Pyroclastic Eruptions

(Pyroclastic from Greek meaning "fire-broken")

I. Pyroclastic Fall (Ash or tephra fall)

II. Pyroclastic Flows
   a) Pumice Flows (ignimbrites)
   b) Block and Ash Flows
      (Nueé ardentes)

III. Pyroclastic Surges
IV. Phreatomagmatic Eruptions

(These all tend to be inter-related and may occur during the same eruption)

Pyroclastic Fragments

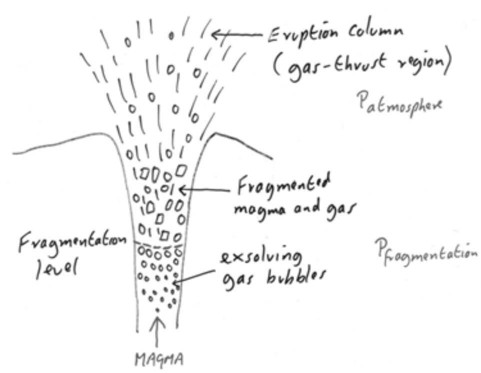
	Size (mm)	Rock Type
BLOCKS/BOMBS	>34	Agglutinate Pyroclastic Breccia
LAPILLI	4 to 32	Lapilli Tuff
ASH (Tephra)	<4	Tuff

(note tuff is further subdivided depending on the predominant particle type e.g. vitric, lithic, crystal)

Some more terminology:

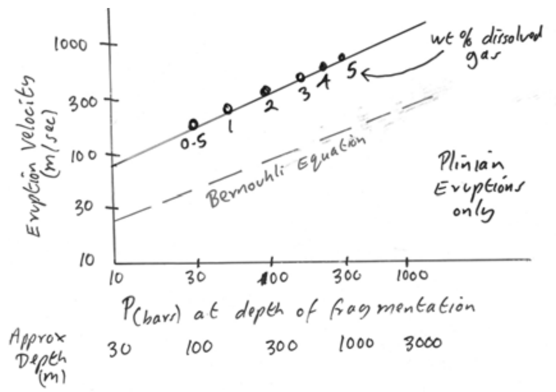
1. Juvenile – magmatic fragments
2. Cognate – fragmented co-magmatic rocks
3. Accidental – material plucked from wall rock

Eruption Dynamics

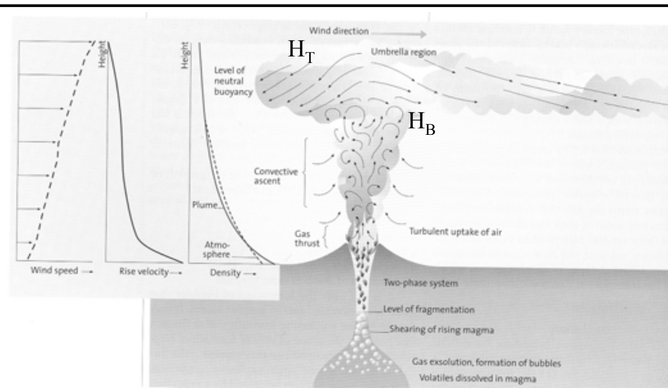


Eruption Velocity (m/sec) ~ ($P_{fragmentation}$ – $P_{atmosphere}$)/Magma Density
(based on Bernouilli equation)

$P_{fragmentation}$ (and almost everything else!) is based on the dissolved gas content

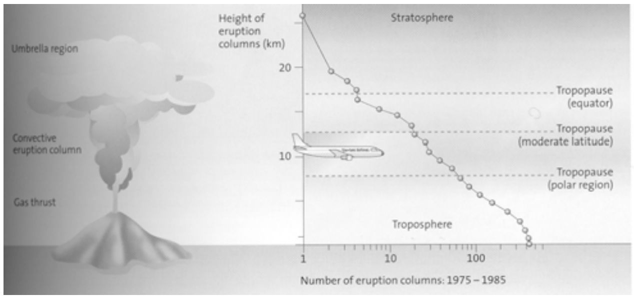


Example Silicic magmas may contain 4-5% dissolved gases Fragmentation will begin at around a km (300 bars) in depth leading to the eruption velocities of over 500 m/sec typical of Plinian eruptions



