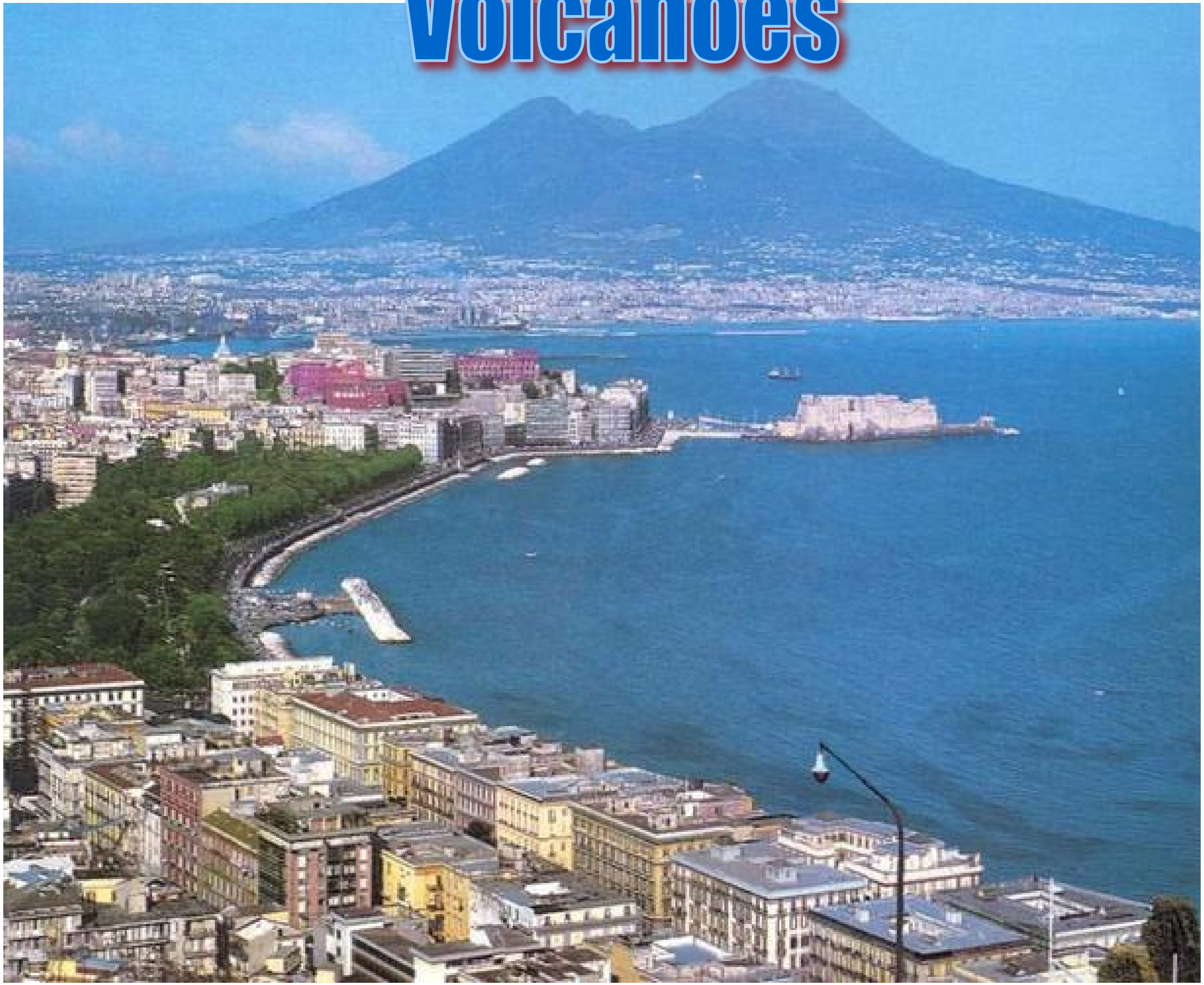
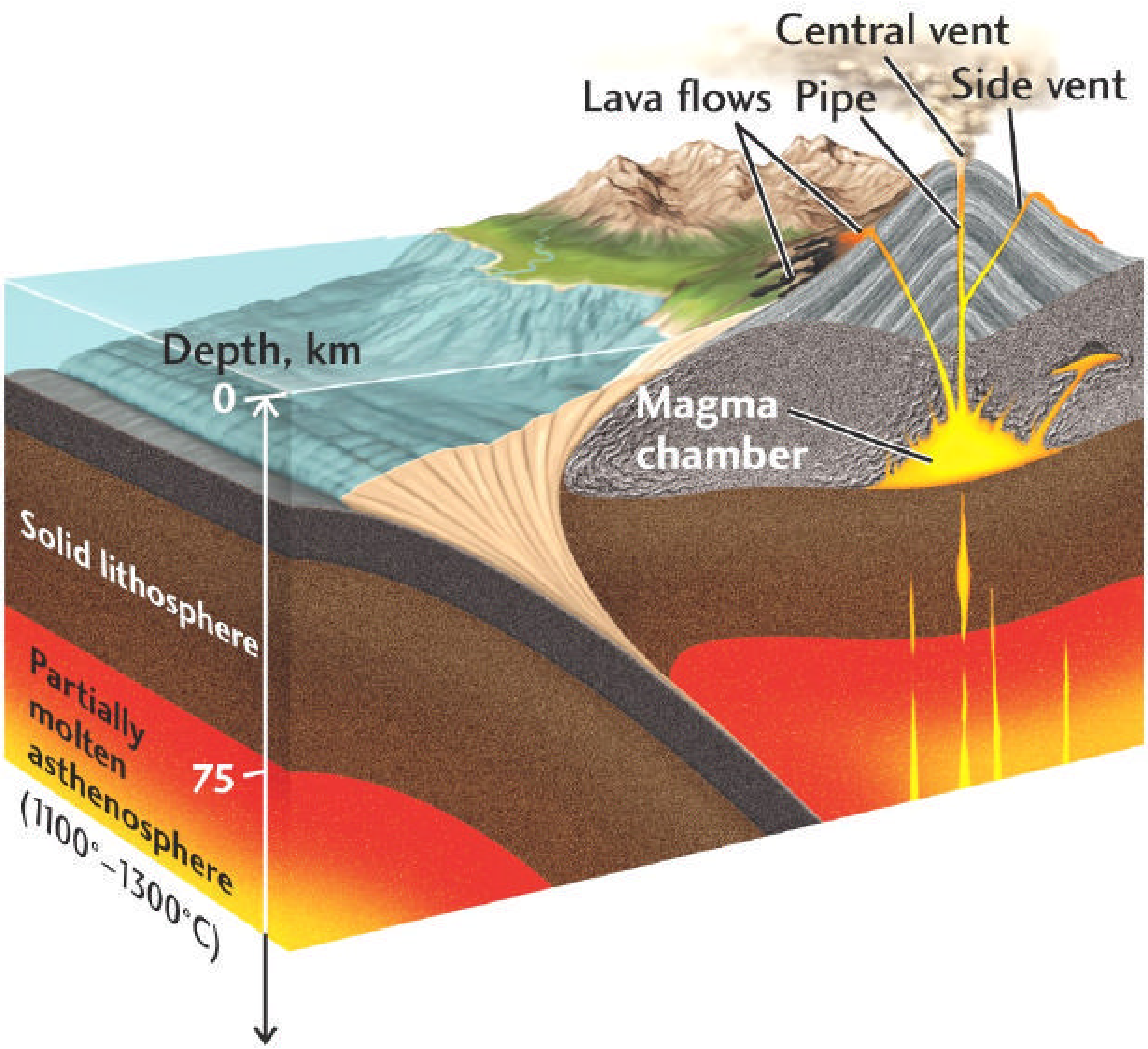
Volcanoes



Earth is a dynamic planet of a pretty dangerous sort

Pyroclastic
Flows
=
DESTRUCTION

Volcanoes in pills



1. Magma, which originates in the partially melted asthenosphere…

2. …rises through the lithosphere to form a magma chamber

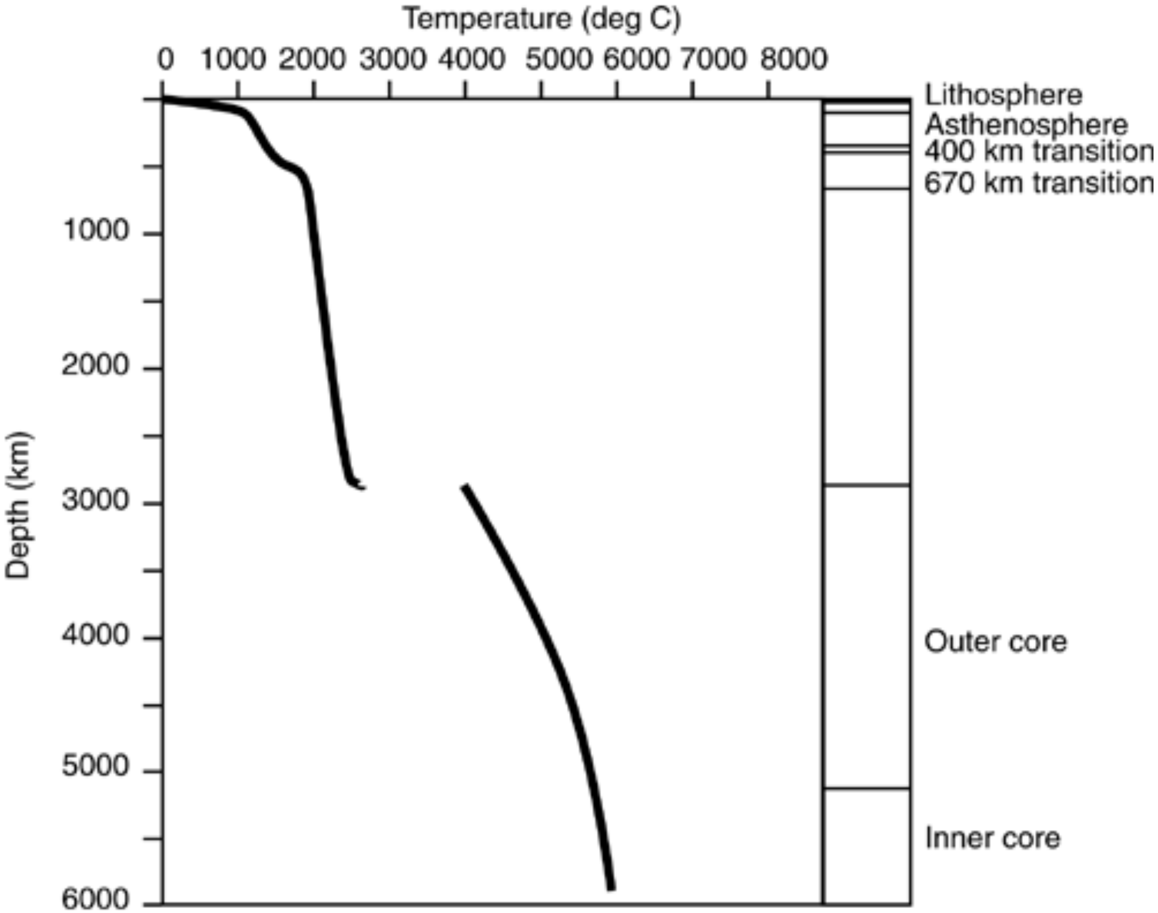
3. …and erupts through central and lateral conduits

4. …accumulating at the surface to form a conical shaped volcano

Earth's internal heat

Earth's internal heat comes from a combination of **residual heat** from planetary accretion and **latent heat** of crystallization during core formation (about 20%) and heat produced through **radioactive decay** (80%).

