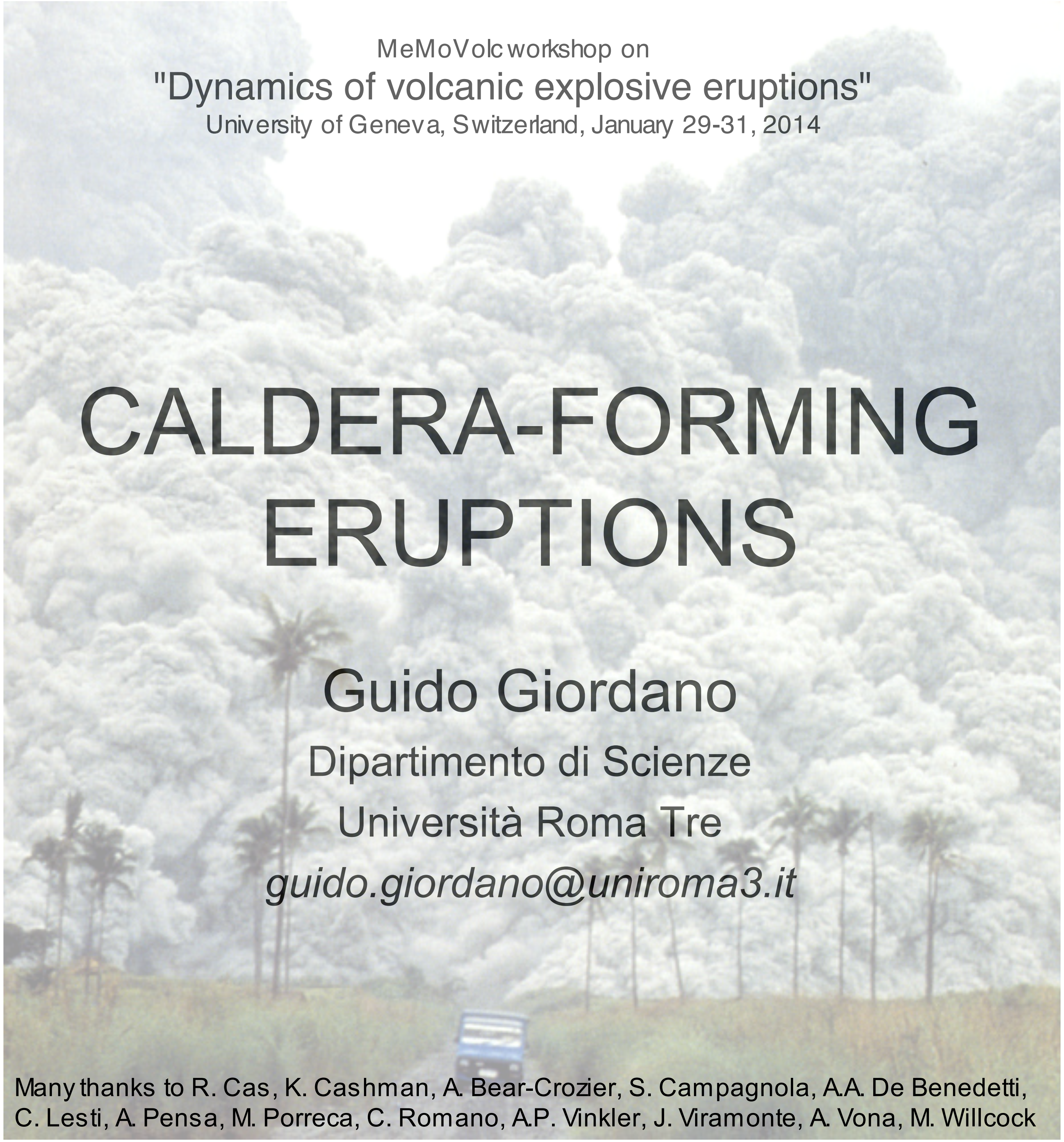

MeMoVolc workshop on

"Dynamics of volcanic explosive eruptions"

University of Geneva, Switzerland, January 29-31, 2014

CALDERA-FORMING ERUPTIONS

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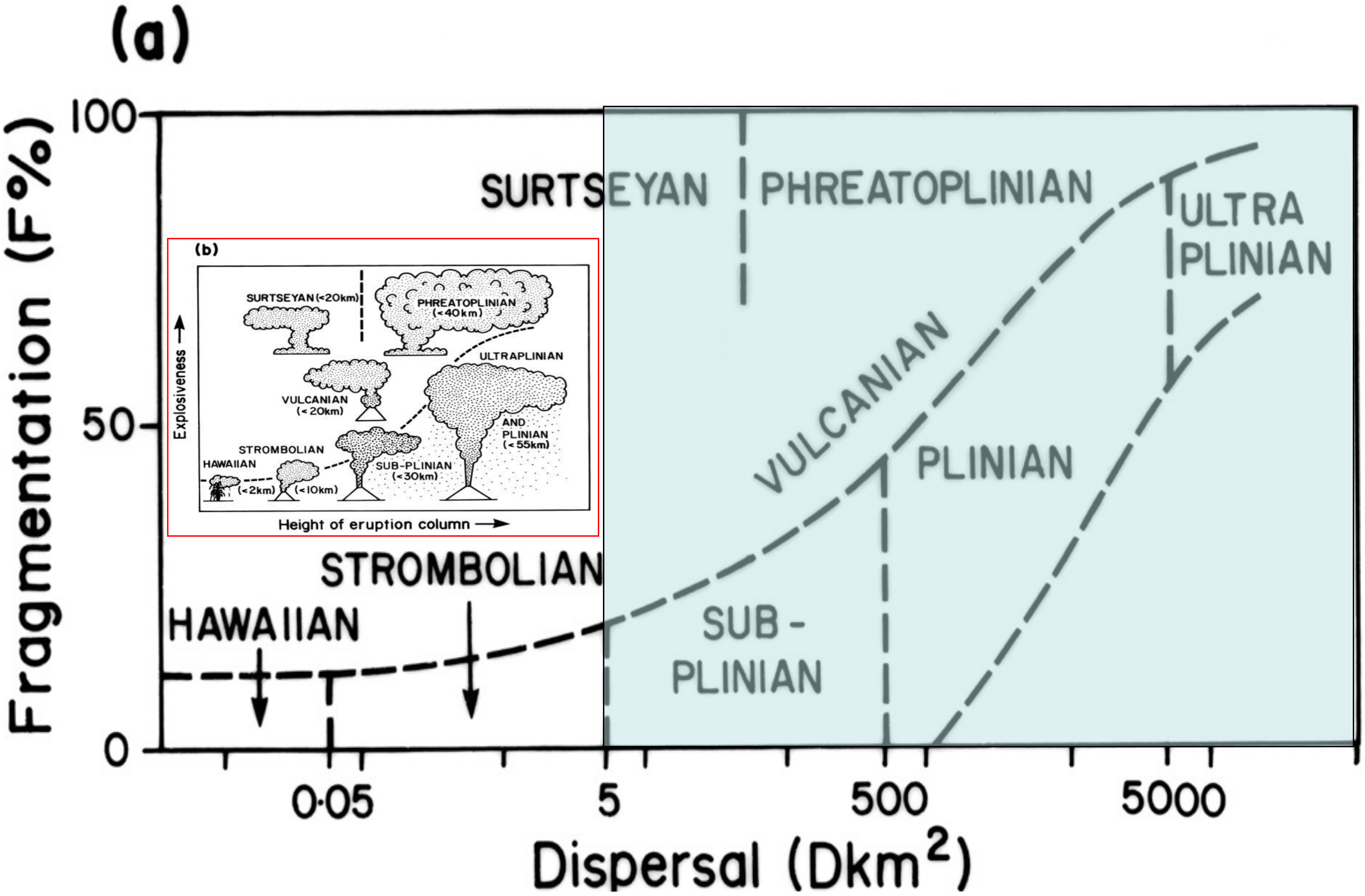
Talk outline

- Current classifications, calderas and ignimbrites
- Caldera-forming ignimbrites: how and when? some examples of end member types
- Discussion on what can be used to describe and classify
- Open questions and future perspectives

Walker's classification: where do we fit ignimbrites and more so caldera-forming ones?



The Volcanic Explosivity Index

VEI
0
1
2
3
4
5
6
7
8

TABLE 1. Criteria for Estimation of the Volcanic Explosivity Index (VEI)

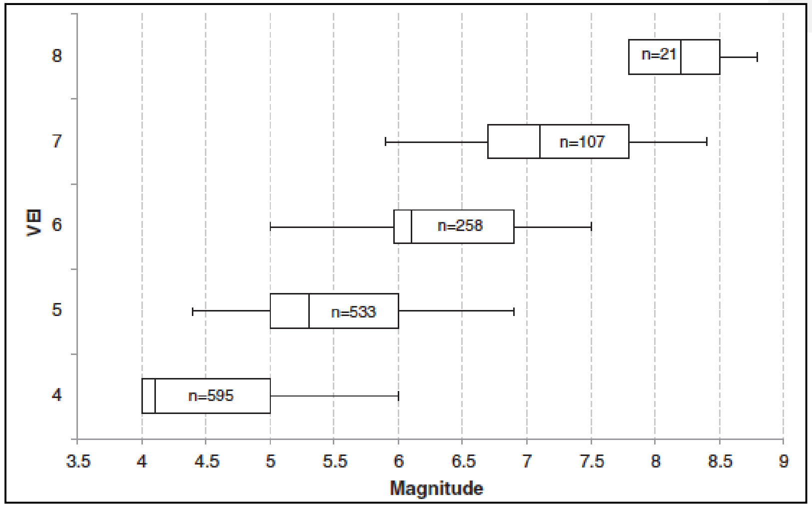
Criteria	VEI: 0	1	2	3	4	5	6	7	8
DESCRIPTION	non-explosive	small	moderate	mod-large	large	very large--			
VOLUME OF EJECTA (m^3)	$<10^4$	10^4–10^6	10^6–10^7	10^7–10^8	10^8–10^9	10^9–10^{10}	10^{10}–10^{11}	10^{11}–10^{12}	$>10^{12}$
(TSUYA CLASSIFICATION)+	(I)	(II-III)	(IV)	(V)	(VI)	(VII)	(VIII)	(IX) ---------	
COLUMN HEIGHT (KM)*	<0.1	0.1-1	1-5	3-15	10-25	>25--			
QUALITATIVE DESCRIPTION	---"gentle, effusive"--		-----"explosive"-------		-----"cataclysmic, paroxysmal, colossal"----------------------				
				"severe, violent, terrific"---					
CLASSIFICATION		----------"Strombolian"-			-------"Plinian"--				
	-------"Hawaiian"------		-------------"Vulcanian"-------------			--------"Ultraplinian"----------------------------			
DURATION (hours)	------------------------<1--------------				------------>12--				
of continuous blast			-------------------1-6----------------						
				--------------------6-12---------------					
CAVW MAX EXPLOSIVITY**	--lava flows-	---------------explosion or nuée ardente---							
		------phreatic---------..							
	-----dome or mudflow---								
TROPOSPHERIC INJECTION	negligible	minor	moderate	substantial--					
STRATOSPHERIC INJECTION	none	none	none	possible	definite	significant---			

+If all eruptive products were pyroclastic ejecta
*For VEI's 0-2, uses km above crater; for VEI's 3-8, uses km above sea level.
**The most explosive activity indicated for the eruption in the Catalogue of Active Volcanoes

Criteria are listed in decreasing order of reliability.

NEWHALL AND SELF: VOLCANIC EXPLOSIVITY INDEX AND HISTORICAL VOLCANISM

Does magnitude tell us anything about the ignimbrites and or collapse styles?



Crosweller et al., JAV 2012

Linearity between caldera area and erupted volume: does it help classification?

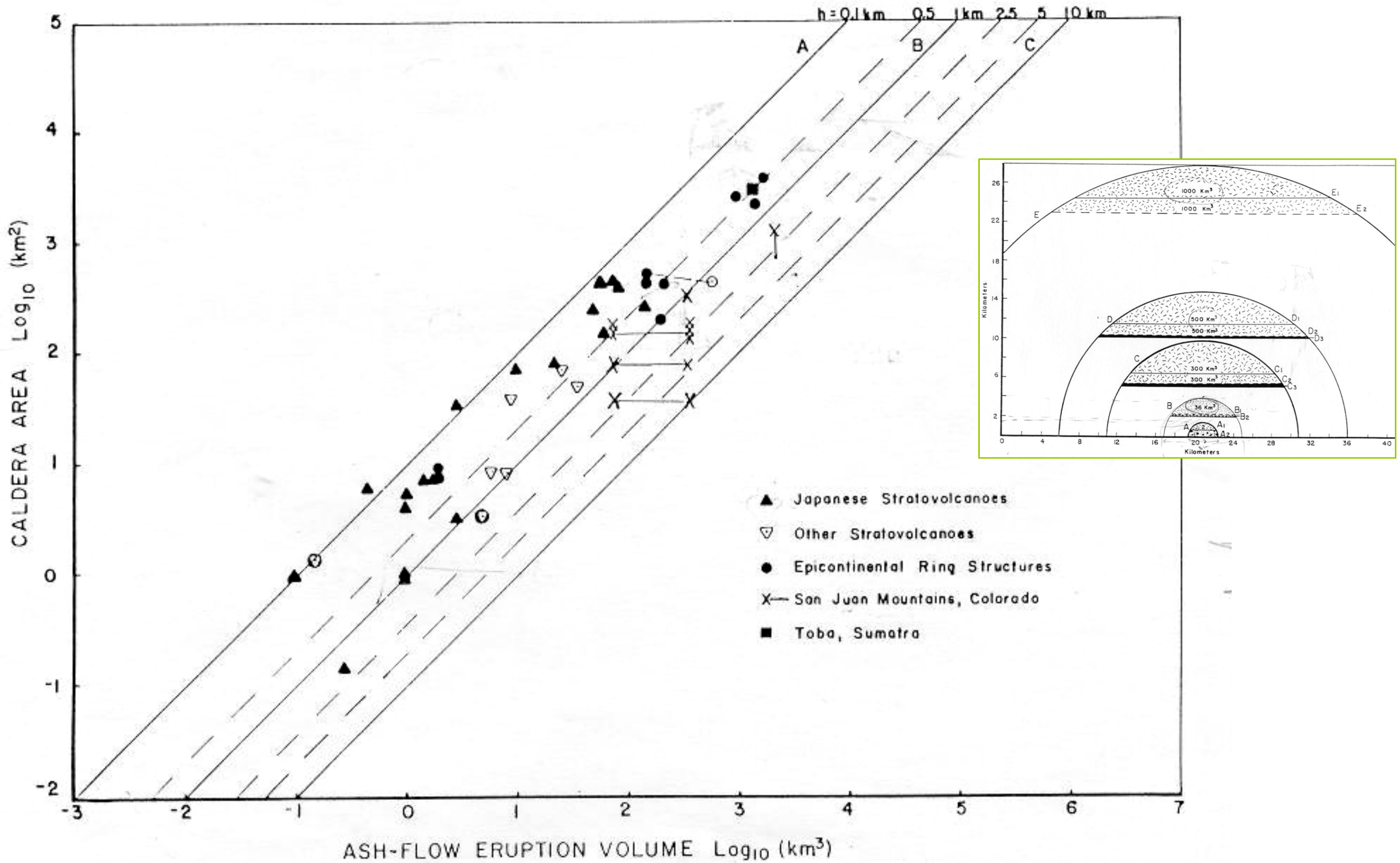
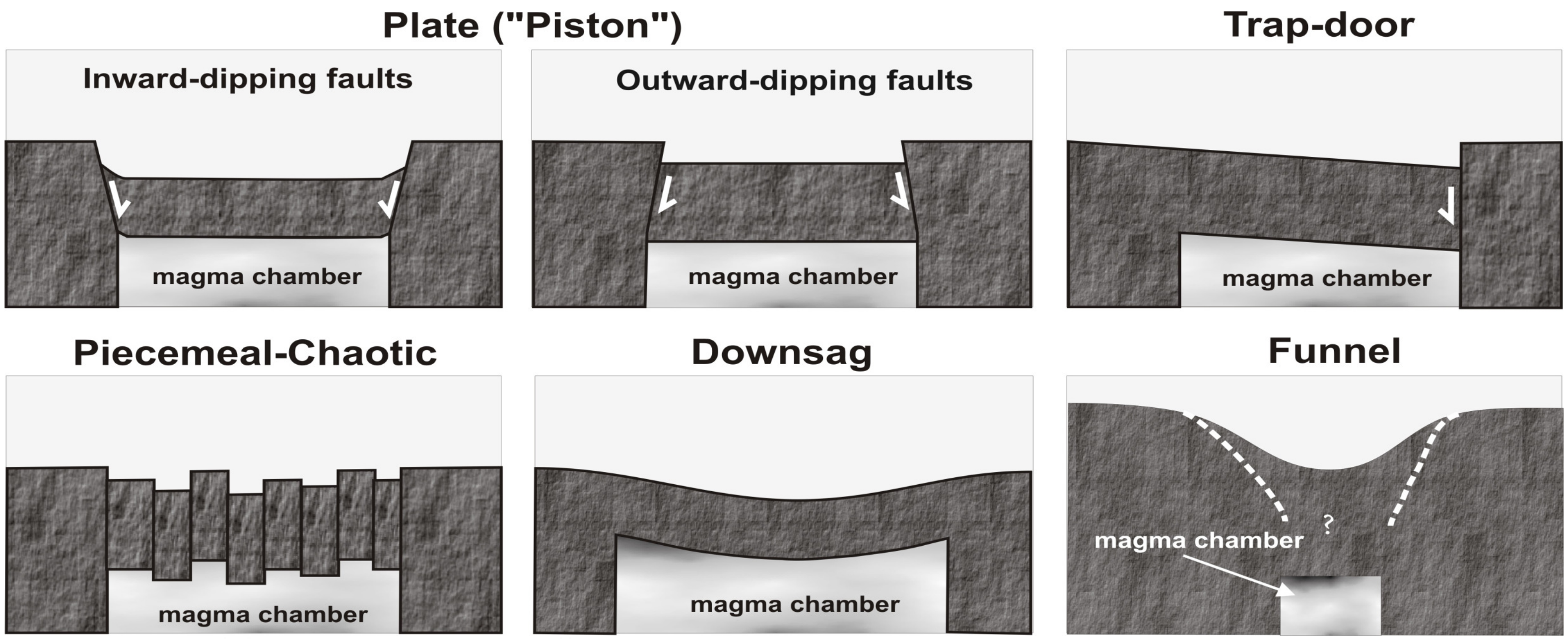
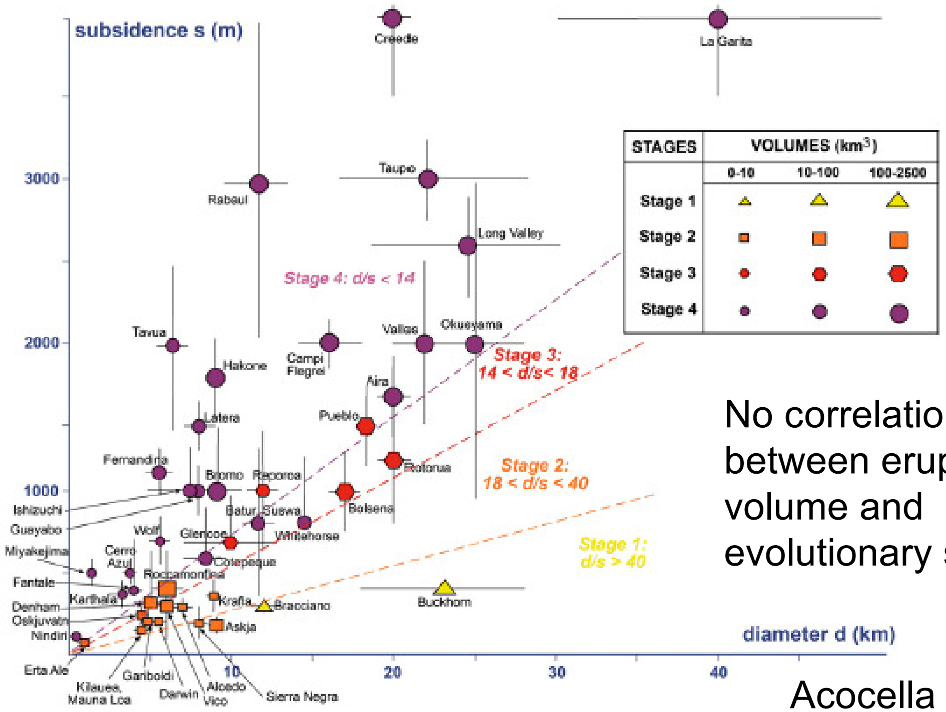