There are three parts to an eruption column:

1. Gas Thrust Region – initial velocity (m/sec) of the mixture of fragments and gases (ranges from ~ 100 in Strombolian to > 600 in Plinian eruptions)
2. Convective Region – air is drawn into the column, heated, reducing the density of the plume, making it buoyant.
3. Umbrella Region – the density of the column is the same as the atmosphere, resulting in lateral spreading



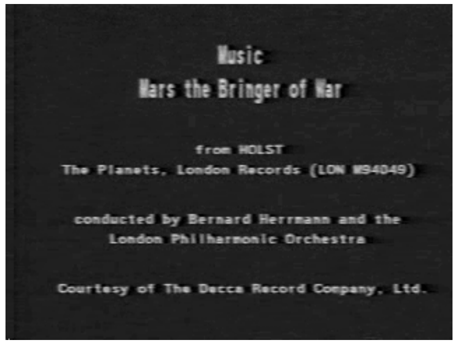
The base of the umbrella region (H_B) often occurs at the tropopause (boundary between atmosphere and stratosphere) because of temperature inversions. An important consequence is that large Plinian eruptions may eject considerable amounts of material into the stratosphere where they are rapidly carried for long distances by the jet stream

Mount Pinatubo, Philippines, 1991

The huge eruption column rose to a height of 40 km into the stratosphere. It was 8 times bigger than Mount St. Helens.

Satellite view of atmospheric aerosols (ash) before and 10 days after the eruption. Note how it has encircled the earth, remaining there for several years and reducing the earth's temperature by 2-3 ^{0}C.

Ash from Pinatubo, 1991 Encircles the Earth



Sunlight extinction due to dust and volcanic ash from 1985 to 1992.

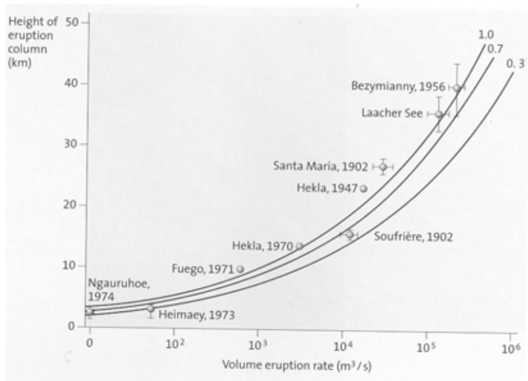
- From 1985 onwards, the atmosphere is clearing following the eruption of El Chichon, Mexico in 1982.
- Ruiz volcano in Columbia erupts in 1985, then the atmosphere clears again.
- Mount Pinatubo erupts in June 1991 and blankets the earth.

The total height (H_T) of a column depends on a variety of complicated factors but can be conveniently related to the Volume Discharge Rate (V)

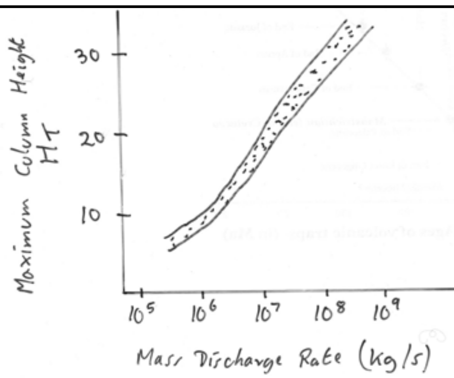
$$\mathbf{H_T = 1.67V^{0.259}}$$

Example – about 5 hrs after initiation the volume discharge rate for the 1991 Pinatubo eruption was estimated at about 210,000 m^3/sec

H_T (Actually this equation was used in reverse to calculate the volume discharge rate from a column height of 40 km!) n



Relationship between column height (km) and volume discharge rate (m^3/sec) for several eruptions