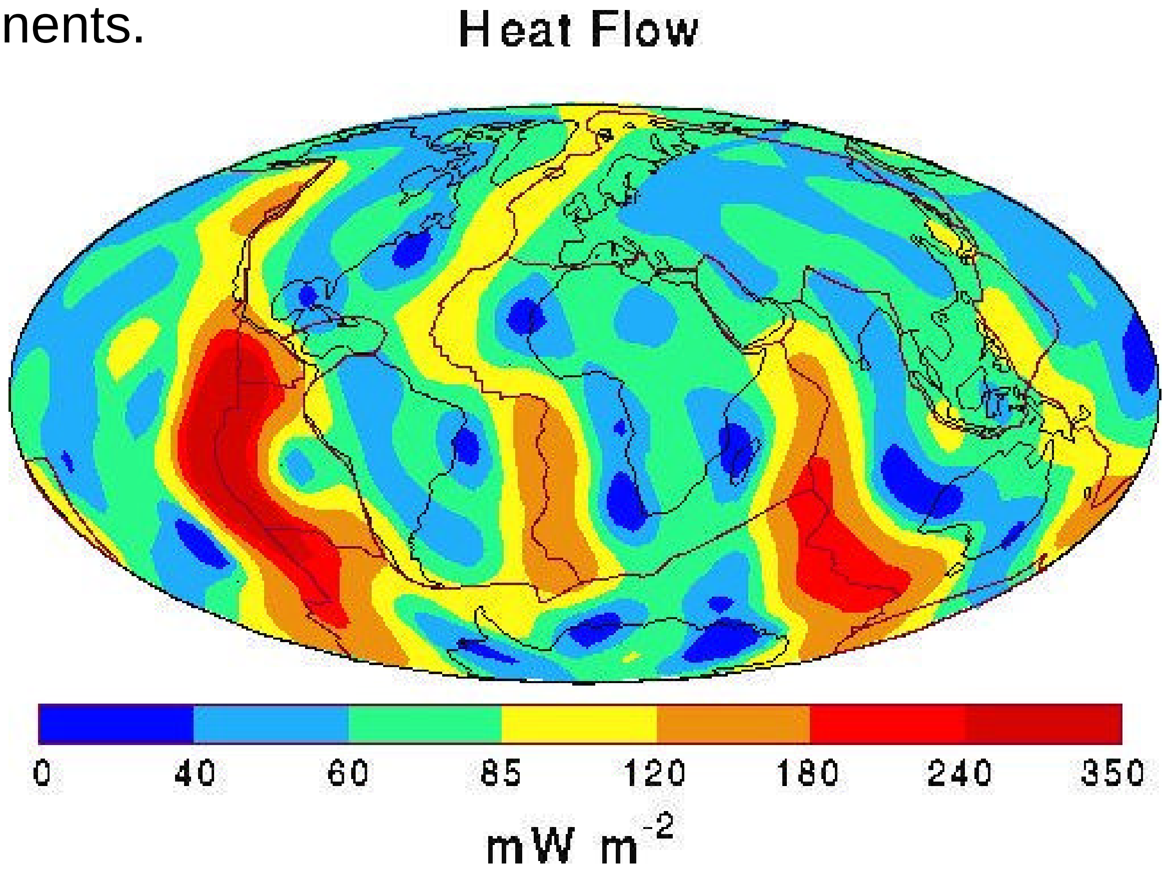
^{238}U, ^{235}U, ^{232}Th, ^{40}K, and ^{87}Rb have half-lives of $>10^9$ yr and generate heat since the *early Earth*.



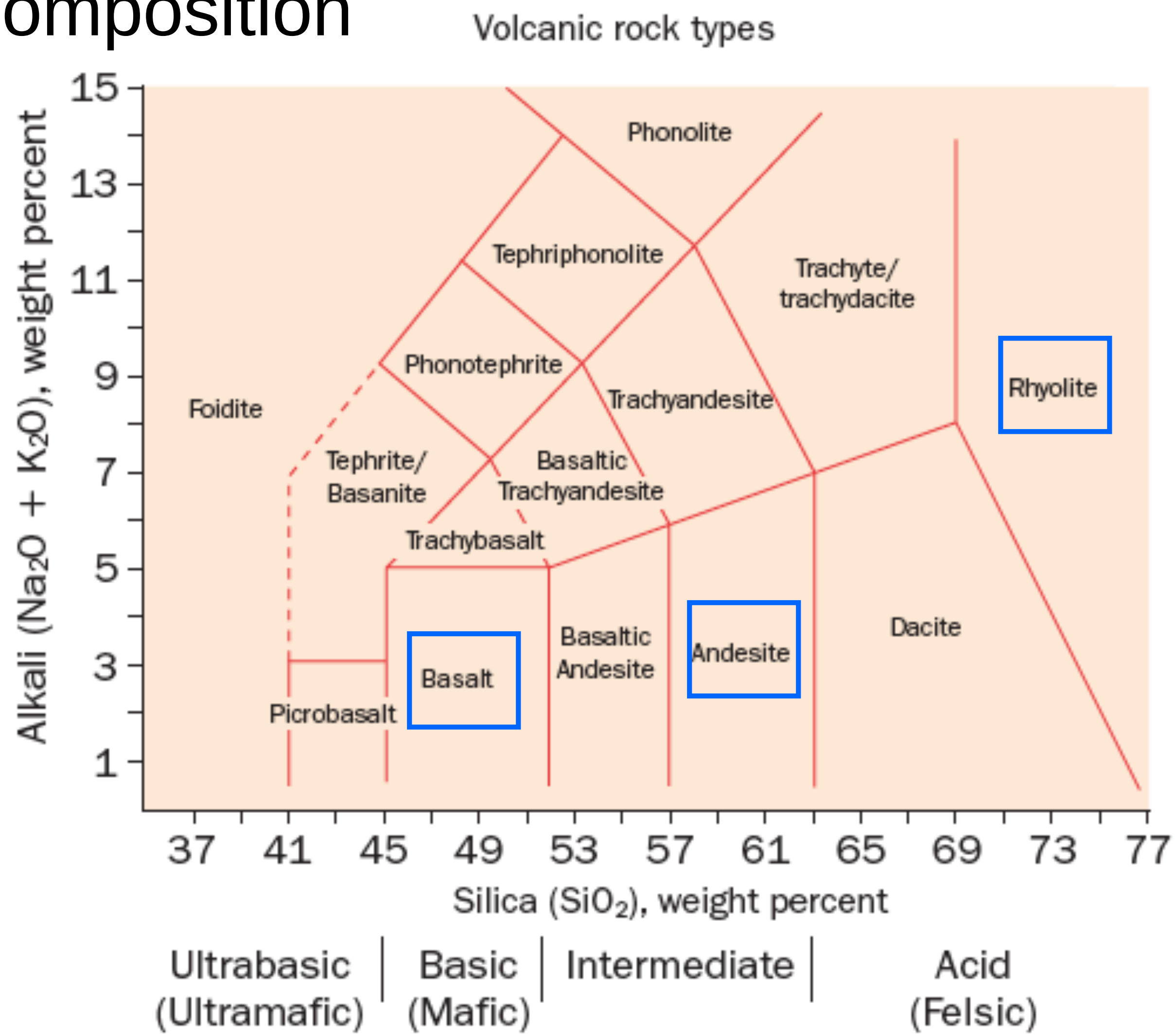
Isotope	Heat release W/kg isotope	Half-life years	Mean mantle concentration kg isotope/kg mantle	Heat release W/kg mantle
^{238}U	9.46×10^{-5}	4.47×10^{9}	30.8×10^{-9}	2.91×10^{-12}
^{235}U	5.69×10^{-4}	7.04×10^{8}	0.22×10^{-9}	1.25×10^{-13}
^{232}Th	2.64×10^{-5}	1.40×10^{10}	124×10^{-9}	3.27×10^{-12}
^{40}K	2.92×10^{-5}	1.25×10^{9}	36.9×10^{-9}	1.08×10^{-12}

The mean **heat flow** (loss) from the Earth is 87 mW/m2, for a global heat loss of 4.42 × 10e13 W. A portion of the core's thermal energy is transported toward the crust by **mantle plumes**; a form of convection consisting of upwellings of higher-temperature rock. These plumes can produce hotspots and flood basalts. More of the heat in the Earth is lost through plate tectonics, by **mantle convection** associated with mid-ocean ridges. The final major mode of heat loss is through **conduction through the lithosphere**, the majority of which occurs in the oceans because the crust there is much thinner than that of the continents.

Areas of high heat flow are commonly associated with volcanoes.



