*MeMoVolc workshop on*
*"The dynamics of volcanic explosive eruptions",*
*Geneva, 29-31 January 2014*

# Eruption classification

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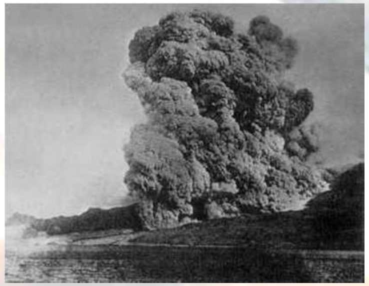
## *FIRST CLASSIFICATIONS OF VOLCANIC ERUPTIONS*

- based on form and location of vent *(e.g. fissure eruptions vs central vent eruptions; summit vs flank eruptions, terminal vs subterminal eruptions; open vs closed vents, lava lake activity as a special variety of open vent)*

- based on character of eruptions
  - *→proportion of explosions: explosive, effusive and mixed eruptions*
  - *→association with type volcanoes:* ***Hawaiian, Strombolian, Vulcanian, Peléean*** *eruptions (Lacroix 1908) (based on the freedom of release of the gas from magma, which is related to magma viscosity)*



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*The fundamental factor is fluidity of the ejected magma (Macdonald 1972)*

## *FIRST CLASSIFICATIONS OF VOLCANIC ERUPTIONS*

*Individual types vary in volume erupted and "strength"! The fundamental factor is fluidity of the ejected magma (Macdonald 1972)*

- Strombolian type ranges from *rhythmic mild explosions* (that throw out sparse showers of scoria to heights of only of a few tens of meters) to *violent blasts (*that project voluminous showers of scoria and bombs to heights of hundreds or thousands of meters, accompanied by a dense black ash cloud)

Mercalli (1907) → "normal Strombolian" vs "Strombolian paroxysm"
Macdonald (1972) → "normal Strombolian" vs "violent Strombolian" (as of long duration)


*Strombolian activity*: mild/gentle, moderate or violent, long-lasting or brief, continuous or rhythmic. Cerro Negro (1968): violent strombolian ≠ Vulcanian eruptions for which ejected magma is more viscous

- Peléean and Plinian eruptions → special variety of Vulcanian (based on ejected magma)

| Eruption type | Physical nature of the magma | Character of explosive activity | Nature of effusive activity | Nature of dominant ejecta | Structures built around vent |
|---|---|---|---|---|---|
| **Basaltic flood** | Fluid | Very weak ejection of very fluid blebs; lava fountains | Voluminous very fluid lava flows | Cow-dung bombs and spatter | Spatter cones; lava plains |
| **Hawaiian** | Fluid | Weak ejection of very fluid blebs; lava fountains | Thin fluid lava flows | Cow-dung bombs and spatter | Spatter cones; flat lava cones |
| **Strombolian** | Moderately fluid | Weak to violent ejection of pasty fluid blebs | Thicker, less extensive fluid lava | Fusiform bombs; cinder; glassy ash | Conder cones |
| **Vulcanian** | Viscous | Moderate to violent ejection of solid or very viscous hot fragments of new lava | Flows commonly absent | Glassy to lithic blocks and ash; pumice | Ash cones; block cones |
| **Peléean** | Viscous | Like Vulcanian | Domes | Like Vulcanian | Ash and pumice cones; domes |
| **Plinian** (exceptionally strong Vulcanian) | Viscous | Paroxysmal ejection of ash, associated with caldera collapse | Ash flows | Glassy ash and pumice | Widespread pumice lapilli and ash beds; no cone building |
| **Rhyolitic flood** | Viscous | Small amount of ash | Voluminous ash flows | Glassy ash and pumice | Flat plain (often with caldera) |
| **Ultravulcanian** | No magma | Weak to violent ejection of solid fragments of old rock | None | Lithic blocks and ash | Block cones; block and ash cones |
| **Gas eruption** | No magma | Continuous or rhythmic gas release at vent | None | None (or minor ash) | None |
| **Fumarolic** | No magma | Long-continued gas discharge | None | None (or minor ash) | None |

*Macdonald (1972) adjusted from: Mercalli (1907); Lacroix (1908); Sapper (1927)*

## *FIRST CLASSIFICATIONS OF VOLCANIC ERUPTIONS: MAIN ISSUES*

- Any one volcano is characterized by a variety of activity

  → *Rittmann (1944) recommended that a new nomenclature of descriptive terms be adopted to replace Lacroix's classification based on specific volcanoes*

- As scientists started observing new eruptions, new names were added that often overlapped adding to the confusion, e.g.:

  → *Basaltic floods (extension of Hawaiian activity); Plinian eruptions (first introduced by Stoppani (1871-73) as a phase of Vulcanian eruptions in which "pine" clouds are developed); Rhyolitic flood eruptions (extension of Plinian eruptions); Ultravulcanian (phreatic eruptions); shallow submarine eruptions (Surtseyan); (Macdonald 1972)*

  → *Icelandic type and Solfataric stage (Bullard 1976) vs Basaltic flood and Fumarolic activity (Macdonald 1972)*

- Classifications that are based on the observations of eruptions rely on the frequency of eruptions and on the opportunity to observe eruptive phenomena

  → *Bias towards more frequent small to moderate eruptions!*

## *A NEW CLASSIFICATION SCHEME BASED ON TEPHRA DEPOSITS:*
***Walker 1973, 1980; Self and Sparks 1978; Wright et al. 1980***

- Progress in physical volcanology relies on the identification and analysis of common features of eruptions having similar characteristics

