VUELCO SUMMER SCHOOL

Quito, Ecuador, 7-13 November, 2014

Overpressure and rupture conditions of magma chambers

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MAGMA: WHAT IS MAGMA?

A magma consists of silicate melt (the liquid portion of magma) and other material including crystals, rock fragments, and bubbles.

↓

It will move as a fluid through a solid (host rock) (ductile or rigid – brittle)

↓

Its movement is controlled by buoyancy, rheological (viscosity) contrast with the host rock, and the stress field

↓

Magma migration is a tectonically controlled process

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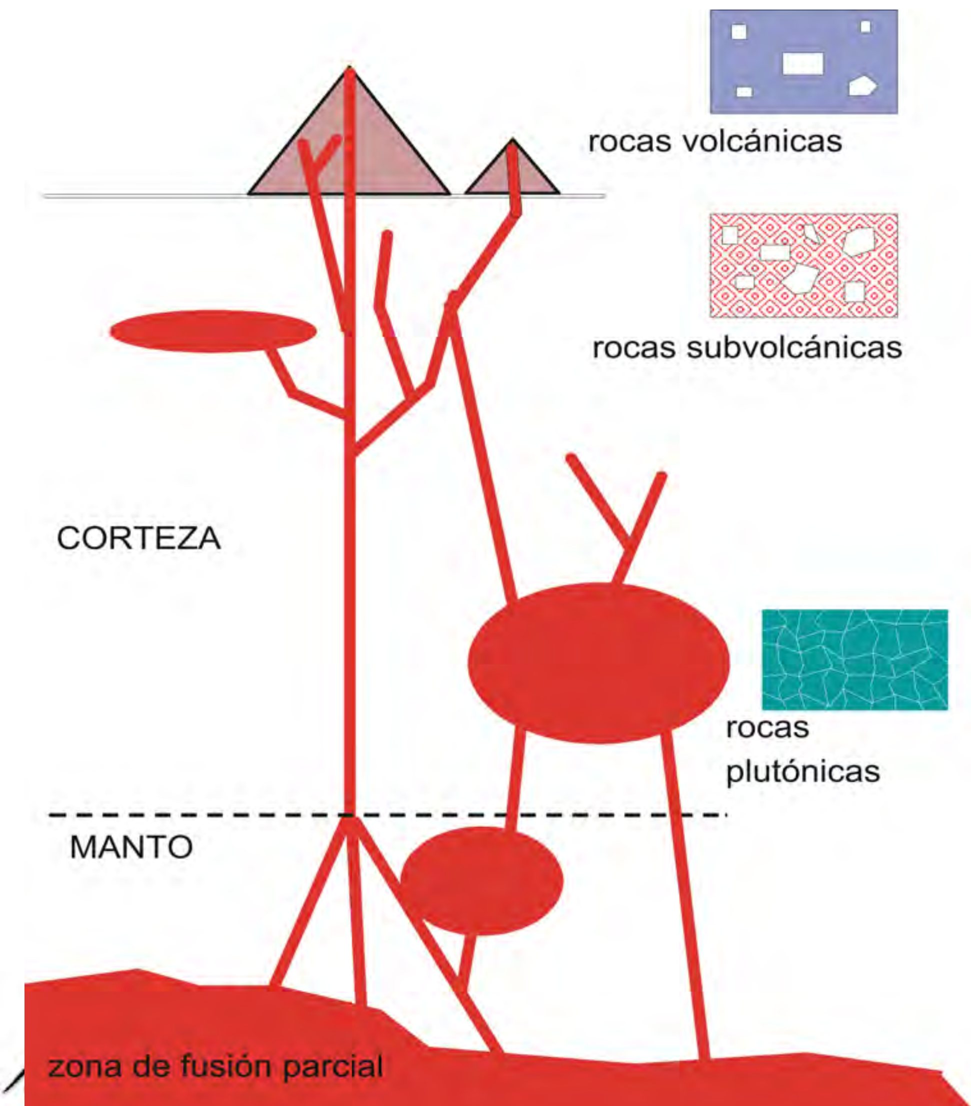
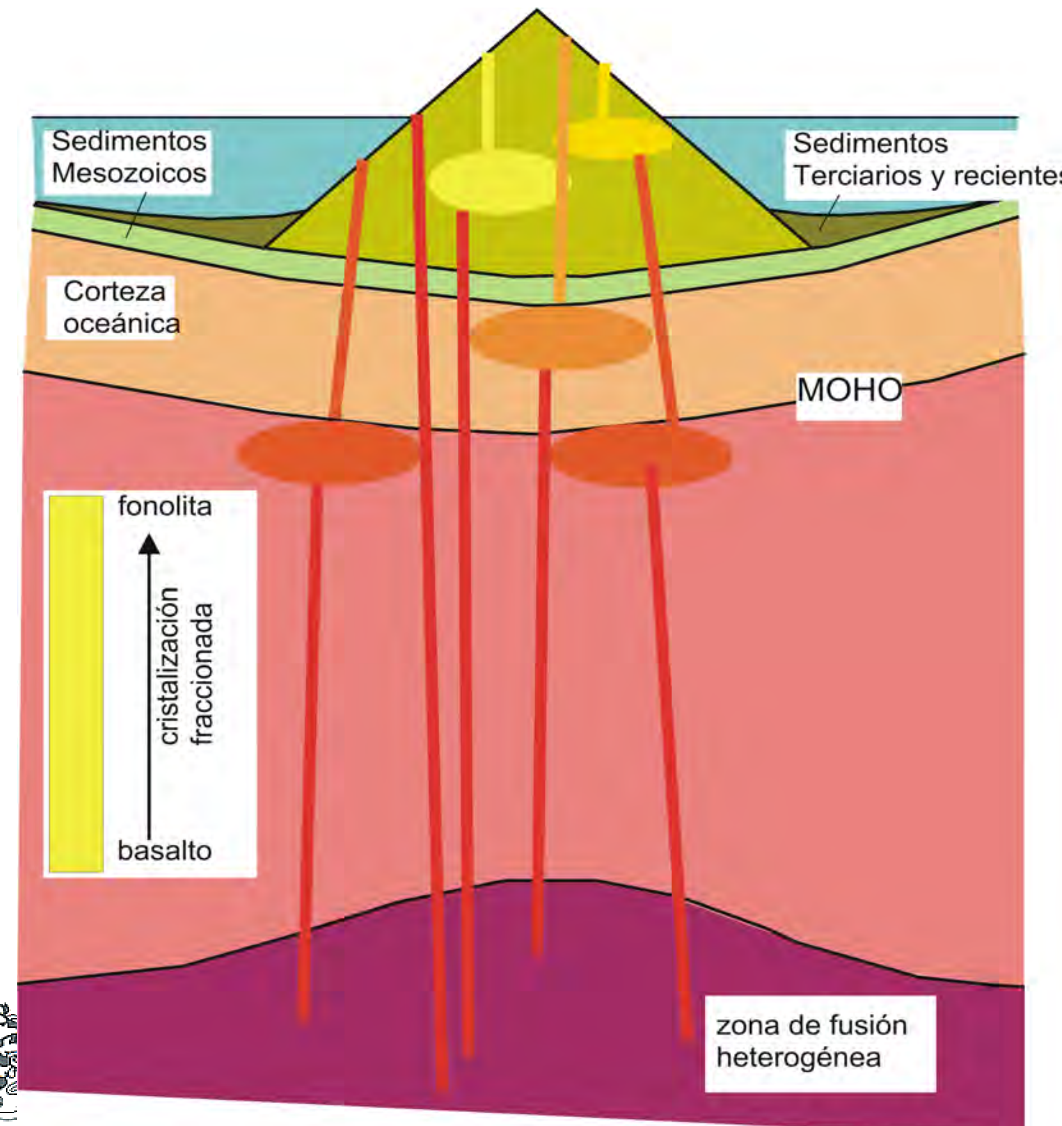
MAGMA ACCUMULATION: CHAMBERS, RESERVOIRS, BATCHES, …..

Any accumulation or portion of magma outside the source region, which may differentiate, crystallise, and solidify or migrate to a new position (including eruption at surface)



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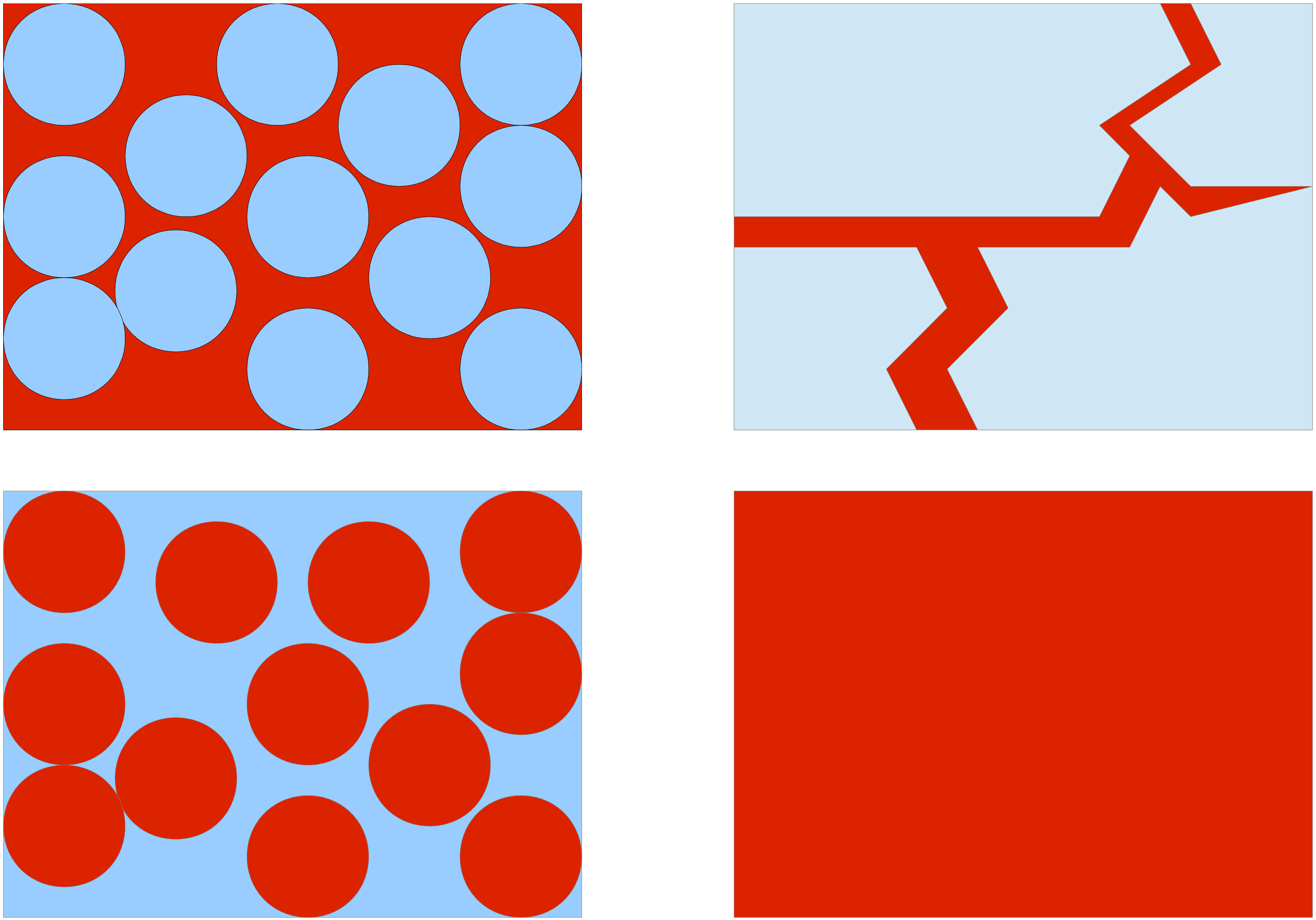
INSIDE A MAGMA CHAMBER



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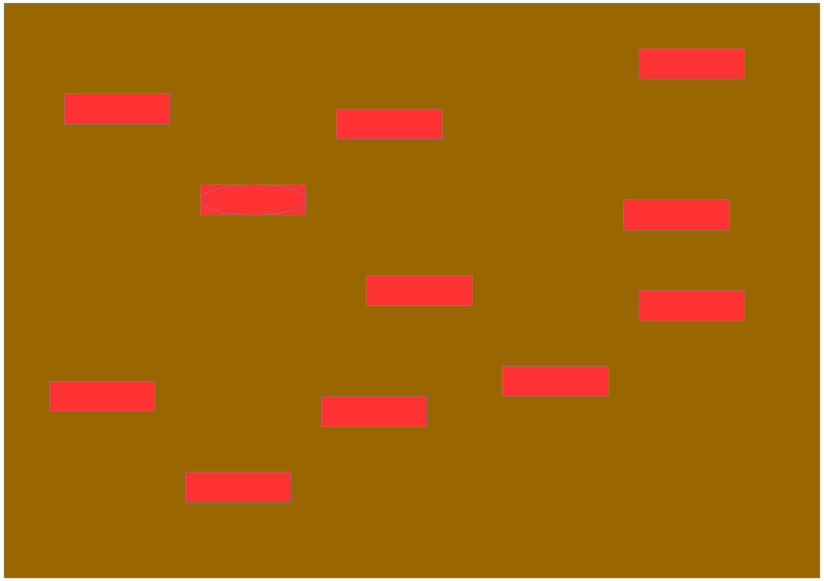
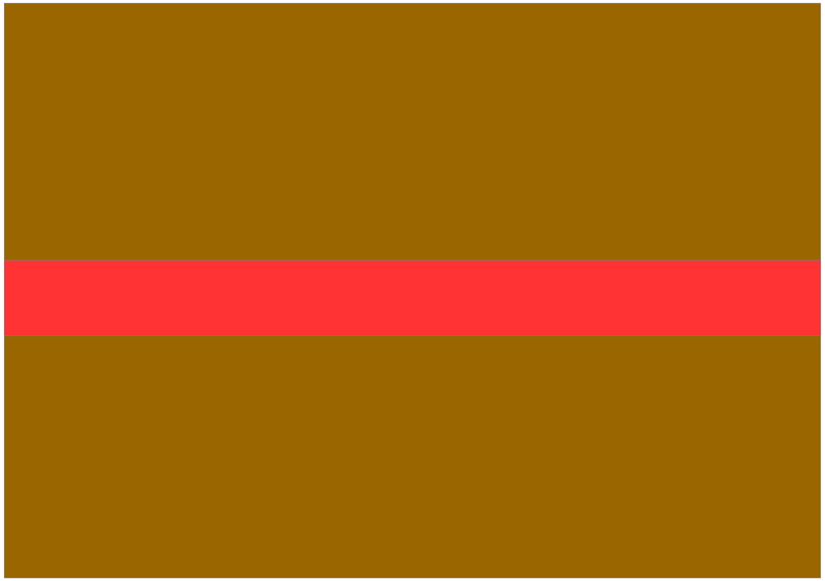
GEOPHYSICAL EVIDENCE FOR MAGMA ACCUMULATION