Magma composition



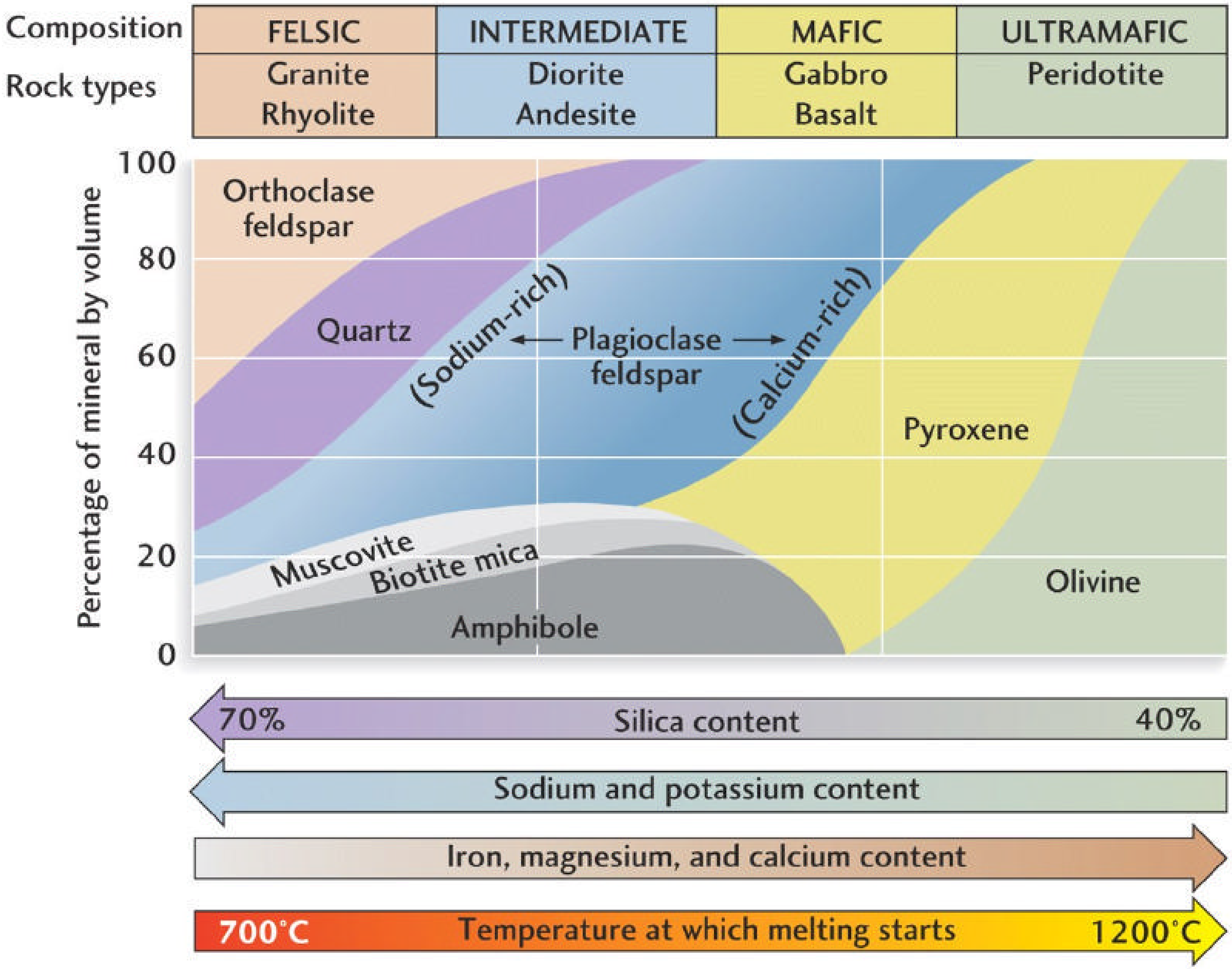
Three most common types of magma:

Basaltic (basic): SiO2 45-55 wt%, high in Fe, Mg, Ca, low in K, Na

Andesitic (intermediate): SiO2 55-65 wt%, intermediate in Fe, Mg, Ca, Na, K

Rhyolitic (acid): SiO2 65-75%, low in Fe, Mg, Ca, high in K, Na

<u>Mineralogical</u> composition of volcanic rocks



Gases in Magmas

At depth in the Earth nearly all magmas contain gas dissolved in the liquid, but the gas forms a separate vapor phase **when pressure is decreased** as magma rises toward the surface of the Earth.

This is similar to carbonated beverages which are bottled at high pressure. The high pressure keeps the gas in solution in the liquid, but when pressure is decreased, like when you open the can or bottle, the gas comes out of solution and forms a separate gas phase that you see as bubbles.

Gas gives magmas their explosive character, because volume of gas expands as pressure is reduced. The composition of the gases in magma are:

* Mostly H_2O (water vapor) & some CO_2 (carbon dioxide)
* Minor amounts of Sulfur, Chlorine, and Fluorine gases

The amount of gas in a magma is also related to the chemical composition of the magma. **Rhyolitic magmas usually have higher gas contents than basaltic magmas. Eruptions involving rhyolitic magmas are more explosive than eruption involving basaltic magmas (e.g., Hawaiian eruptions).**

Temperature of Magmas

The eruption temperature of various magmas is as follows:

* Basaltic magma - 1000 to 1200°C
* Andesitic magma - 800 to 1000°C
* Rhyolitic magma - 650 to 800°C.

Viscosity of Magmas

Viscosity is the resistance to flow (opposite of fluidity). Viscosity depends on primarily on the composition of the magma, and temperature:

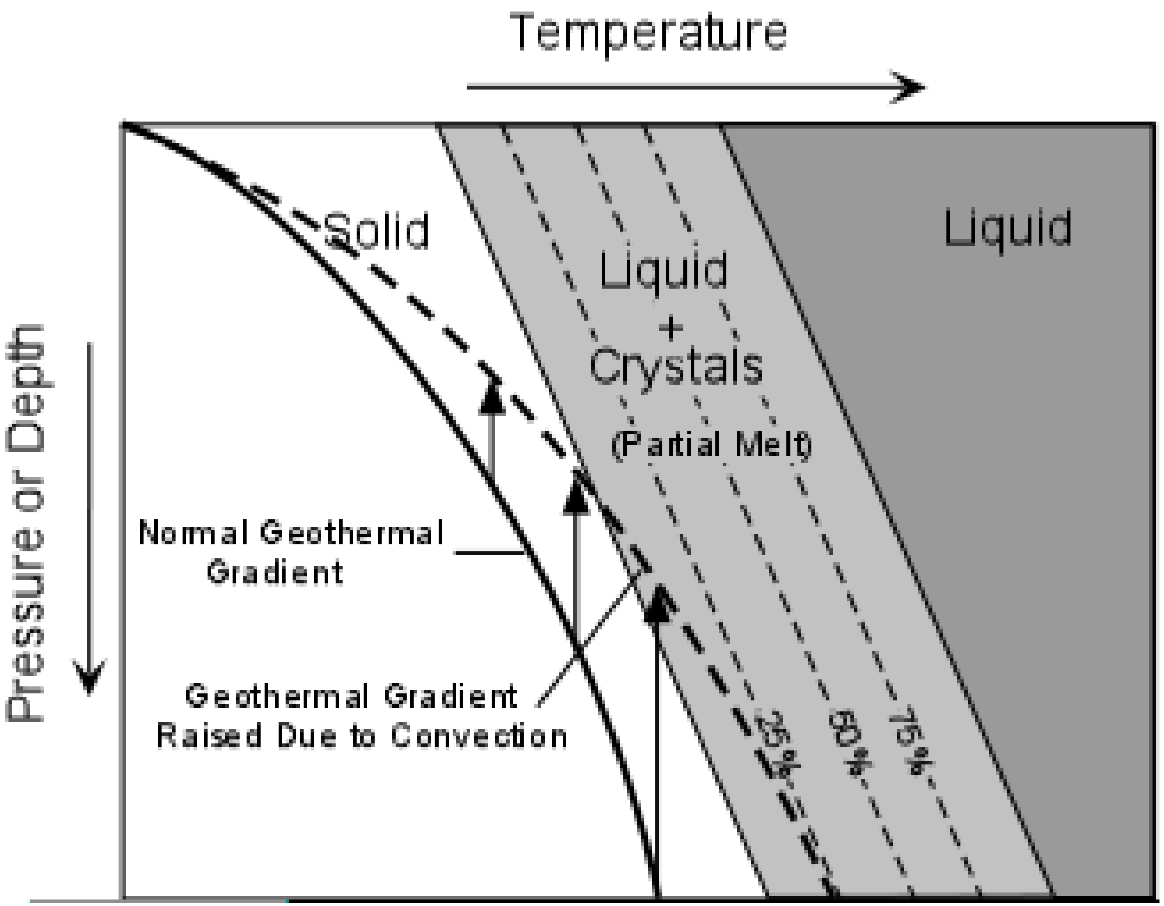
- Higher SiO_2 (silica) content magmas have higher viscosity than lower SiO_2 content magmas.
- Lower temperature magmas have higher viscosity than higher temperature magmas (viscosity decreases with increasing temperature of the magma).

Thus, basaltic magmas tend to be fairly fluid (low viscosity) relative to rhyolitic magmas. Viscosity is an important property in determining the eruptive behavior of magmas.

Origin of Basaltic Magma

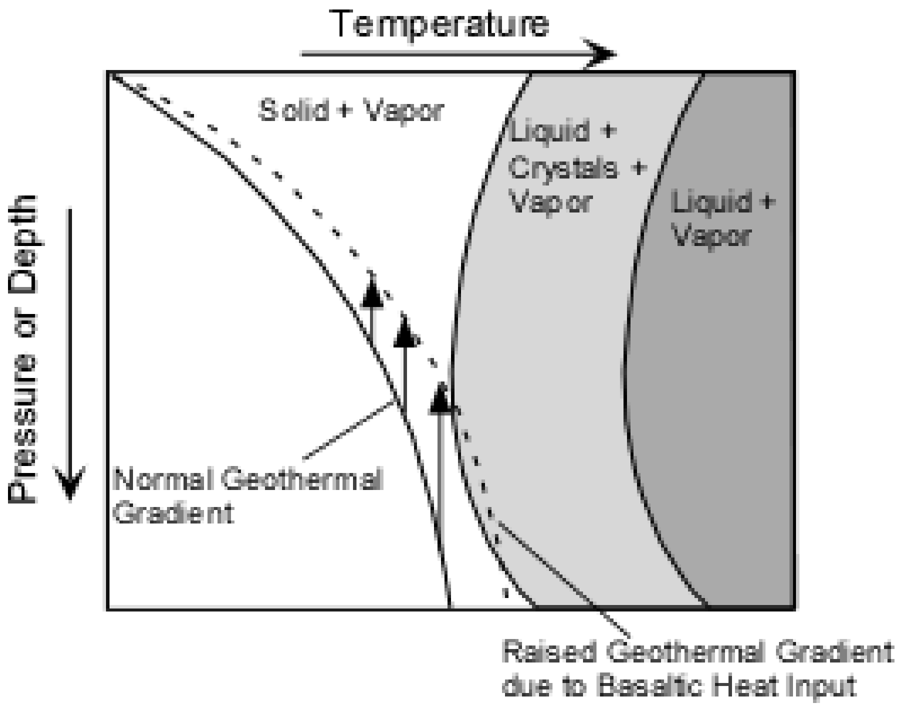
Basaltic magma results from dry melting (no water) mantle peridotite (olivine + pyroxene + garnet). Under normal conditions, the temperature in the Earth (normal geothermal gradient) is lower than the beginning of melting of the mantle.