- Link between volcanic eruptions and pyroclastic deposits

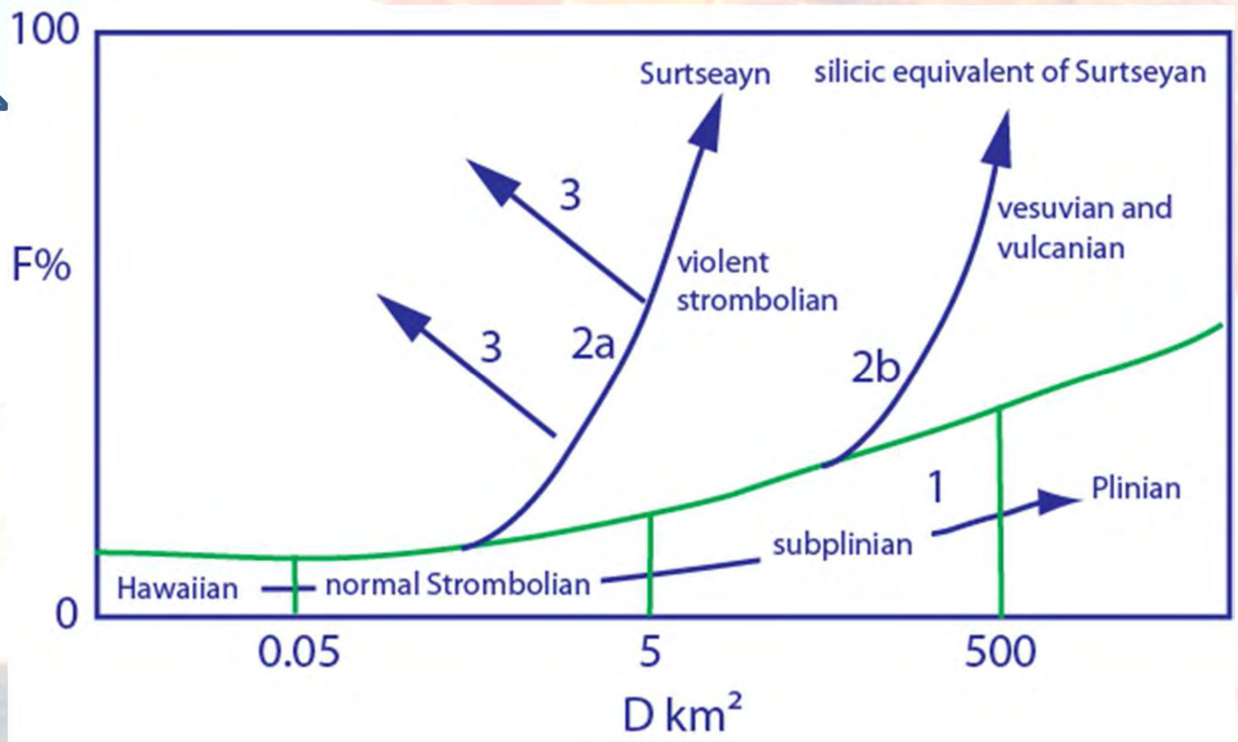
- Five parameters ("bigness") for the estimation of the scale of explosive eruptions:
  → magnitude (volume of erupted material typically converted to DRE)
  → intensity (volume of ejecta per unit time)
  → dispersive power (related to the total area of dispersal and, therefore, to plume height)
  → violence (related to kinetic energy)
  → destructive potential (related to the extent of devastation)

- Currently used parameters:
  → plume height
  → bulk erupted volume (deposit volume)
  → Volcanic Explosivity Index (Newhall and Self 1982)
  → DRE (volume of dense, unvesiculated magma)
  → mass eruption rate
  → destructiveness index (Pyle 2000)
  → magnitude and intensity scale (Pyle 2000)

## *A NEW CLASSIFICATION SCHEME BASED ON TEPHRA DEPOSITS:*

***Walker 1973, 1980; Self and Sparks 1978; Wright et al. 1980***

(fragmentation)
Decreasing grainsize




1: Increasing viscosity and/or gas content

2: Increasing violence → higher fragmentation

3: weak explosions related to conduit clearing (ash emissions)

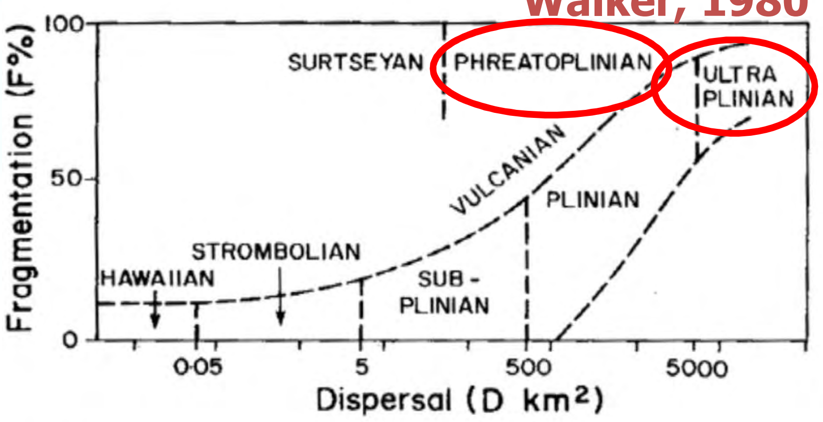
(area of pyroclastic dispersal)
increasing eruption intensity and dispersal power