Shaded area reflects temp from 600 – 1000^0C

Column Height (H_T) can also be related to mass discharge rate (kg/sec)

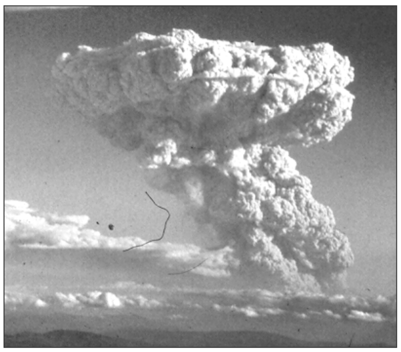
Which reflects:-

1) Volume discharge rate
2) Density of the column (kg/cm^3)
3) Vent diameter

Eruption Column Width – the column widens with height – for a simple thermal plume (rising smoke) the basic relationship is:-

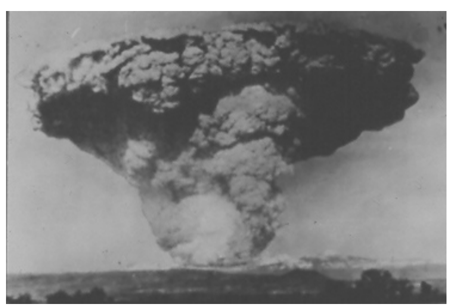
Column Width = Initial Width + 0.125 (Column Height)

For volcanic columns the factor is higher (0.2 - 0.5), mostly because of entrainment and expansion of hot air



This means that at a height of 20 km a column could expand to a width of around 4 – 10 km

The Umbrella Region



Radial expansion of the umbrella region is highly variable but roughly related to column height:-

Height (km)	Radial Expansion (km)
7	1 – 10
20	10 – 100
>30	20 - 200

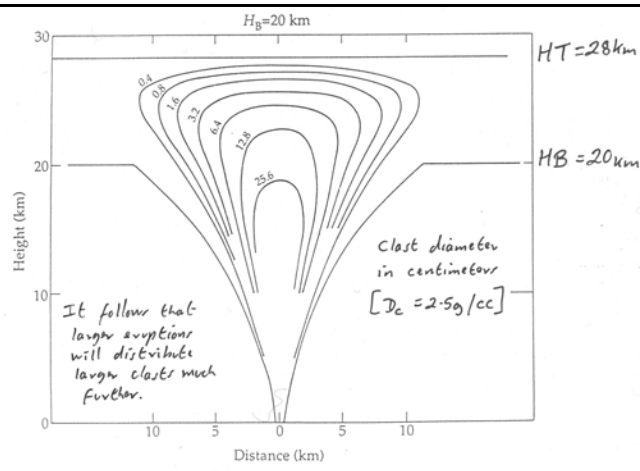
Fallout of Tephra

(What goes up must come down!)

If the upward velocity of the eruption column is less than the terminal fall velocity (TFV) of clasts and particles in the column, then these fragments will fall out of the column:-

$$TFV = C_d \sqrt{((2RgD_c)/D_a)}$$

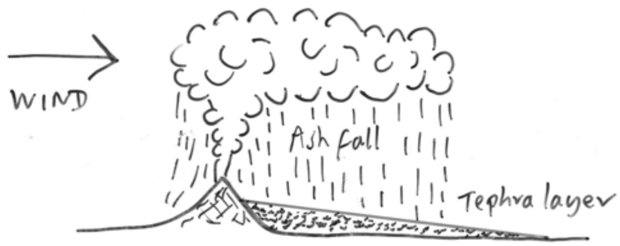
Where: C_d = drag coefficient (~ 1.0)
2R = clast diameter (cm)
g = gravitational constant
D_c = clast density
D_a = atmospheric density



Self evident that:-

a) Large clasts fall closest to the vent
b) Finer material is spread further
c) Large eruptions will distribute material further