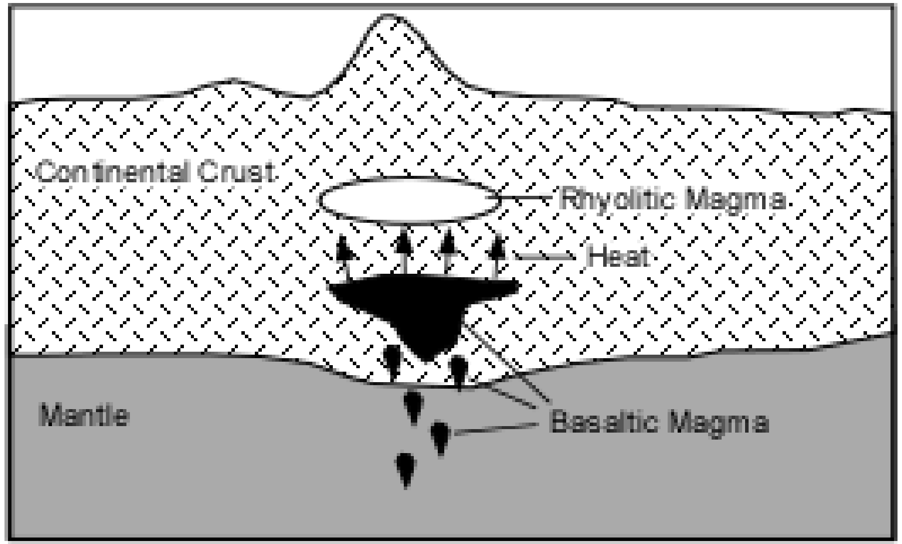
A mechanism to **raise** the geothermal gradient and trigger dry melting is **convection**: hot mantle material rises to lower pressure or depth, carrying its heat with it. This causes the local geothermal gradient to rise, and a partial melt can form. Liquid from this partial melt can be separated from the remaining crystals because, in general, liquids have a lower density than solids.



Origin of Rhyolitic Magma

Rhyolitic magma results from wet melting (with water) of **continental crust** (crustal rocks generally contain water, either in pore spaces or minerals in the rocks). Water tends to decrease the temperature of beginning of melting with increasing pressure or depth. Still, the temperature in continental crust is usually not high enough to cause the melting of the crust. Thus another heat source is necessary. Basaltic magma generated in the mantle, as discussed above, rises into the continental crust. If it stops in the crust and crystallizes, It releases its heat into the surrounding crustal rocks, rising the local geothermal gradient, and causing wet partial melting of the crust to produce rhyolitic magmas.

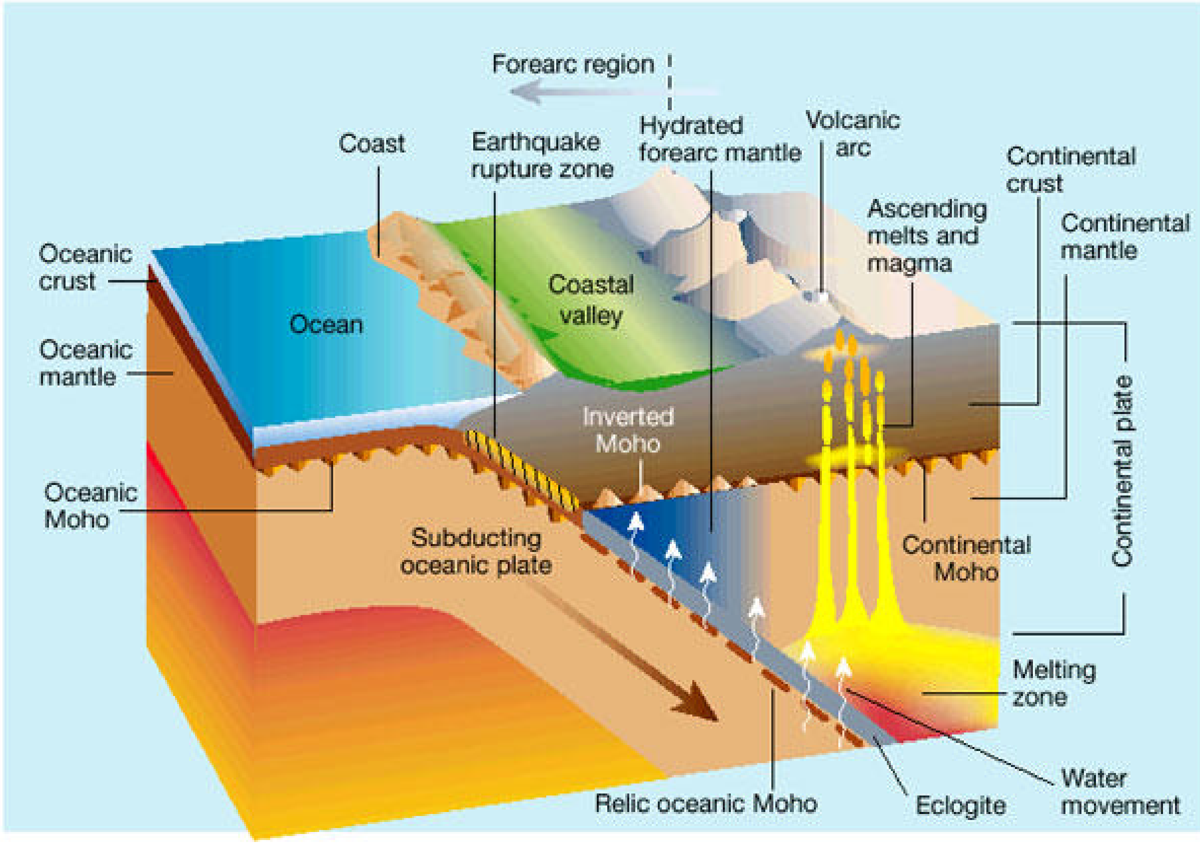




Origin of Andesitic Magma

Andesitic magmas erupt in areas above subduction zones by the wet partial melting of mantle peridotite. Since the oceanic lithosphere is in contact with ocean water there should be much water in the pore spaces of upper oceanic crustal rocks as well as water contained within clay minerals that have settled to the sea floor. When this material is subducted, it begins to heat up and water is driven off. If the water enters the **overlying asthenospheric mantle**, it will lower its melting temperatures and thus melting will occur.

This melting will produce basaltic magmas, which can undergo change as they pass trough the continental crust. If the crust gets hot enough, it can melt and this siliceous melt can mix with the basaltic magma to make an intermediate **andesitic magma.**



Lava types

Pāhoehoe and `A`ā

Hawaiians (to whom the distinction was critical, as they usually went barefoot!) called the smooth-surfaced flow type **pāhoehoe** and the rough-surfaced type **`a`ā** (Table 6.1). Icelanders called the two types **helluhraun** and **apalhraun**, respectively (Thorarinson & Sigvaldason 1962). The rough-surfaced type was called **marubi** in Japan, and **malpais** ("bad country") in Mexico. When C. E. Dutton introduced the Hawaiian terms into the scientific literature in 1884, they met with strong opposition from British geologists. Bonney (1899, p. 79) scoffed that the terms are "the barbarous [expressions] of an insignificant and uncivilized race in a small archipelago in the North Pacific," and preferred the (more civilized?) terms **slaggy** and **clinkery**. T. A. Jaggar went to Greek civilization for his now-forgotten terms **dermolith** and **aphrolith** (1917, p. 280). In the end, the Hawaiian words won out, and pāhoehoe (properly pronounced PAH-hoy-hoy) and `a`ā (ah-AH) are universally used (Fig. 6.12). These terms are presently used not only to describe the surface appearances of cold flows, but also the active lava that forms them.

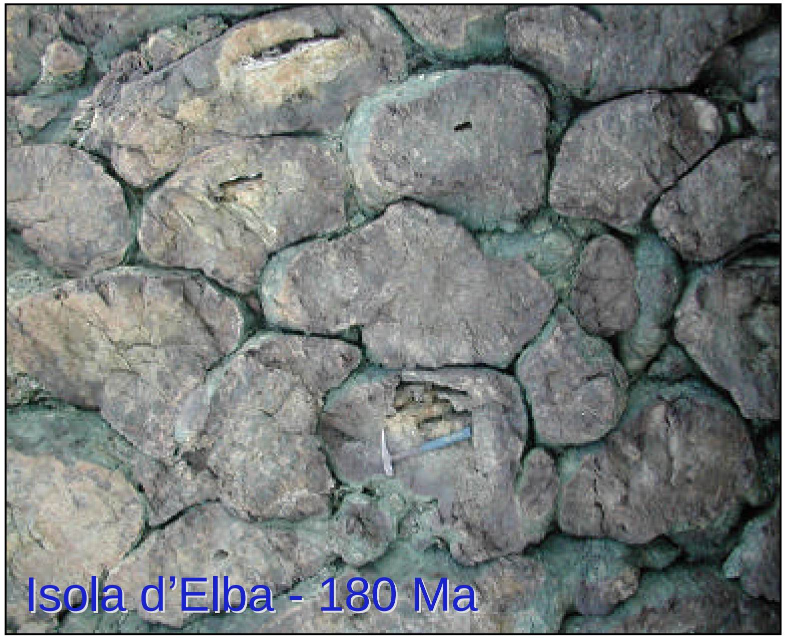
Fig. 6.12 Pāhoehoe and `a`ā flows formed during different phases of the 1972 Kīlauea eruption. Where both lava types are produced during the same eruption, it is most common for the pāhoehoe to be younger. Photo by J. P. Lockwood.