30% of magma



30% of magma

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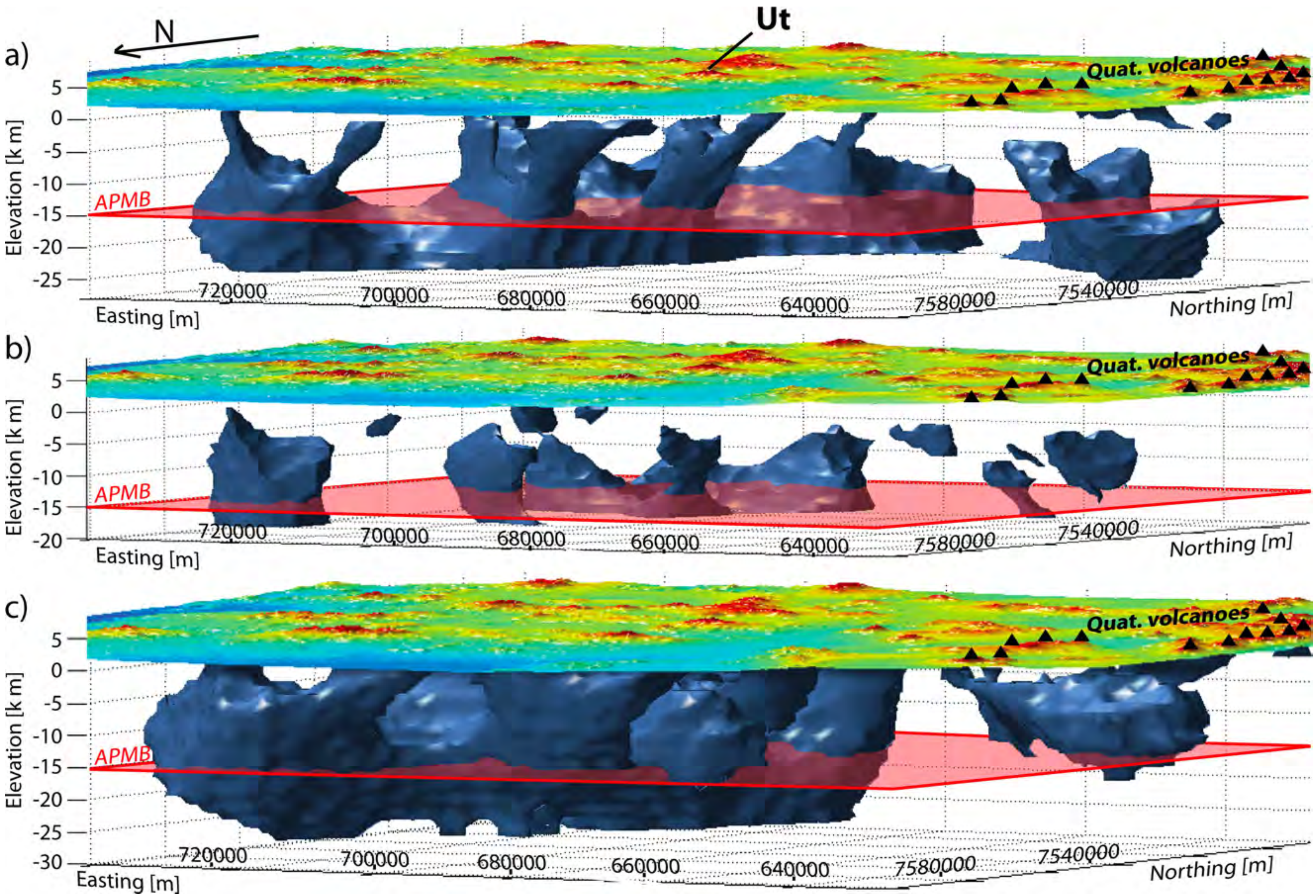
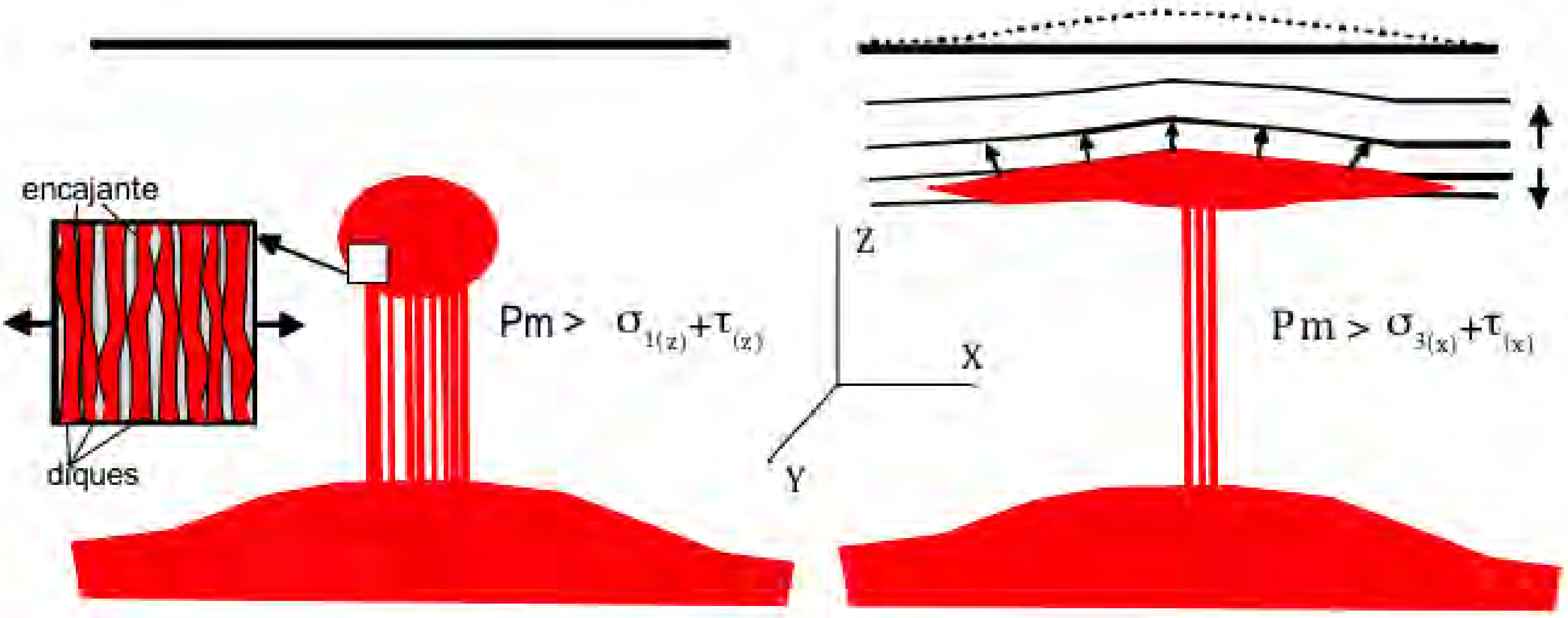
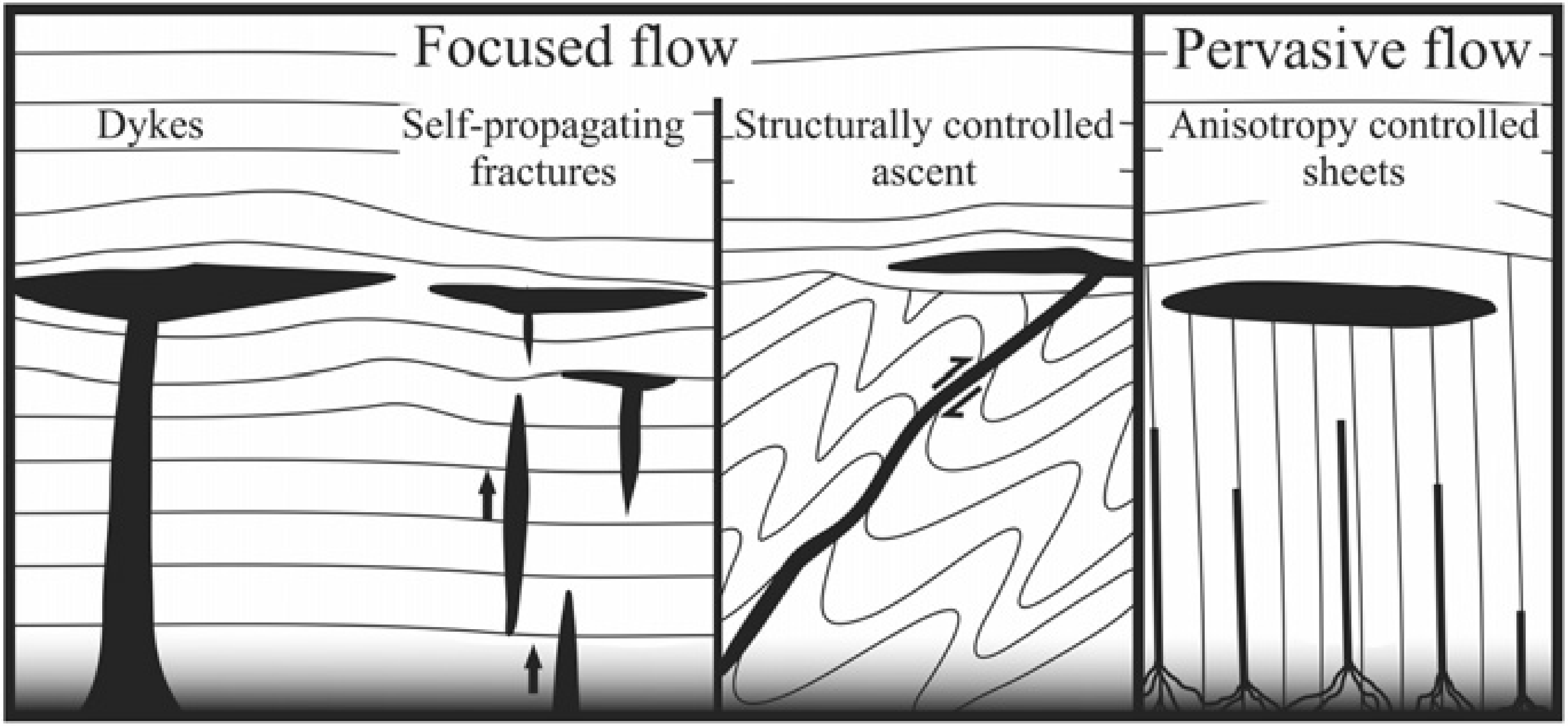


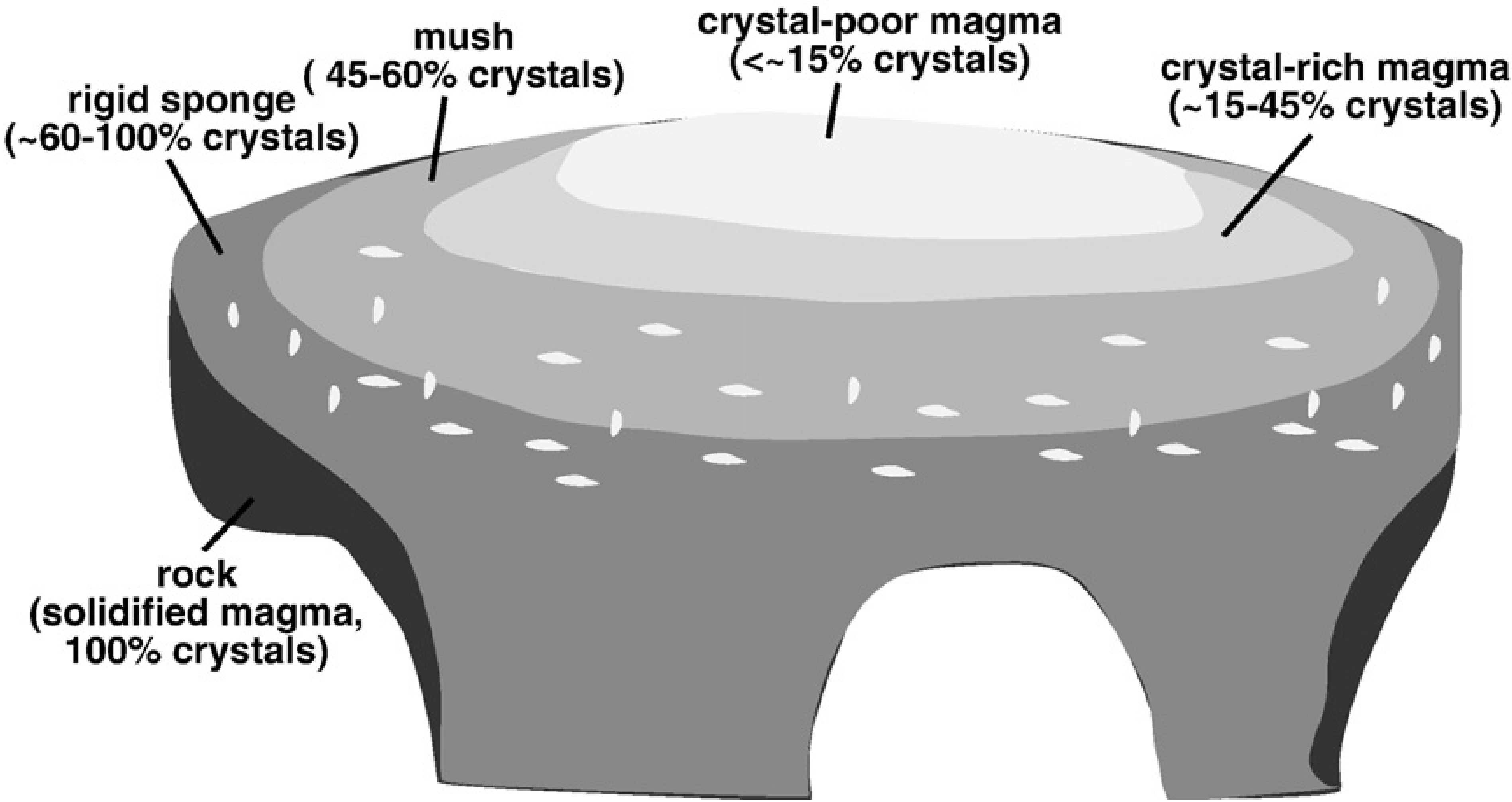
Del Potro et al 2013

HOW MAGMA CHAMBERS FORM?