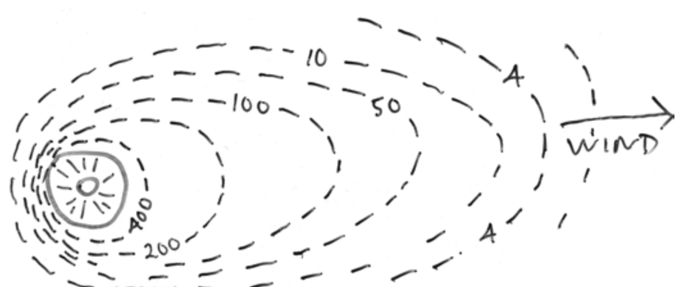
Wind Effects



Wind will effect the direction and movement of an eruption column – especially the umbrella region.

Note that the ash is thickest nearer the volcano. Also larger fragments fall close to the volcano and finer material further away

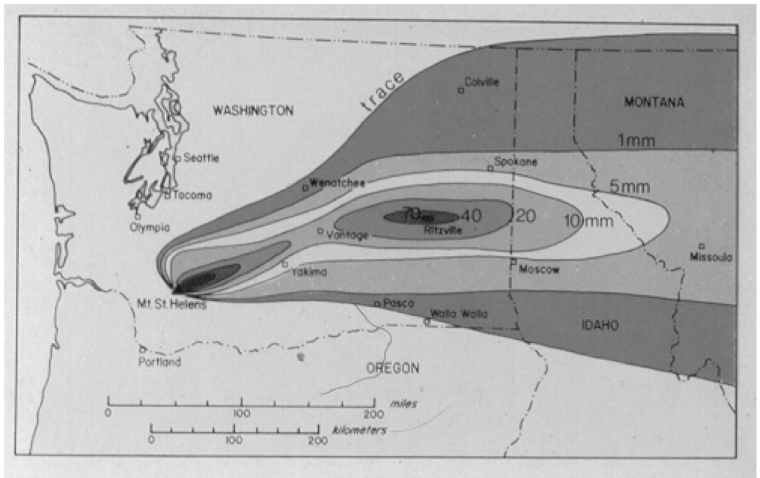
Isopach Maps



Thickness in cms

Maps showing the thickness of the ash are isopach maps

A measure of the area of the tephra (and therefore an indication of the size of the eruption) is given by:-
D = Area encloded by the $T_{0.01max}$ contour (in this case 4 cms)

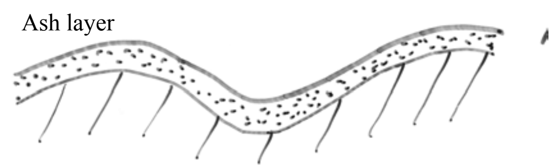


Isopach map of the ash deposits from the Mount St Helens May 18th eruption.

Isopach maps, together with information on particle size (how coarse or fine it is) can be used to tell a lot about an eruption (it is particularly useful for understanding past eruptions).

- How big it was.
- What type of eruption (vulcanian, plinian)
- Height of the eruption column.
- Mass discharge rate
- How violent it was.

Ash Fall Deposits

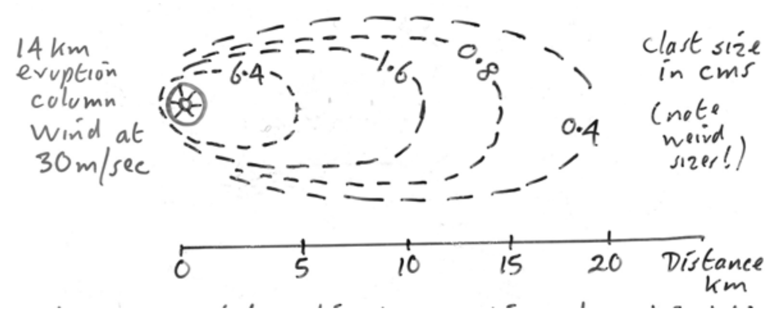


At any one locality Ash Fall Deposits:

