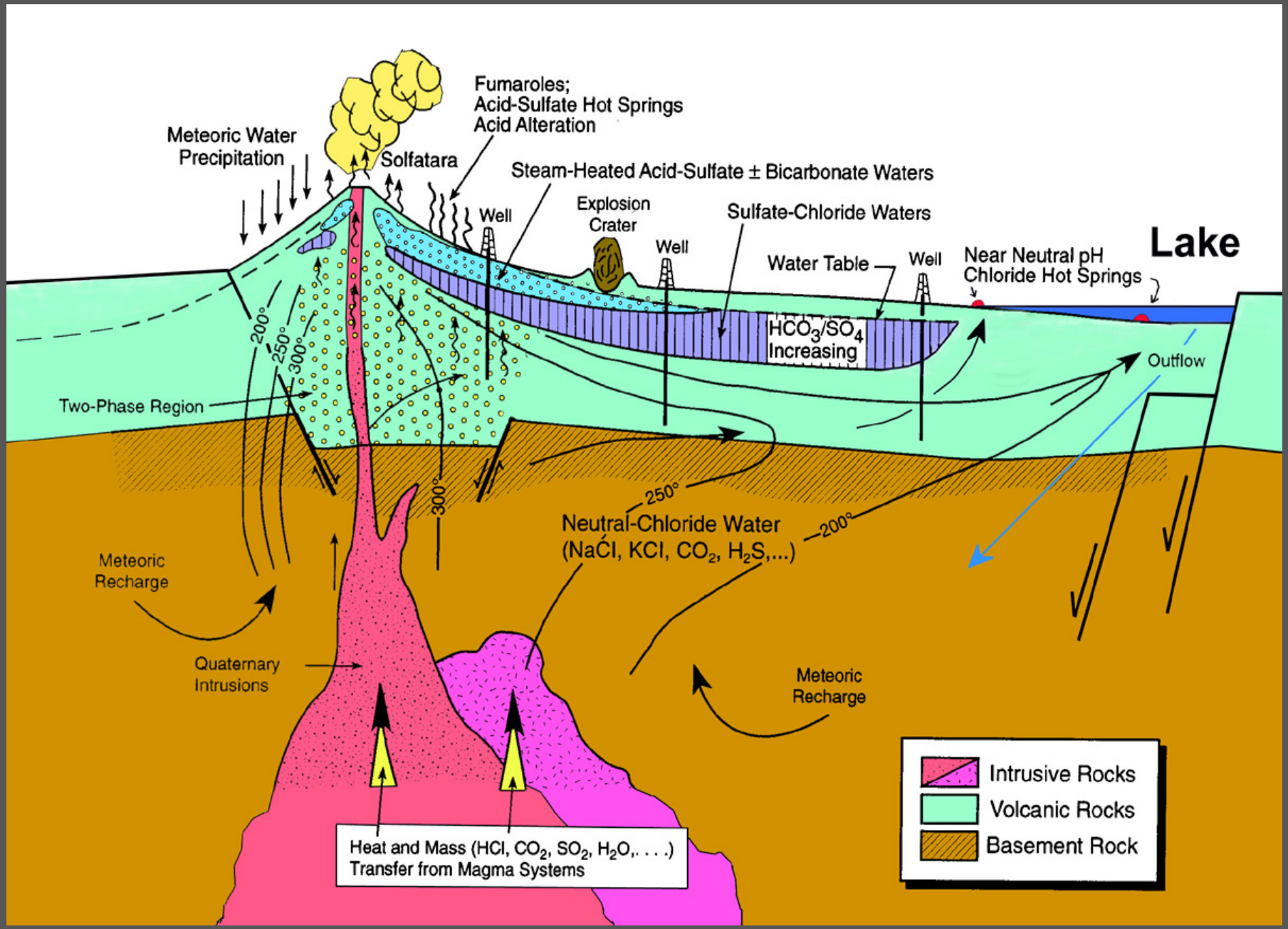
Bouguer Gravity Anomaly

- The difference between the expected value of gravity at a given location (taking into account factors such as latitude, longitude, altitude, and the rotation of the Earth) and its actual value.