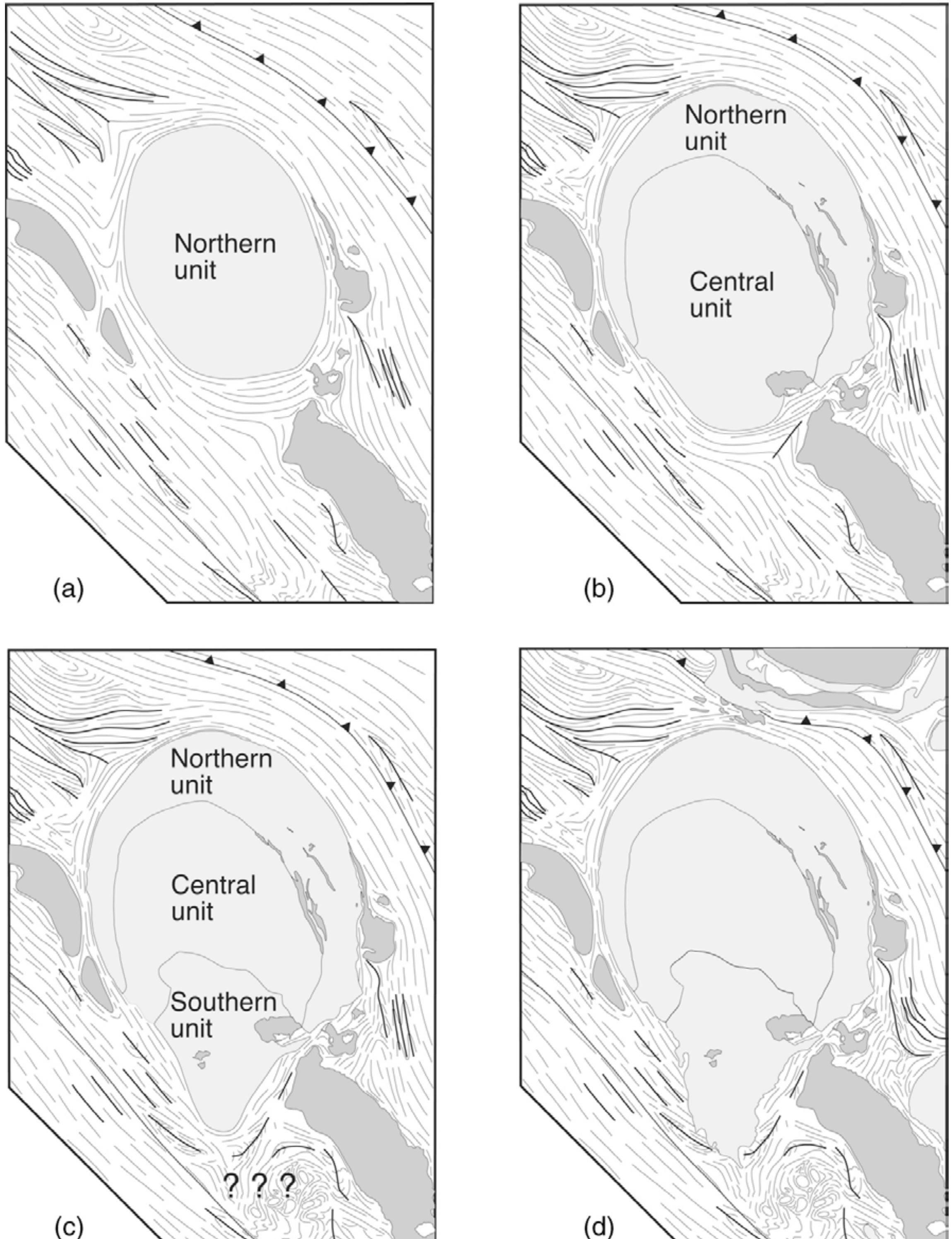




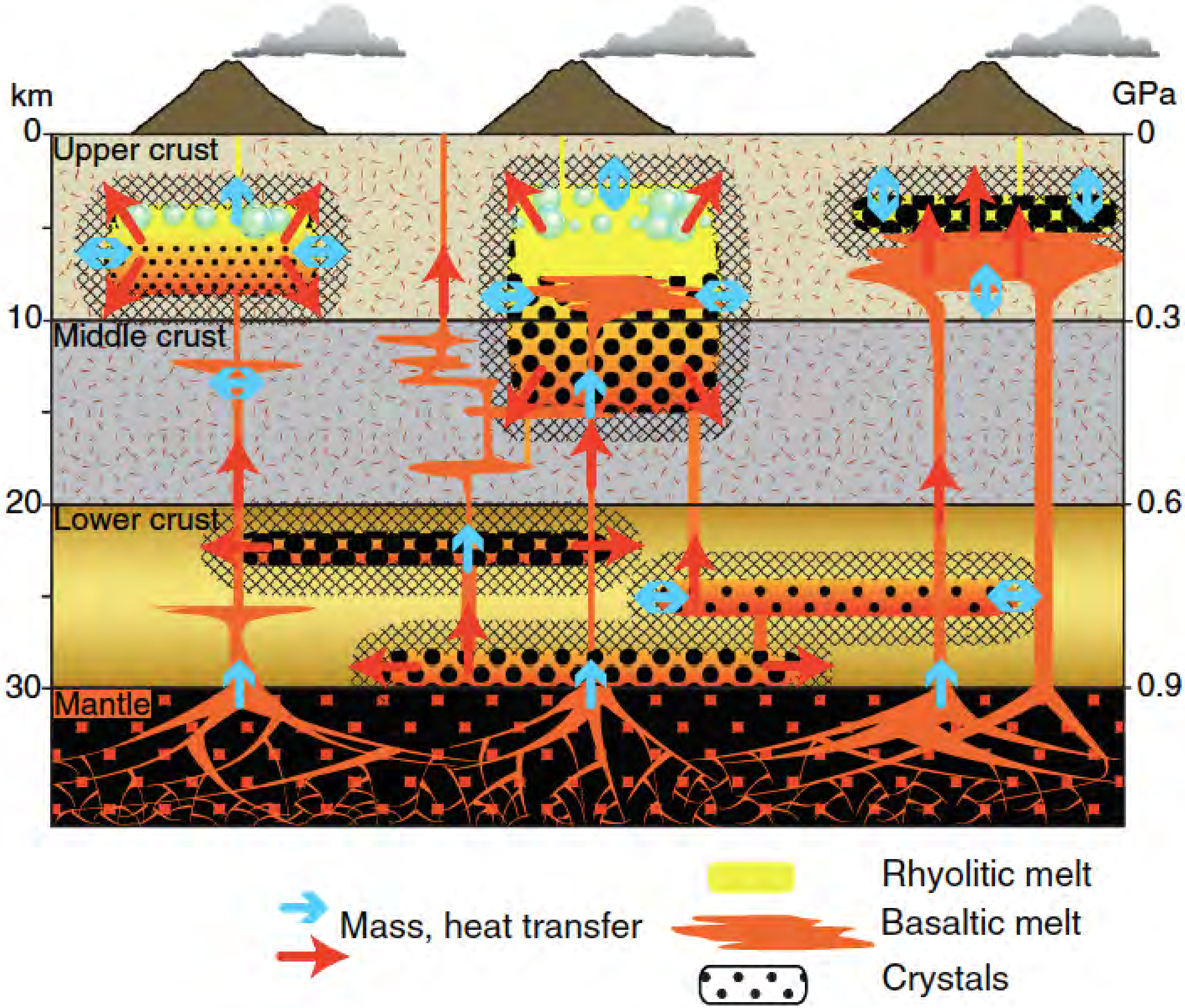
Hall and Kisters, 2012



Miller et al , 2011

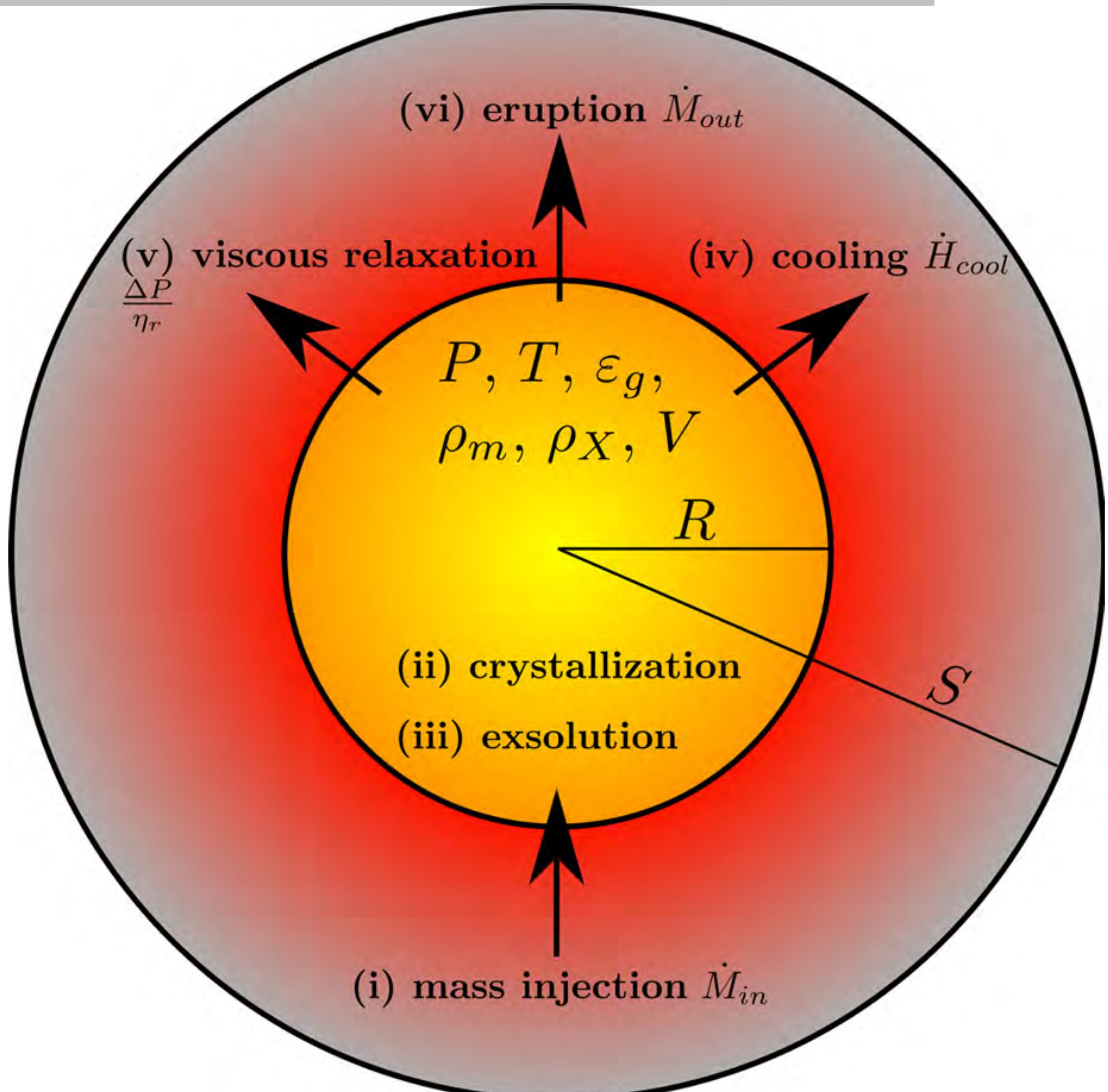


Johnson et al 2003



Fowler and Spera, 2010

THERMAL EFFECTS OF MAGMA INTRUSIONS



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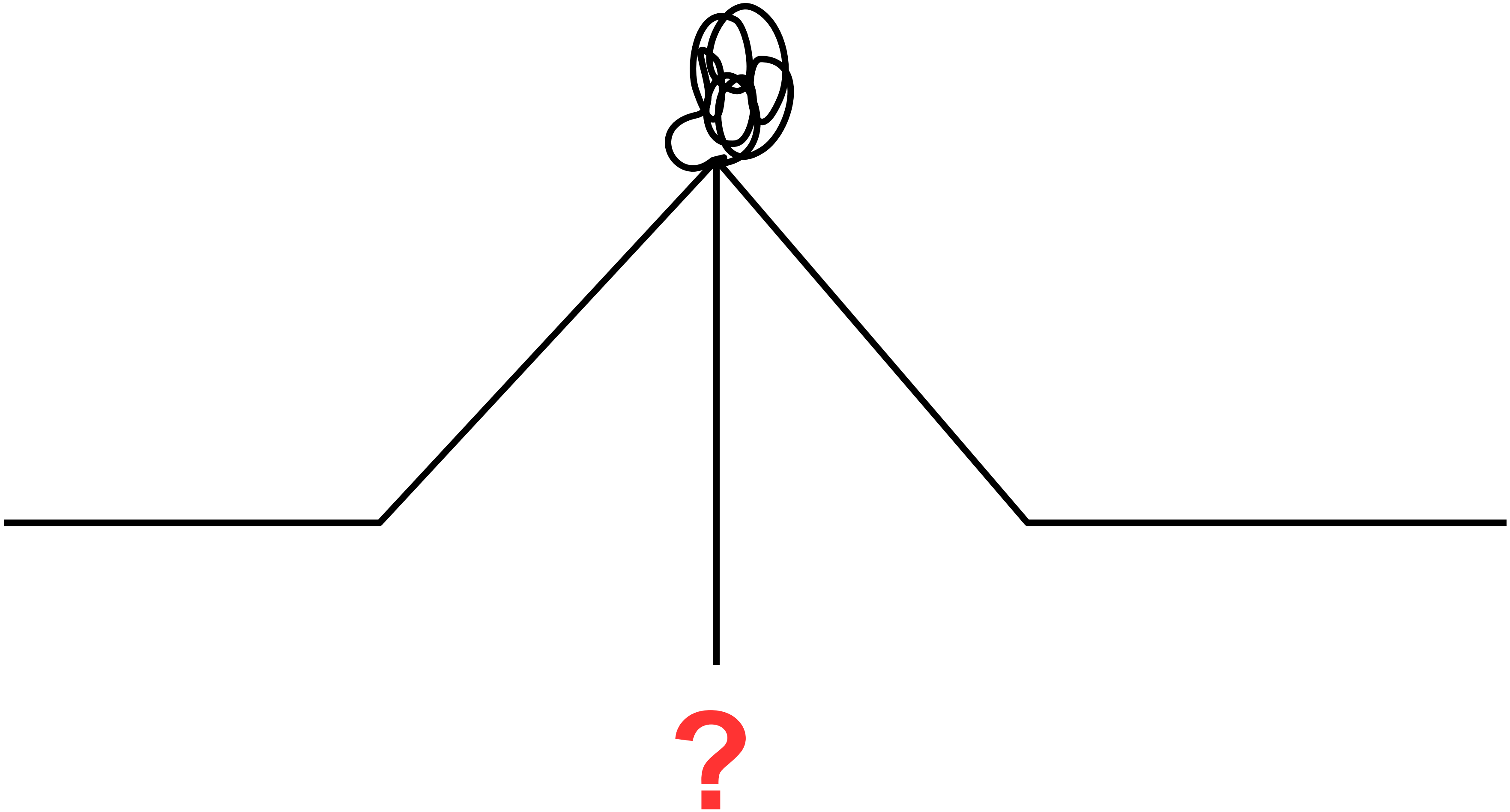
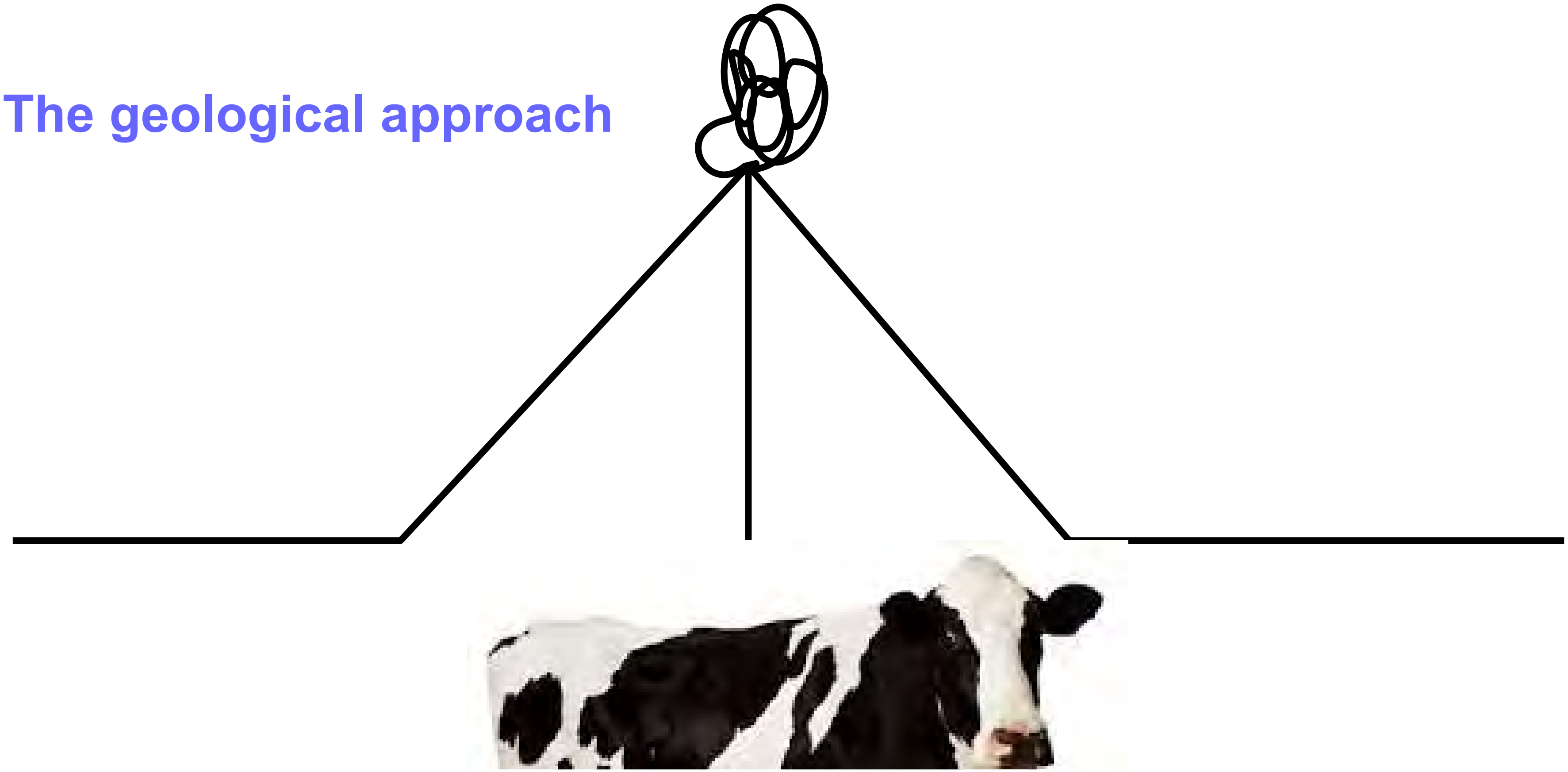
MODELLING MAGMA CHAMBERS



The geological approach



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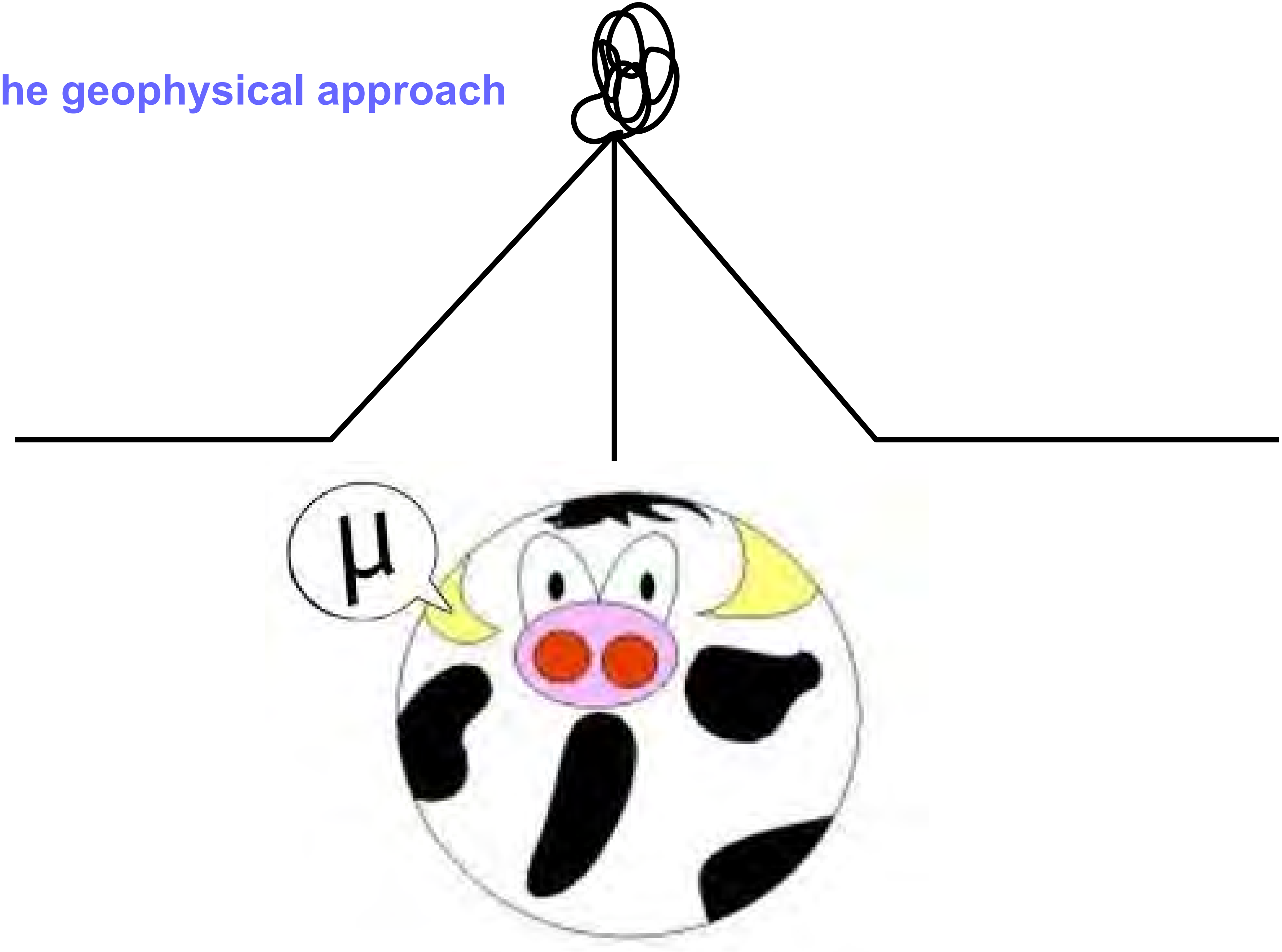
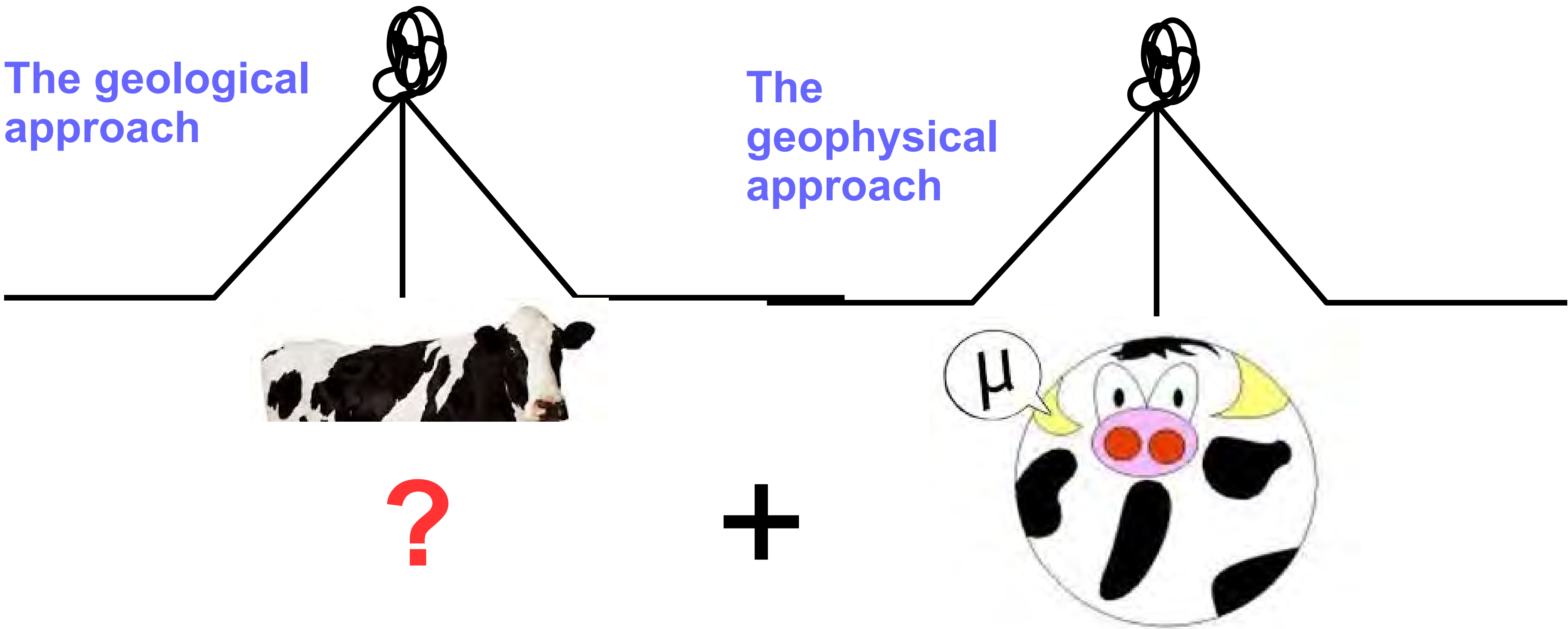
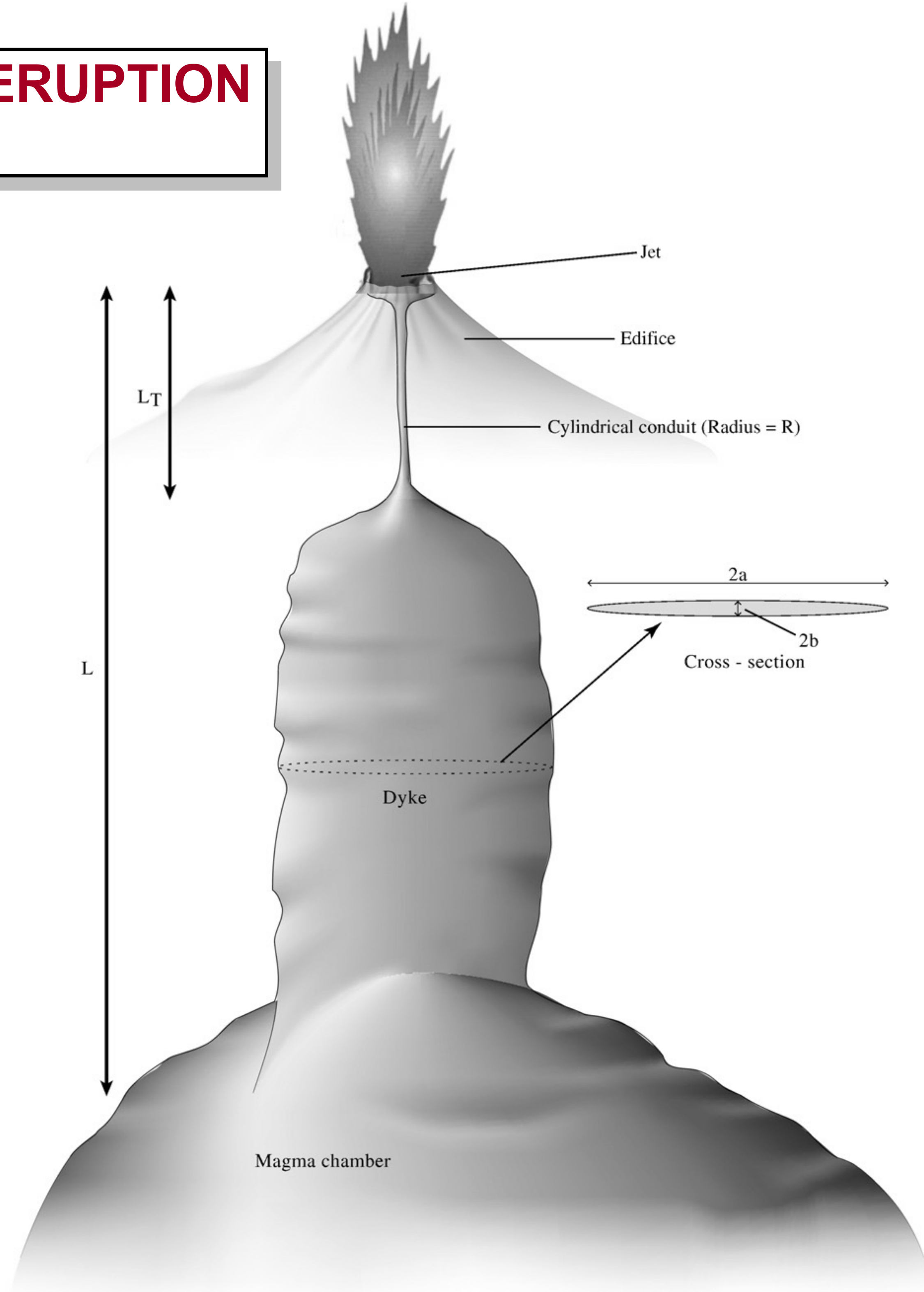
The geophysical approach