Figure 2. Plot of caldera area versus ash-flow eruption volume. Diagonal lines give depths of draw-down in magma chamber, assuming vertical walls and a flat roof. Data from many published sources.

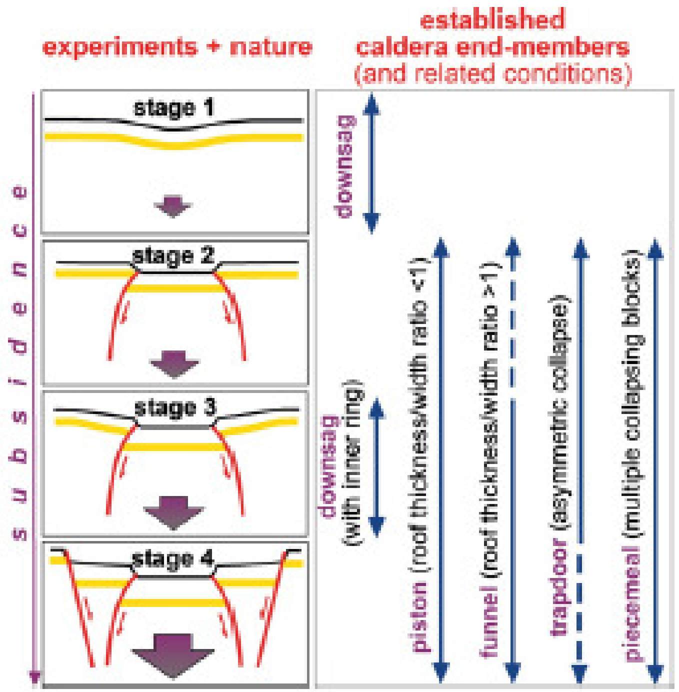
Smith '79

Caldera collapse processes and kinematics



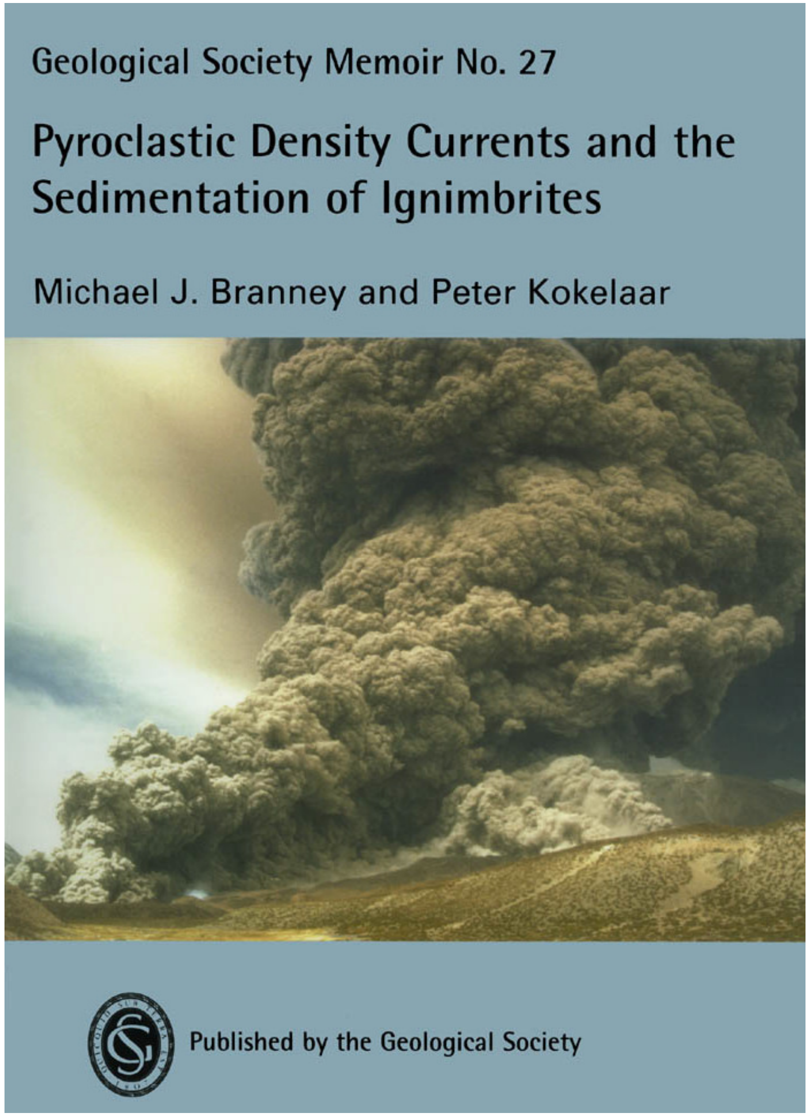


No correlation between erupted volume and evolutionary stage

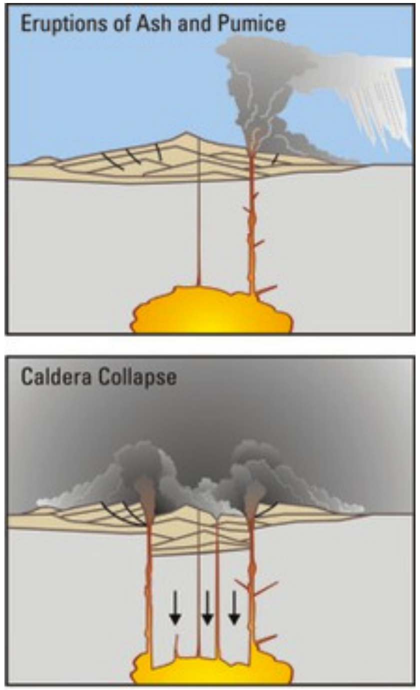


Acocella ESR 2007

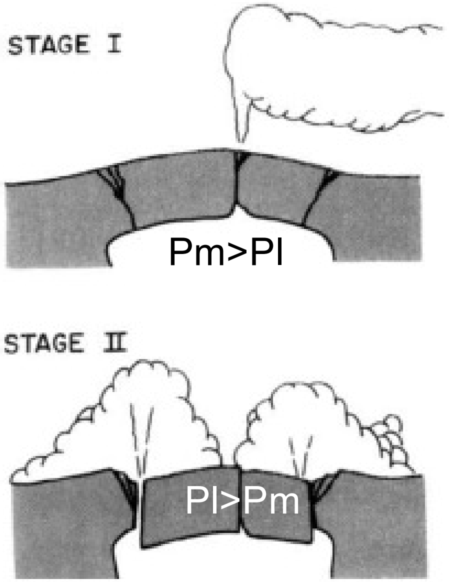
Available caldera classifications so far have not explicitly related collapse styles to deposit types although there is a general agreement that stratigraphy should record the timing (?style?) of collapse



Caldera collapse - the classic model: internally triggered by volatile supersaturation and initial overpressure

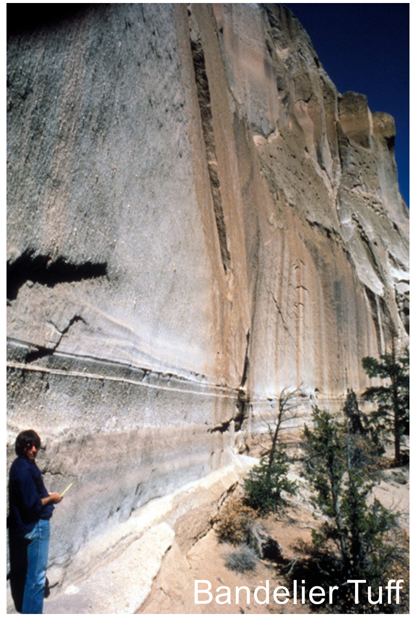


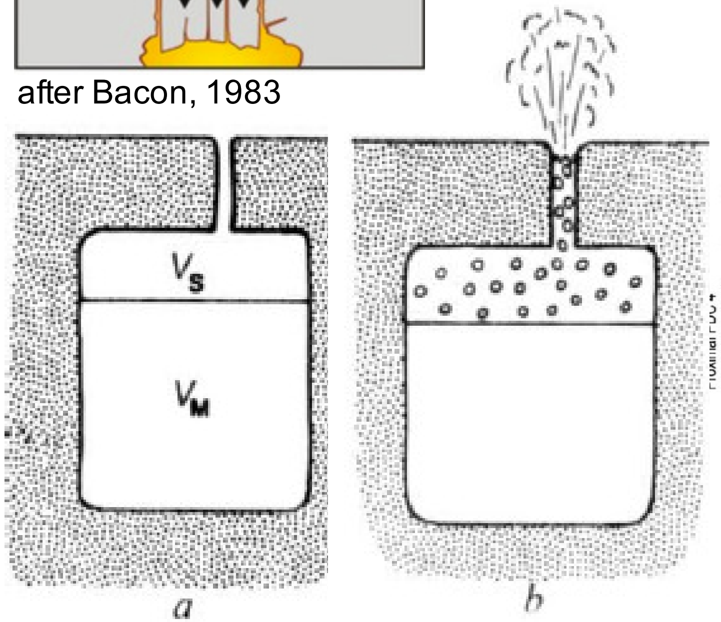
after Bacon, 1983



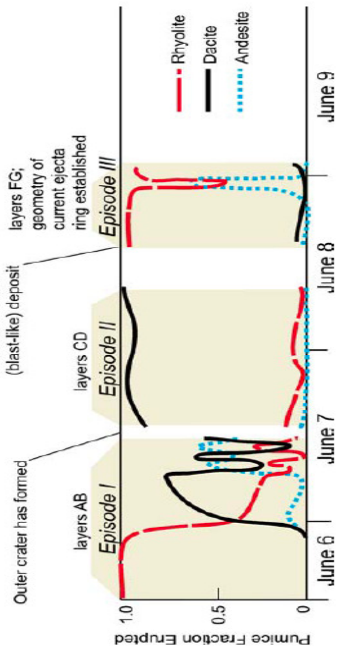
Pre-collapse: early single conduit - fall deposits +/- early ignimbrites

Syn-collapse: transition to ring conduits - breccias and climactic ignimbrites (crystal poor-to-rich and maybe chemically zoned)





Druitt and Sparks, Nature 1984



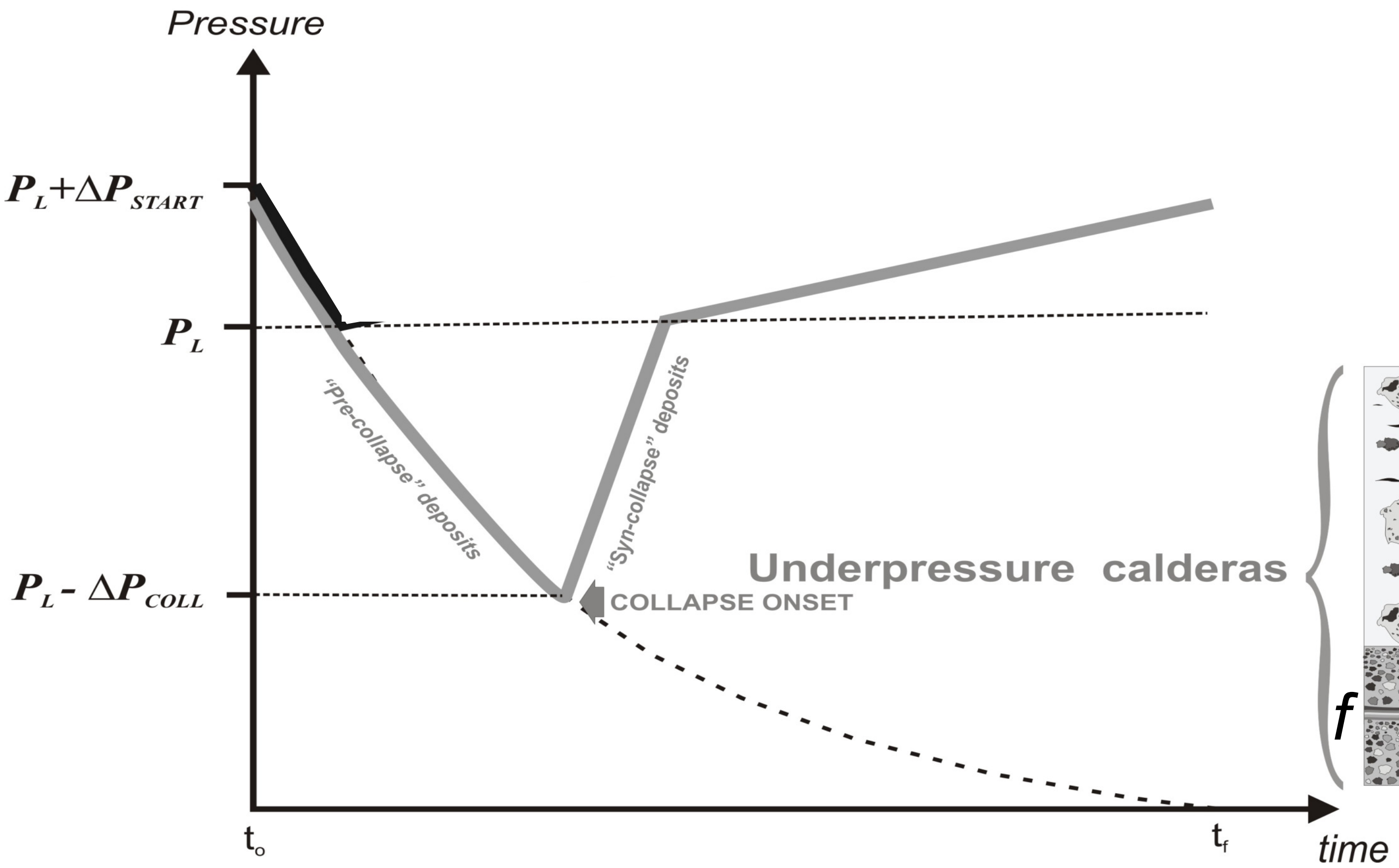
VTTS 13.5 km3 Adams et al BV 2006

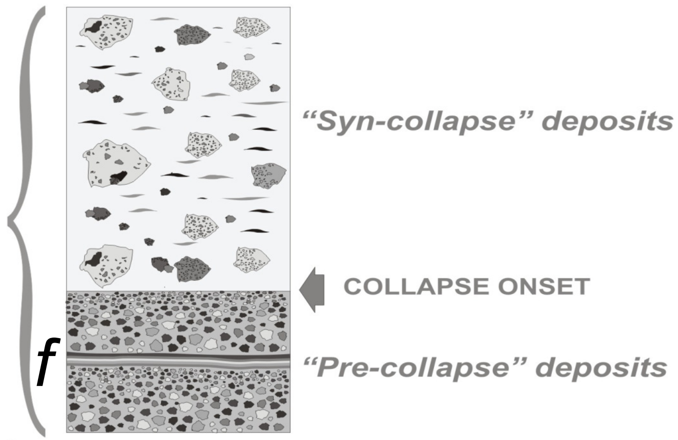
Crater Lake, 55 km3, Druitt and Bacon CMP 1989