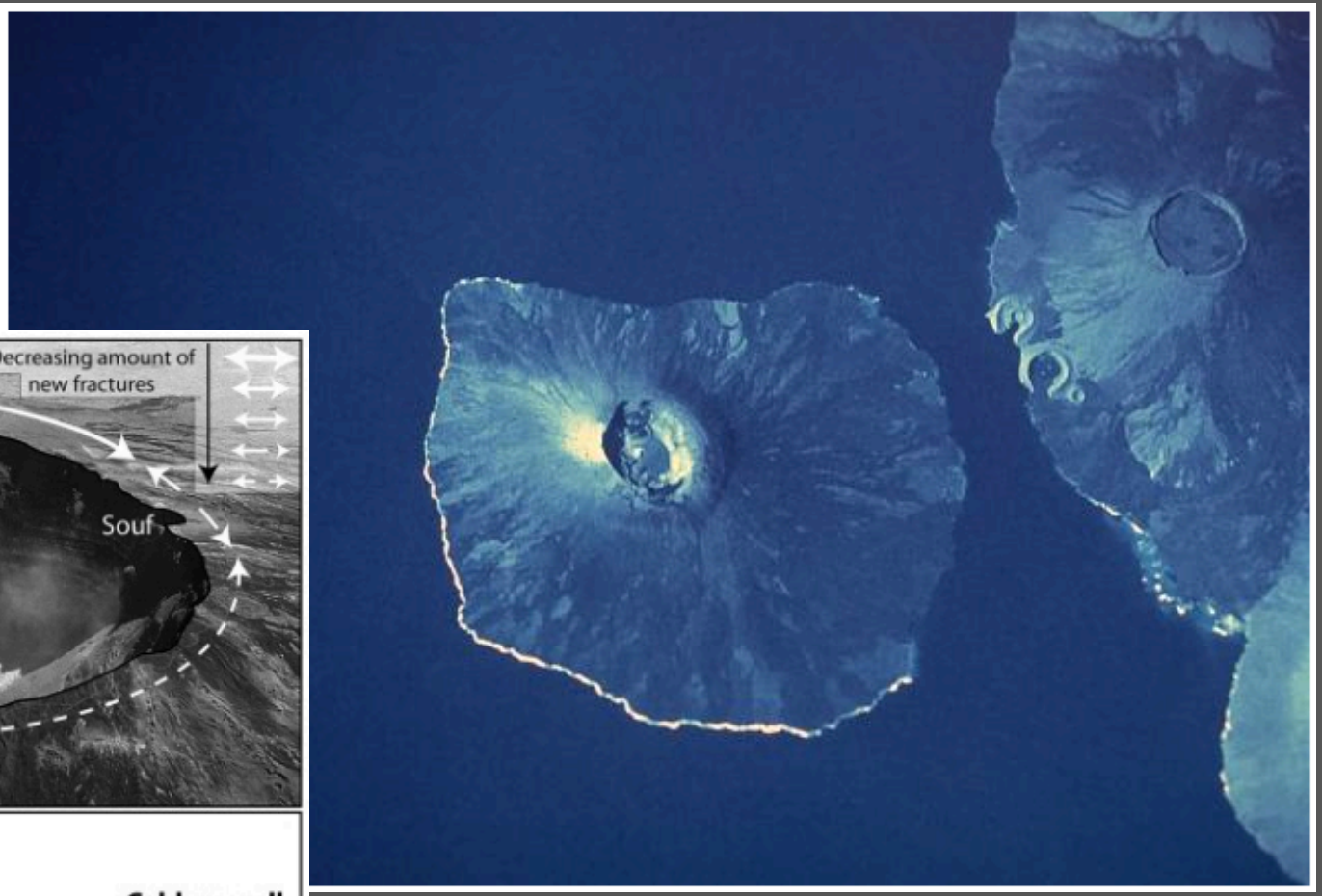
Postcaldera intrusions



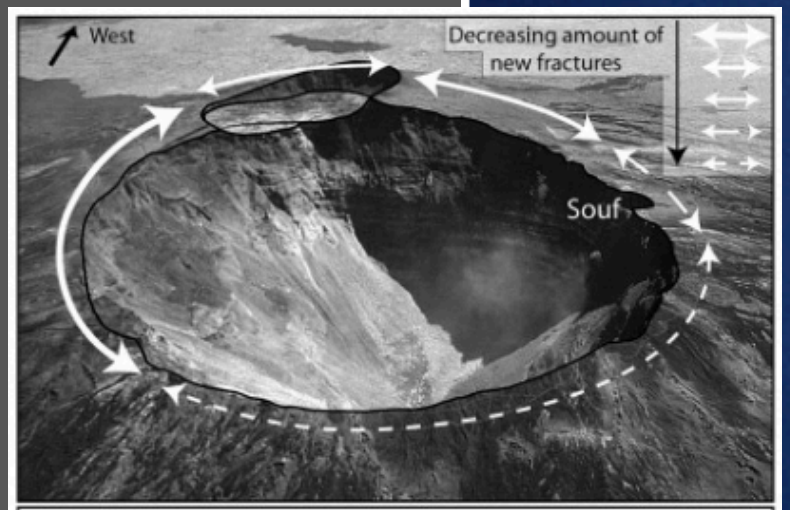
Drenth
Et al. 2011)

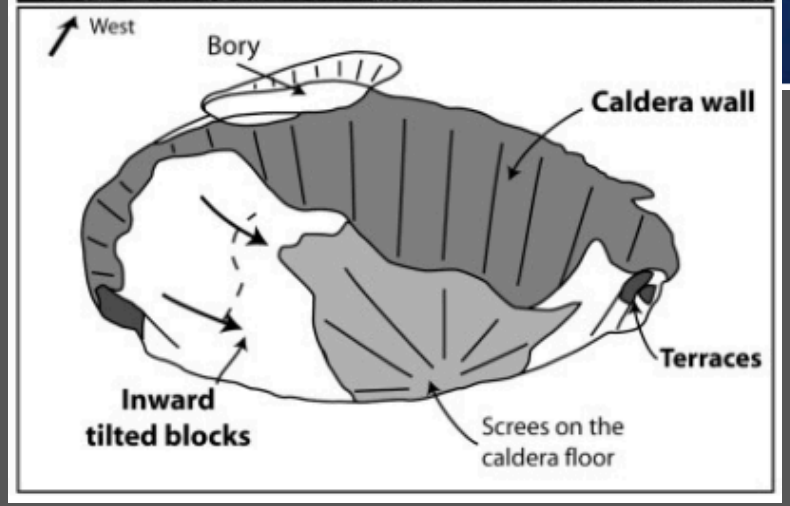

Meteoric Water Precipitation
Solfatara
Fumaroles;
Acid-Sulfate Hot Springs
Acid Alteration
Steam-Heated Acid-Sulfate ± Bicarbonate Waters
Well
Explosion Crater
Well
Sulfate-Chloride Waters
Water Table
Well
Near Neutral pH Chloride Hot Springs
Lake
200°
250°
300°
HCO_3/SO_4 Increasing
Outflow
Two-Phase Region
300°
250°
200°
Neutral-Chloride Water
(NaCl, KCl, CO_2, H_2S,...)
Meteoric Recharge
Quaternary Intrusions
Meteoric Recharge
Heat and Mass (HCl, CO_2, SO_2, H_2O,. . . .)
Transfer from Magma Systems
Intrusive Rocks
Volcanic Rocks
Basement Rock

Basaltic Calderas



Fernadina Caldera





Piton de la Fournaise
(Michon et la., 2007)