THE SOLUTION



MAGMA AND ERUPTION CONDUITS



Costa et al 2009

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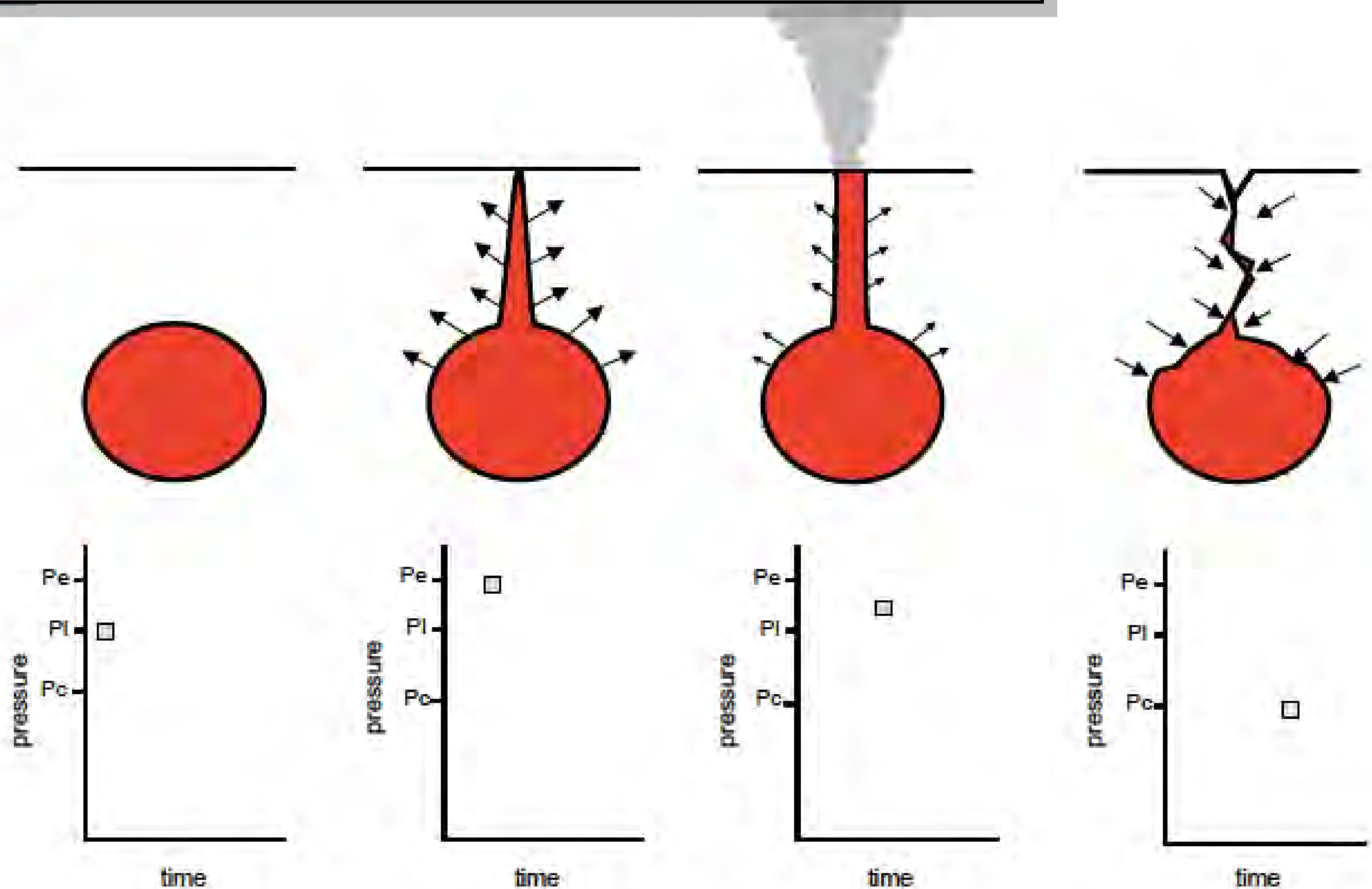
PRESURE EVOLUTION DURING ERUPTIONS



$Pl = \rho_r gh$

$Pe = Pl + Te$

$Pc = Pl - 2S$

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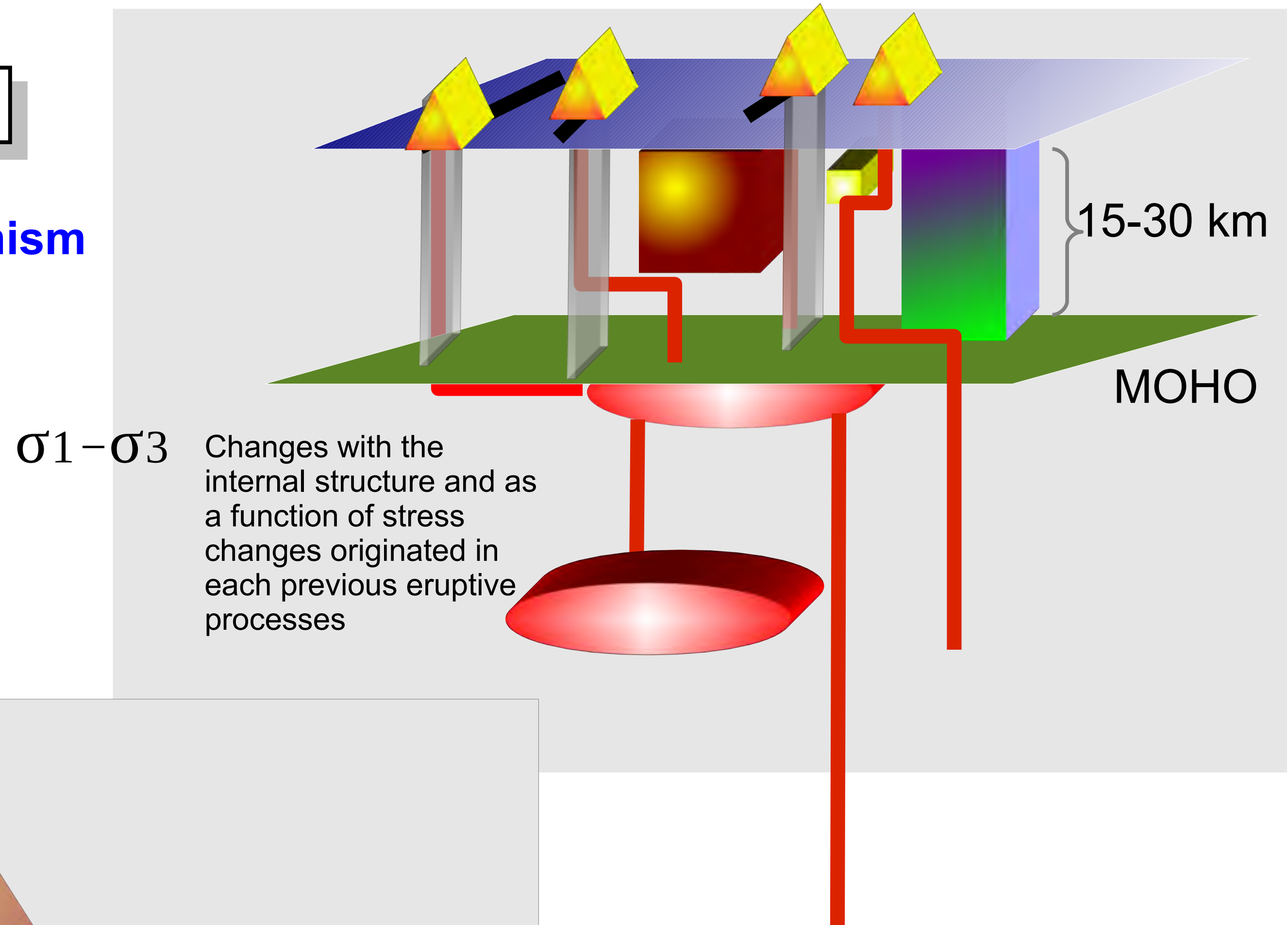
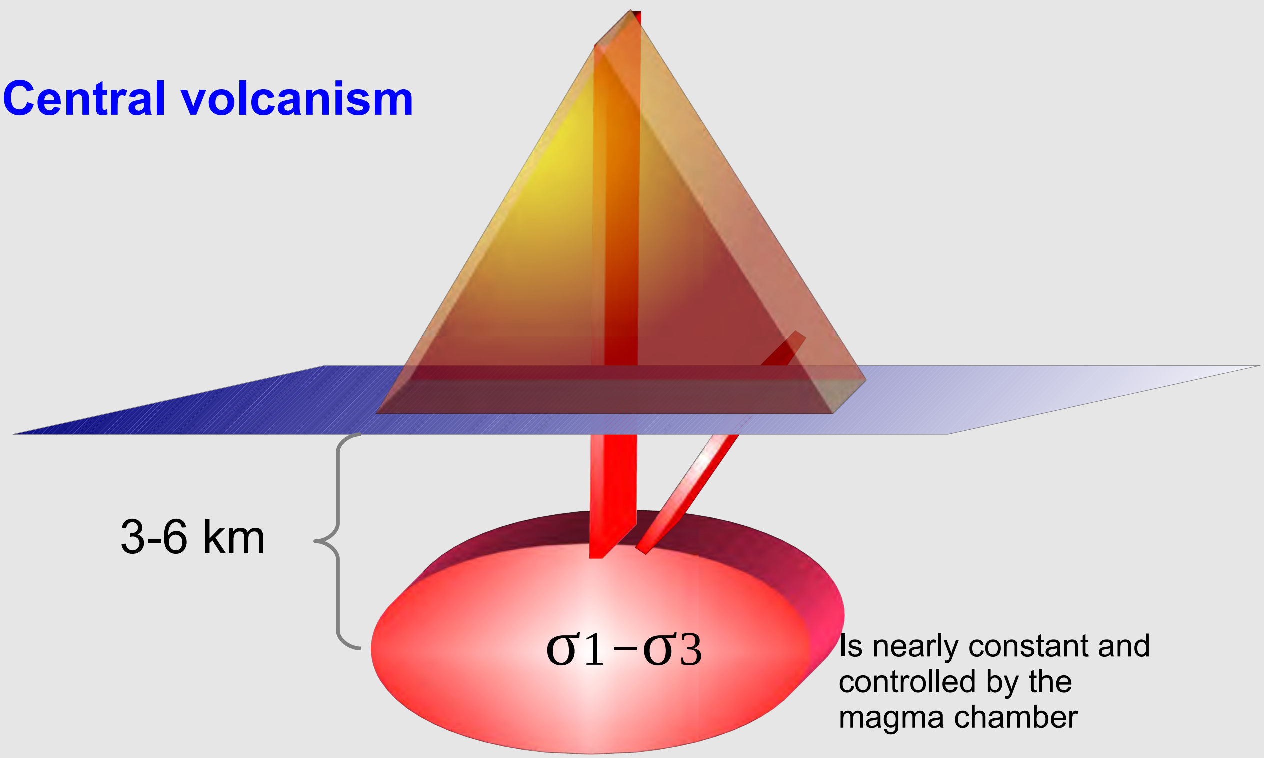
TYPES OF VOLCANISM