Timing of caldera collapse and stratigraphy

Pressure evolution inside the magma chamber

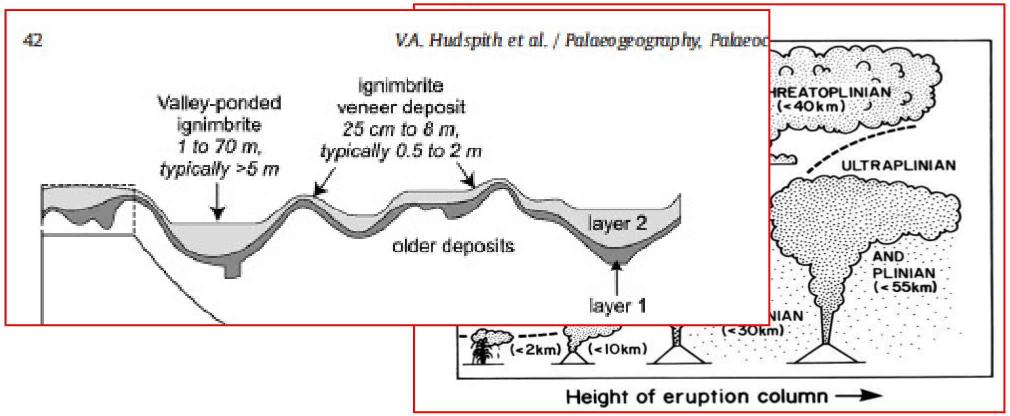
Caldera-forming sequence





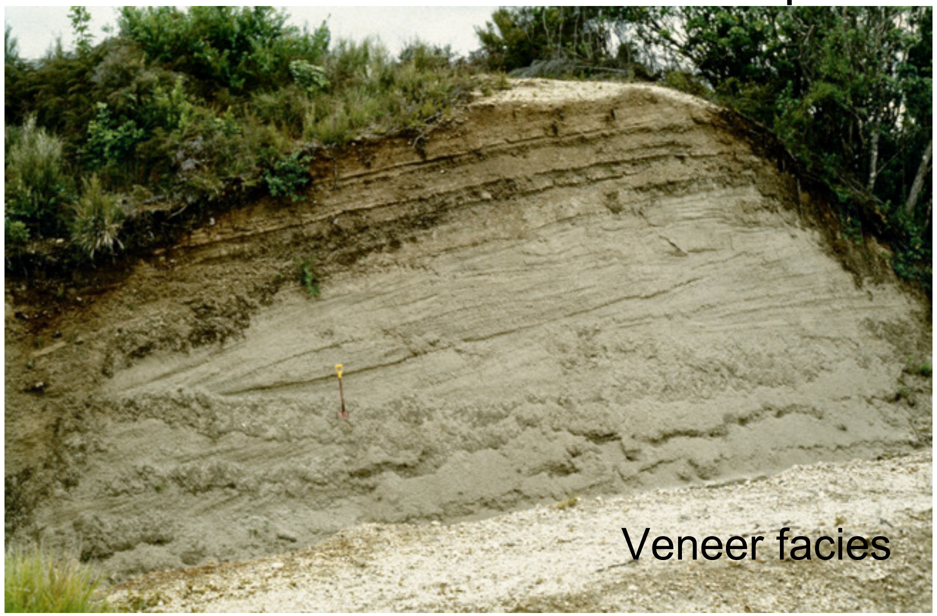
CCDB, Geyer et al., 2011

Volatile-driven eruptions and ignimbrites mobility: low aspect ratios



- Examples of LARIs
  - Taupo 186 A.D. Ignimbrite, New Zealand
  - Rabaul Ignimbrite (c1 Ma)
  - Koya Ignimbrite, Japan
  - Campanian Ignimbrite, Italy (39 ka)
  - Kos Plateau Tuff, Greece (160 ka)

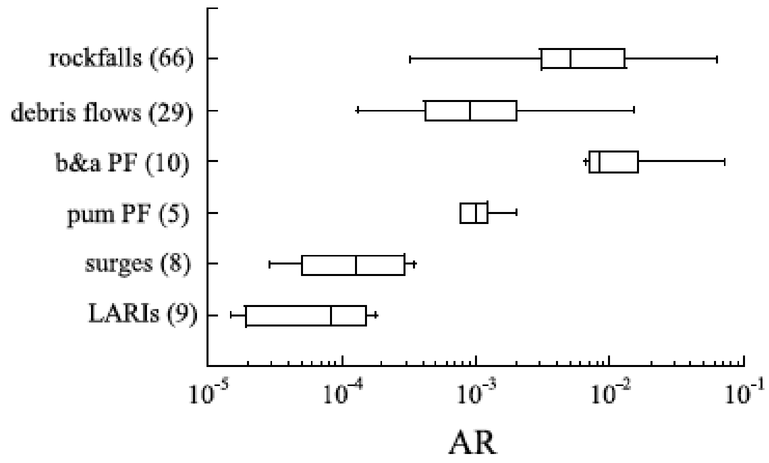
Imply short-lived, highly violent events from transformation of potential to kinetic energy due to high eruption columns or sedimentation from turbulent suspensions



Ignimbrites and mobility - low aspect vs high aspect ratios

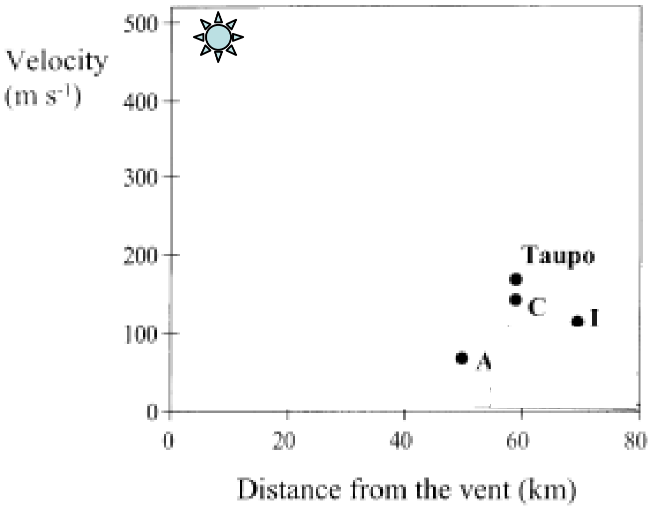
Table 1. Observed Properties of Pyroclastic Surge Deposits and LARIs, and Inferred Properties of Their Parent Eruptions and Flows[a]

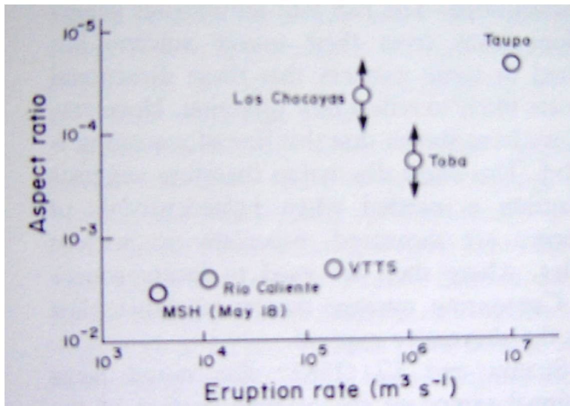
	V_s, (km^3)	A, km^2	L, km	λ	AR, $\times 10^{-4}$	C_o, $\times 10^{-2}$	T, s	Q, $m^3 s^{-1}$	U_{av}, $m s^{-1}$	L_o, km	Yield, J	Θ	References
							Surge Deposits						
Montserrat 6/97	0.0008	4	6.7	0.1	3.5	0.4	191	4×10^3	35	0.4	3×10^{11}	0.5	*Calder et al.* [1999]
Montserrat 12/97	0.0025	9.8	5	0.4	2.9	0.7	127	2×10^4	40	0.5	1×10^{13}	0.6	*Calder et al.* [1999]
Taal	0.0050	50	4	π	0.5	0.2	162	3×10^4	25	0.8	4×10^{13}	0.3	*Waters and Fisher* [1971]
El Chichón S1	0.0325	93	6	π	1.3	0.9	130	3×10^5	46	1	3×10^{14}	0.9	*Sigurdsson et al.* [1987a, 1987b]
El Chichón S2	0.0450	104	6	π	1.5	1.2	117	4×10^5	52	1	4×10^{14}	1.1	*Sigurdsson et al.* [1987a, 1987b]
Lamington	0.1	200	8	π	1.3	1.1	145	7×10^5	55	1.3	1×10^{15}	1.3	*Francis* [1993]; *Simkin and Seibert* [1994]
Mt. Saint Helens	0.1	527	20	1.3	0.3	0.1	587	2×10^5	34	2.8	3×10^{15}	0.5	*Moore and Sisson* [1983]
Rabaul	0.6	1200	20	3	0.5	0.5	360	2×10^6	55	3.2	2×10^{16}	1.3	*Walker*, 1983; *McKee et al.* [1985]
							LARIs						
Vulsini B	1.8	1250	20	π	1.4	2.1	216	8×10^6	93	2.7	5×10^{16}	3.5	*Sparks* [1975]
Koya	5	11000	60	3	0.2	0.1	1137	4×10^6	53	10	5×10^{17}	1.1	*Walker et al.* [1980]
Tosu	5	10000	100	1	0.2	0.1	1807	3×10^6	55	11	5×10^{17}	1.3	*Susuki-Kamata and Kamata* [1990]
Taupo	15	20000	80	π	0.2	0.2	1180	1×10^7	68	12	2×10^{18}	1.9	*Wilson* [1985]
Guatamala H	18	16000	125	1	0.3	0.2	1506	1×10^7	83	12	2×10^{18}	2.8	*Koch and McLean* [1975]
Ito	50	15000	70	3	1	2.2	490	1×10^8	143	8	4×10^{18}	8.3	*Walker et al.* [1980]
Kidnappers	225	45000	120	π	0.8	2.4	686	3×10^8	175	13	3×10^{19}	12.5	*Wilson et al.* [1995]
Campanian	250	31400	100	π	1.6	5.7	453	6×10^8	220	10	3×10^{19}	19.9	*Fisher et al.* [1993]
Rattlesnake	330	35000	120	2.4	1.8	6.1	499	7×10^8	240	11	4×10^{19}	23.6	*Streck and Grunder* [1995]



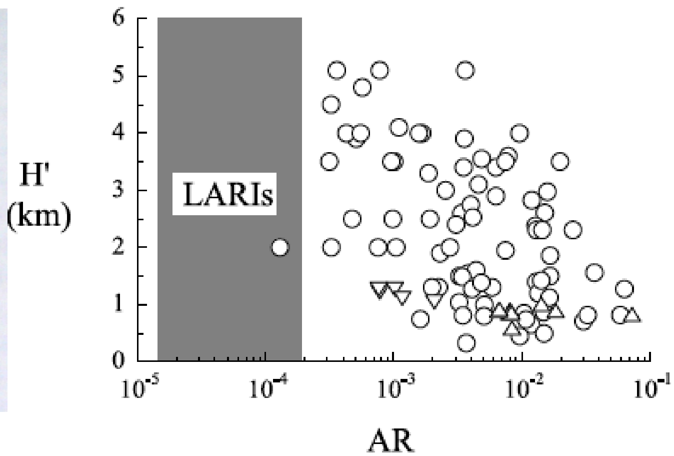
Dade, JGR 2003

F. Legros, K. Kelfoun / Journal of Volcan

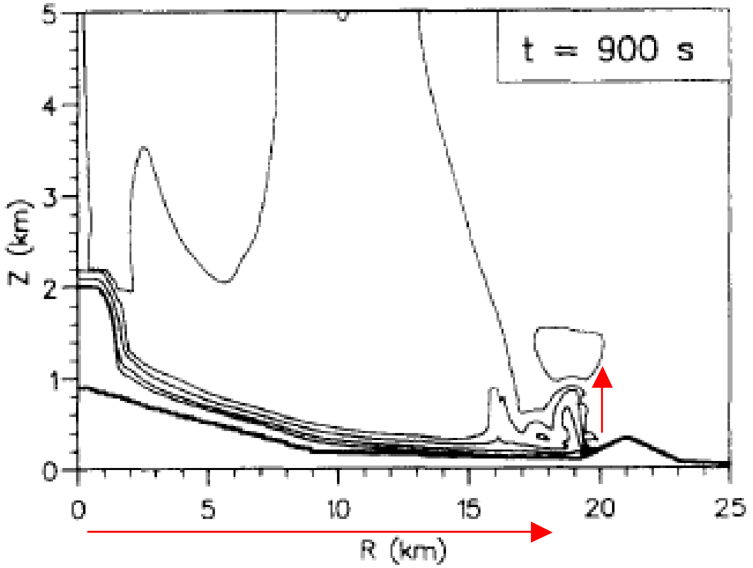




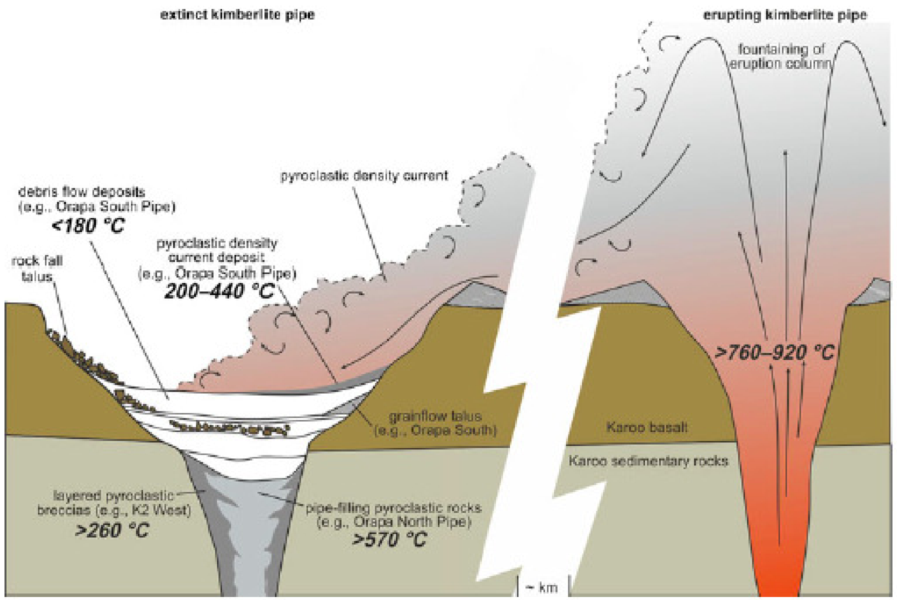
Cas and Wright 1987



Temperature of emplacement: a proxy for heat dissipation, eruption and transport styles



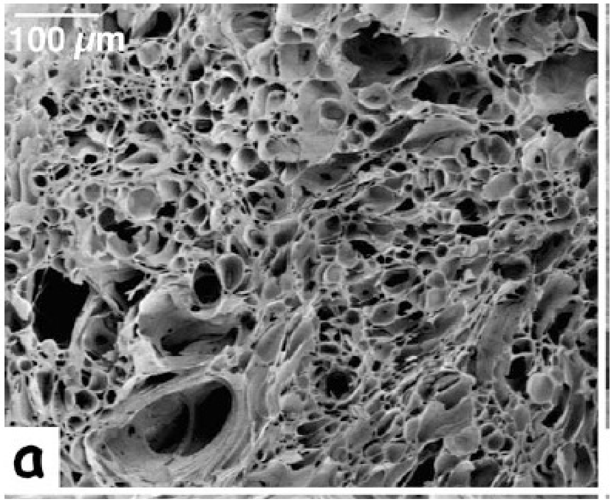
Giordano & Dobran JVGR 1994



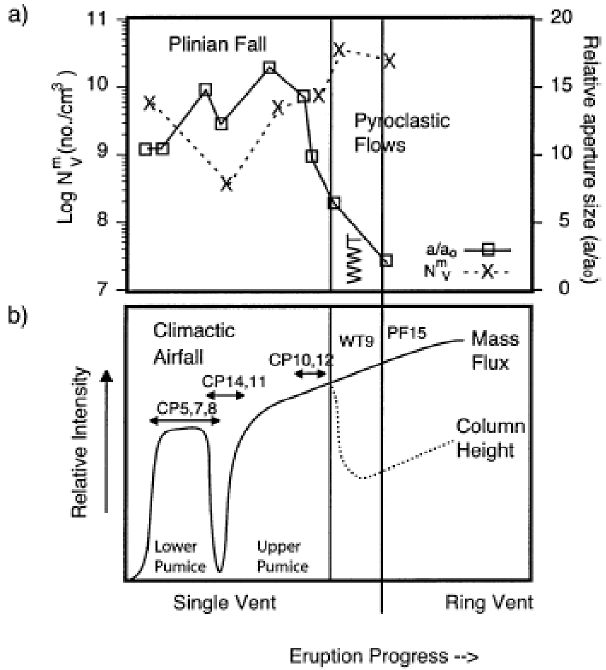
Fontana et al BV 2011

REFERENCE	DEPOSIT	T°C	METHOD	VOLUME	NOTES
Paterson et al 2010	St Helens May 18 1980	330-390/>634	TRM		
Paterson et al 2010	St Helens June 12 1980	510-590	TRM		HARI
Paterson et al 2010	St Helens Jul 22 1980	>577	TRM		boil over
Paterson et al 2010	Colima 2005	cold	TRM		
Banks and Hoblitt 1996	St Helens 1980	300->600	direct measurement		
Banks and Hoblitt 1996	St Helens June 12 1980	540+-30	direct measurement		HARI
Banks and Hoblitt 1996	St Helens Jul 22 1980	>600			boil over
Cioni et al. 2004	Vesuvio- 79	180-380	TRM	5	
McClelland and Druitt 1989	Santorini - Cape Riva Middl	250->580	TRM	30	
McClelland et al. 2004	Taupo 186 AD	150-300/400-500	TRM	35	LARI
Hudspith et al 2010	Taupo 186 AD	200-400°C	charcoal	35	LARI
Porreca et al. 2006	Stromboli - SdL	<140	TRM	0.0001	phreatomagmatic
Porreca et al. 2006	Stromboli - COA	300-340	TRM	0.0001	phreatomagmatic
Porreca et al. 2008	Colli Albani - Peperino	240-350	TRM	0.8	phreatomagmatic
Zanella et al. 2008	Vesuvio - Pollena	260-360	TRM	5	
Sulpizio et al. 2008	El Chicón	380	TRM		
Gurioli et al 2012	Vulcano - Commenda	160-360	TRM		
Lesti et al. 2011	Galan	>580°C	TRM	630	crystal-rich; parly welded