*Walker 1973*

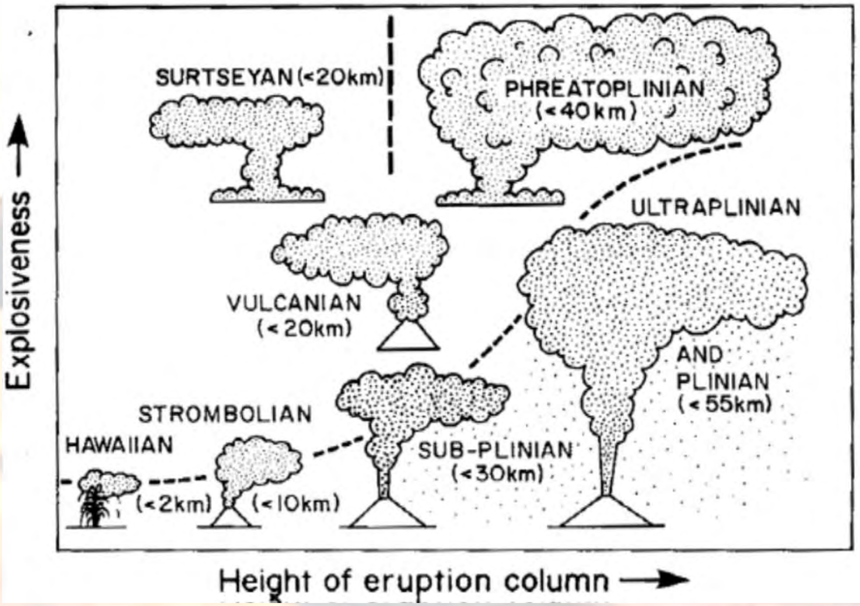
## *A NEW CLASSIFICATION SCHEME BASED ON TEPHRA DEPOSITS:*

***Walker 1973, 1980; Self and Sparks 1978; Wright et al. 1980***

**Walker, 1980**



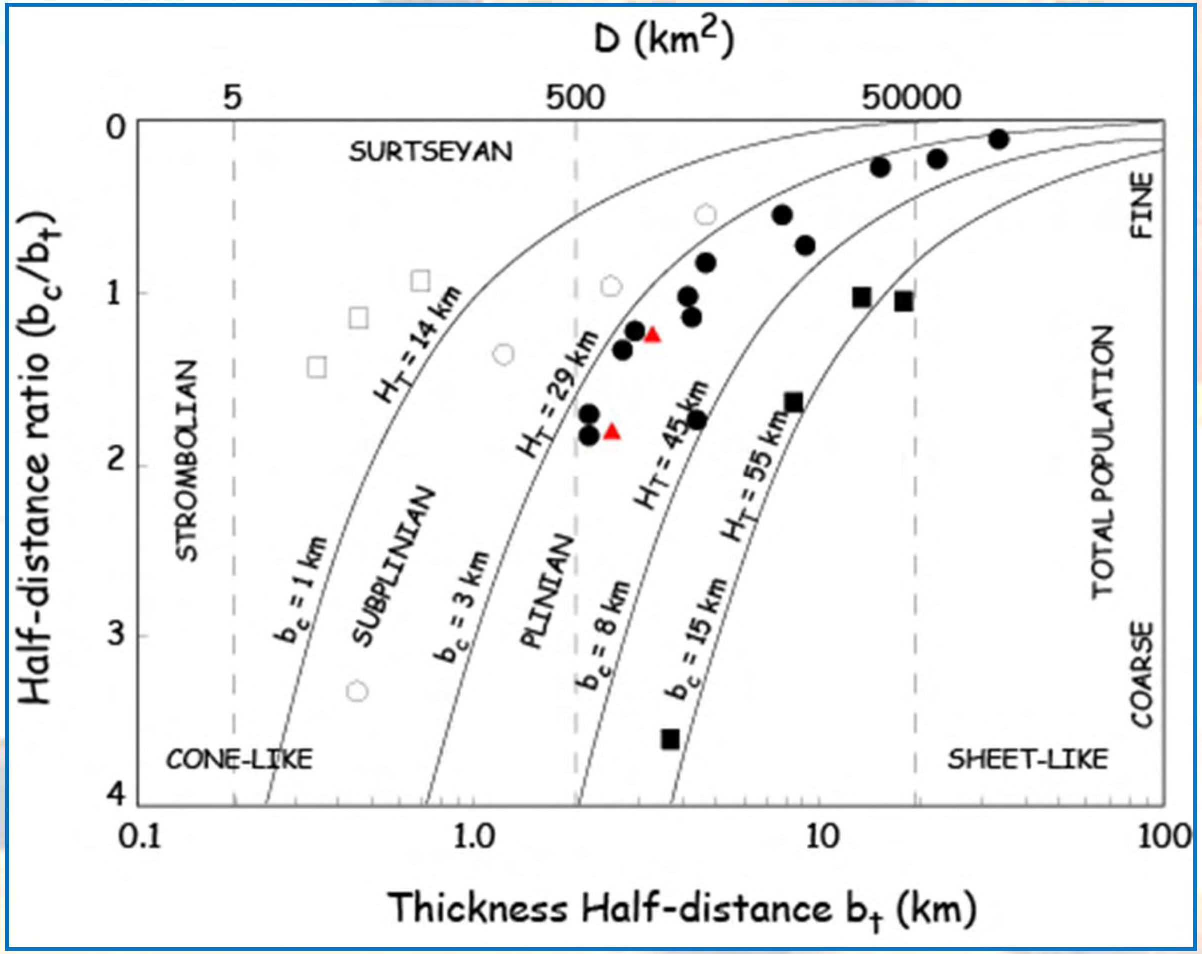

**Cas et al., 1988**




### *MAIN ISSUES:*

- difficulty in determining F and D (mainly max thickness)
- time-consuming sieve analysis
- meaning of fragmentation index: *not only controlled by magma fragmentation but also by premature fallout of fine ash due to aggregation processes*
- poor constraint on Hawaiian field *(e.g. Houghton and Gonnermann 2008)*
- deposits with poor-preservation potential
- absence of volcanic products other than tephra *(e.g. Pioli et al. 2009)*
- absence of hybrid and multi-style eruptions