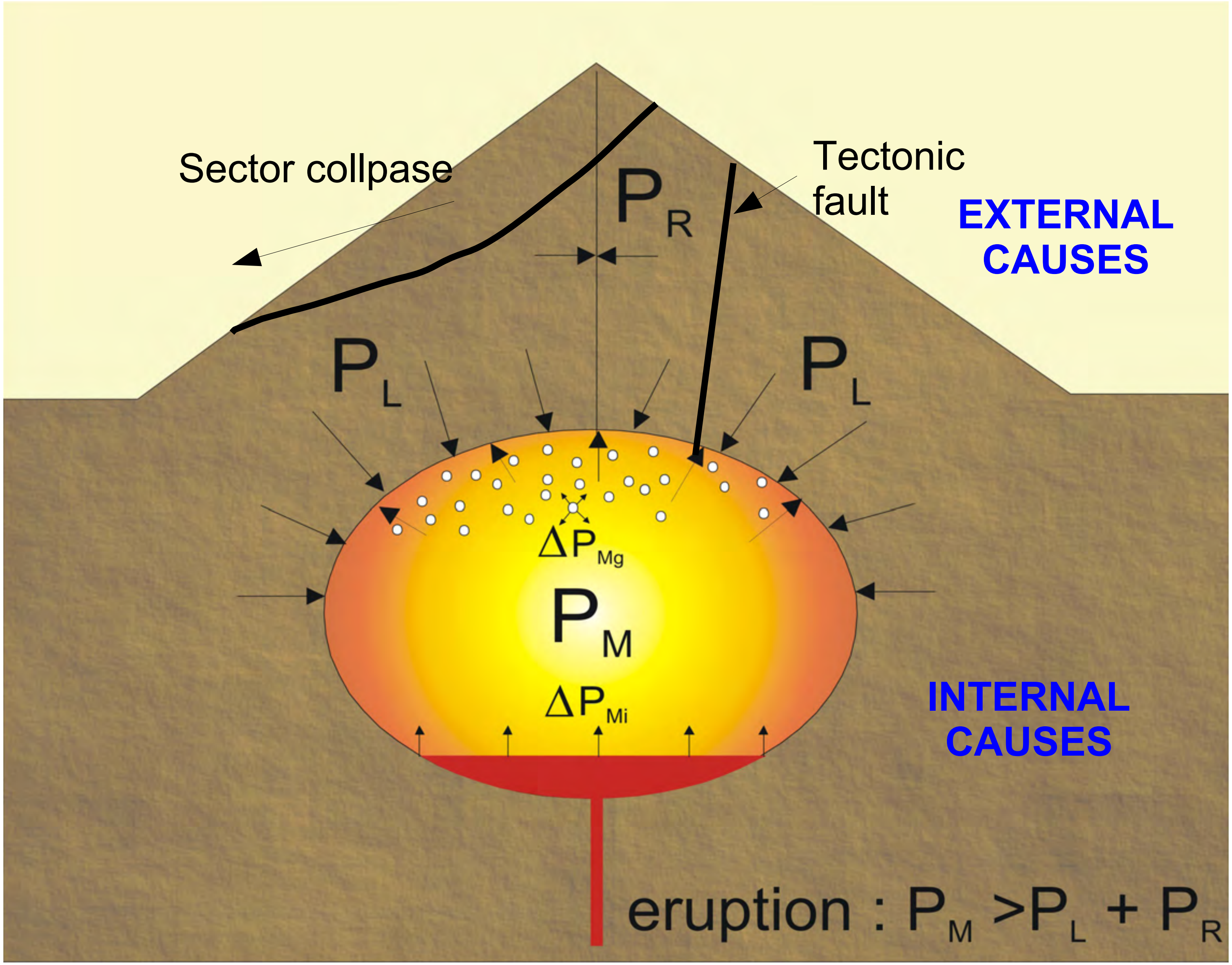
Monogenetic volcanism

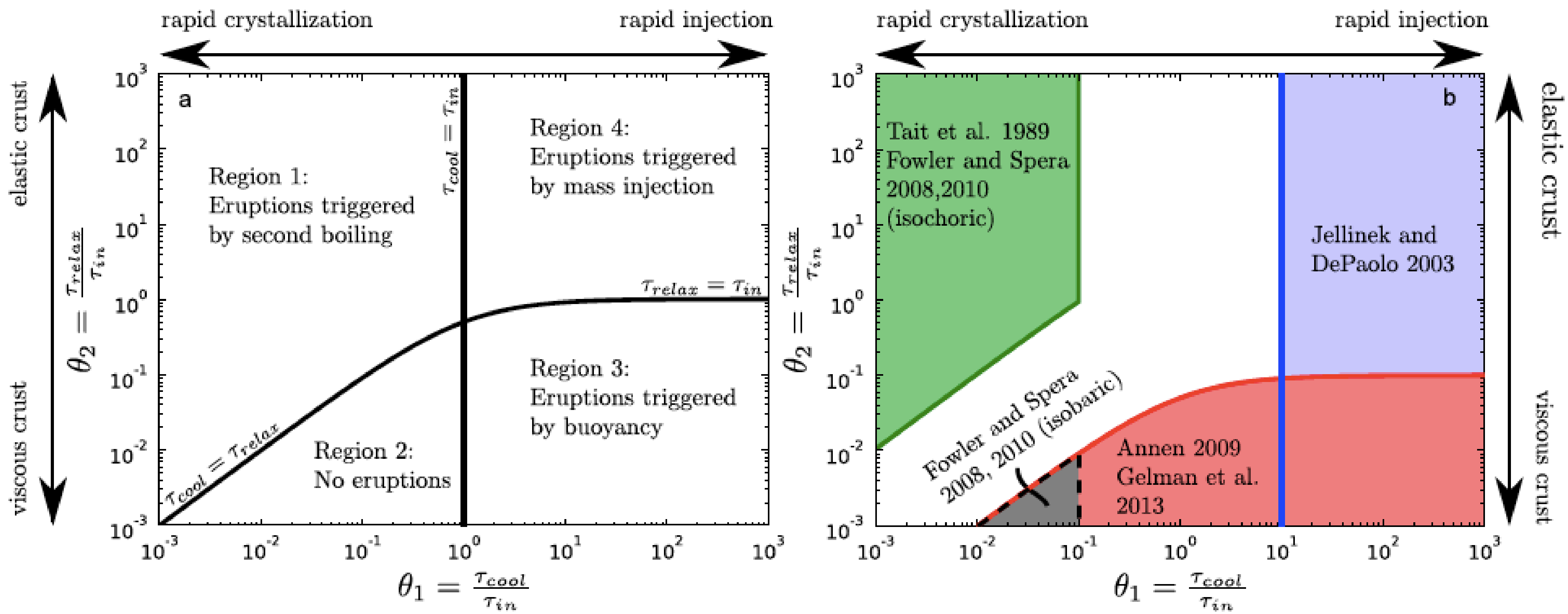


Central volcanism

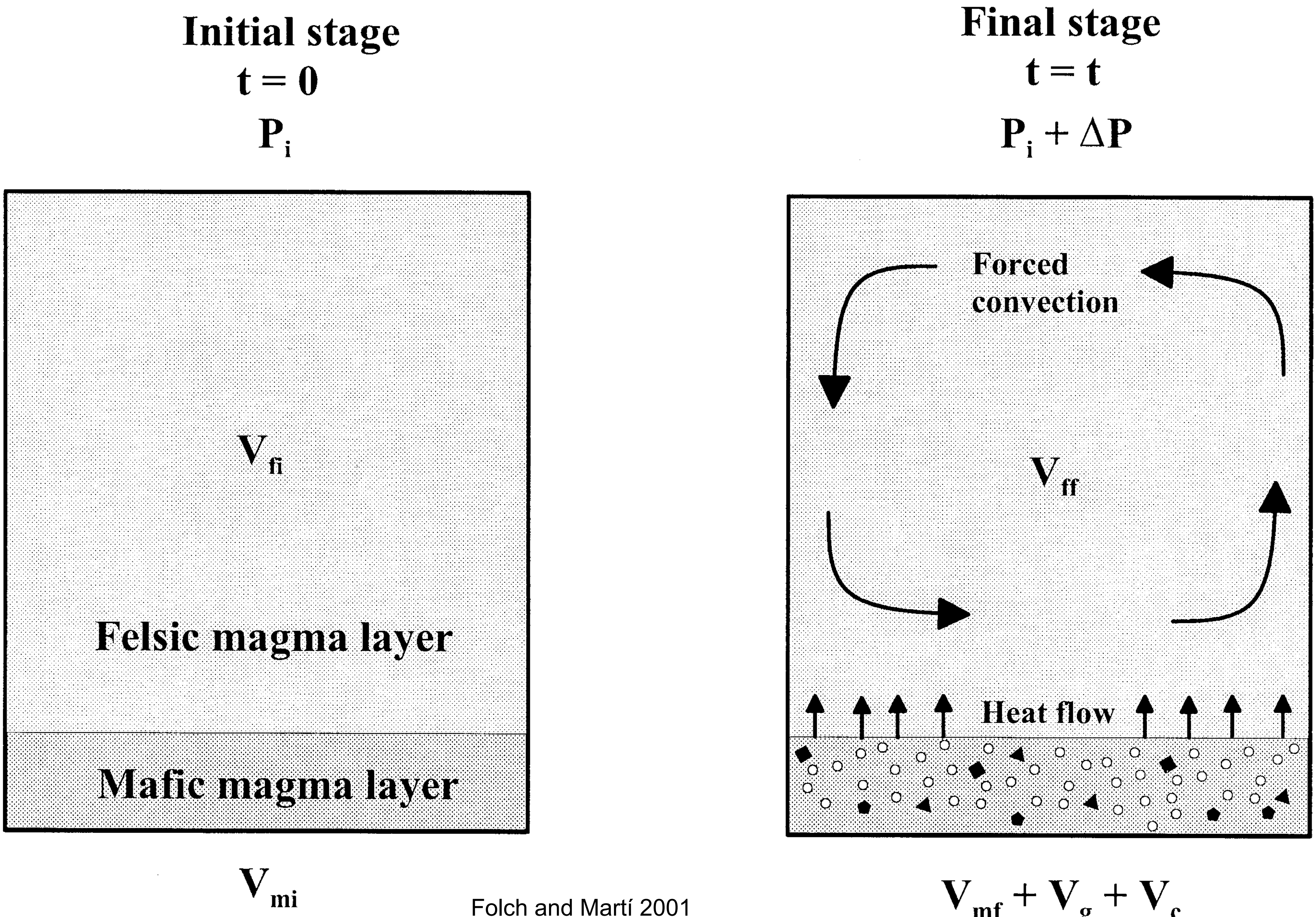


OVERPRESURING A MAGMA CHAMBER





W.Degruyter,C.Huber/EarthandPlanetaryScienceLetters403(2014)117–130



Folch and Martí 2001

THE PINATUBO ERUPTION (1991)

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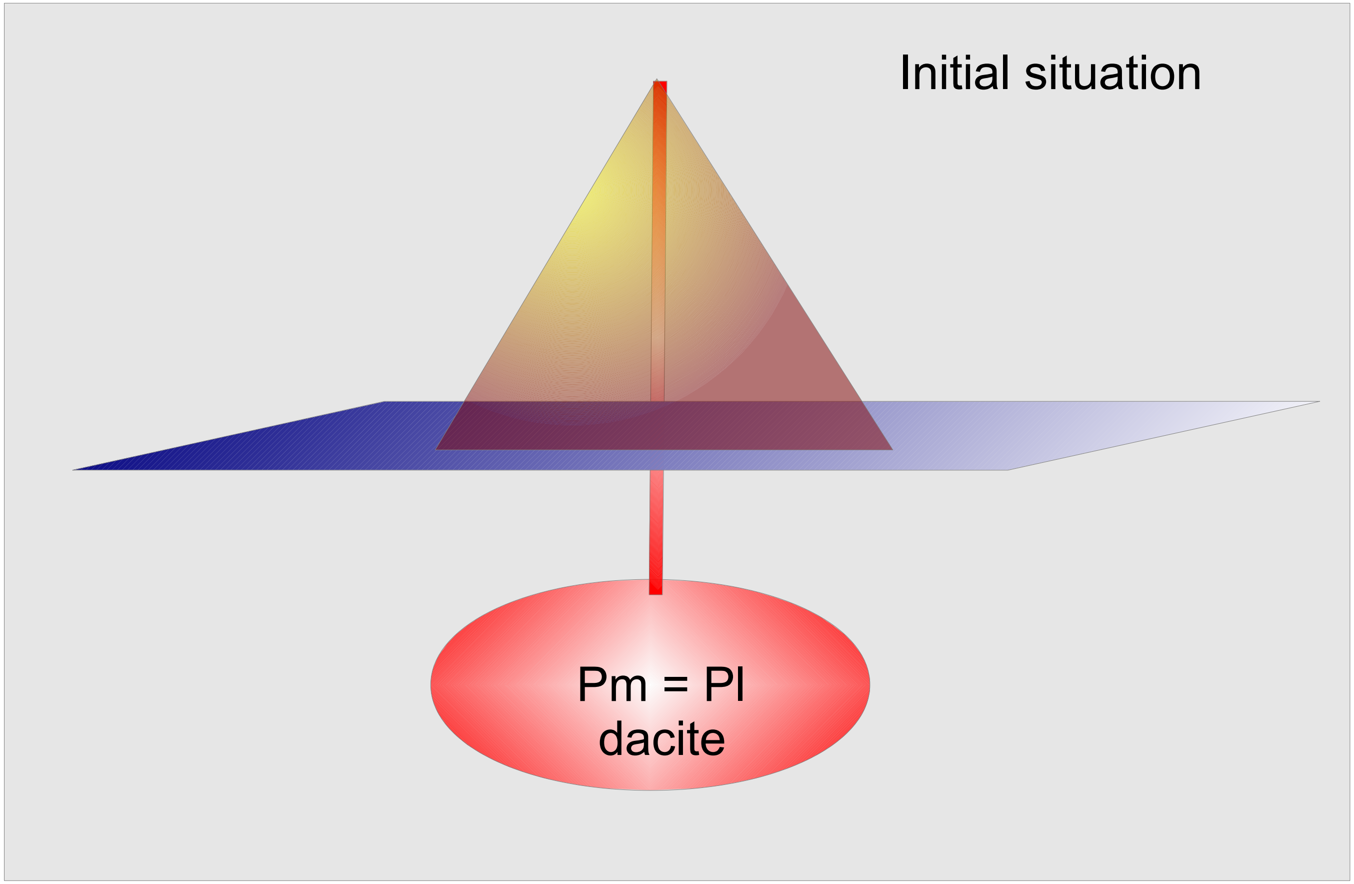

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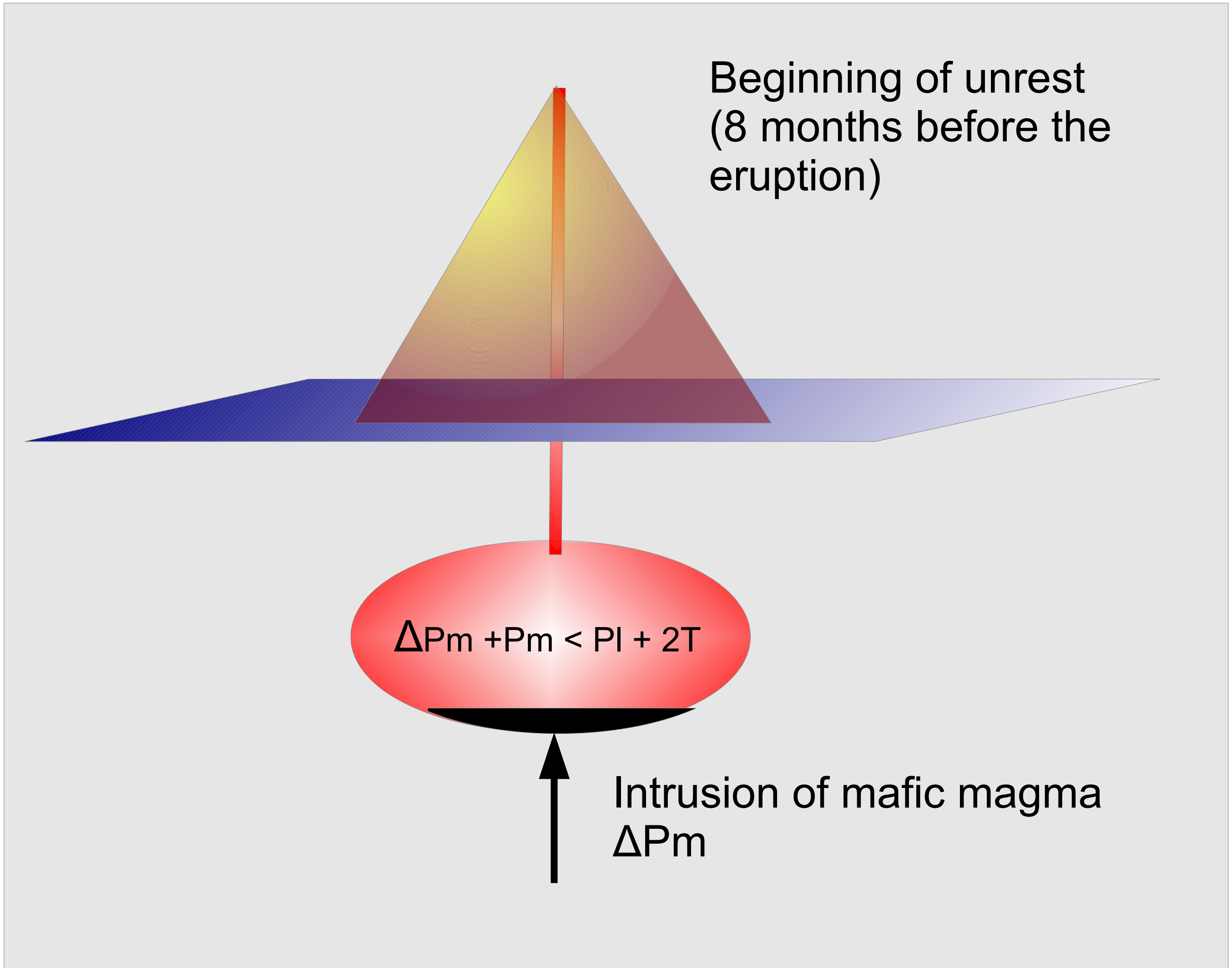
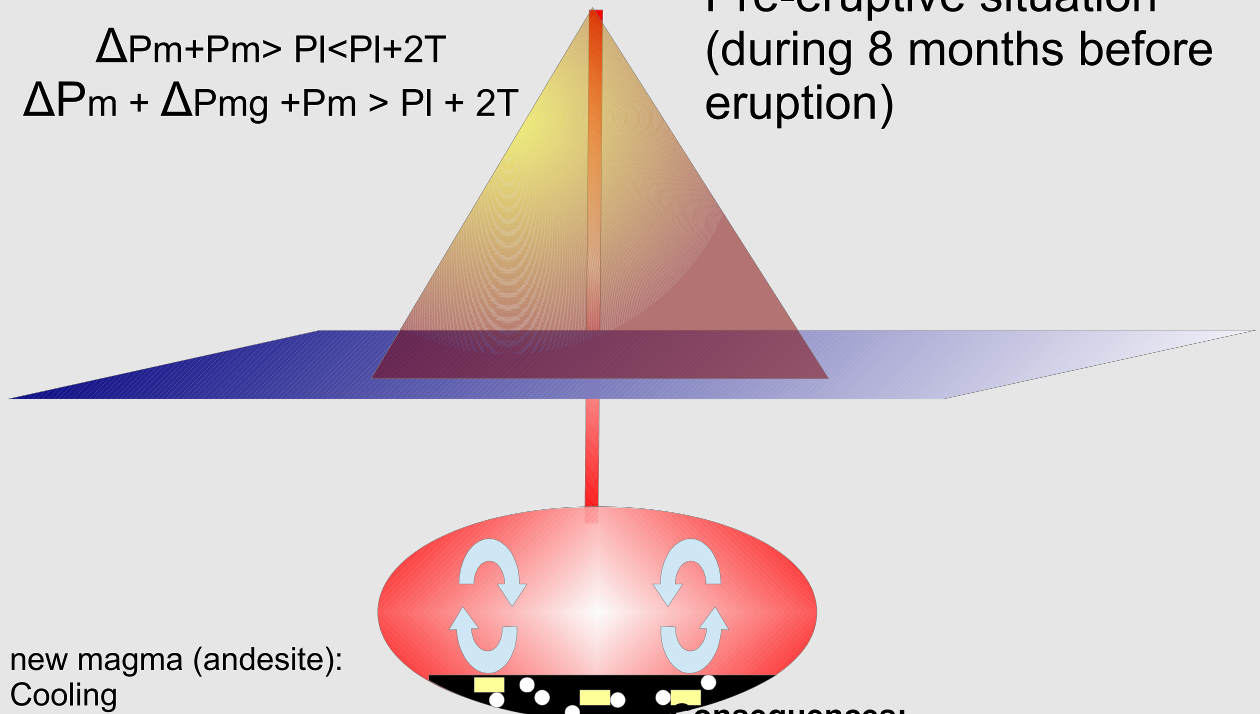