Vescicularity eruption history [+hiatuses] and grain size



Klug et al BV 2002 Crater Lake



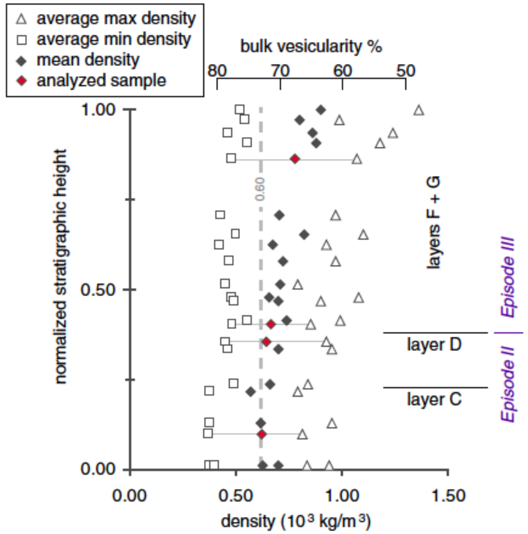
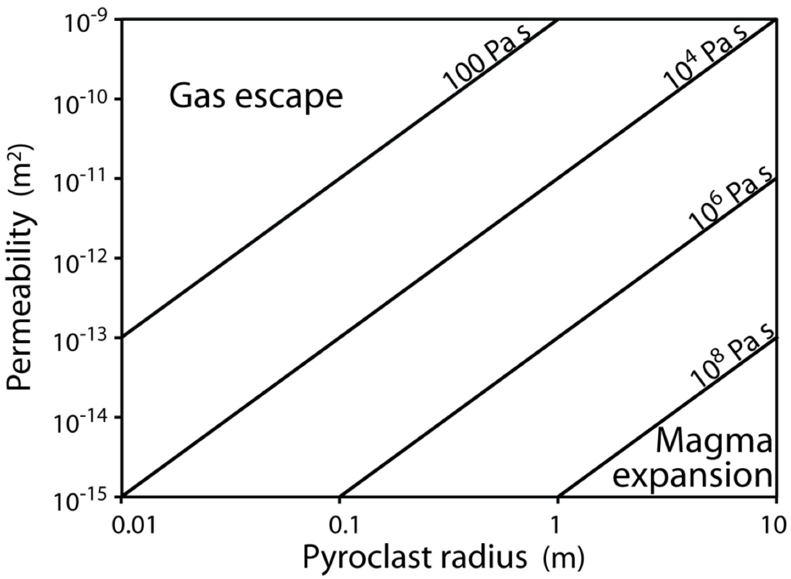


Fig. 4 Low, mean, and high-density values for samples collected at site 94-1 against normalized stratigraphic height. *Open triangles* represent an average of the three maximum density clasts per sample; *open squares* an average of the three minimum density clasts. Samples used during thin section analyses are *shown in red*. Mean density value (*filled diamonds*) increased from Layer C (600 kg/m³, as indicated by the *gray dashed line*) to Layer G (880 kg/m³), i.e., as the eruption progressed

Adams et al., BV 2006 VTTS



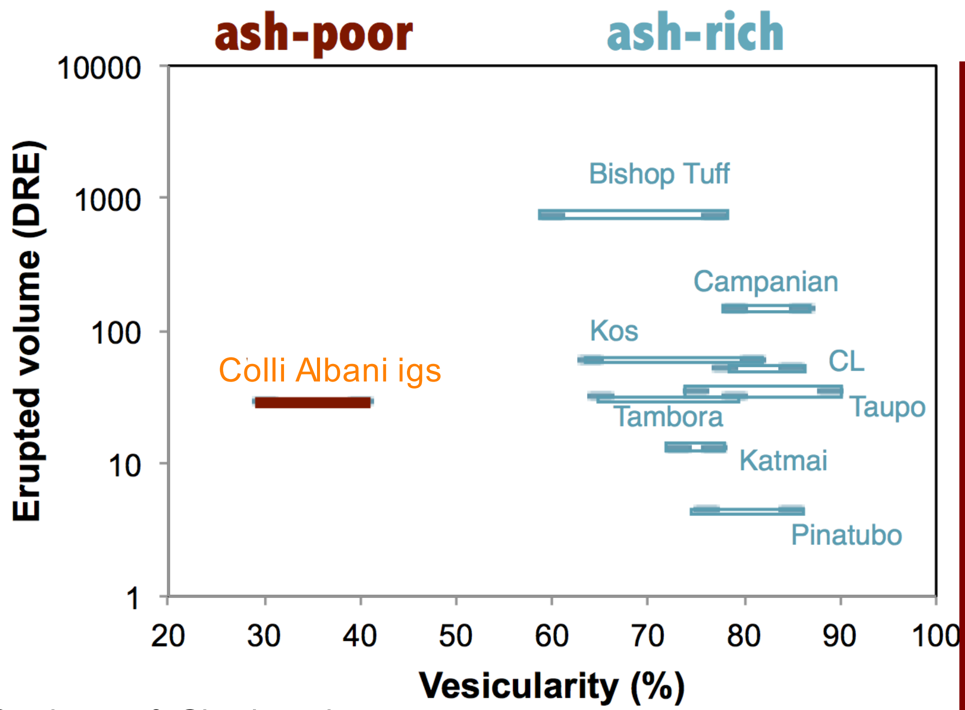
Rust & Cashman JGR 2011

Table III. Vesicle measurements from explosive silicic eruptions.

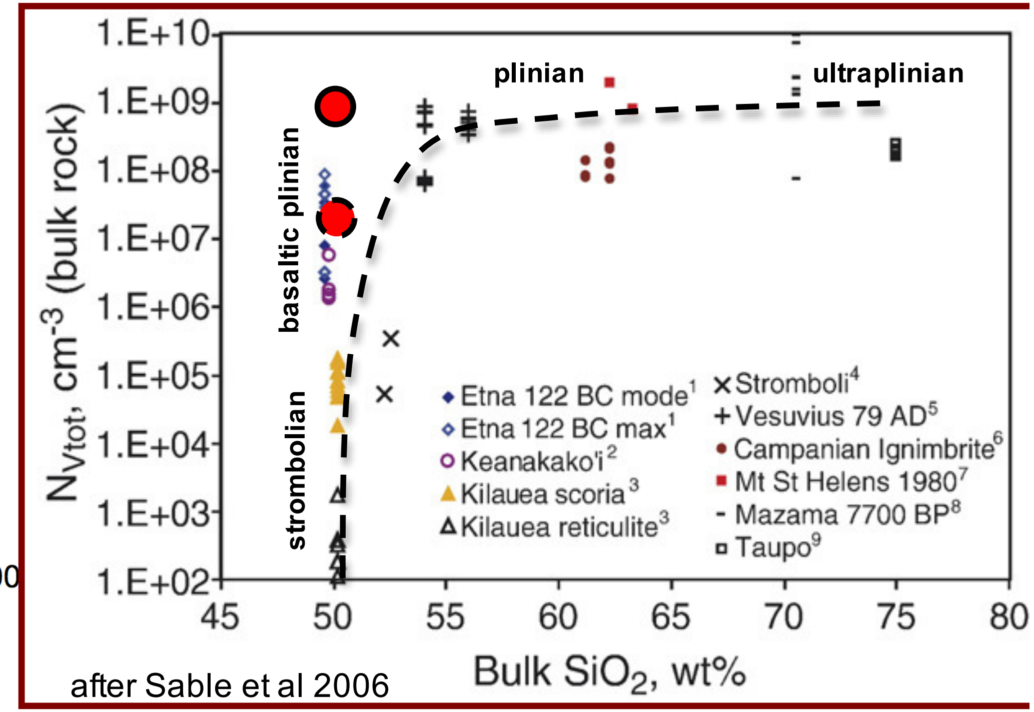
Eruption	Pumice type	Bulk vesicularity from image analysis	Average density-derived bulk vesicularity	Average bulk vesicle *n* density (cm^{-3})	Average gm *D*
*CI	*m*	0.85-0.94 (0.89)	0.78	1×10^8	0.390
	t	0.87-0.92 (0.89)	0.75	1×10^8	0.591
	e	-	0.81	-	-
**Pinatubo	White	0.76-0.85 (0.81)	0.60	1×10^8-10^9	0.371
	Foliated	0.72-0.82 (0.77)	-	1×10^9	0.383
	Gray	0.68-0.82 (0.74)	0.66	1×10^8-10^9	0.234
***Quilotoa	White	(0.80)	0.66	8.9×10^8	0.413
	Gray	(0.84)	0.71	8.1×10^8	0.274
^Mt. Mazama	Different types	-	0.82	1.0×10^9	-
^^Mt. St. Helens	White	(0.80)	0.80	8.2×10^8	-
	Gray	(0.60)	0.61	2.0×10^9	-

Polacci Ann. Geophys. 2005

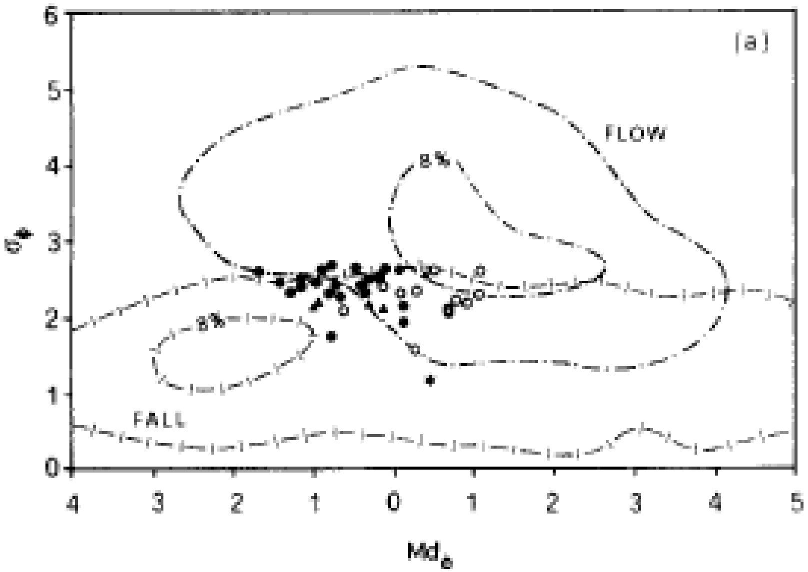
Vescicularity and grain size

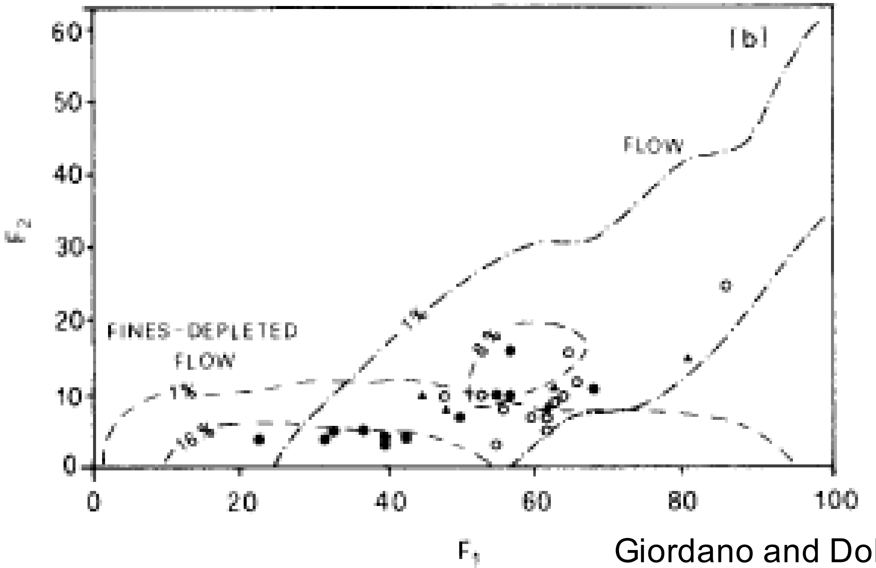


Cashman & Giordano in prep



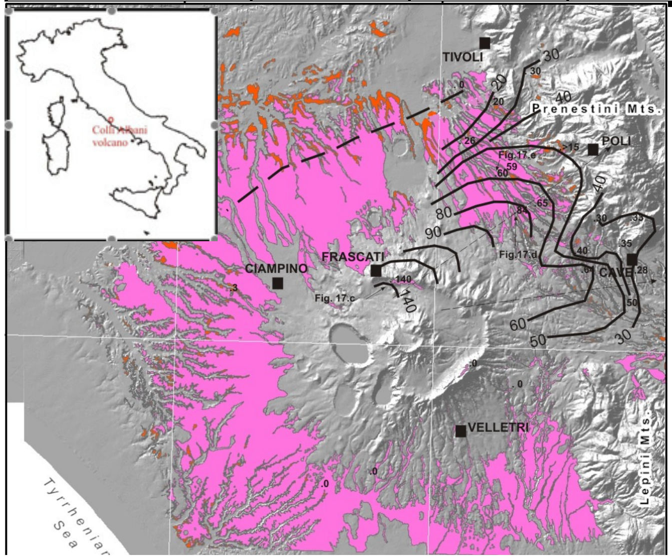
after Sable et al 2006





Giordano and Dobran 1994

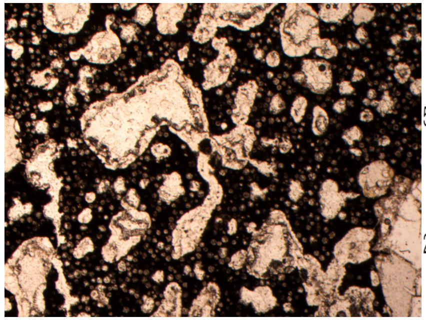
Ignimbrite unit - Age	Deposit volume[1] (km^3)	D.R.E. volume[2] (km^3)	Composition	Area Max runout Aspect ratio	Min subsidence 8 x 8 km caldera	Max hight climbed	(VEI)
Villa Senni Formation (VSN; 355 ka)	30 + 18 (intra-caldera)	18 + 10	Tephri-phonolitic/phono-tephritic (SiO2 54-48wt%)	>1600 km^2 30 km (VSN1) $3x10^{-4}$	281-437 m	> 250 m at 20 km from source	6



Density 1000-1900 kg/m^3
Vesicularity 14-64%
Connected 85-99%
$k1$ $1.9x10^{-13}$ - $7.8x10^{-12}$ m^2
Max viscosity $10^{-4.5}$ Pa-s