## *A NEW CLASSIFICATION SCHEME BASED ON TEPHRA DEPOSITS:*
### *(Exponential best fit) Pyle 1989*




- Easier determination of bc and bt vs F and D

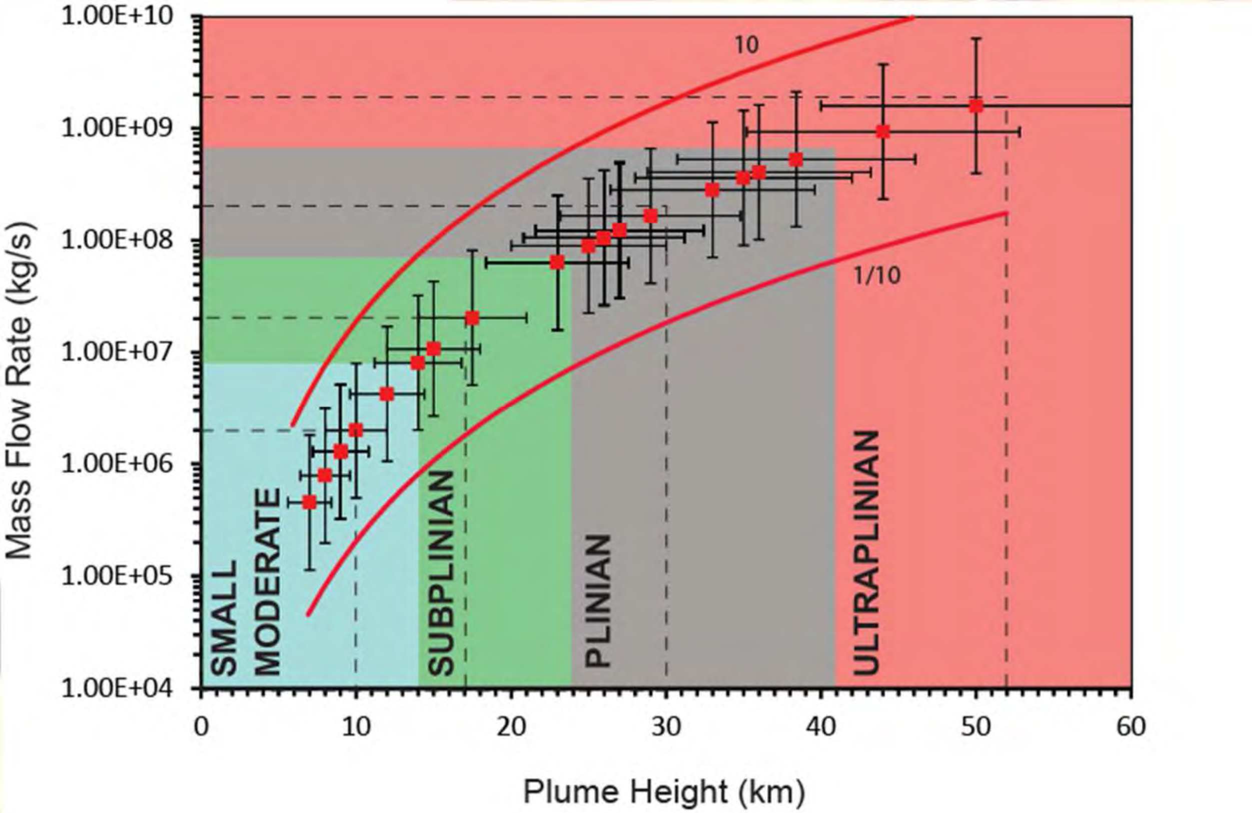
***MAIN ISSUE:***

- often thinning and grainsize decrease of tephra deposits are better characterized by multiple exponential segments (i.e. multiple values of bc and bt)
- boundary identification

- bt: thinning half-distance (≡ distance over which the max thickness decreases by 1/2)
- bc/bt: half-distance ratio