Beginning of unrest
(8 months before the
eruption)
ΔPm +Pm < Pl + 2T
Intrusion of mafic magma
ΔPm

Pre-eruptive situation (during 8 months before eruption)

$\Delta P_m + P_m > P_l < P_l + 2T$

$\Delta P_m + \Delta P_{mg} + P_m > P_l + 2T$



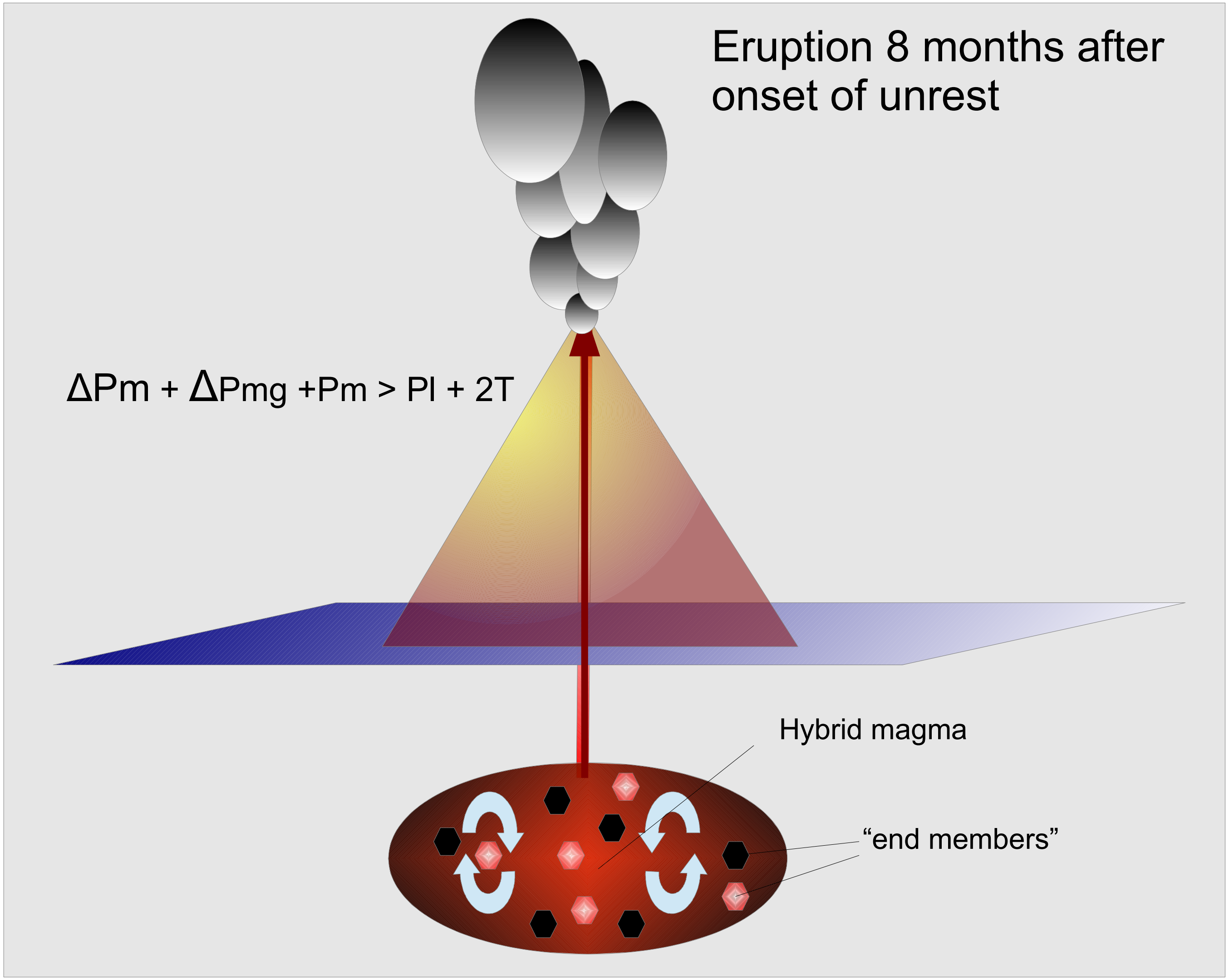
In new magma (andesite):
1. Cooling
2. Massive Crystalisation of plagioclase
3. Oversaturation and exsolution of volatiles

In host magma (dacita):
1. Heating at the contact
2. Forcec convection
3. Mingling
4. Mixing

Consequences:

1) Initial increase of magma chamber pressure due to intrusion (Δpm)

2) Further increse of magma chamber pressure due to gas exsolution (ΔPmg)


Eruption 8 months after onset of unrest
ΔPm + ΔPmg +Pm > Pl + 2T
Hybrid magma
“end members”

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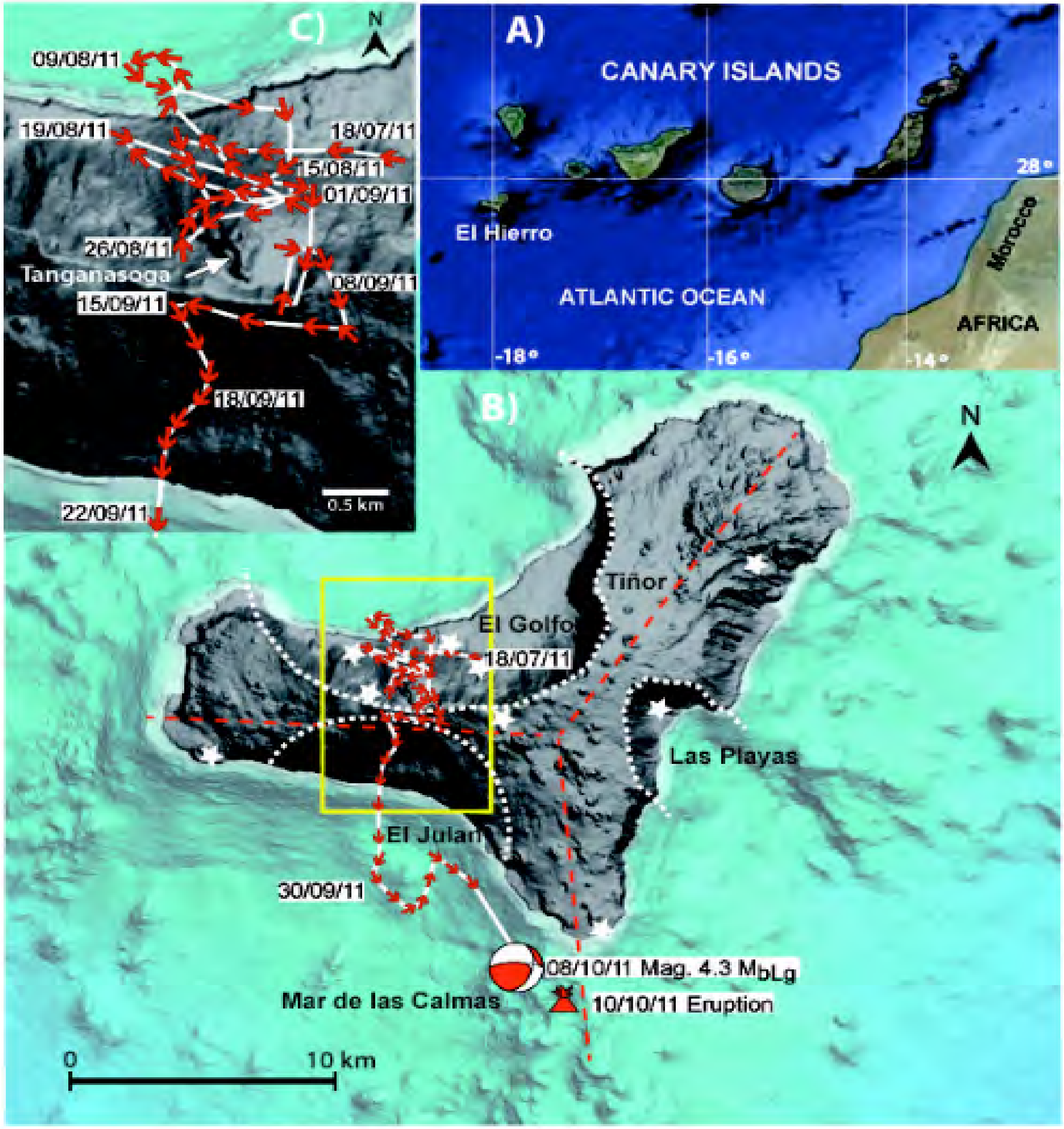
El HIERRO ERUPTION (2011-2012)



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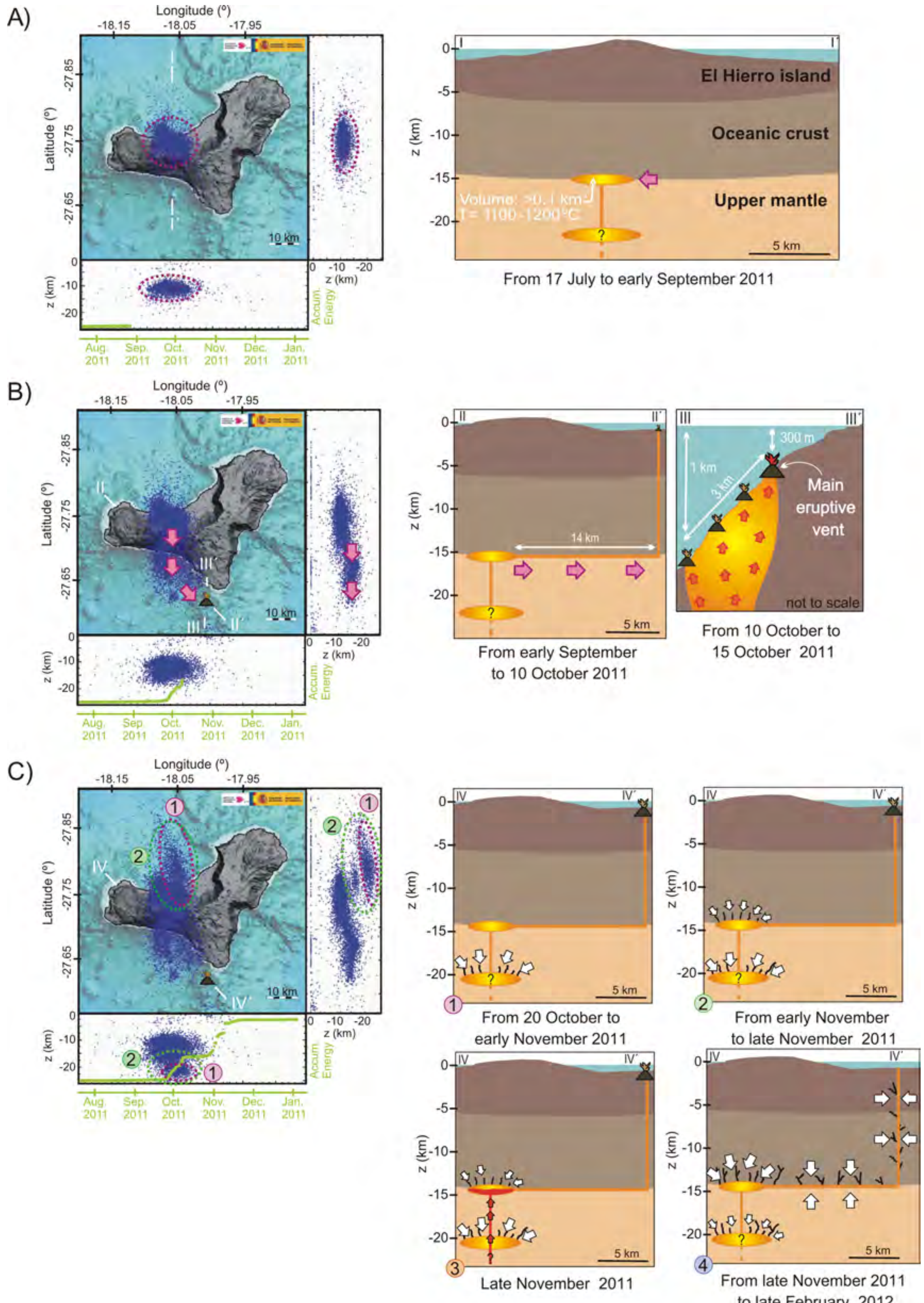
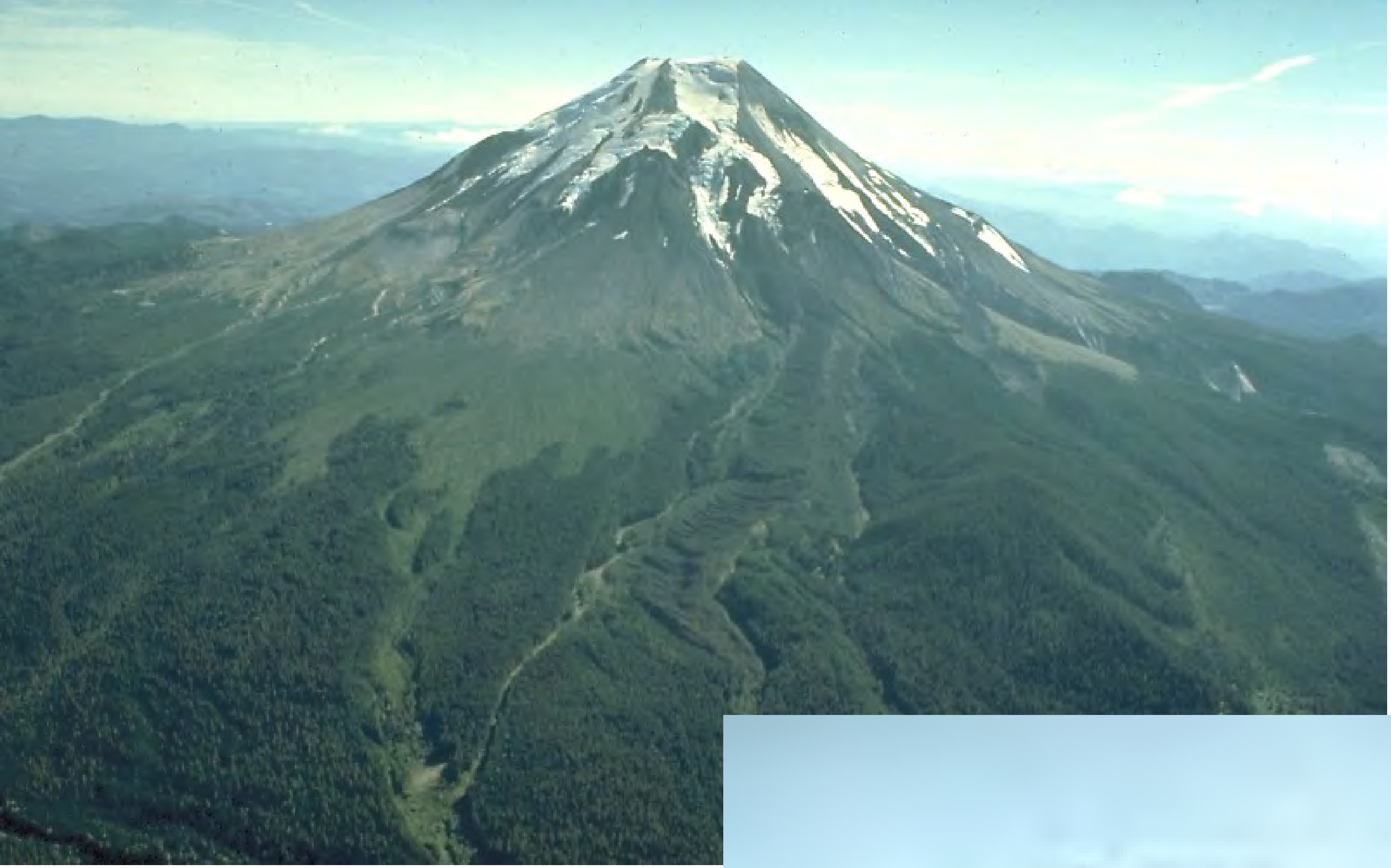

A)
Longitude (°)
-18.15
-18.05
-17.95
Latitude (°)
-27.85
-27.75
-27.65
10 km
z (km)
-10
-20
Accum. Energy
Aug. 2011
Sep. 2011
Oct. 2011
Nov. 2011
Dec. 2011
Jan. 2011
I
I'
El Hierro island
Oceanic crust
Upper mantle
Volume: >0.1 km³
T= 1100-1200°C
5 km
From 17 July to early September 2011
B)
II
II'
III
III'
14 km
From early September to 10 October 2011
300 m
1 km
3 km
Main eruptive vent
not to scale
From 10 October to 15 October 2011
C)
IV
IV'
1
2
3
4
From 20 October to early November 2011
From early November to late November 2011
Late November 2011
From late November 2011 to late February 2012