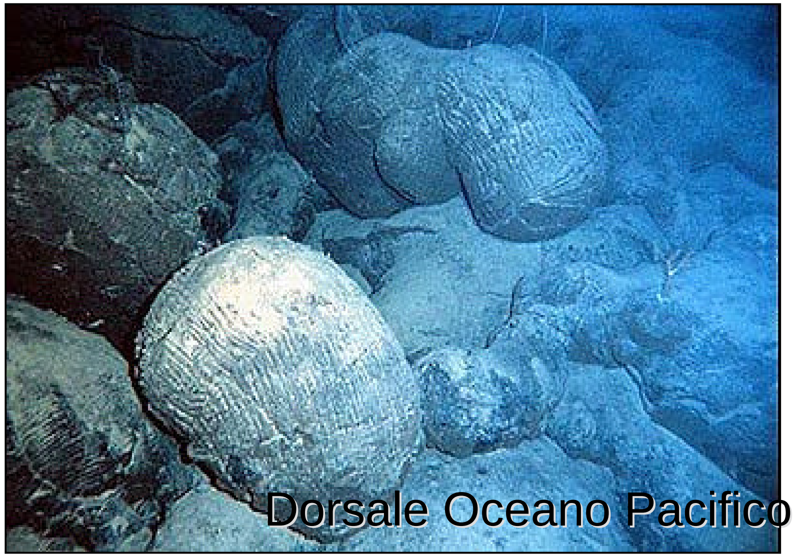
Submarine pillow basalts

When basalt erupts underwater or flows into the sea, contact with the water quenches the surface and the lava forms a distinctive pillow shape, through which the hot lava breaks to form another pillow.

This pillow texture is very common in underwater basaltic flows and is diagnostic of an underwater eruption environment when found in ancient rocks.

Pillows typically consist of a fine-grained core with a glassy crust and have radial jointing. The size of individual pillows varies from 10 cm up to several meters.


Isola d'Elba - 180 Ma


Dorsale Oceano Pacifico

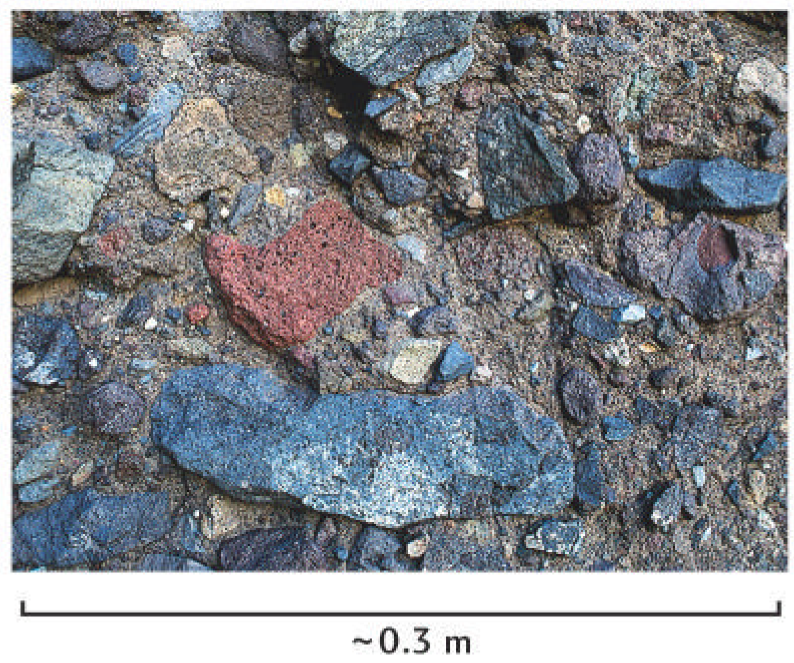
Tephra and Pyroclastic Rocks

TABLE 7.1 PARTICLE SIZE SCALE FOR VOLCANIC TEPHRA.

Volcanic Clast Name	*Blocks* (angular) *Bombs* (rounded)		*Lapilli*						*Coarse ash*				*Fine ash*				*Dust*
φ No.	−8	−7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7	8
Maximum Diameter (mm)	256	128	64	32	16	8	4	2	1	0.5	0.25	0.125	0.062	0.031	0.016	0.008	0.004

Source: After Schmidt (1981).

>64mm	Bombs or Blocks
2 - 64mm	Lapilli (Tuff)
<2mm	Ash (Ash Tuff)



(a)

(b)

(c)

Fig. 7.4 Ballistically emplaced lava bombs, showing effect of fluidity. a) "Cow-pie" bomb formed as fluid spatter impacted the ground during a 1969 eruption of Kīlauea volcano, Hawai'i. b) Classic breadcrust bomb from the rim of Bolshoye Tol'batchik volcano, Kamchatka. This bomb, erupted in 1975, shows the crustal surface fracturing that occurred after impact as the bomb's fluid interior expanded. c) A more viscous breadcrust bomb that shattered from internal fracturing after impact on the rim of Gamalama volcano, Ternate Island, Indonesia. USGS photos by J. P. Lockwood.

ASH

Volcanic ash is in no sense a product of burning, as are other "ashes." It is simply pulverized or finely fragmented magmatic material, with individual grains less than 2 mm in diameter.

Fig. 7.7 Fallout scoria and ash deposits downwind from a prehistoric eruptive vent on Mauna Kea volcano, Hawai`i. Note the uniform thickness of individual layers, which mantle pre-existing topography – hallmarks of tephra deposits. Photo by J. P. Lockwood.

By far the most common variety of ash is vitric ash formed by the explosive disruption of liquid lava as gas expands in an open volcanic conduit. The gas exsolves to form a froth as the magma wells up from deep in the conduit, and as the bubbles continue to grow, the froth is literally torn apart as the molten rock approaches the surface.

Ash and **tuff** (solidified ash) beds often contain some fragments of larger size, quite apart from crystals. Those in which moderately to very abundant lapilli-sized ejecta (Table 7.1) of lithic material or pumice are scattered through the finer matrix are called **lapilli-ash** or **lapilli tuff**. Those containing blocks are known as **tuff-breccia**, and those containing bombs may be called **tuff-agglomerate**.

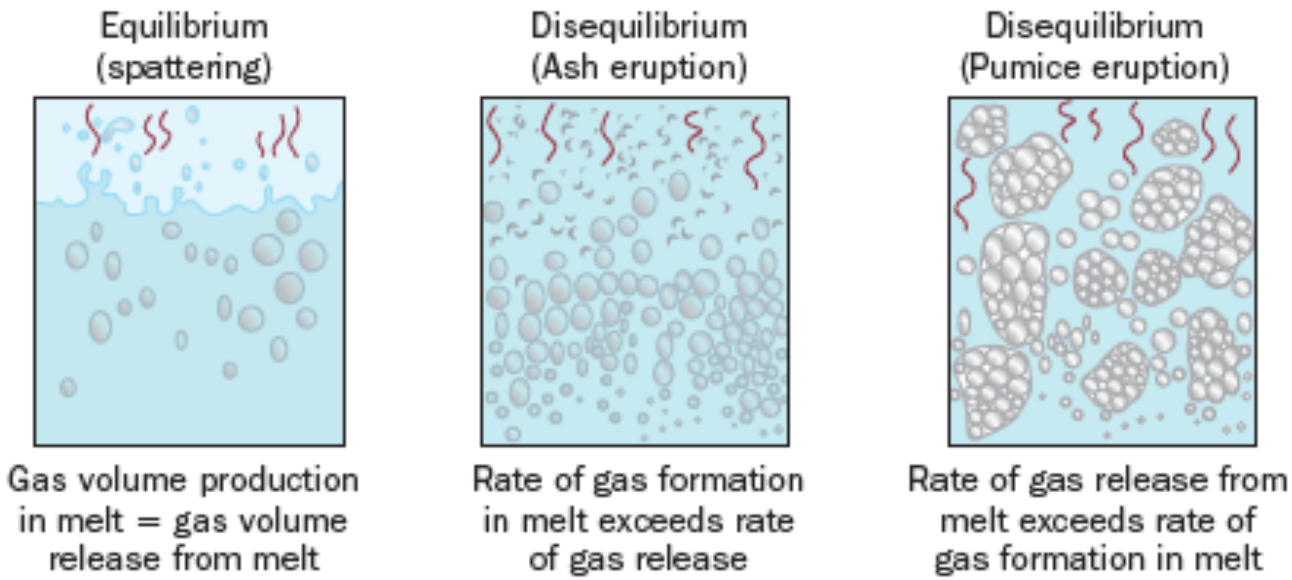
Lapilli Explosive eruptions produce vast amounts of finely divided ash particles that form the principal solid components of eruption clouds. All of this ash will eventually fall to Earth as discrete particles, but in many cases, ash particles will coalesce to form layered ash balls called **accretionary lapilli**, or ash **pisolites** in older literature. These distinctive lapilli are commonly thought to form around water droplets, or by the adherence of moist ash particles in ash clouds to form muddy raindrops, which develop in much the same way that hailstones form around ice or particulate nuclei in thunderstorms (e.g., Gilbert & Lane 1994),

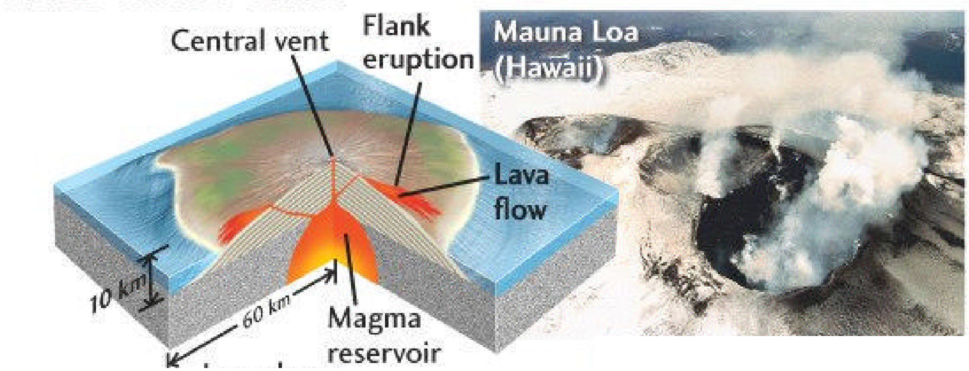
a) b)

Fig. 7.8 Accretionary lapilli deposits. a) Most common type, where accretionary lapilli were deposited simultaneously with ashfall (Laguna maar explosion debris, Gamalama volcano, Ternate Island, Indonesia). b) Concentrated deposits, where accretionary lapilli fell out of eruption cloud before ashfall (1790 Keanakakoi Ash, Kīlauea volcano, Hawai'i). Knives 8 cm long. Photos by J. P. Lockwood.

PUMICE Bombs and lapilli that consist mostly of gas bubbles (vesicles) result in a low density highly vesicular rock fragment called **pumice**.