## *A NEW CLASSIFICATION SCHEME BASED ON TEPHRA DEPOSITS:*
### *Bonadonna and Costa 2013*

- *Identification of eruptive styles based on plume height and MFR*

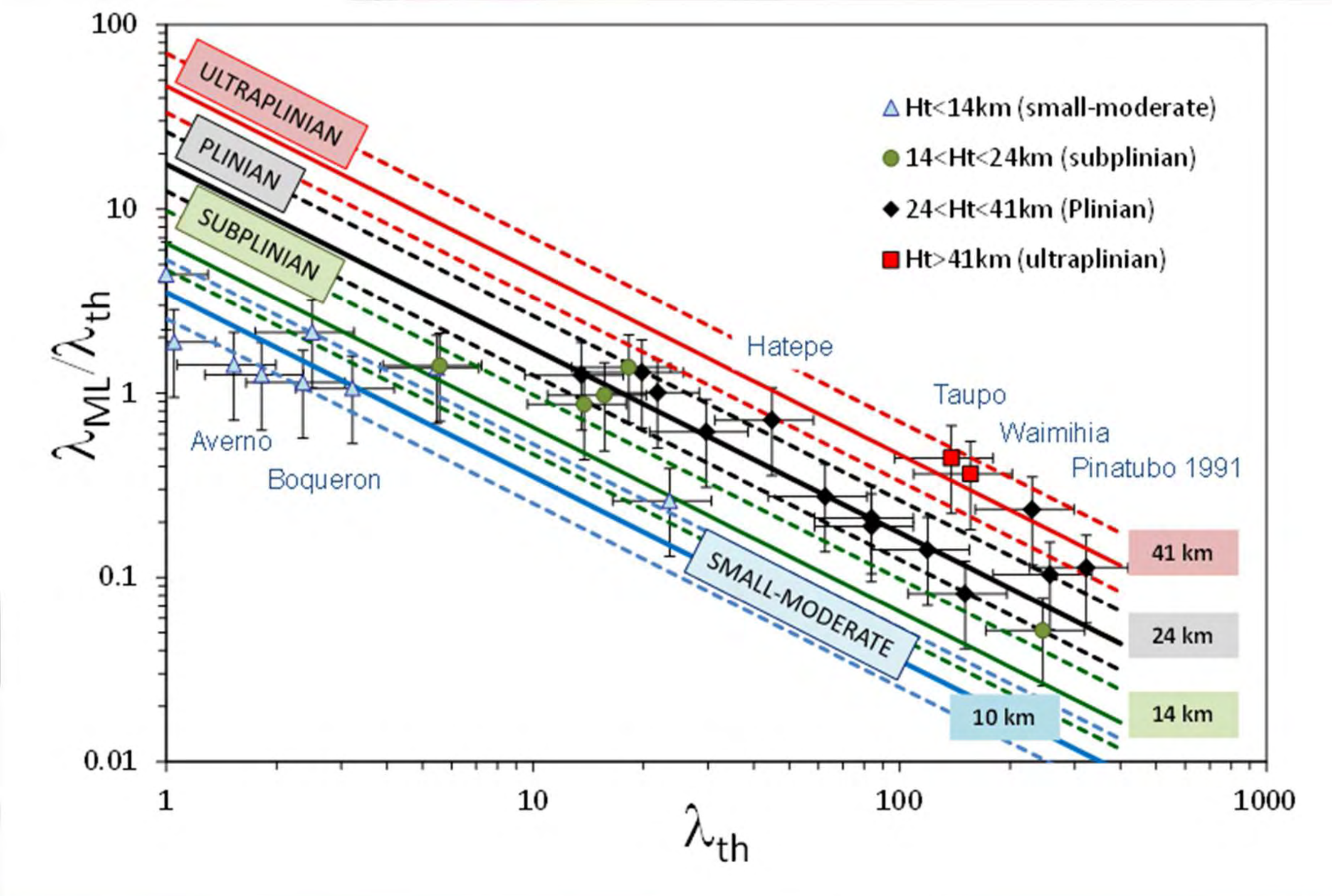



- Choice of boundaries based on a simple quantitative scaling of intensity (MFR; Mastin et al. 2009)
- No attempt to describe eruptions associated with complex fragmentation mechanisms (ie Surtseyan and Phreatoplinian)
- No attempt to distinguish amongst small-moderate explosive eruptions

Small-moderate : Hawaiian, Strombolian, violent Strombolian, Vulcanian, ash emissions
⟶ These are better described based on source dynamics and textural features of the products

## *A NEW CLASSIFICATION SCHEME BASED ON TEPHRA DEPOSITS:*

***(Weibull fit) Bonadonna and Costa 2013***



## *VOLCANIC EXPLOSIVITY INDEX*

(Newhall and Self 1982)

| VEI | Ejecta volume | Classification | Description | Plume | Frequency |
|---|---|---|---|---|---|
| 0 | < 10,000 m³ | Hawaiian | non-explosive | < 100 m | constant |
| 1 | > 10,000 m³ | Hawaiian/Strombolian | gentle | 100-1000 m | daily |
| 2 | > 1,000,000 m³ | Strombolian/Vulcanian | explosive | 1-5 km | weekly |
| 3 | > 10,000,000 m³ | Vulcanian/Peléan | severe | 3-15 km | yearly |
| 4 | > 0.1 km³ | Peléan/Plinian | cataclysmic | 10-25 km | ≥ 10 yrs |
| 5 | > 1 km³ | Plinian | paroxysmal | > 25 km | ≥ 50 yrs |
| 6 | > 10 km³ | Plinian/Ultra-Plinian | colossal | > 25 km | ≥ 100 yrs |
| 7 | > 100 km³ | Plinian/Ultra-Plinian | super-colossal | > 25 km | ≥ 1000 yrs |
| 8 | > 1,000 km³ | Ultra-Plinian | mega-colossal | > 25 km | ≥ 10,000 yrs |