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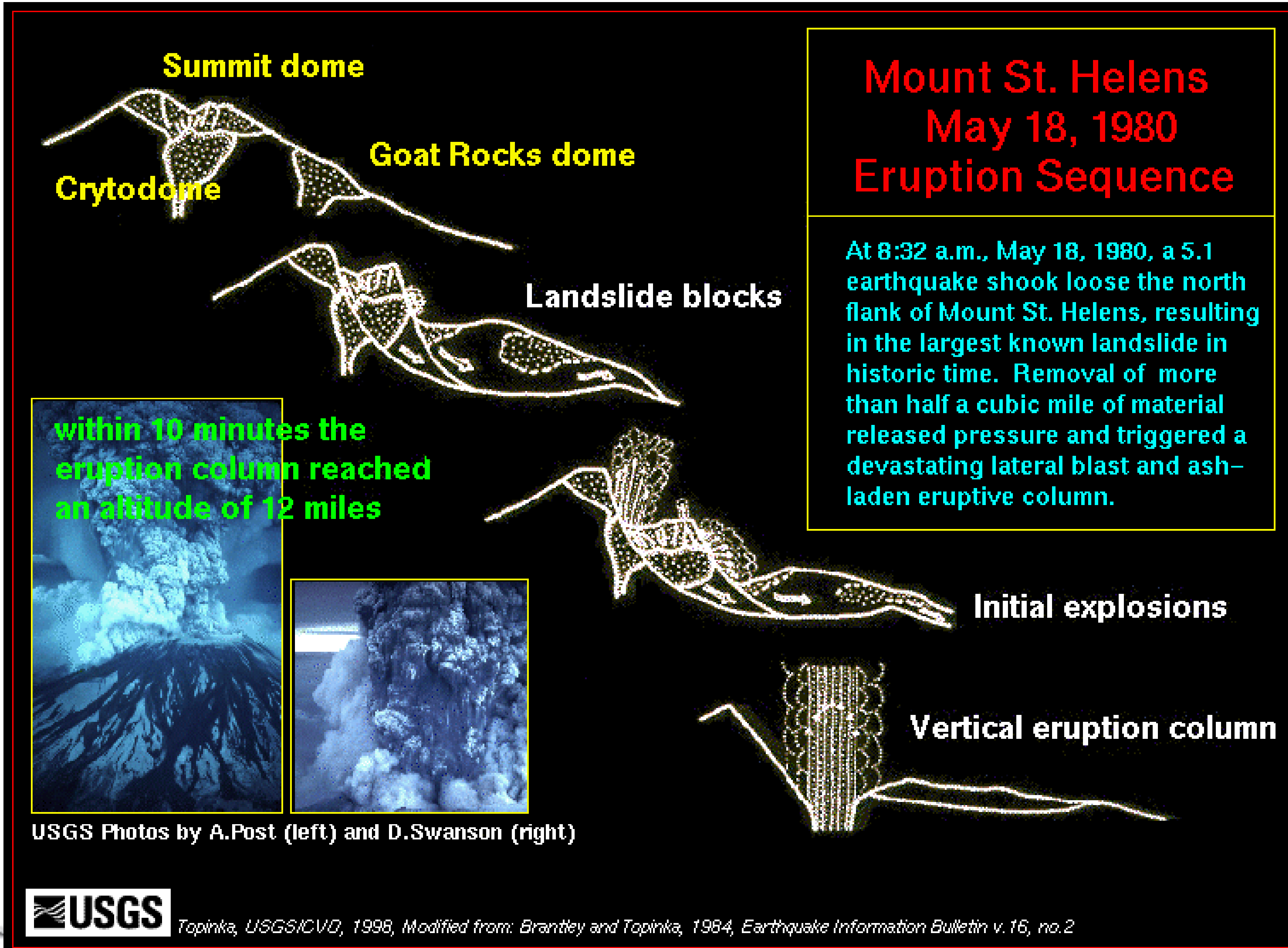

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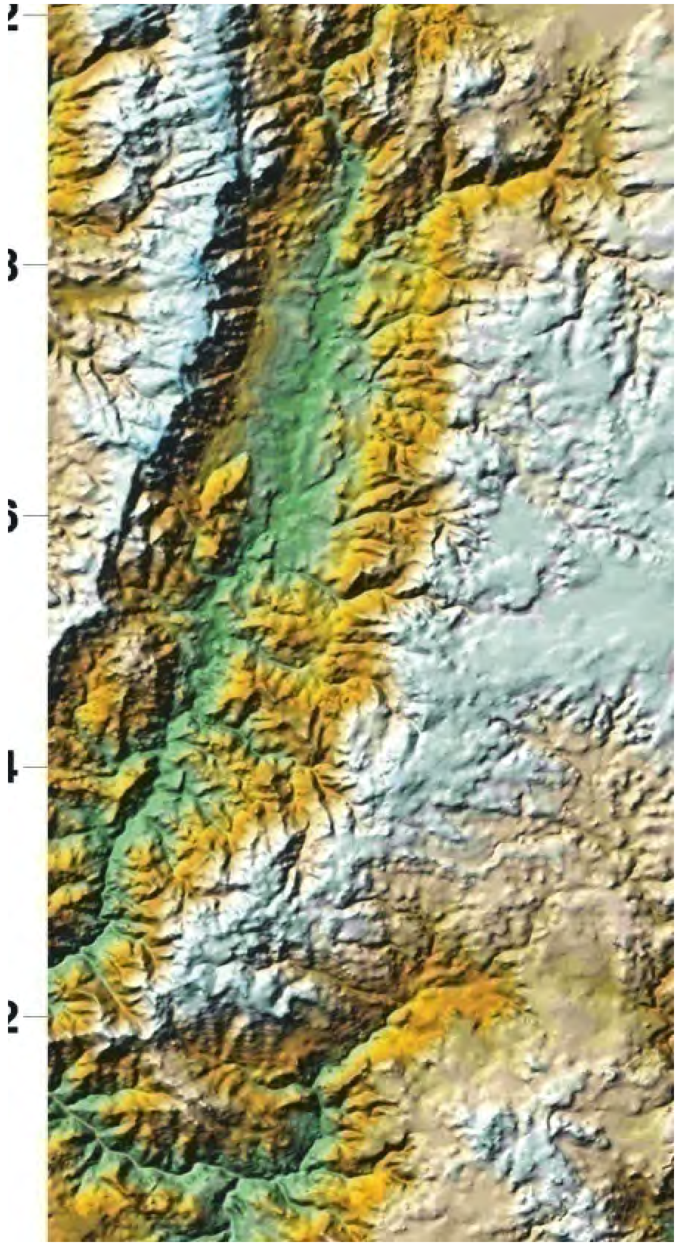
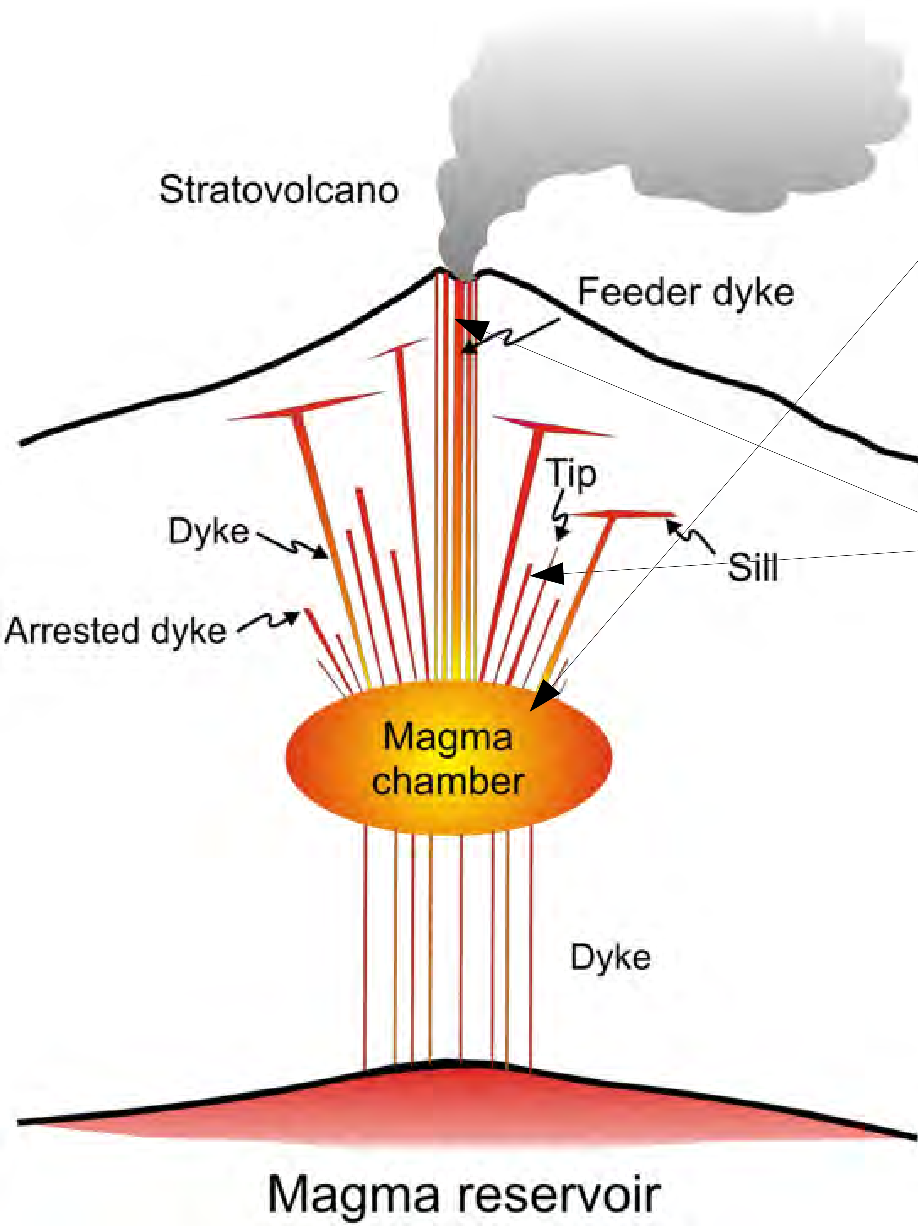


MAGMA CHAMBER RUPTURE



Hydrofracture initiation (Jaeger et al 2007):

Pt = σ3 + To (To is in situ tensile strength of host rock)

Pt = Pl + Pe (Pl: lithostatic pressure; Pe: excess Pressure)

Pl + Pe = σ3 + To

Po = Pe + (ρr + ρm) gh + σ3

(Po: magmatic overpressure in the dyke)
(h: dip dimension or height of that part of the dyke above the point of rupture and dyke initiation, and σd is the differential stress (σd=σ1−σ3) at the level where the dyke is examined

Gudmundsson 2012

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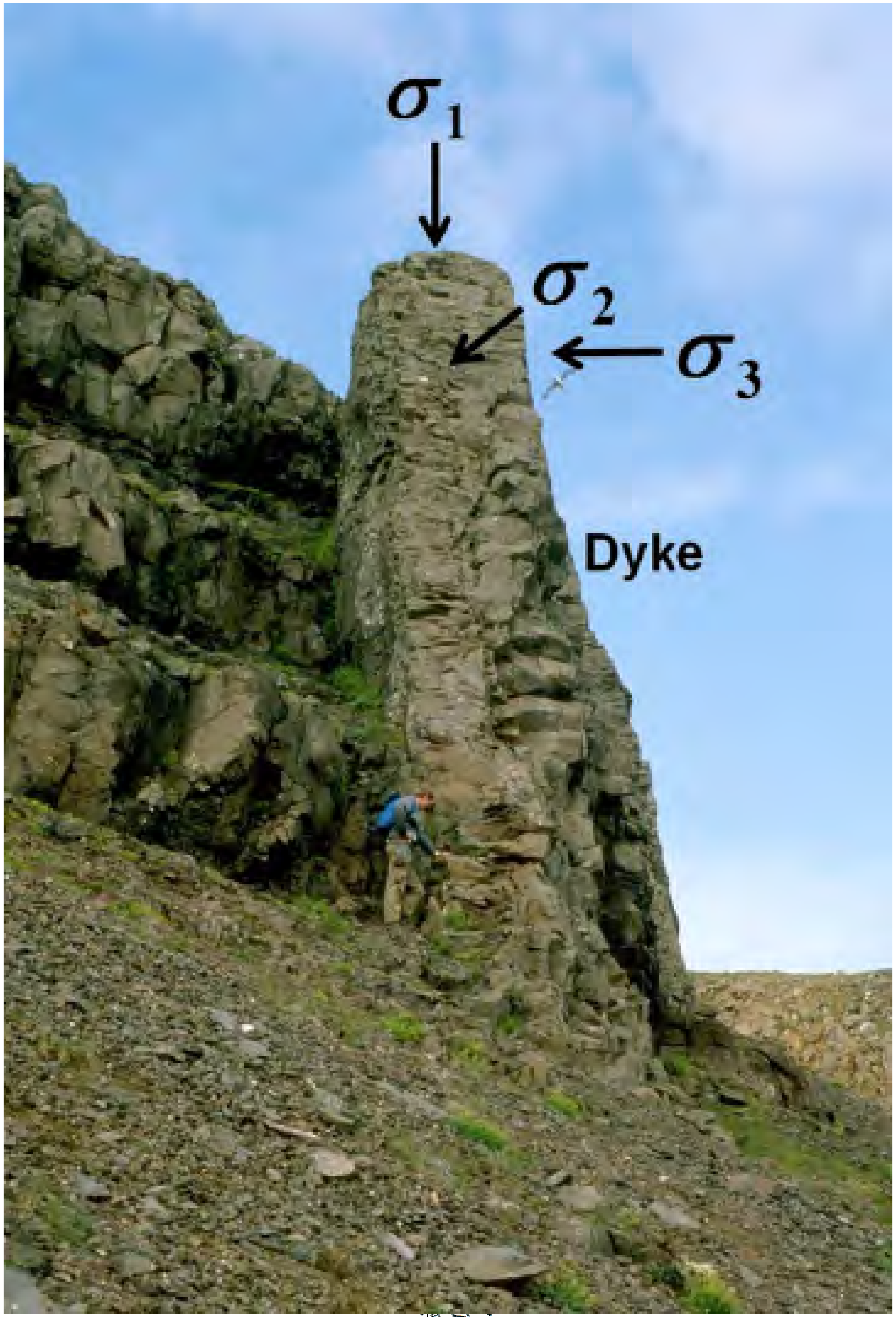

Gudmundsson 2012

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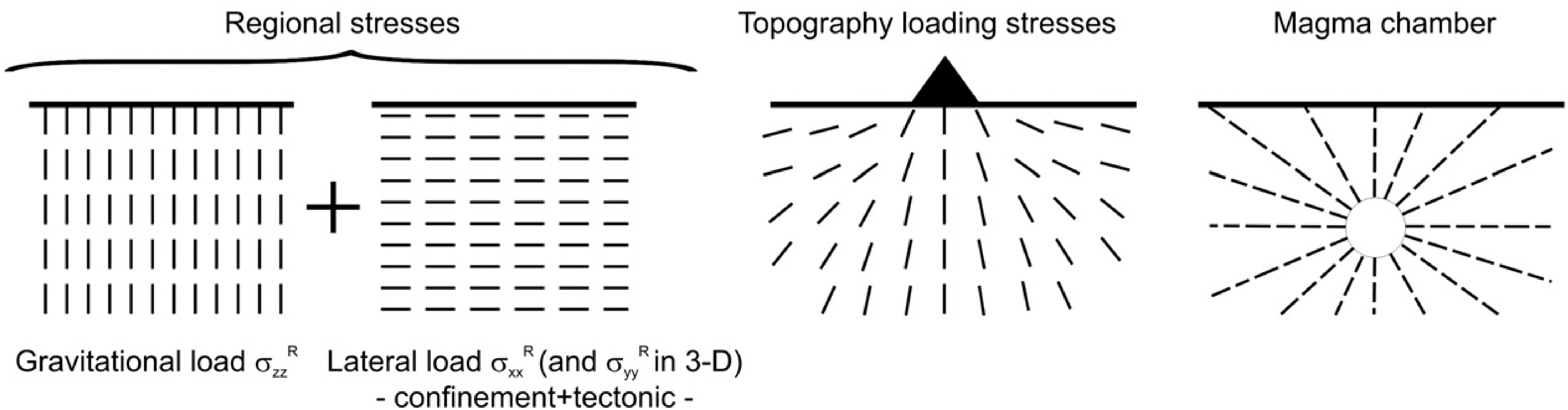
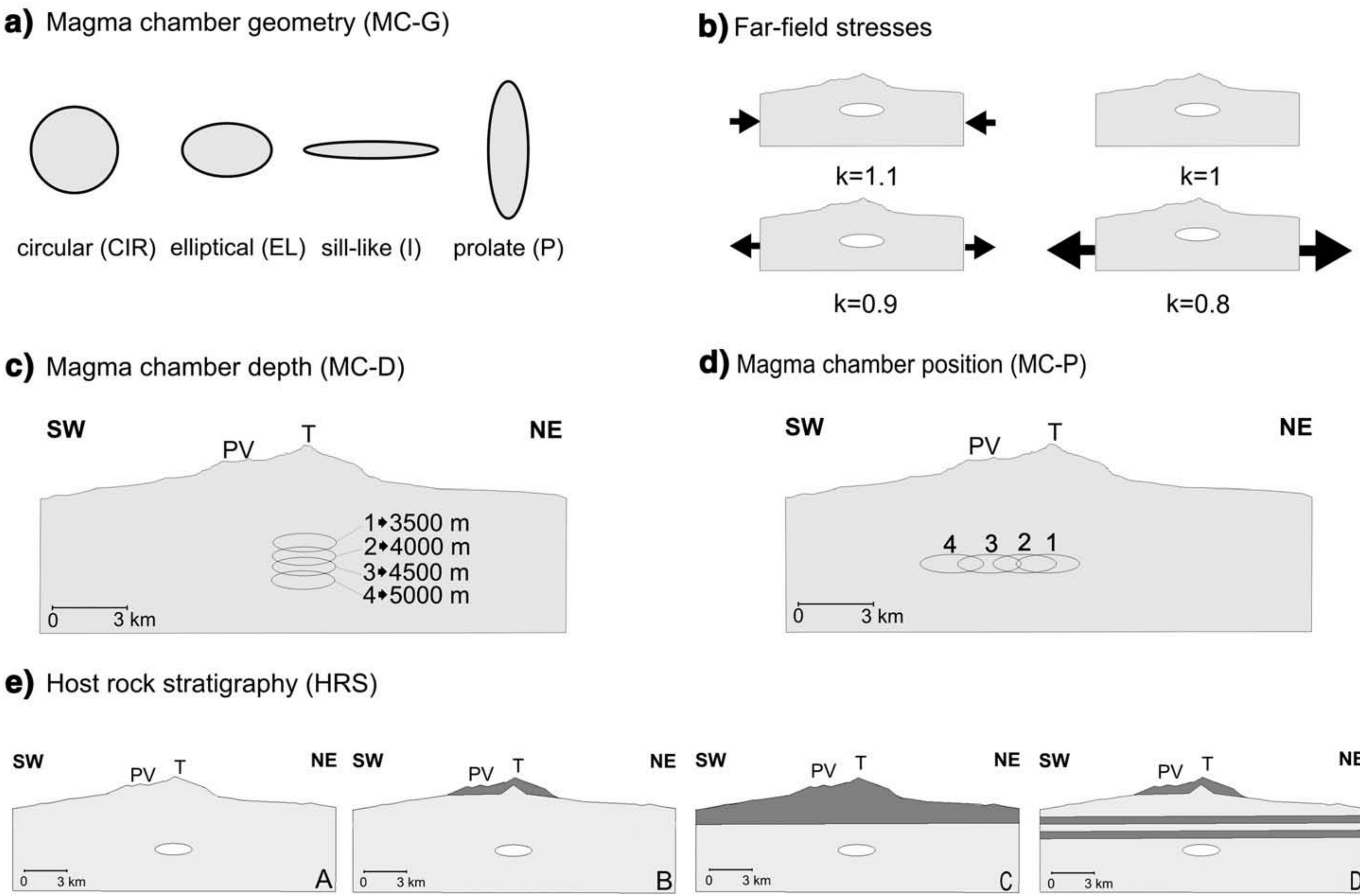
Stress field components