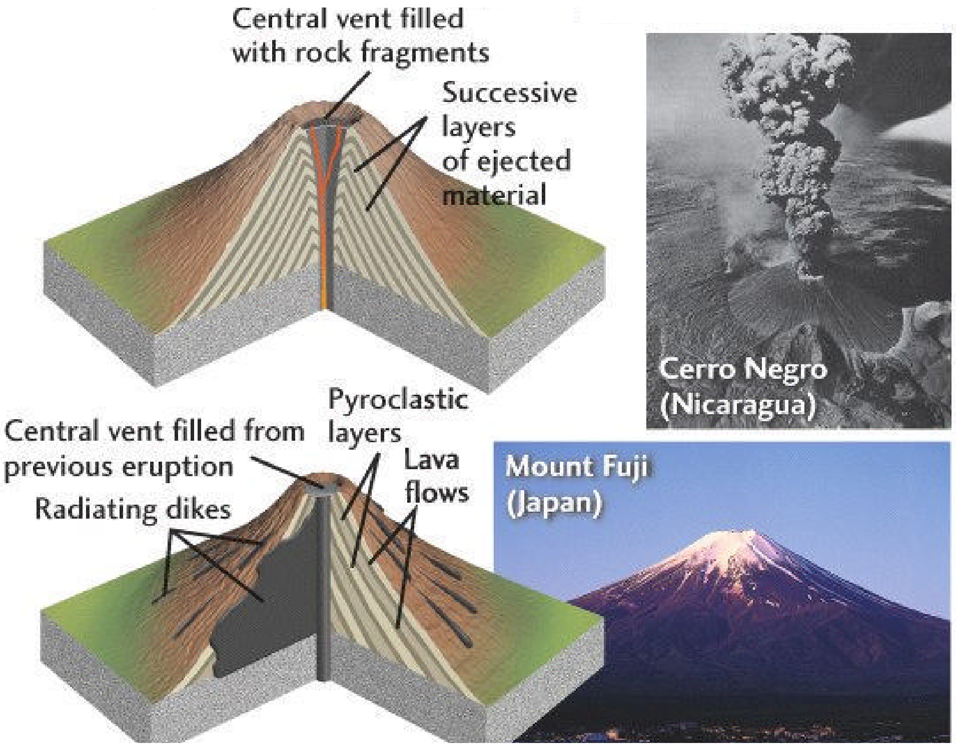
Both ash and pumice are commonly erupted *together* during large eruptions, and usually have the same composition. The proportions of each may relate to variable ability of gas bubbles to coalesce within the magma in the moments leading up to an eruption
: The melt in an erupting conduit may be visualized as having some areas in **volumetric equilibrium**, in which the volume of gas bubble formation is matched by the total volume of gas escaping from the magma (Fig. 7.10). In this situation, typical for basaltic magmas, molten rock is erupted as spatter or lava flows. **Volumetric disequilibrium** prevails for erupting siliceous magmas, leading to explosive discharge of pumice and ash. If the formation and expansion of gas bubbles exceeds the rate of gas release, then bubble walls burst into small, curved ash shards. On the other hand, if the rate of gas release exceeds that of bubble expansion, then the melt becomes foamy and is blown into pumice fragments.





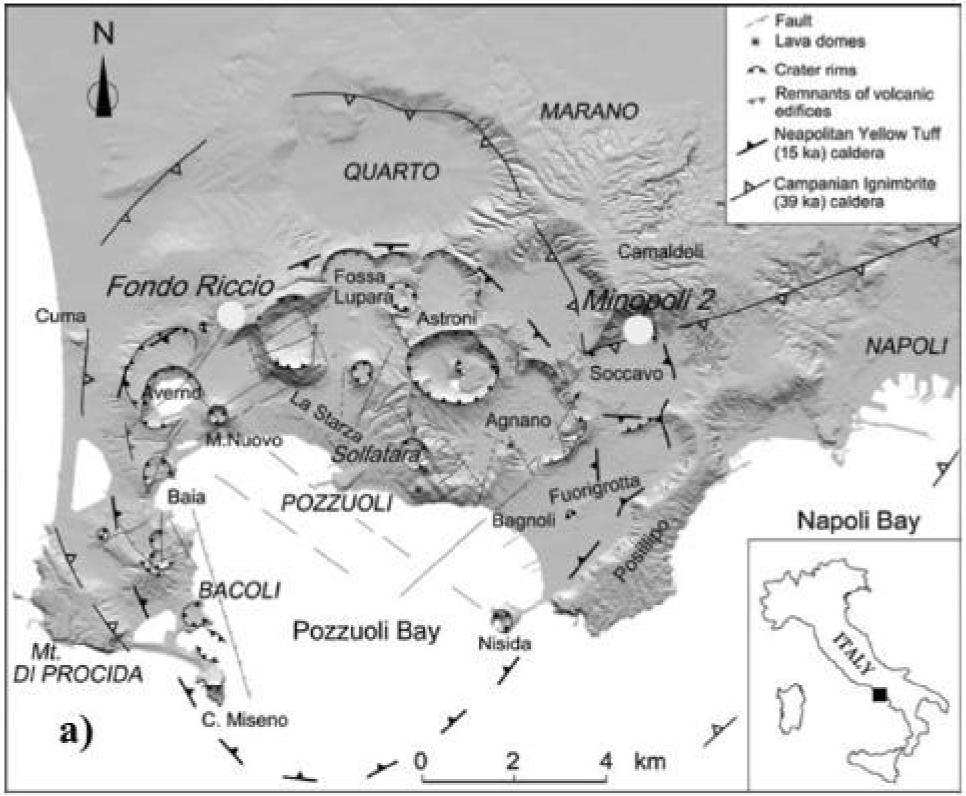
Shield volcanoes are built almost entirely of fluid lava flows and have large size and low profile. This is caused by the highly fluid basic lava they erupt, which travels farther than lava erupted from more explosive volcanoes.

The largest shield volcano in the world is Mauna Loa in Hawai‘i, which projects 4,169 m above sea level and is over 97 km wide.



Stratovolcanoes and composite volcanoes are tall, conical volcanos built up by many layers of hardened lava, tephra, pumice, and volcanic ash. They are characterized by a steep profile and periodic, explosive eruptions. The lava is often acid, having high-to-intermediate levels of silica (as in rhyolite, dacite, or andesite). **Etna and Vesuvius are stratovolcanoes.**

A **caldera** is a cauldron-like volcanic feature usually formed by the collapse of land following a volcanic eruption, such as the one at Yellowstone National Park in the US or the Campi Flegrei in Italy. They are not to be confused with volcanic craters, which may be contained within the caldera.



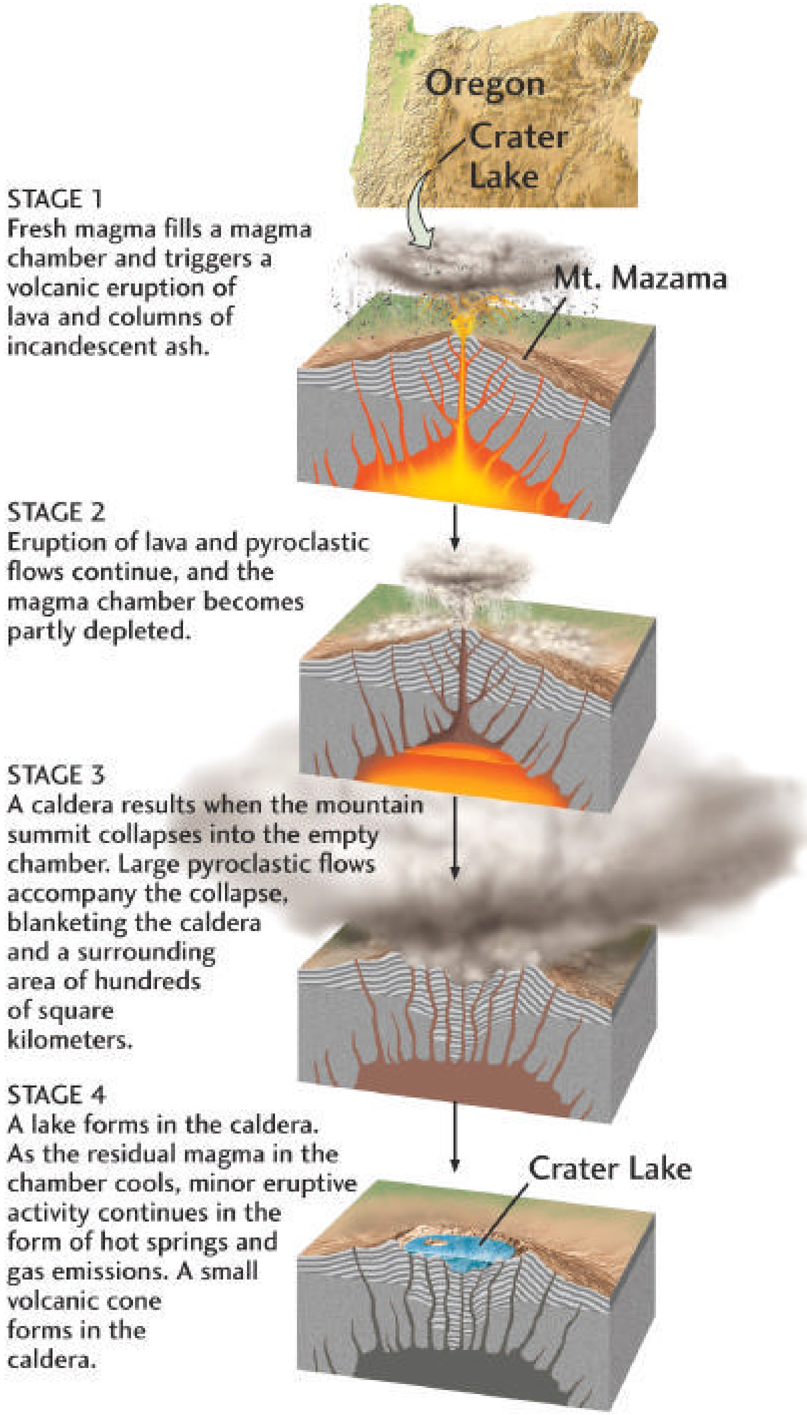


TABLE 5.1 MODIFIED LACROIX SYSTEM OF CLASSIFYING ERUPTIVE BEHAVIOR.