VSN2

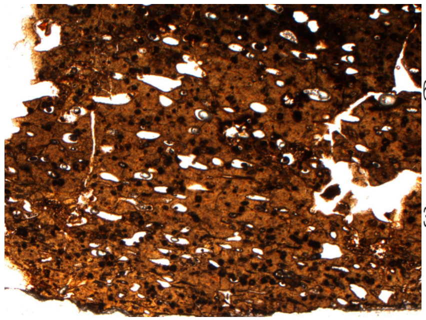
20 km3



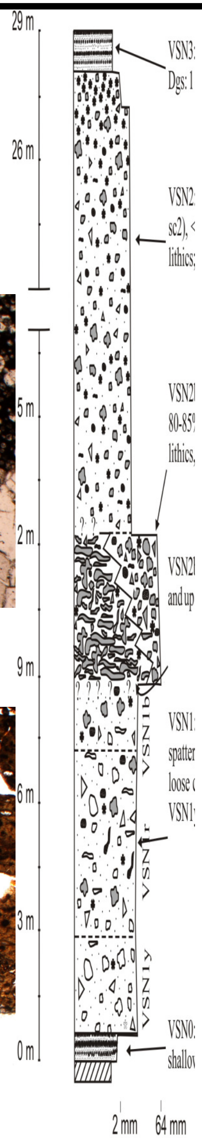
Caldera collapse breccia

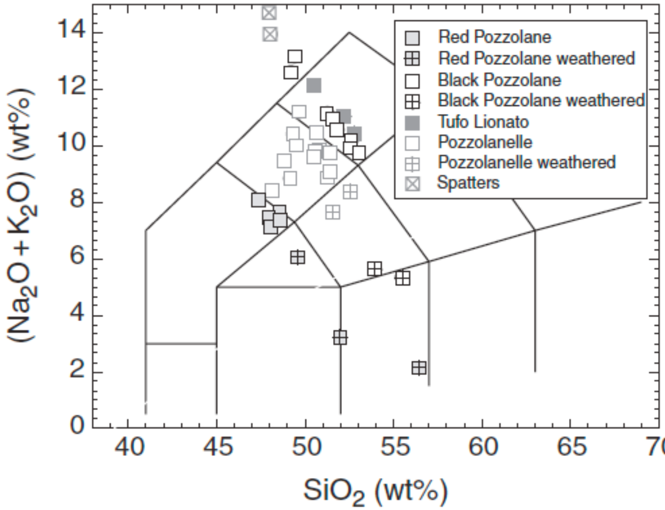
VSN1

10 km3



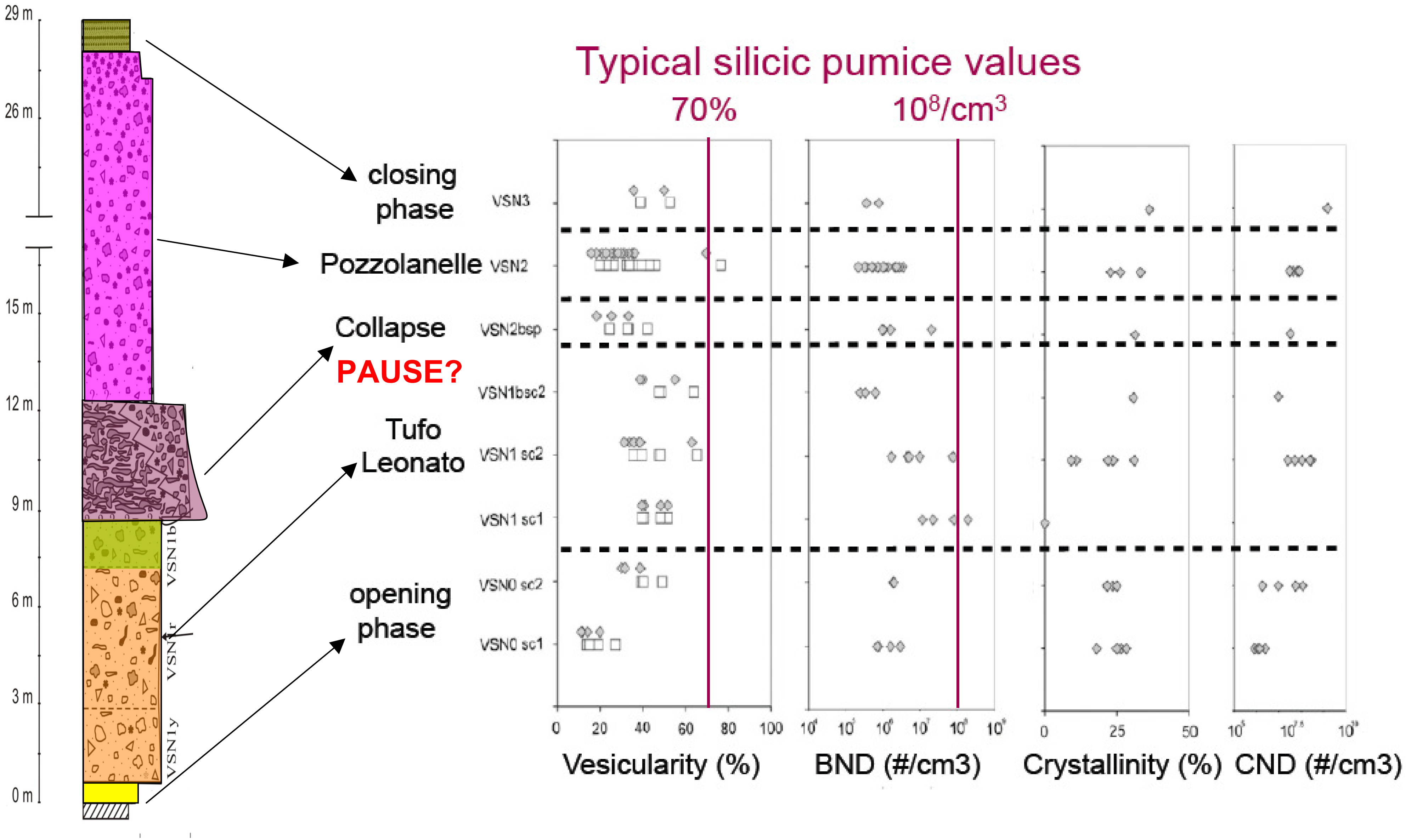
Early fall 0.3 km3





Vinkler et al JVGR 2012

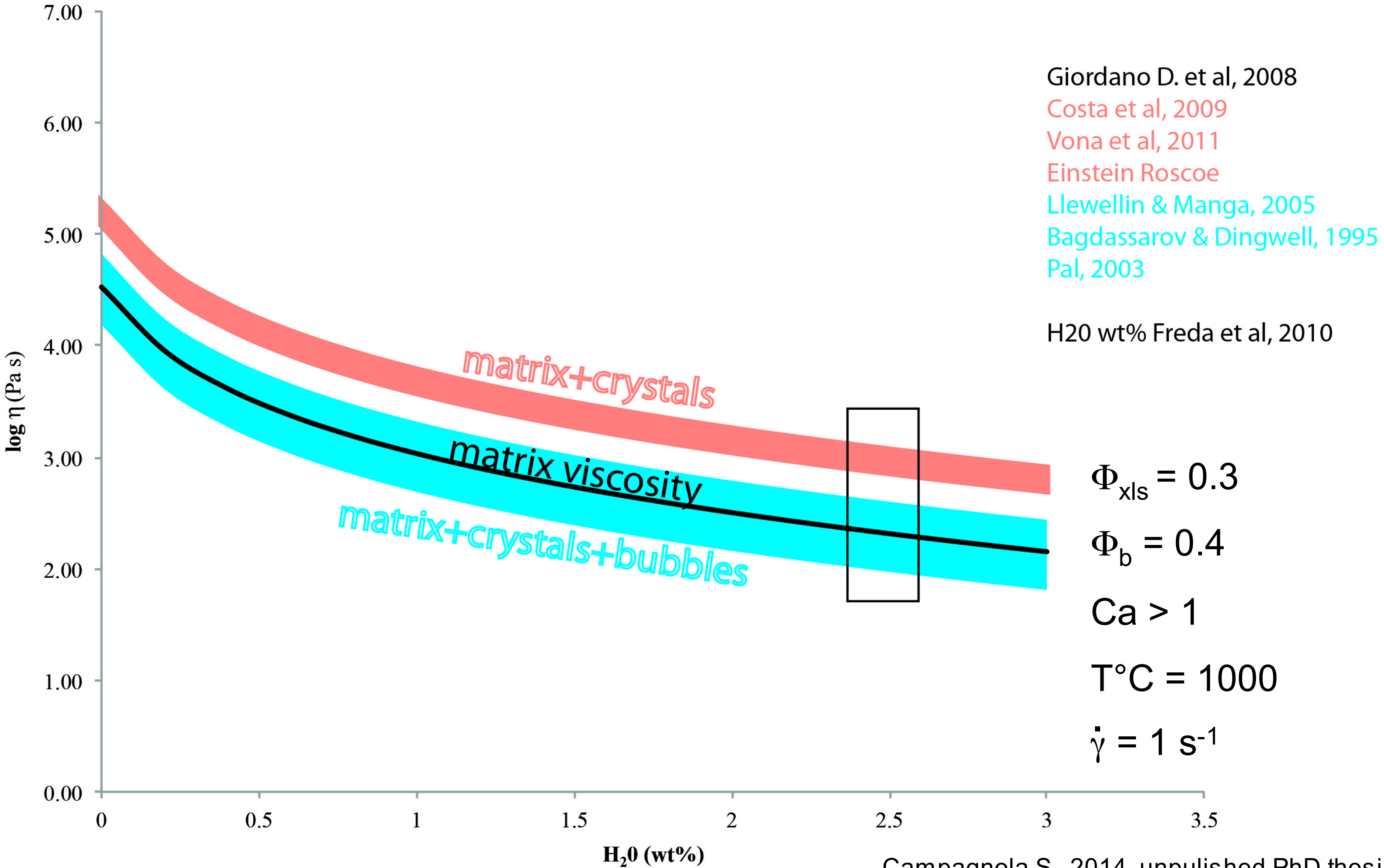
Eruption history: $f = 30$



Vinkler et al., JVGR 2012

What drives the sustained explosivity of these mafic magmas ?

- Crystals → change of viscosity?



$\Phi_{xls} = 0.3$

$\Phi_b = 0.4$

Ca > 1

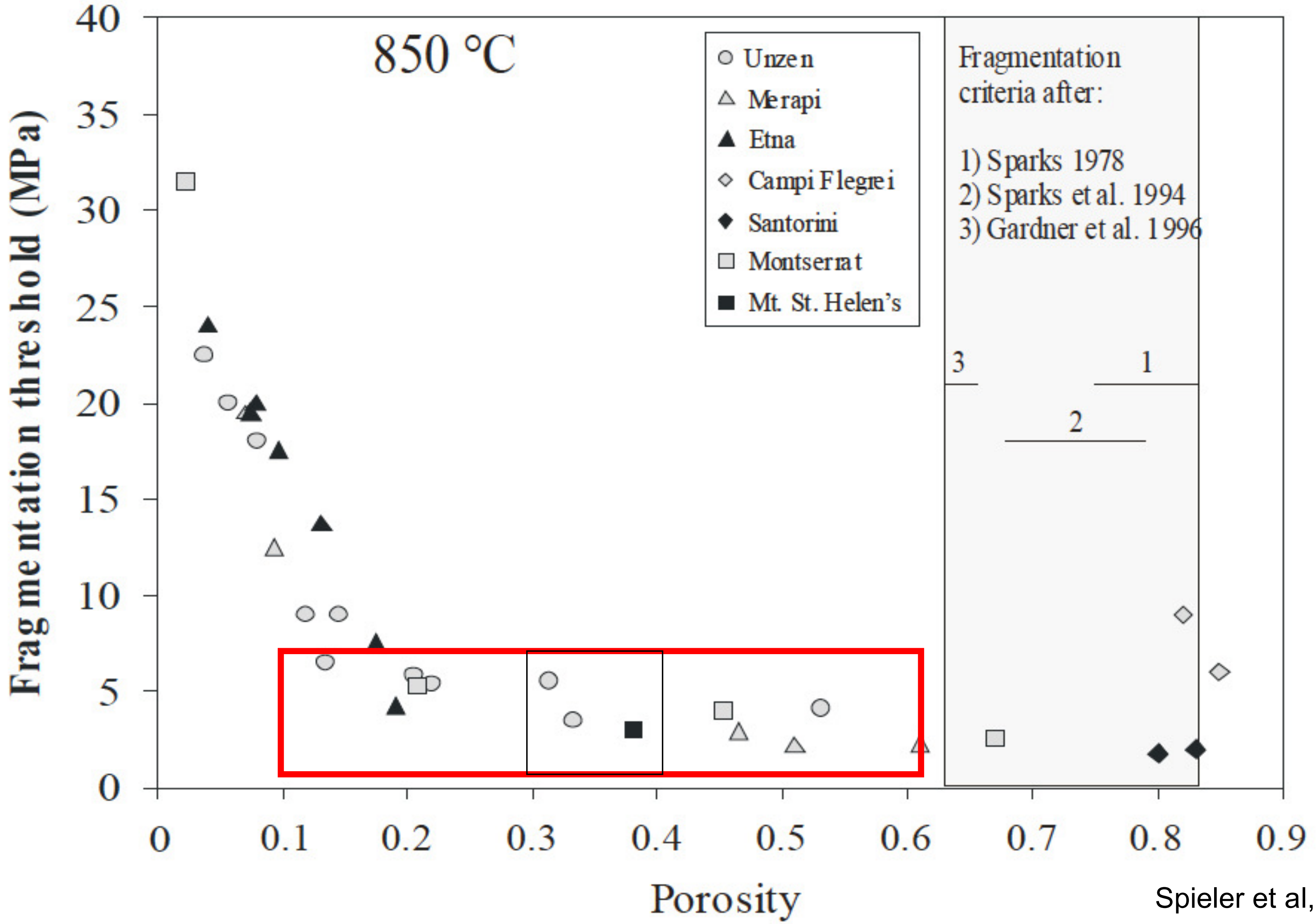
T°C = 1000

$\dot{\gamma} = 1\ s^{-1}$

Campagnola S., 2014, unpulished PhD thesis

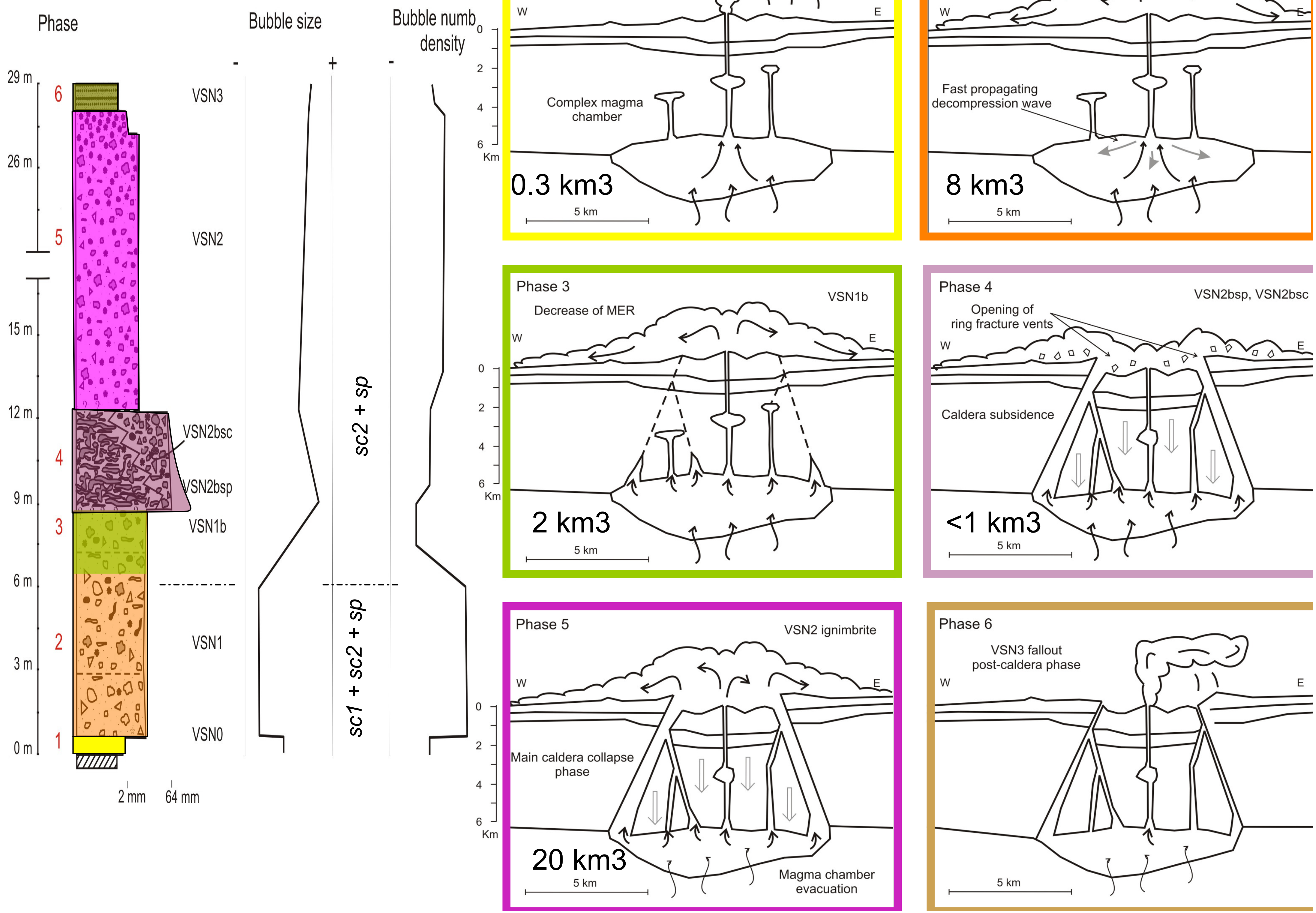
What drives the sustained explosivity of these mafic magmas ?

- Decompression?