Silicic Calderas

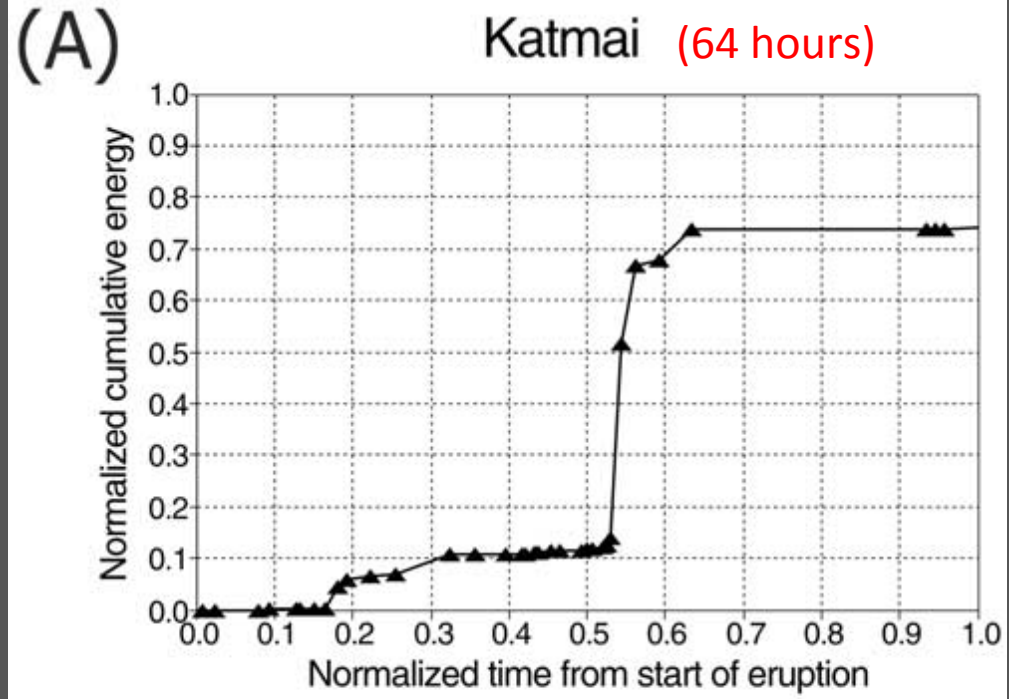
- 2-5 km collapse
- Volume = >100 km3
- Extensive pre and postcaldera eruptions
- ± resurgence
- rapid release of energy

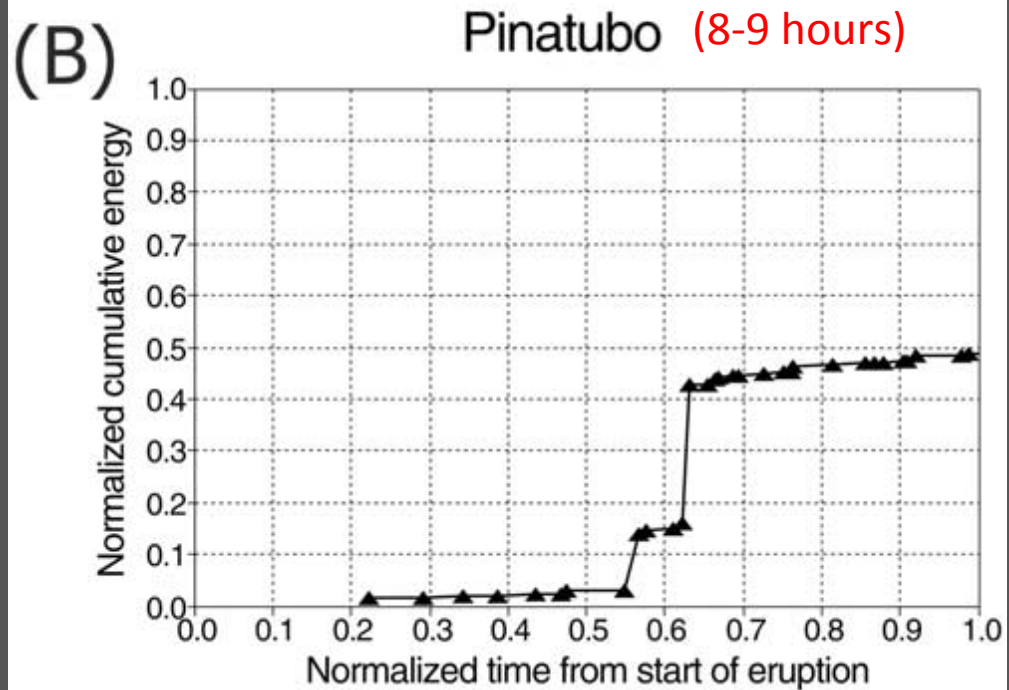
Basaltic Calderas

- 100s of meters collapse
- Volume = 1-10 km3
- Limited pre and postcaldera volcanism
- no resurgence
- slow release of energy