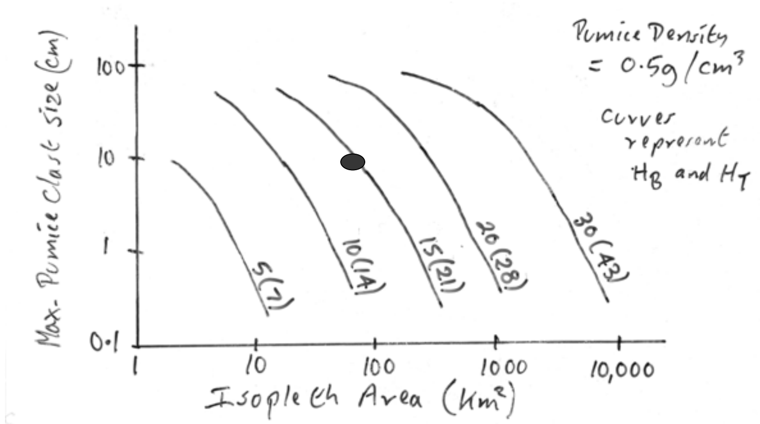
- ❑ Mantle the ground uniformly
- ❑ Are relatively well-sorted

In this way they can be distinguished from pyroclastic flow deposits which are not well-sorted and tend to follow topography

Grain Size

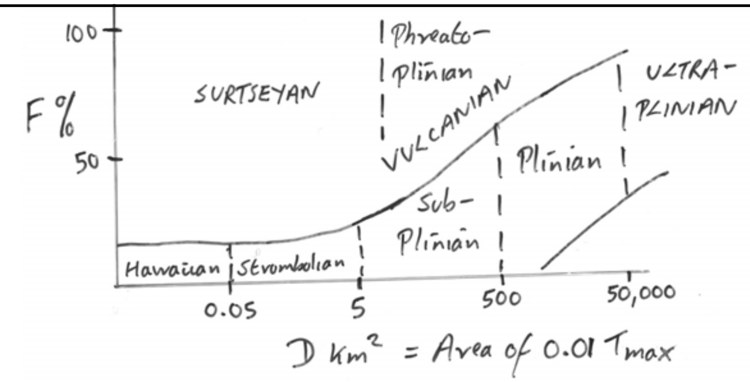


Maps showing the distribution of clast size are known as **isopleth maps**. This one is actually a synthetic map constructed to show the expected distribution of clasts from a 14 km high eruption column, dispersed by a 30m/sec wind from the west.



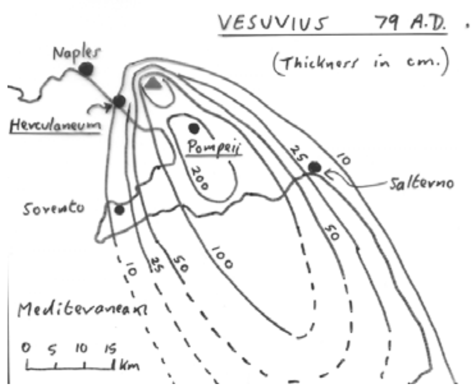
Note log scale

The distribution and area of clast sizes can be used to estimate column height (H_B and H_T). For example if the isopleth area for 10 cm pumice clasts is about 100 km^2, then the column height H_T would be about 20 km. Obviously this is useful for providing information about past eruptions.