Class	Description
Hawaiian	Effusive eruptions of lava with little or no explosive activity apart from lava fountaining. Primarily basaltic. Originate at fissure vents. Associated with building of shield volcanoes and flood-basalt plains. VEI* = 0–2 (and higher for flood-basalt eruptions).
Strombolian	Moderately explosive eruptions producing cinder, bombs, and ash which are initially incandescent as they leave the vent. Blasts often periodic, associated with bursting of very large gas bubbles in the vent. Typically basaltic and andesitic, with steam-rich light-colored ash clouds. VEI = 1–3.
Vulcanian	Moderate to violent ejection of solid fragments of cold rock (Ultravulcanian eruption), or of solid, recently hardened lava (ordinary Vulcanian eruption). Associated with the clearing of conduits, often plugged with domes. Blast clouds tend to be notably darker (more ash and less steam rich) than in the case of Strombolian eruptions. In addition to numerous blocks, large amounts of ash are produced. Eruption columns feature much lightning, and accretionary lapilli may be abundant with ordinary ash fall. Dense, ground-hugging pyroclastic clouds (PDCs) possible. Any composition, but not often basaltic. VEI = 2–5†
Plinian	Highly violent eruption of large amounts of pumice and ash, generally associated with PDCs. Airfall pumice beds and ash-flows, sometimes including ignimbrites, are characteristic. Caldera collapse is often associated with Plinian eruptions. Eruption columns 20–55 km high penetrate the stratosphere, injecting large quantities of water and sulfur aerosols into the upper atmosphere. Temporary global cooling may ensue. VEI = 4–8

Ranking is from least explosive to most explosive.

* Volcanic Explosivity Index, described later in the text.

† The older term "Pelean eruption" refers to a form of Vulcanian eruption specifically involving the clearing of a dome or cryptodome above a volcanic conduit. Many Pelean eruptions have been directed blasts (not necessarily accompanied by debris avalanches) that are followed almost at once by Plinian eruptions.

TABLE 5.3 THE VOLCANIC EXPLOSIVITY INDEX (VEI): CRITERIA FOR DETERMINATION.

Criteria VEI →	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Size description	Non-explosive	Small	Moderate	Moderate-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}	$> 10^{12}$
Eruption column height (km)*	< 0.1	0.1–1	1–5	3–15	10–25	> 25 →			
Description of explosivity	← gentle, effusive →		← explosive →		cataclysmic, paroxysmal, colossal →				
Classification		← Strombolian →			← Plinian →				
	← Hawaiian →		← Vulcanian →			← Ultraplinian →			
Duration of continuous blasts (hr)	← < 1 →					> 12 →			
Injection of lower atmosphere (troposphere)	Negligible	Minor	Moderate	Substantial →					
Injection of upper atmosphere (stratosphere)	← None →			Possible	Definite	Significant →			

VEIs of the nine most powerful volcanic eruptions since 1400† *CE*

Year	Volcano	VEI
1991	Pinatubo, Philippines	6
1912	Novarupta, Alaska	6
1907	Santa Maria, Guatemala	6
1883	Krakatau, Indonesia	6
1815	Tambora, Indonesia	7
1660(?)	Long Island, New Guinea	6
1641	Parker, Philippines	6
1580(?)	Billy Mitchell, Solomon Islands	6
1452	Kuwae, Vanuatu	6

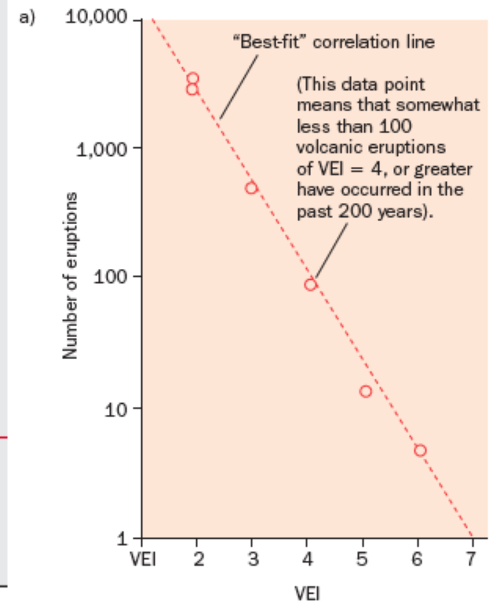
Other well-known eruptions

1982	El Chíchón, Mexico	5
1980	Mount St Helens, USA	5

* For VEIs from 0 to 2, the column height is km above the vent; for VEIs greater than 2, column height is km above sea level.

† Data from Briffa et al. (1998).

Source: Newhall & Self (1982).



HAWAIIAN-TYPE ERUPTIONS

François-Antoine LaCroix proposed using the term **Hawaiian eruptions** to identify all forms of effusive volcanic activity that involve the eruption of fluid lavas, typically basaltic in composition, and usually involving both lava fountains and flows. A Hawaiian-style eruption begins where a dike breaches the surface. Swarms of sharp, shallow earthquakes precede the opening of a fissure in advance of the dike. Dilation of the ground above the ascending dike may form a narrow, linear graben. A fissure opens on the floor of the graben, parallel to its margins. The magma at first shoots into the air all along the length of the fissure, forming a curtain of incandescent, fountaining lava which may reach a few tens, or even hundreds of meters into the air. Such sheets of erupting lava present spectacular panoramas typically stretching from a few hundred meters to 10 or 20 km in length, the celebrated Hawaiian "Curtain of Fire" (Fig. 1.12).

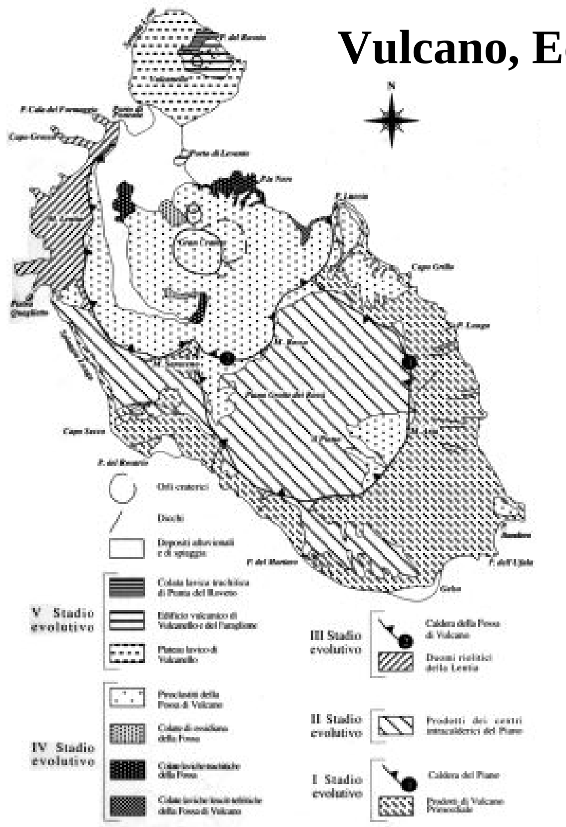
Fig. 1.12 July, 1974 eruption of Kilauea volcano as viewed from the Hawaiian Volcano Observatory a few minutes after outbreak of typical "curtains of fire" from multiple en echelon vents near Keanakako'i crater. A USGS monitoring crew is observing the middle vents. USGS photo by John Forbes.

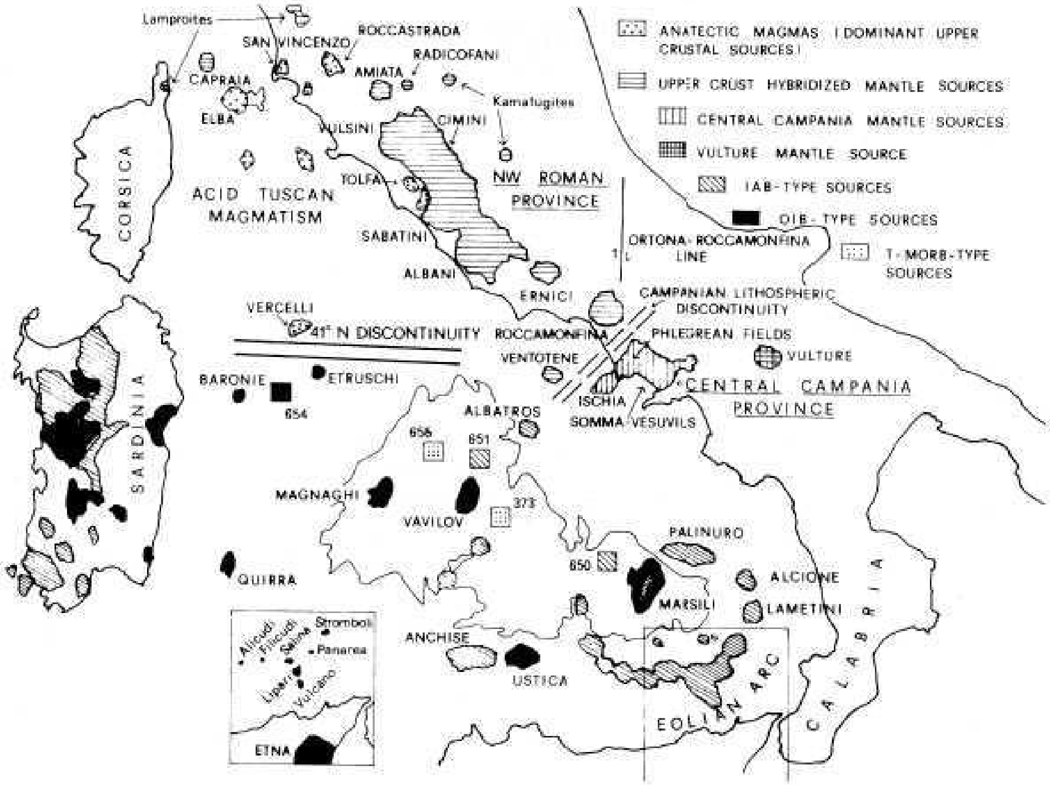
VULCANIAN ERUPTIONS

Vulcanian eruptions are commonly driven by shallow explosions involving the expansion of water or carbon dioxide . They range from **Ultravulcanian** blasts, which only eject solid, older rock material, not directly related to the magma or heat-source triggering the eruption, to blasts of freshly-solidified lava commonly derived from recently emplaced domes or plugs . This latter debris is the trademark product of "ordinary" Vulcanian eruptions.