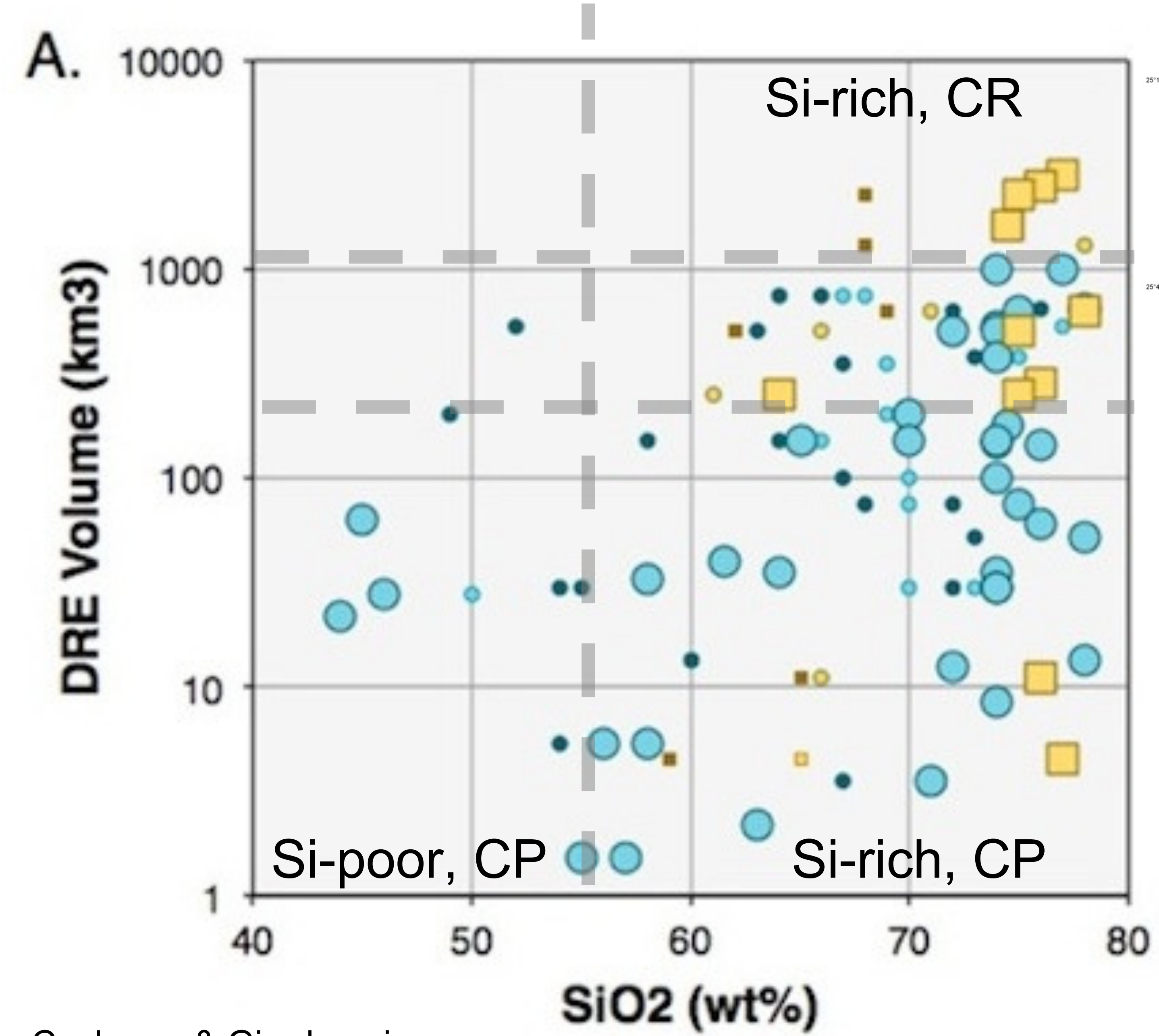


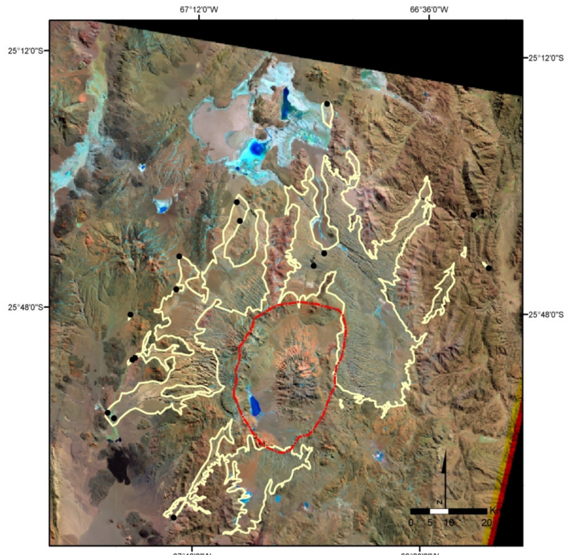
Spieler et al, 2004

ERUPTION HISTORY

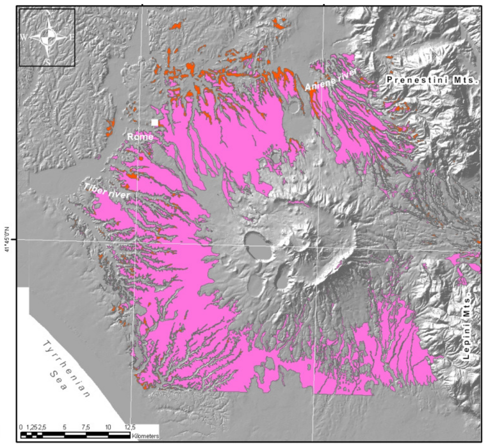


Ignimbrites and chemical composition





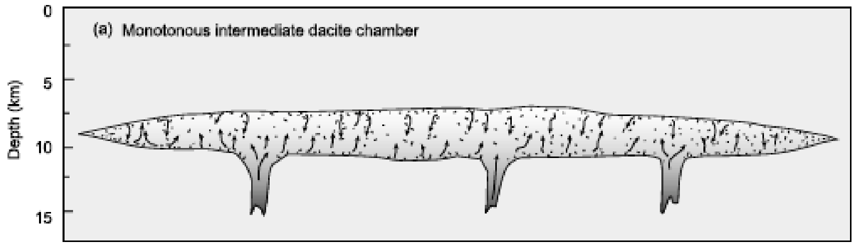
Cerro Galan, CR rhyodacite



Colli Albani, CP mafic

Cashman & Giordano in prep

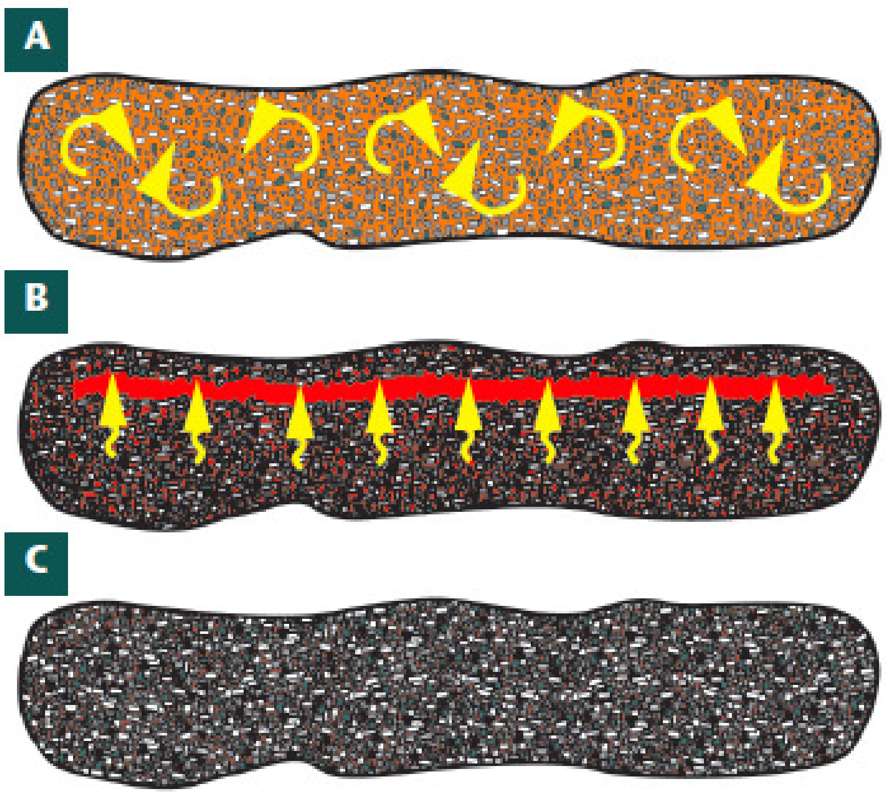
The dilemma of crystal-rich monotonous intermediates: why and when?



Rising and sinking plumes as well as replenishment, *mix* magma, precluding development of composition gradients in lens-shaped chamber.

Maughan et al., JVGR 2002

	Ignimbrite	Caldera	Volume	Crystallinity	Plinian phase
1	Fish Canyon tuff, USA	La Garita	2200km3	37-54%	Yes
2	Lund Tuff, USA	White Rock	>3000km³	>25%	No
3	Huckleberry Ridge tuff, USA	Yellowstone	~2500km³	<20%	Yes
4	Youngest Toba tuff, Indonesia	Toba	2800km3	35-50%	Yes
5	The Ora Ignimbrite, Italy	Ora	>1290km³	~45%	NO
*	The Cerro Galan Ignimbrite, Argentina	Cerro Galan	~630km3	~55%	NO

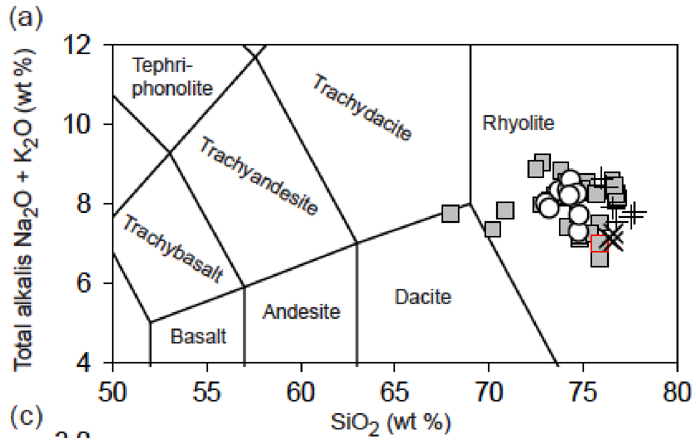


Immature or rejuvenated stage - wholesale mush eruption (large volume <45% xls)

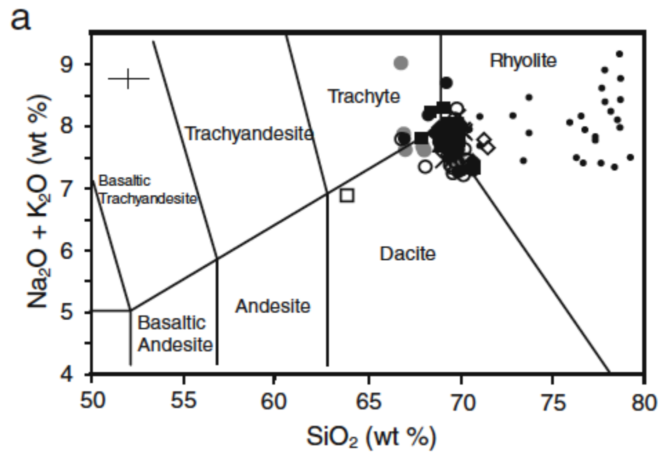
Mature stage - high silica residual rhyolites and zoned chambers

Non-eruptible reservoir

Bachmann & Bergantz Elements 2008

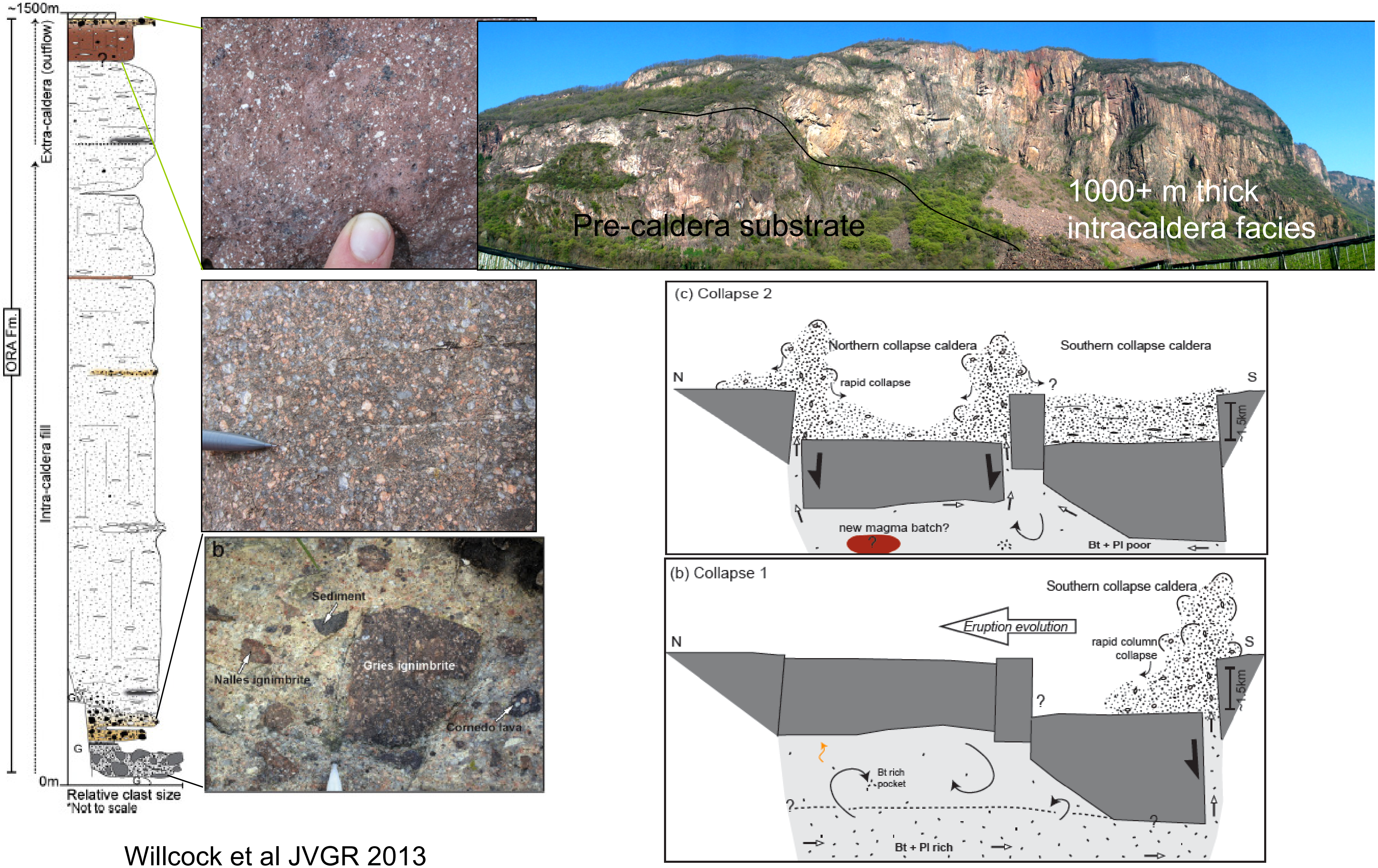


Ora ig., 1290 km3, 45% xls Willcock et al., JVGR 2013



Galan ig., 630 km3, 50% xls; Folkes et al., BV 2011

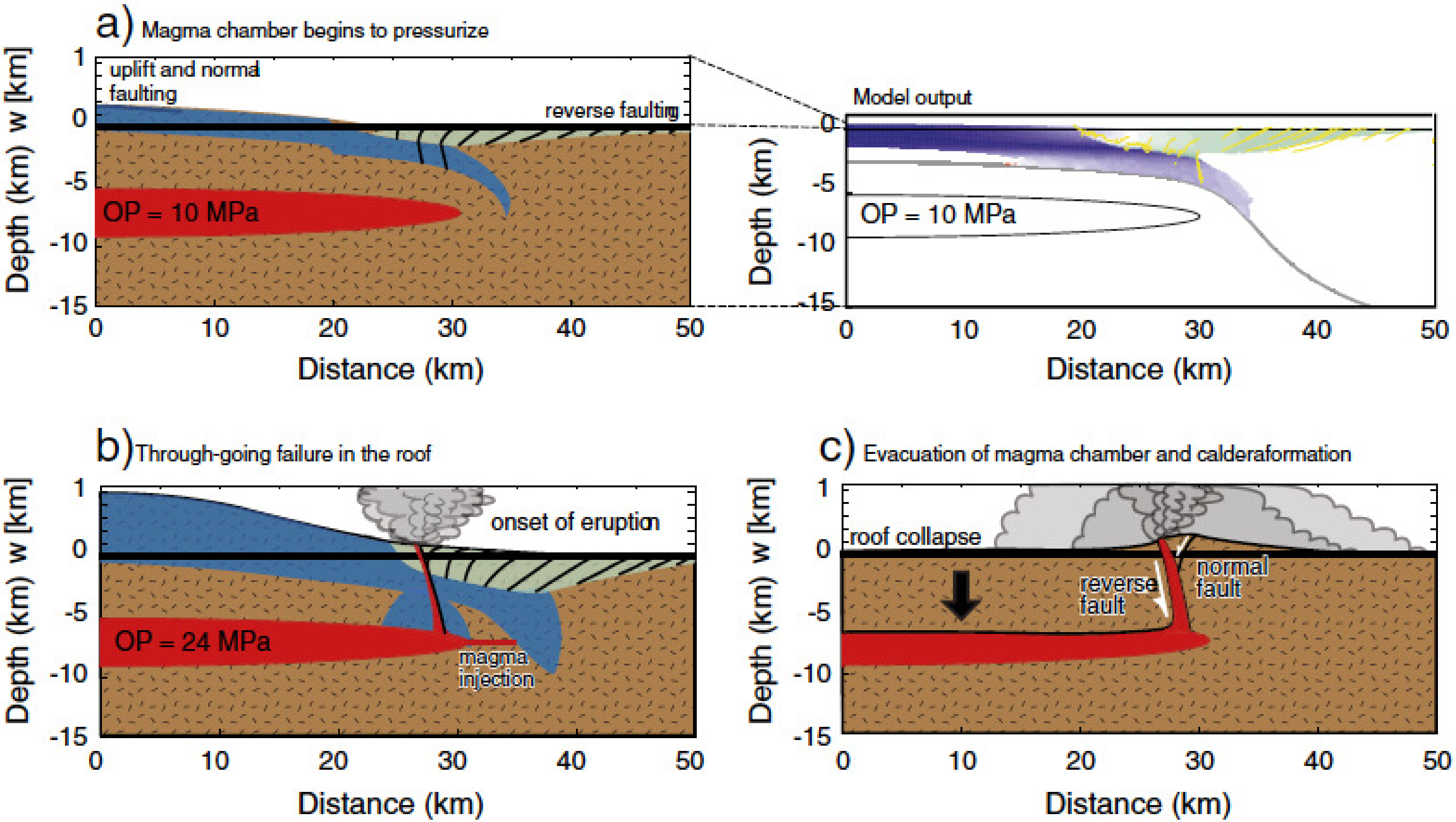
Ignimbrites and stratigraphy/timing of collapse (Ora ig. 1290 km3; MI; f=0) no basal fall deposit; lithic poor; welded; crystal rich 45%



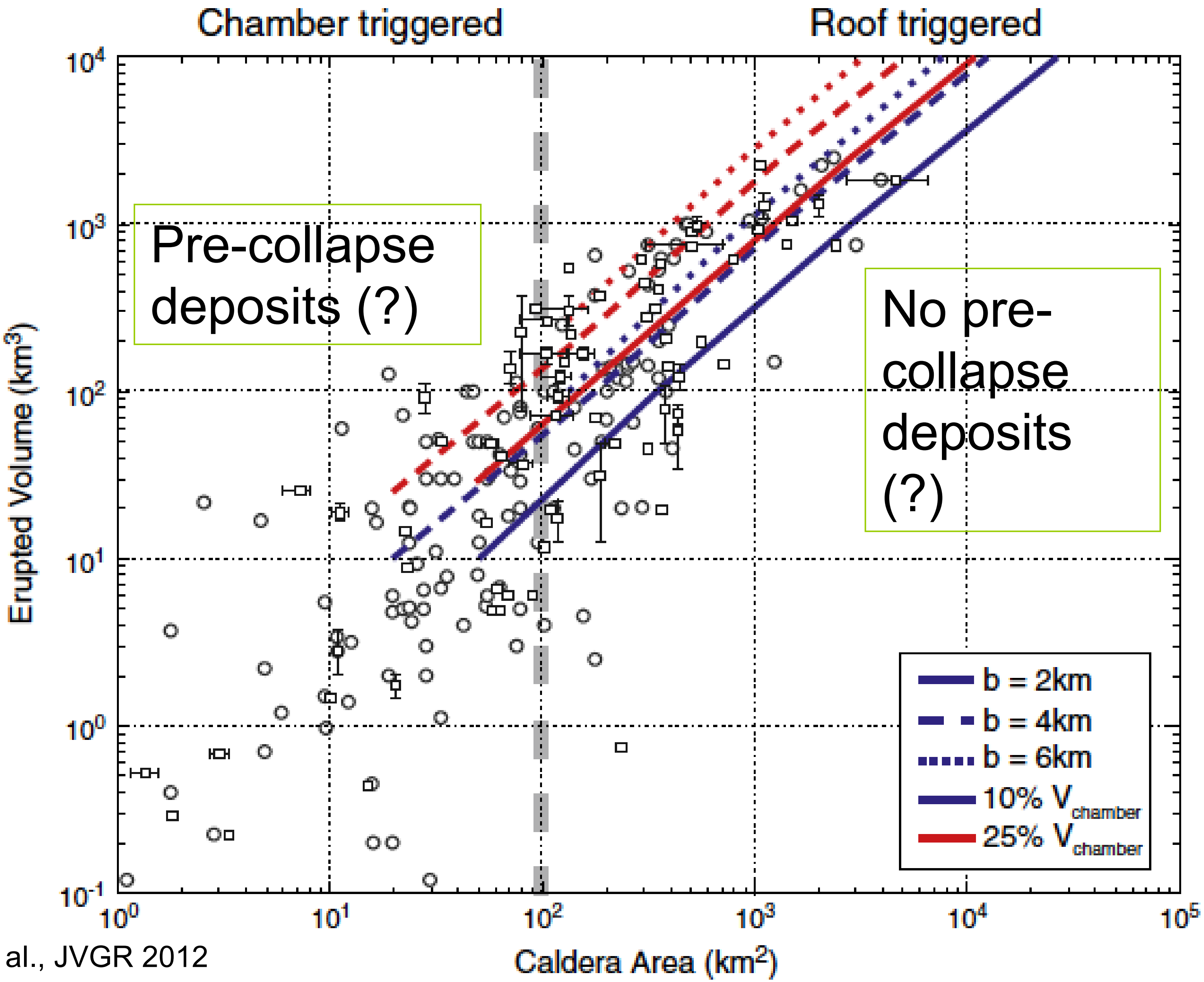
Willcock et al JVGR 2013

Caldera collapse - overpressure model in a viscoelastic crust

PM. Gregg et al. / Journal of Volcanology and Geothermal Research 241–242 (2012) 1–12