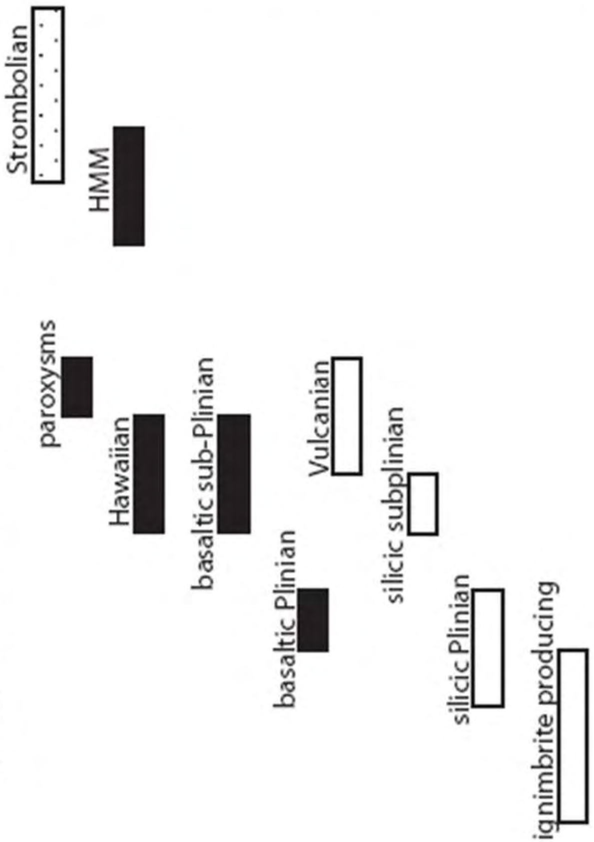
***MAIN ISSUES:***

- It assumes a link between magnitude and intensity
- Modern eruptions defined by plume height vs ancient eruptions defined by maximum erupted volume
- Not useful for effusive (lava) eruptions, which by default get VEI of 0, 1
- Deposits in category 0 cover at least six orders of magnitude of eruptive volume

# *VOLCANIC EXPLOSIVITY INDEX*

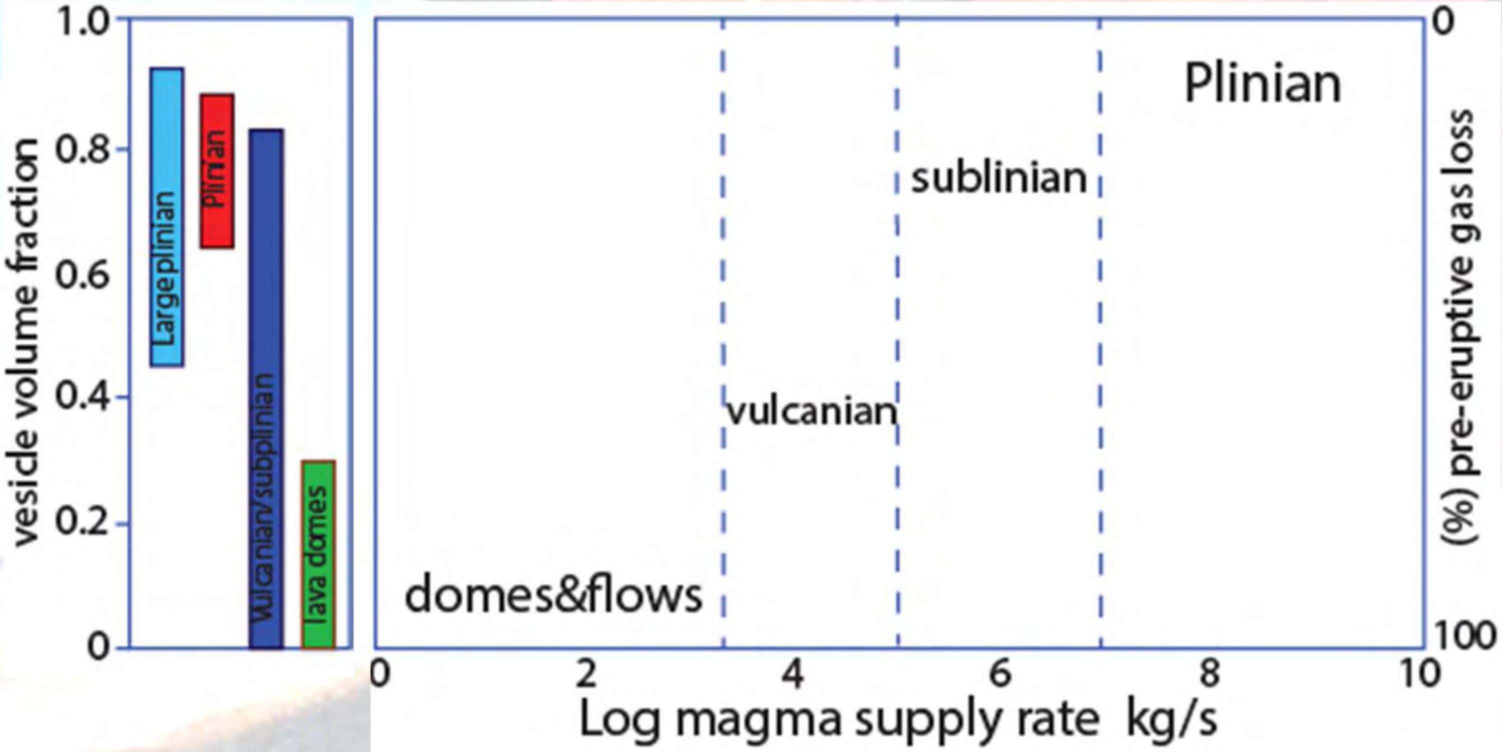
| New VEI | Old VEI | Volume range m³ |
|---|---|---|
| -6 | 0 | 1E-2 to 1E-1 |
| -5 | 0 | 1E-1 to 1E0 |
| -4 | 0 | 1E0 to 1E+1 |
| -3 | 0 | 1E+1 to 1E+2 |
| -2 | 0 | 1E+2 to 1E+3 |
| -1 | 0 | 1E+3 to 1E+4 |
| 0 | 1 | 1E+4 to 1E+5 |
| 1 | 1 | 1E+5 to 1E+6 |
| 2 | 2 | 1E+6 to 10E+7 |
| 3 | 3 | 1E+7 to 1E+8 |
| 4 | 4 | 1E+8 to 1E+9 |
| 5 | 5 | 1E+9 to 1E+10 |
| 6 | 6 | 1E+10 to 1E+11 |
| 7 | 7 | 1E+11 to 1E+12 |
| 8 | 8 | >1E+12 |