Katmai 1912, Pinatubo 1991

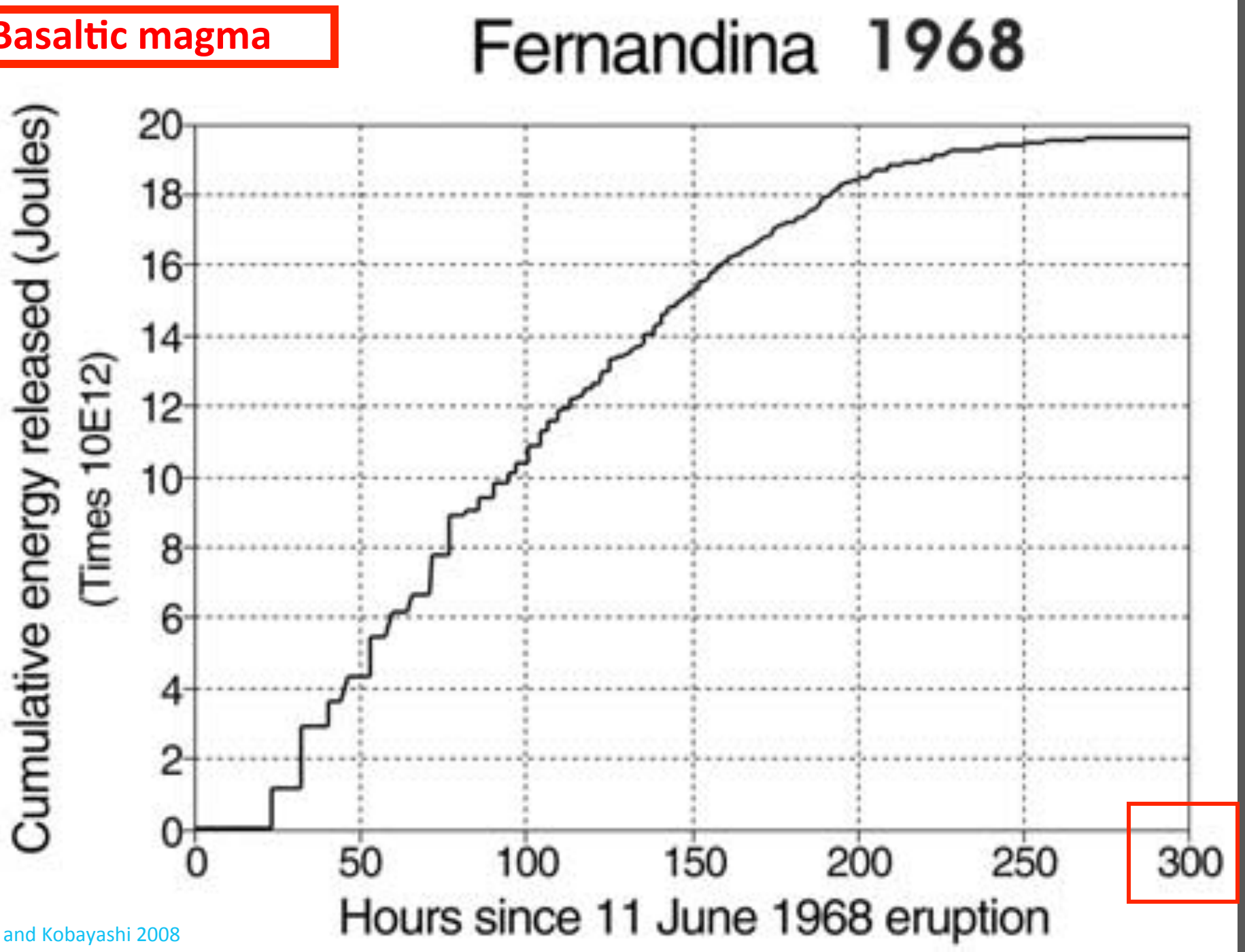
Silicic magma





Stix and Kobayashi 2008, JGR

Basaltic magma



Stix and Kobayashi 2008