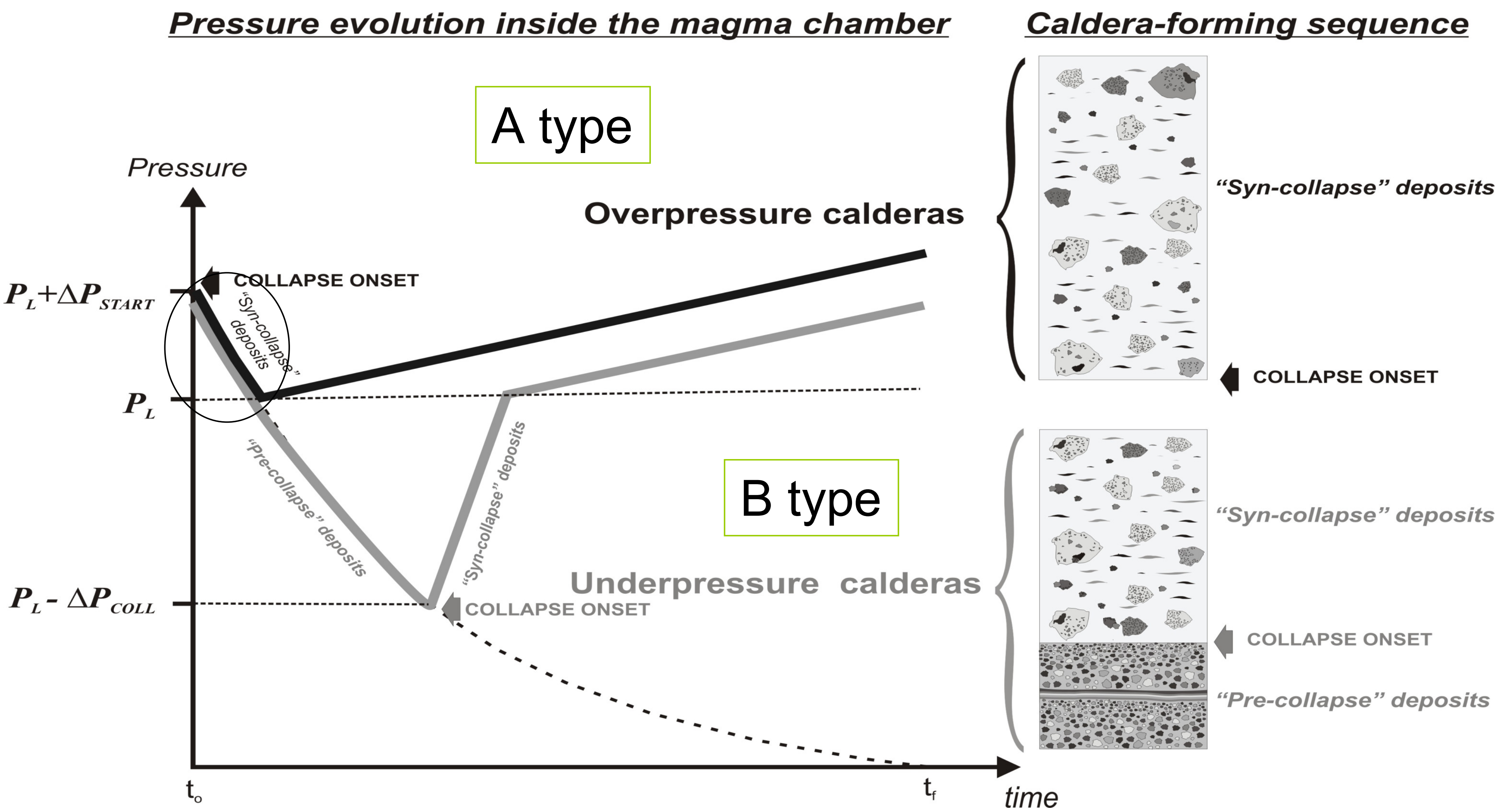


A twofold classification based on collapse style + indirect stratigraphic evidence



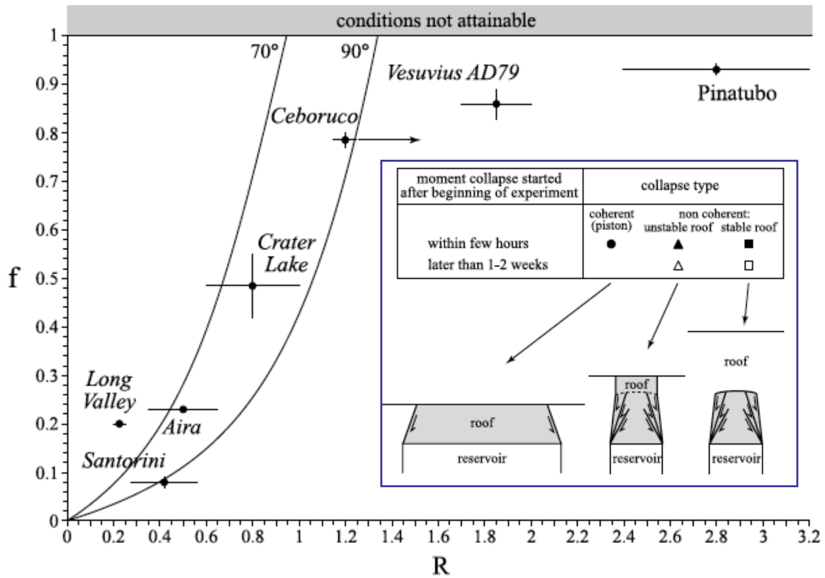
Gregg et al., JVGR 2012

Timing of caldera collapse and stratigraphy

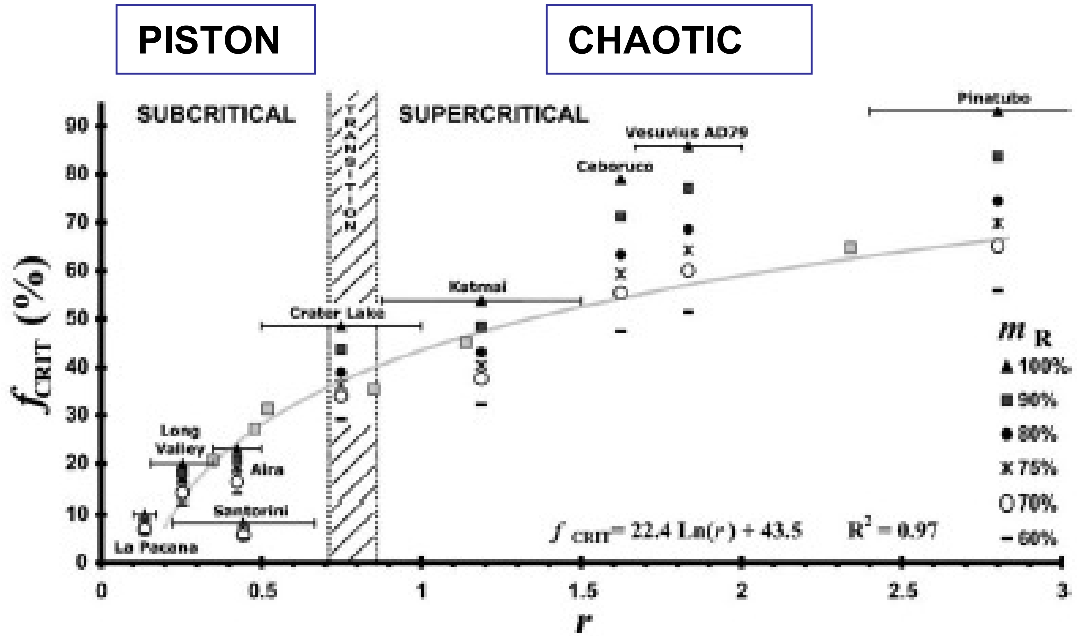


CCDB, Geyer et al., 2011

Depth and radius of magma chamber vs f --> twofold classification of collapse and magma withdrawal



Roche and Druitt EPSL 2001



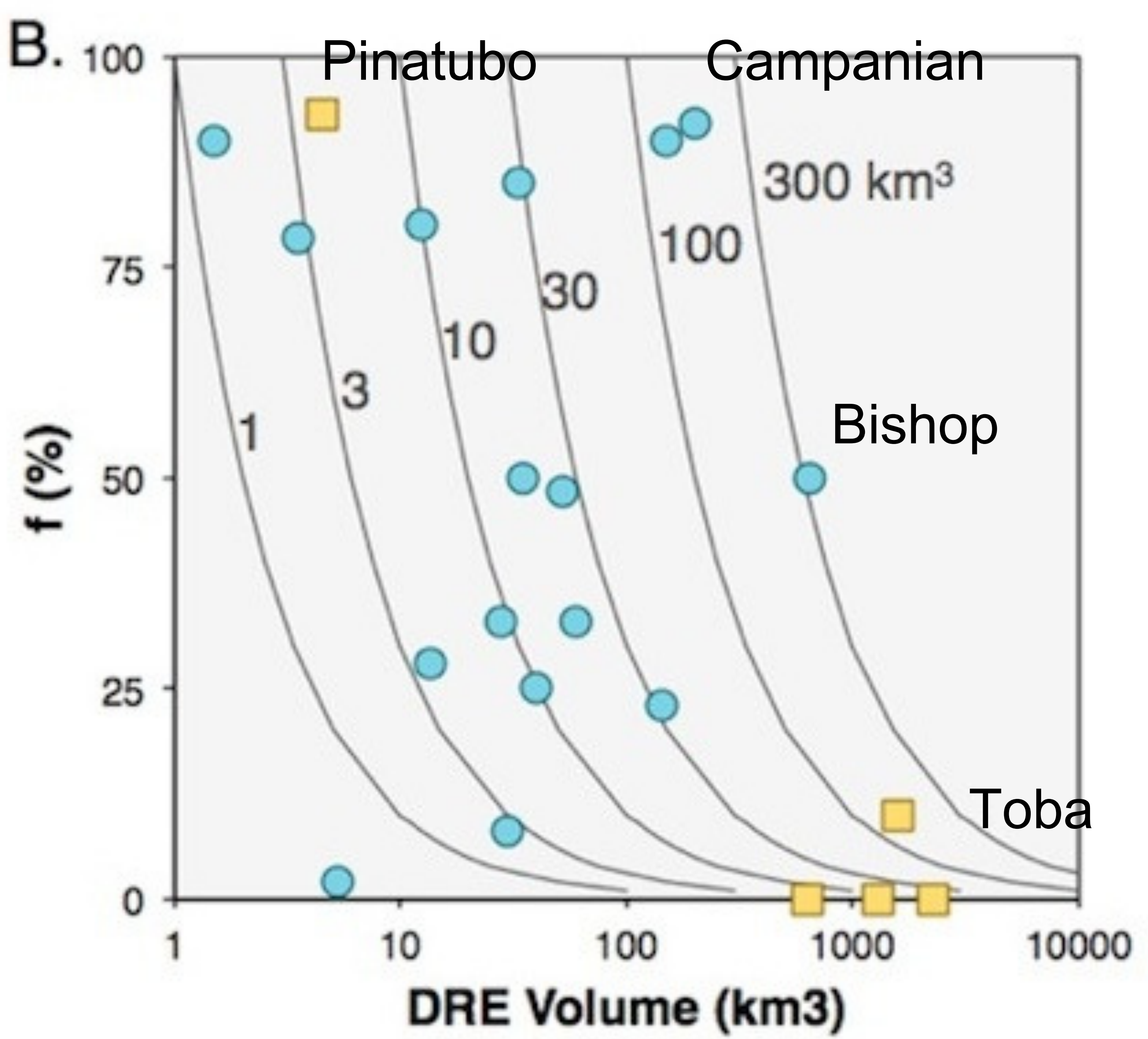
384 A. Geyer et al. / Journal of Volcanology and Geothermal Research 157 (2006) 375–386

Table 3

Natural examples. V_{TD}, total volume of deposits given in DRE (dense-rock equivalents); V_{PC}, volume of the pre-caldera deposits given in DRE; P (P_{min}–P_{max}), magma chamber depth; D (D_{min}×D_{max}) caldera diameter, i.e. magma chamber diameter; r, roof aspect ratio

Caldera, *Formation*	V_{TD} (km^3)	V_{PC} (km^3)	P (km)	D (km)	r[a]
La Pacana[b], *Atana Ignimbrite*	1600	<160	6	60×35	0.1–0.17
Long Valley[c], *Bishop Tuff*	750	150	5–6	17×32	0.16–0.35
Santorini[d], *Minoan Tuff*	27–33	2–3	2–3	6×9	0.22–0.67
Aira[e], *Ito Tuff*	143	33	7–10	20	0.35–0.5
Katmai[f]	13	7	3.5–4.5	3×4	0.88–1.5
Crater Lake[g], *Climactic*	40–64	17–35	5–8	8×10	0.5–1
Ceboruco[h], *Jala Pumice*	3–4	2.5–3	>6	3.7	1.62
Vesuvius[i], *Pompeii Pumice*	1.2–1.7	1–1.5	5–6	3	1.67–2
Pinatubo e	3.7–5.3	3.4–5	6–8	2.5	2.4–3.2

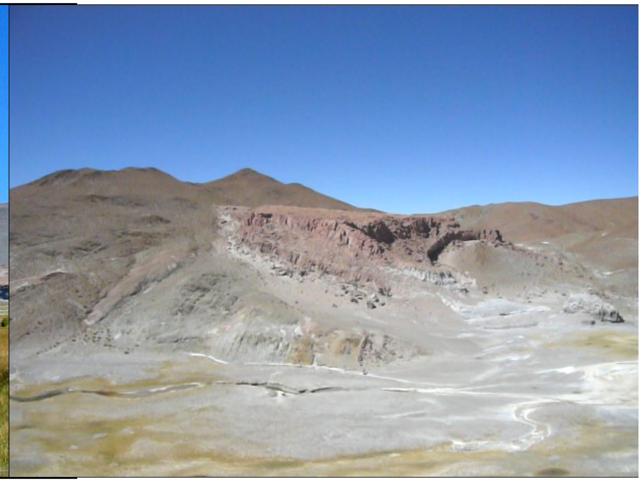
Ignimbrites and stratigraphy/timing of collapse (f)