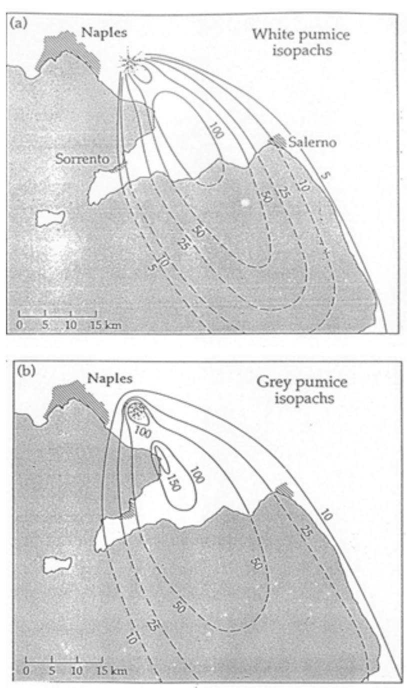


Walker Eruption Classification

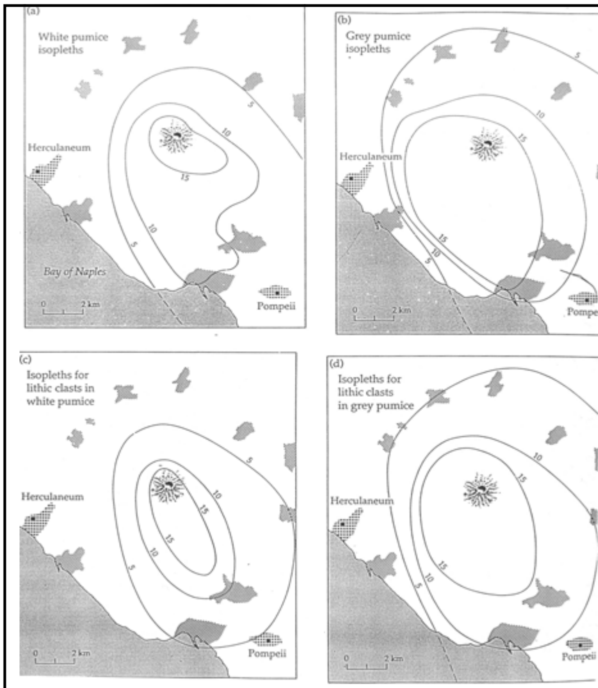
Depends on isopach area (D km^2) at 0.01 T_{MAX} and particle size (isopleth map). F% is the weight % of particles < 1mm at 0. 1 T_{MAX} .



- Two meters of ash fell on Pompeii. Some roofs collapsed, but this is unlikely to be responsible for the 2-3,000 deaths. Now known to result from pyroclastic flows and surges.
- Large Plinian eruption (named after Pliny the Younger). Note the extensive ash fall.



Pompeii 79 AD
Isopach maps for ash fall on August 23rd.
The rate was about 12 – 15 cm/hour.
The white pumice (higher SiO_2) was deposited before the gray pumice (lower SiO_2).
The greater extent and thickness of the gray pumice suggests that the eruption got larger as time progressed.



This deduction is confirmed by the isopleth maps.
Notice how the isopleths for the gray pumice are more widely dispersed than the white pumice. This is especially true for the lithic clasts – which are less influenced by wind.

From this we may conclude that the eruption column increased in height from about 27 to 33 km, probably due to widening of the vent and an increase in the mass discharge rate.

Ash Fall Hazards

- Ash falls are the most widespread of all volcanic hazards - may cover 1000-10,000 km^2 with >10 cm of ash during a large eruption.
- Fine ash may spread across continents (Mt St. Helens, 1980) or even encircle the globe (Pinatubo, 1991).
- Hazards are closest to the vent, decreasing with increasing distance.
- About <u>11,000 deaths</u> have been attributed to ash fall since 1600 A.D. (probably an overestimate). Most caused by <u>collapsing roofs</u> due to weight of ash (worse if wet).

Nature of ash fall hazards

More of a nuisance than a hazard

- Damages or kills crops (even a few cms).
- Causes respiratory problems.
- Pollutes water supplies and drainage.
- Disrupts transportation and lifestyle.
- Can poison grazing animals (fluorosis).
- Damage aircraft, with the potential to cause fatal crashes.

Ash cloud over central Washington, Mount St. Helens

Ash fall 3 km from Pinatubo

Ash fall at Clark airbase, about 25 km from Pinatubo

Ash fall at Rabaul, Papua New Guinea, 1994

Rabaul again

Ash fall from Mt.Spurr 1992
closes Anchorage airport.

Aviation Safety

Ash clouds can cause considerable damage to aircraft, endanger lives and interrupt transportation and commerce.