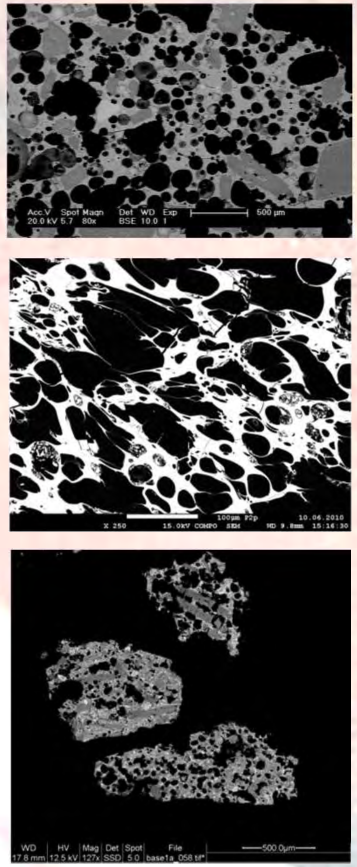
Eruption style




*Houghton et al. 2013: Pushing the Volcanic Explosivity Index to its limit and beyond: Constraints from exceptionally weak explosive eruptions at Kilauea in 2008*

## CLASSIFICATION SCHEME BASED ON MAGMA SUPPLY RATE AND EXSOLUTION/DEGASSING STYLE



Volatiles provide the primary force for volcanic eruptions → understanding degassing is fundamental to understanding volcanic activity

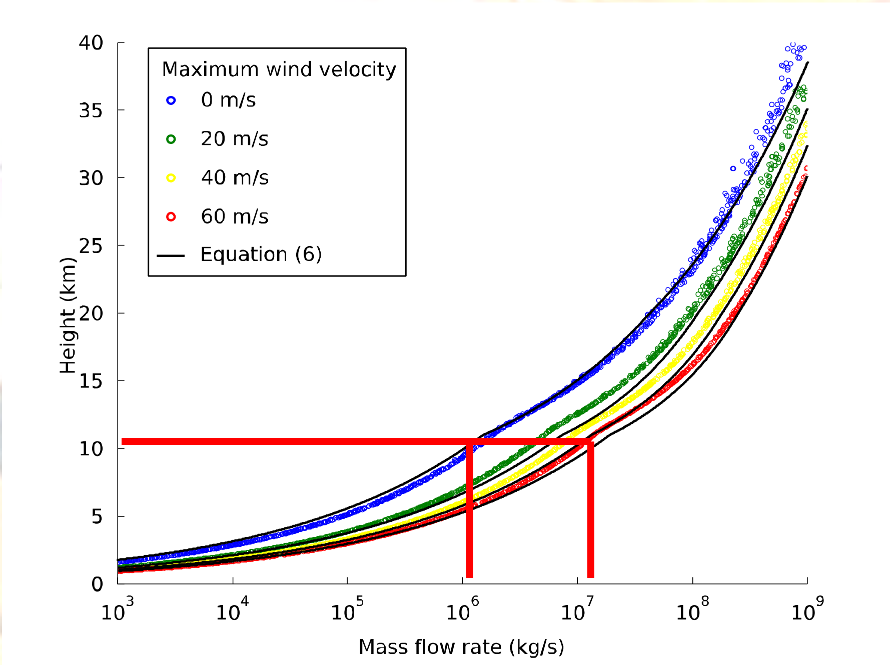
Magma degassing history → clast texture (vesicles and crystals)

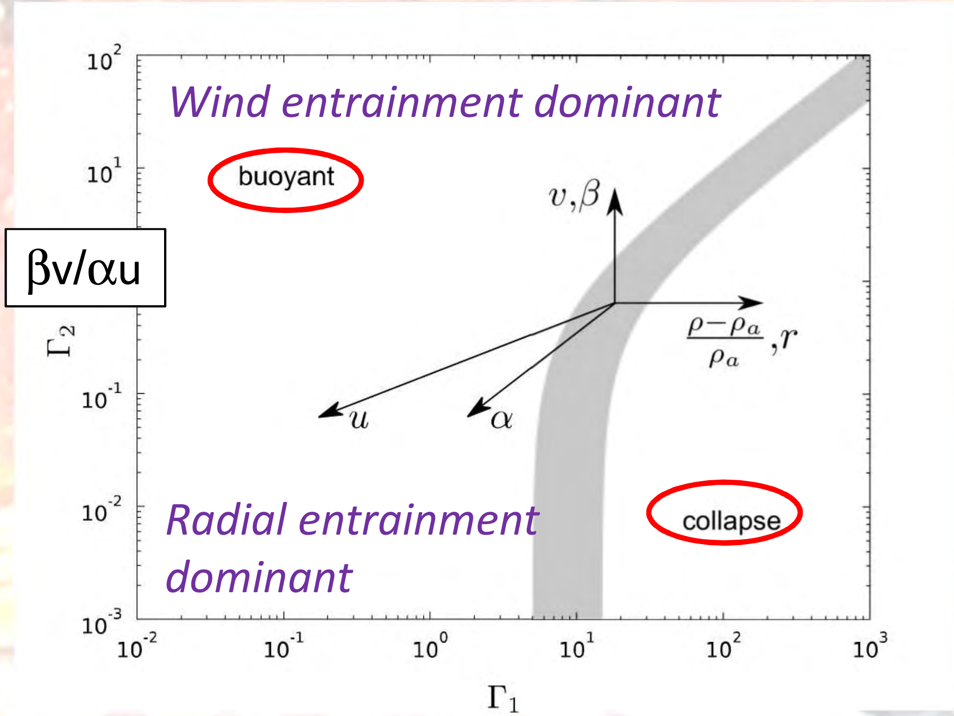
*Cashman 2004; Volatile Controls on Magma Ascent and Eruption*