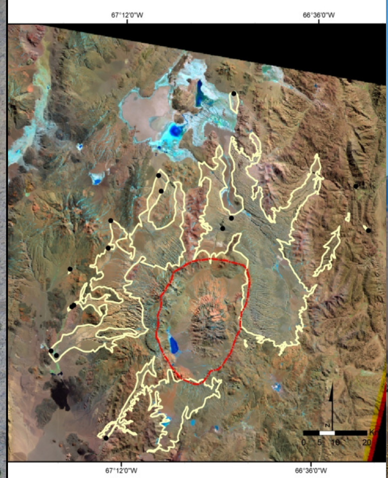


Cashman & Giordano in prep

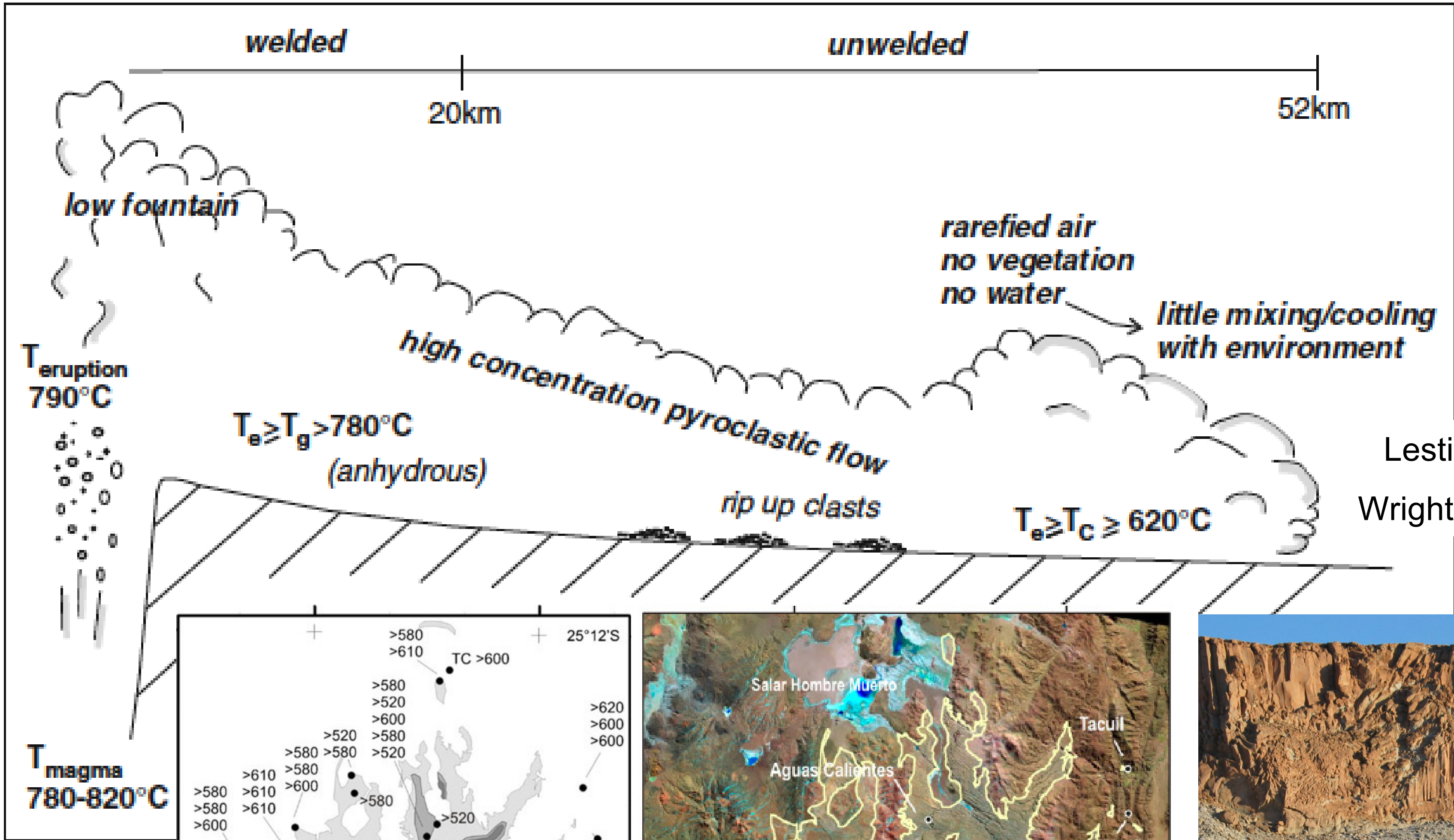
Monotonous Intermediates mobility

Unit	age (Ma)	chemistry	extracaldera bulk (preserved) volume (km3)	dispersal (preserved) area (km2)	average thickness H (m)	max preserved distance (km)	average radius (km)	circle diametre L (km)	aspect ratio H/L	deposit type	basal fallout	max height climbed (at distance)	crystal concentration	% < 1/16 mm
Cerro Galan	2.1	rhyodacite	364.7 (97.2)	7500 (2160)	45	74	50	100	4.5*10-4	VP	no		no	> 20 %



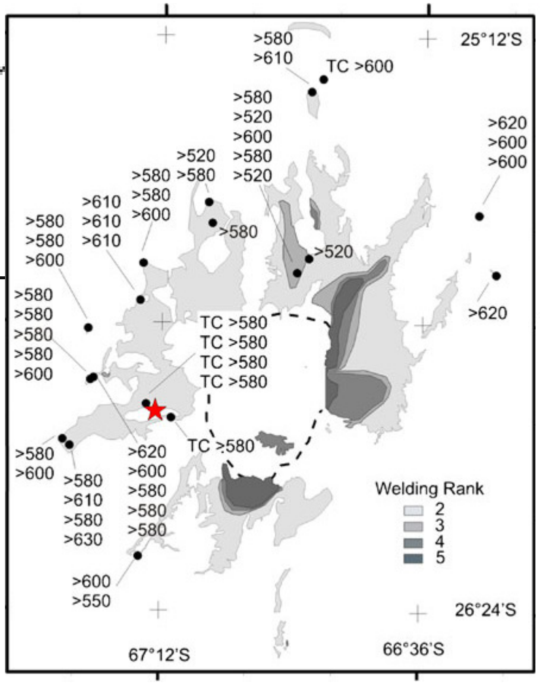


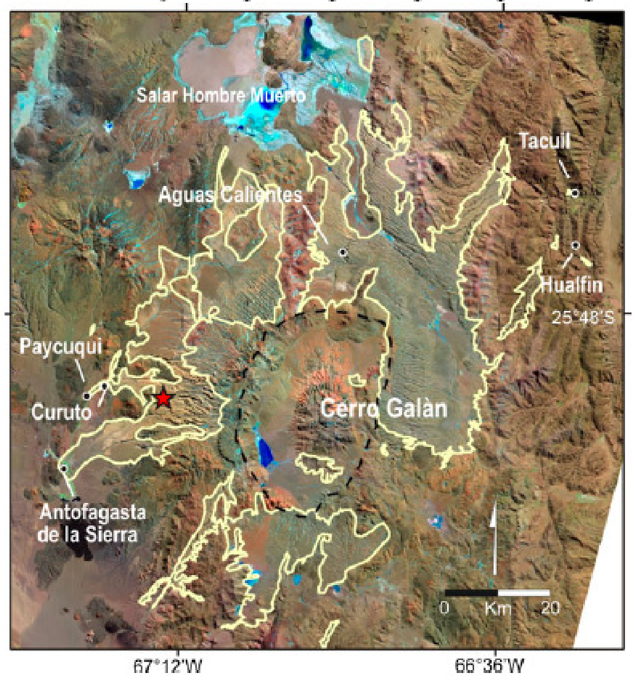
Monotonous intermediate temperatures

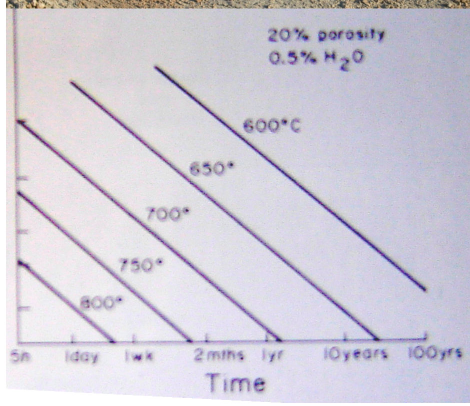


Lesti et al., BV 2011

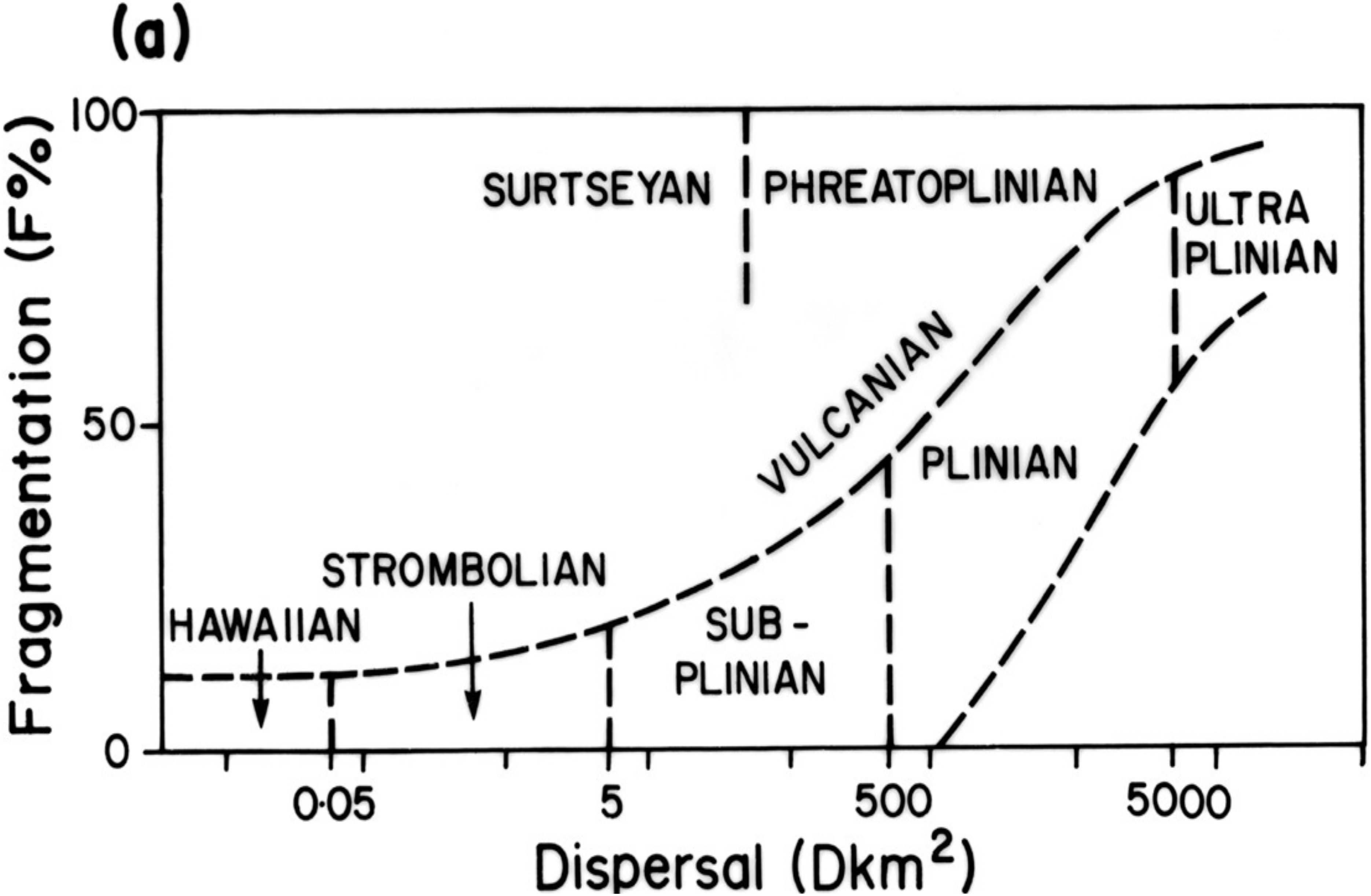
Wright et al., BV 2011



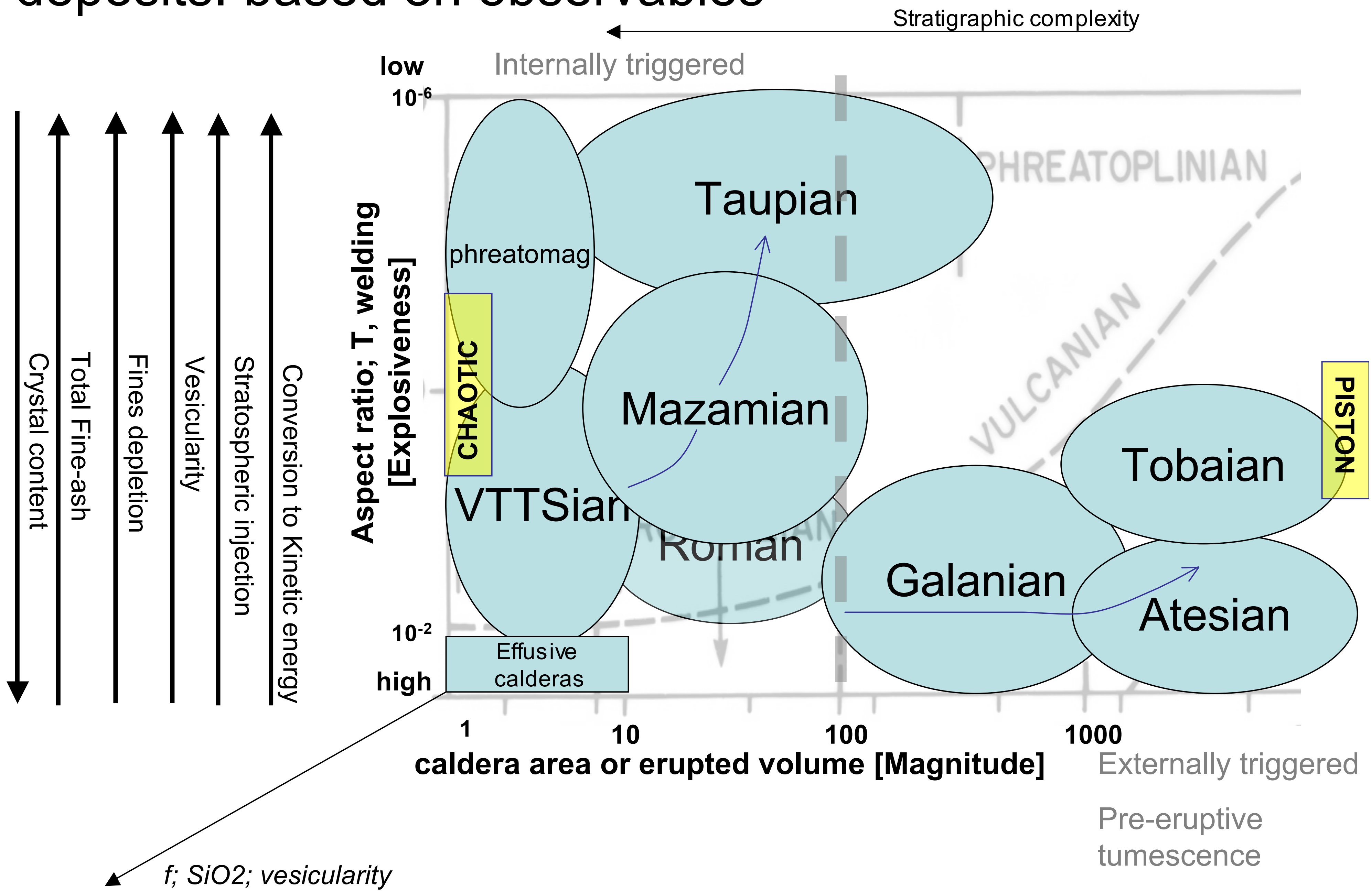




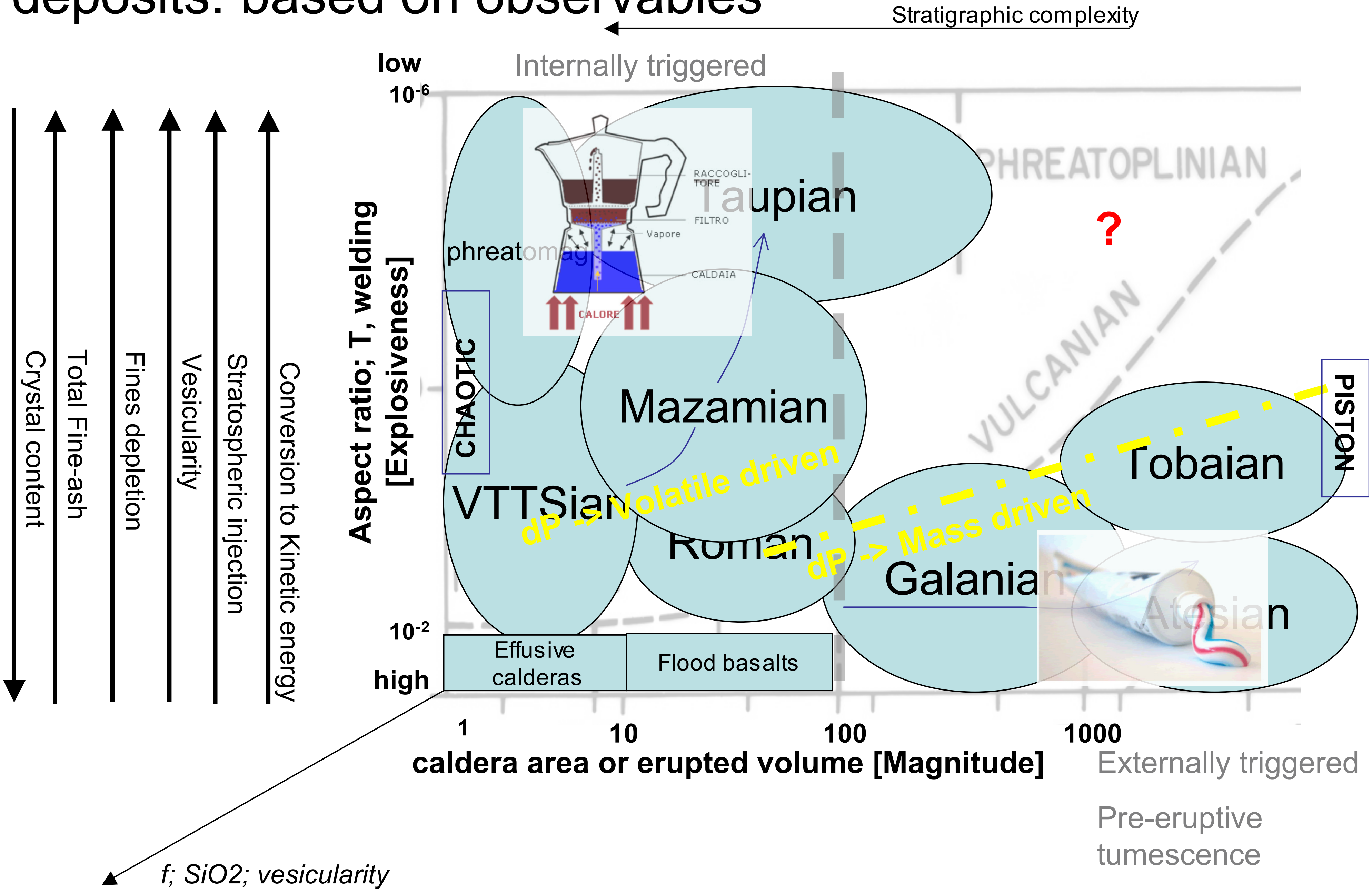
Back to Walker's classification: based on observables



Applying Walker's approach to caldera forming deposits: based on observables



Applying Walker's approach to caldera forming deposits: based on observables



Points for discussion

1 - do we need a classification for caldera forming eruptions?

2 - is it viable to build it on observables?

3 - what variables and how many?

4 - what is the extent of uncertainties when calculating:

- caldera area (morphological vs structural)
- deposit volume (bulk vs DRE) vs total mass
- aspect ratios
- emplacement temperature
- stratigraphic timing of caldera collapse (breccia? texture?)

5 - is it meaningful to try relating calssification based on collapse models to eruption styles?

6 - how to include repose intervals?

7 - should we use some geophysical parameters (for active calderas)