Martí and Geyer 2009

Variations in the models with one magma chamber

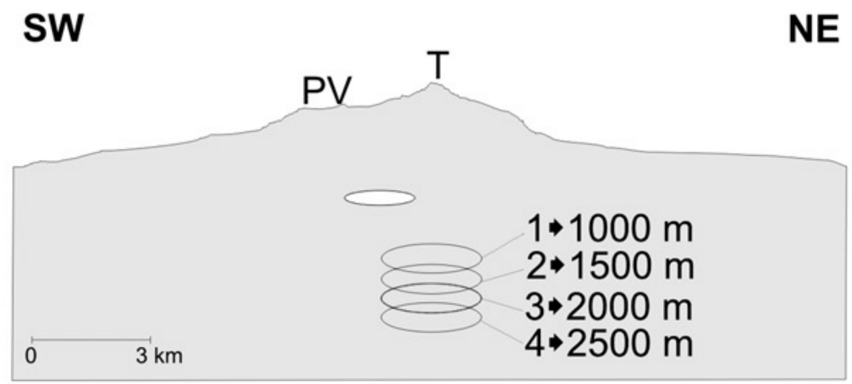


Host rock materials (Mat)

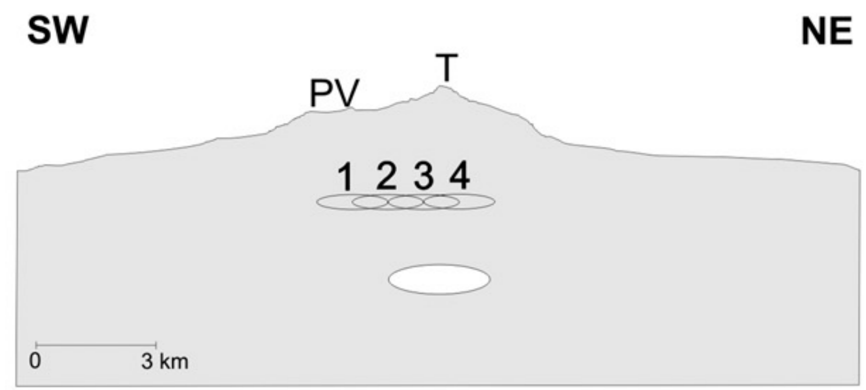
1: E=50 GPa ν=0.25 ρ=2750 kg/m³ or **2:** E=60 GPa ν=0.25 ρ=2800 kg/m³ **3:** E=40 GPa ν=0.18 ρ=2400kg/m³

Variations in the models with two magma chambers

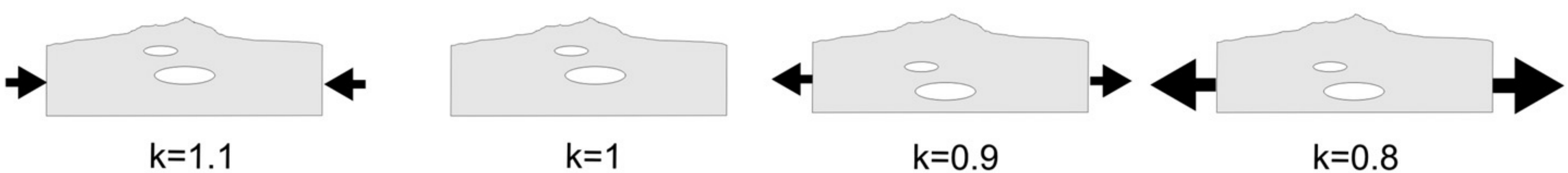
a) Relative magma chambers distance (MC-dis)



b) Secondary magma chamber position (MC-pos)



c) Far-field stresses



Host rock material (Mat)

1: E=50 GPa ν=0.25 ρ=2750 kg/m^3

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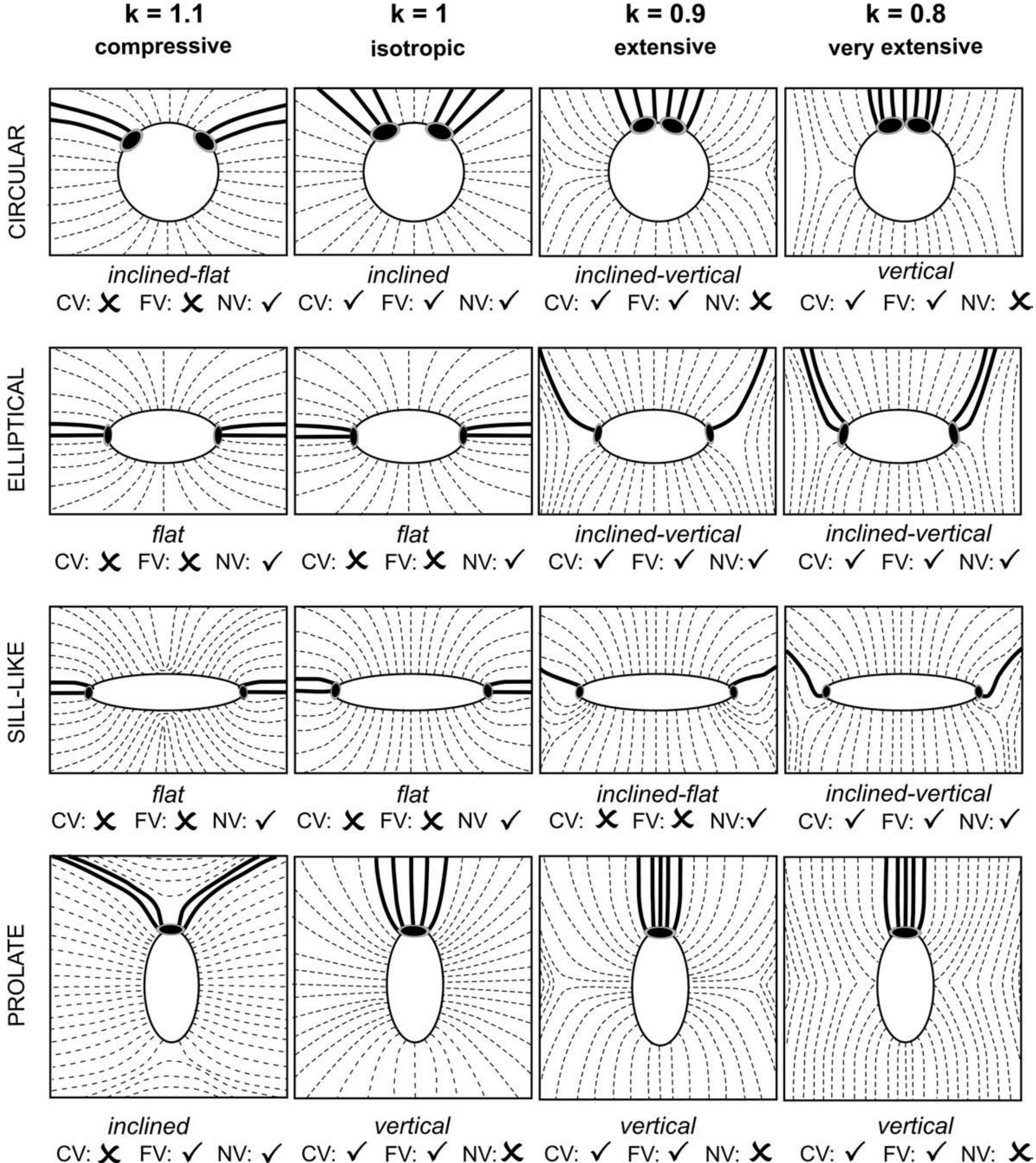
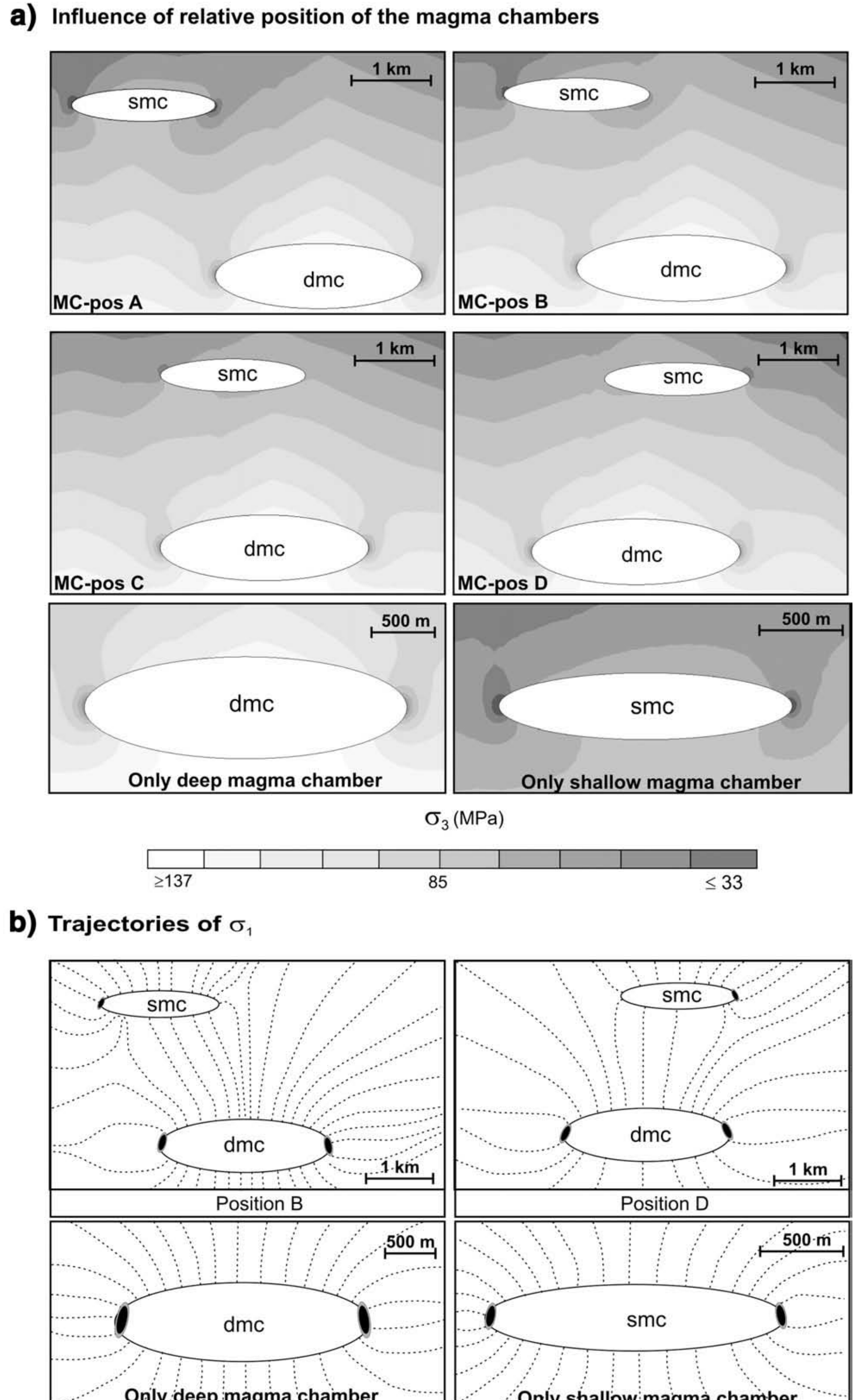
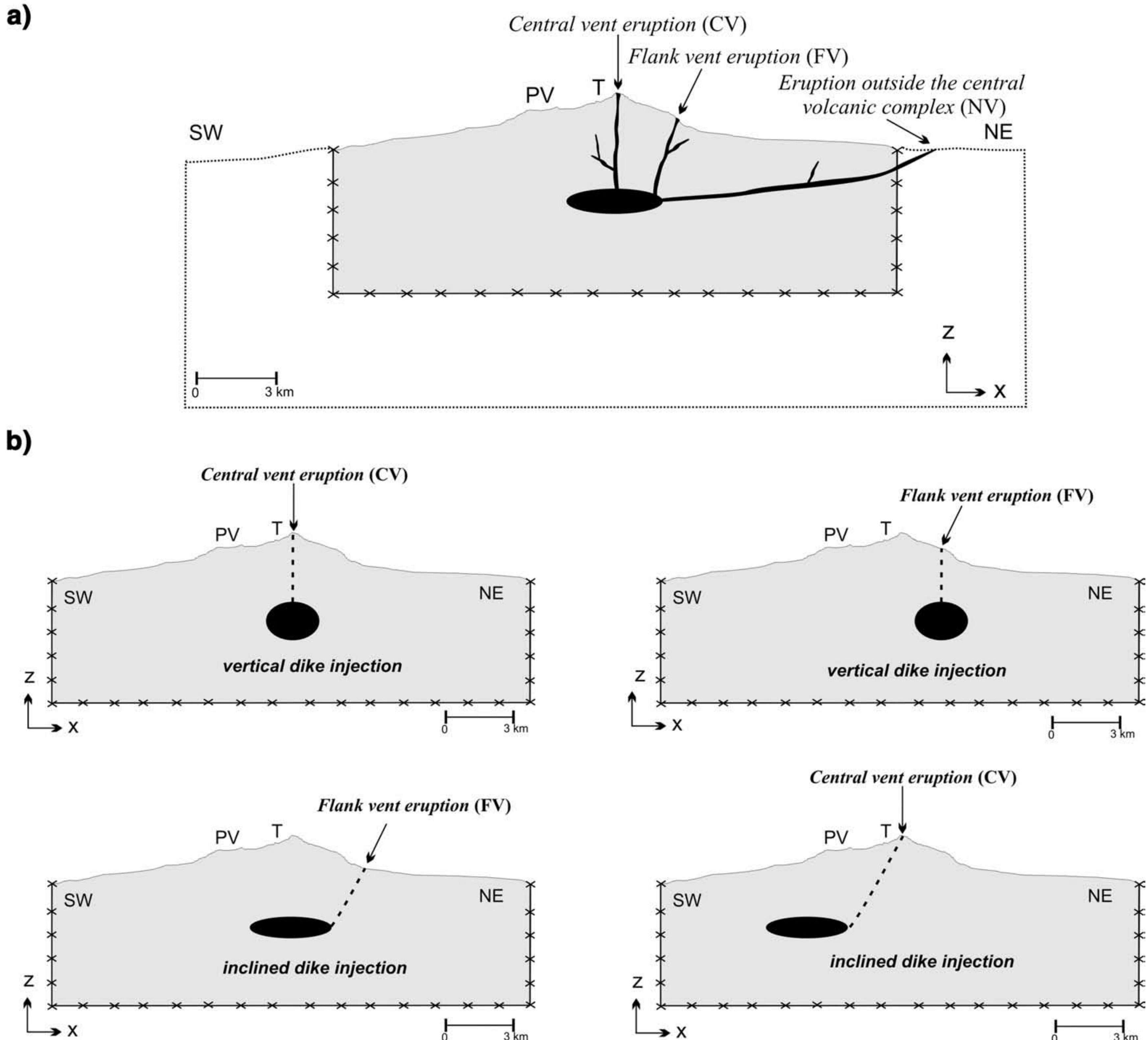


k = 1.1
compressive
k = 1
isotropic
k = 0.9
extensive
k = 0.8
very extensive
CIRCULAR
inclined-flat
CV: ✗ FV: ✗ NV: ✓
inclined
CV: ✓ FV: ✓ NV: ✓
inclined-vertical
CV: ✓ FV: ✓ NV: ✗
vertical
CV: ✓ FV: ✓ NV: ✗
ELLIPTICAL
flat
CV: ✗ FV: ✗ NV: ✓
flat
CV: ✗ FV: ✗ NV: ✓
inclined-vertical
CV: ✓ FV: ✓ NV: ✓
inclined-vertical
CV: ✓ FV: ✓ NV: ✓
SILL-LIKE
flat
CV: ✗ FV: ✗ NV: ✓
flat
CV: ✗ FV: ✗ NV ✓
inclined-flat
CV: ✗ FV: ✗ NV: ✓
inclined-vertical
CV: ✓ FV: ✓ NV: ✓
PROLATE
inclined
CV: ✗ FV: ✓ NV: ✓
vertical
CV: ✓ FV: ✓ NV: ✗
vertical
CV: ✓ FV: ✓ NV: ✗
vertical
CV: ✓ FV: ✓ NV: ✗


a) Influence of relative position of the magma chambers
1 km
smc
dmc
MC-pos A
1 km
smc
dmc
MC-pos B
1 km
smc
dmc
MC-pos C
1 km
smc
dmc
MC-pos D
500 m
dmc
Only deep magma chamber
500 m
smc
Only shallow magma chamber
σ_3 (MPa)
≥137
85
≤ 33
b) Trajectories of σ_1
smc
dmc
1 km
Position B
smc
dmc
1 km
Position D
500 m
dmc
Only deep magma chamber
500 m
smc
Only shallow magma chamber


a)
Central vent eruption (CV)
Flank vent eruption (FV)
Eruption outside the central volcanic complex (NV)
PV
T
SW
NE
0
3 km
Z
X
b)
Central vent eruption (CV)
PV
T
SW
NE
vertical dike injection
Z
X
0
3 km
Flank vent eruption (FV)
PV
T
SW
NE
vertical dike injection
Z
X
0
3 km
Flank vent eruption (FV)
PV
T
SW
NE
inclined dike injection
Z
X
0
3 km
Central vent eruption (CV)
PV
T
SW
NE
inclined dike injection
Z
X
0
3 km