## *CHARACTERIZATION OF ERUPTIVE STYLE BASED ON 1D MODELLING AND SCALING ARGUMENTS*

$$\dot{M} = \pi \frac{\rho_{a0}}{g'}\left(\frac{2^{\frac{5}{2}}\alpha^2 \overline{N}^3}{z_1^4} H^4 + \frac{\beta^2 \overline{N}^2 \overline{v}}{6} H^3\right)$$

$$\Pi = 6\frac{2^{\frac{5}{2}}\overline{N}H}{z_1^4 \overline{v}}\left(\frac{\alpha}{\beta}\right)^2$$




*Kinetic energy dominant*

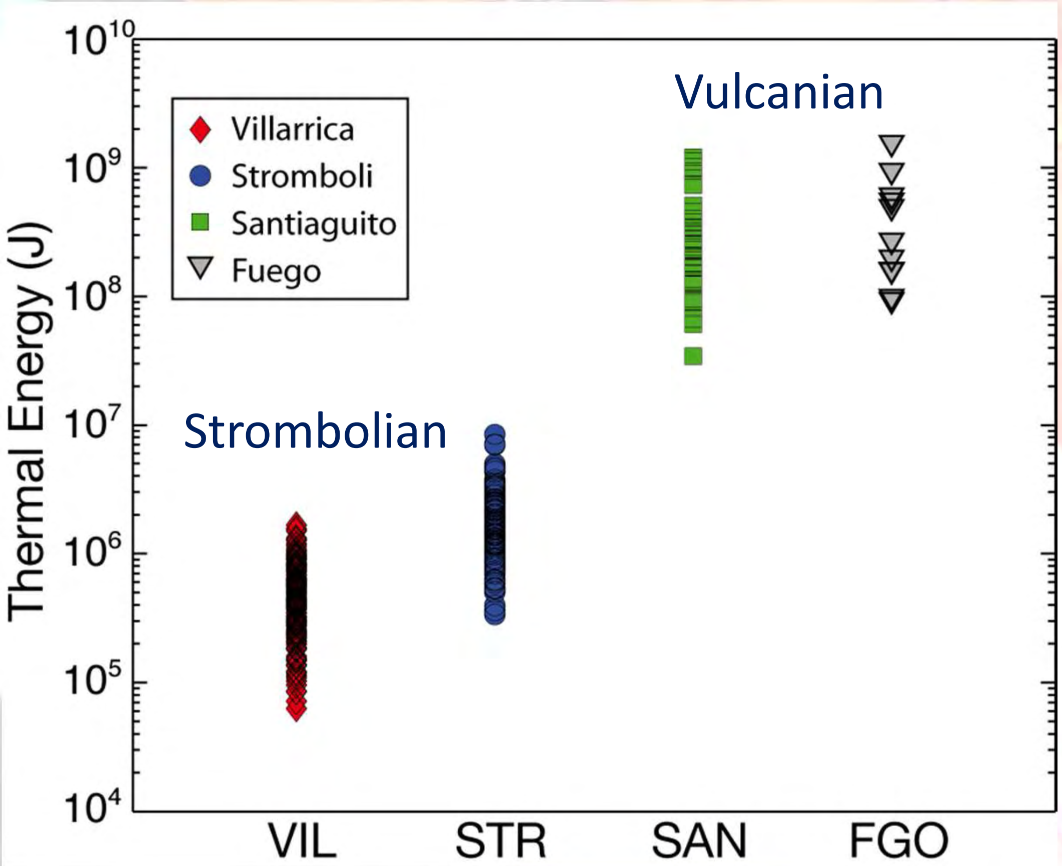
-Ri/α

*Potential energy dominant*

*Degruyter and Bonadonna (2012)*

*Degruyter and Bonadonna (2013)*

## *GEOPHYSICAL CLASSIFICATION SCHEMES: Thermal Energy*




Vulcanians have same acoustic energy as Strombolians but larger thermal energy. Thermal energy is proportional to the volume of material transported in the atmosphere → Vulcanian eruptions are more efficient than Strombolian.

*Marchetti et al. 2009*

# CONCLUSIONS

- Observations →Quantification (Link between observations and tephra deposits) → Quantification of additional parameters (e.g. clast texture, geophysics, modelling)

- Do we still need to classify volcanic eruptions? Purpose based!

  - LONG-TERM HAZARD ASSESSMENT, REAL-TIME FORECASTING (source term parameters)

  - UNDERSTANDING OF VOLCANIC BEHAVIOUR (and precursory activity!)
    - simplify a complex system by identifying first-order processes
    - process interpretation that goes beyond simple quantification

    → multidisciplinary approach *(field observations, textural studies, geophysics, numerical and experimental modelling)*

- Fundamental need: Reconcile volcanic deposits with volcanic processes!

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**The purpose of classification is not to set forth final and indisputable truths, but rather to afford stepping stones towards better understanding – *LC Graton (1880-1970)***

# ***Thanks!***