Vulcanian deposits are characterized by large amounts of poorly sorted blocks and lapilli-sized angular lithic fragments mixed together with ash. Sorting improves with distance from a vent,

Vulcano, Eolie

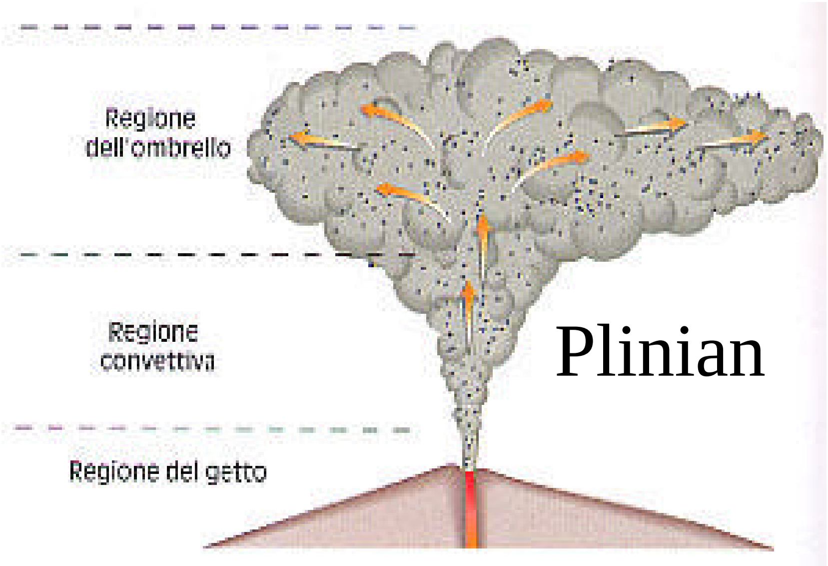


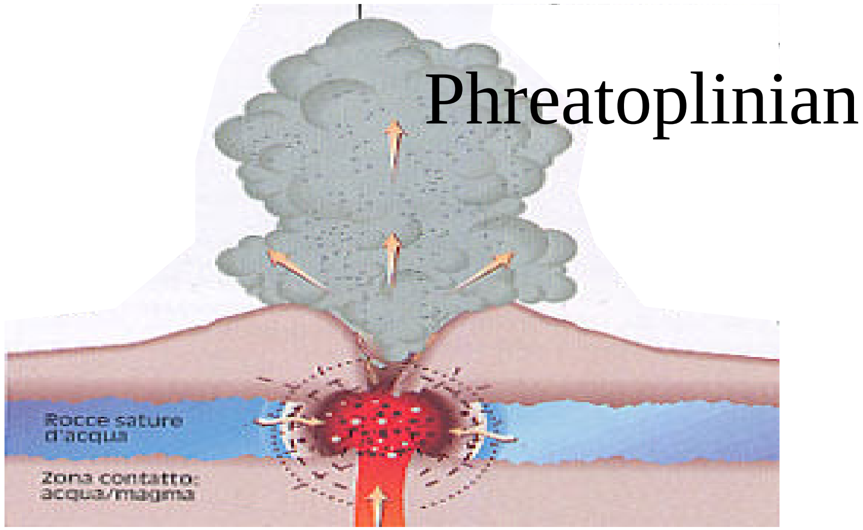


Plinian eruptions

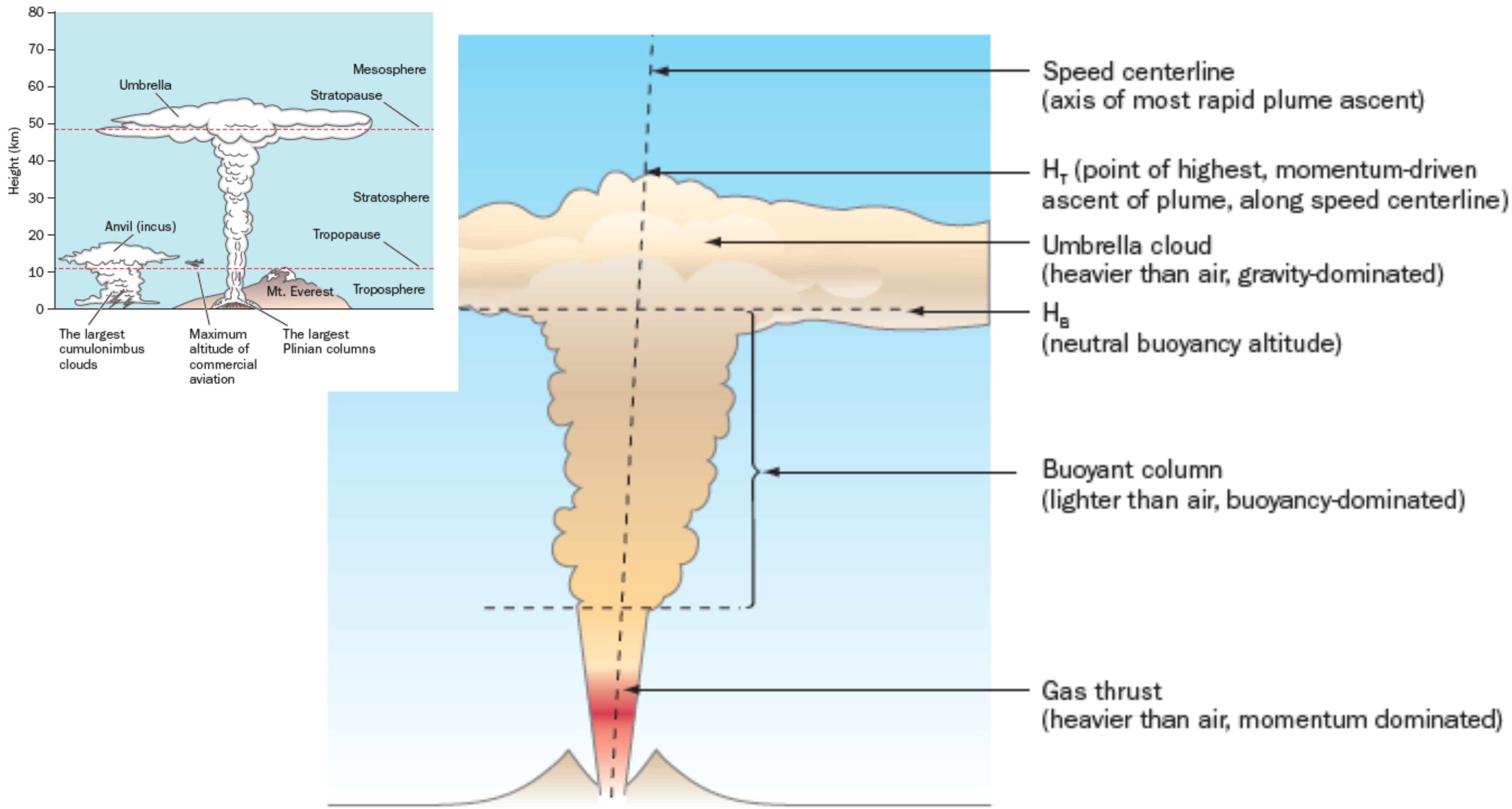
Individual Plinian eruptions produce prodigious amounts of juvenile ash and pumice, with subsidiary lithic fragments. A typical eruption culminates in a towering eruption column of hot gas and steam mixed with millions of tons of ejecta blasted above the vent at speeds of up to hundreds of meters per second. Sheer inertial momentum sustains this column initially, but expanding steam and entrained, heated air sucked into the base of the column give it the convective boost it needs to climb kilometers higher into the atmosphere (Bursik et al. 1992).

Phreatoplinian eruptions, which are closely related, are essentially just Plinian eruptions that break out in shallow bodies of water. They tend to be even more powerful than ordinary Plinian eruptions because of the added explosive energy provided by larger volumes of incorporated steam.

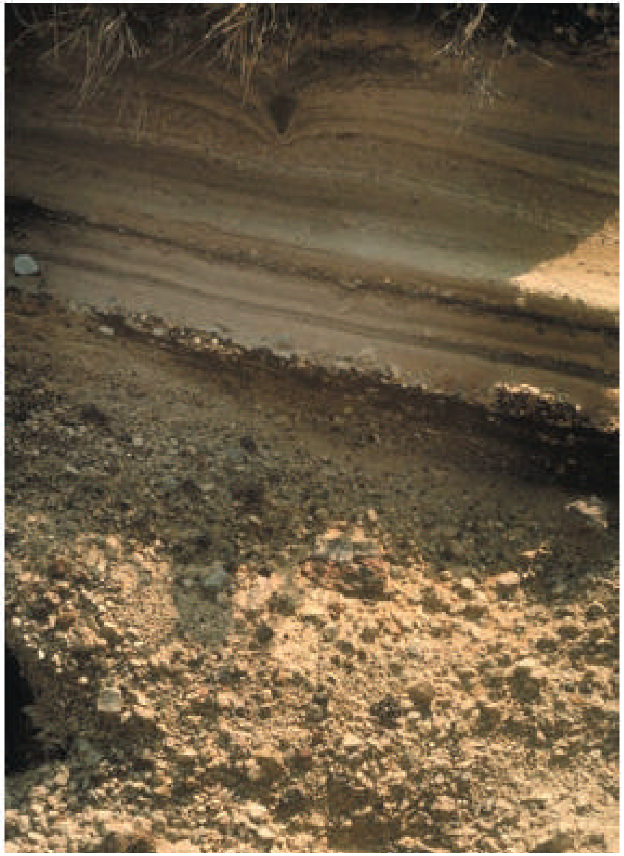




The term **Plinian column** is used to describe these boiling clouds of ash and steam that rise more than about 15–20 km above volcano tops, and **sub-Plinian** for clouds that rise to lesser heights. **Ultraplinian** describes those those rare columns that rise above 40 km or so into the stratosphere (Fig. 7.18). Eruptions of Krakatau (1883) and Tambora (1815) may be the only historic examples of this latter category. Most of



Plinian eruption deposits:



Pyroclastic surge and fall deposits overlie pumice-rich, fine-depleted air fall.

1 well-sorted basal pumice fall beds up to several meters thick; overlain by
2 cross-laminated pyroclastic surge beds; capped by
3 pyroclastic flow deposits that can be as much as several tens of meters thick. These latter deposits are typically a poorly-sorted mixture of ash, pumice, and minor lithic fragments, with concentrations of angular lithic rubble at their bases and larger pumice fragments toward the top; and
4 a capping layer of well-sorted, unstratified ash up to several tens of centimeters thick (termed "co-ignimbrite ash").

Jurado-Chichay and Walker (2001) related this "standard" Plinian depositional sequence to eruption dynamics, beginning with the basal pumice fall layer which represents the initial, heavier-particle fallout from the plume as it begins to spread from the top of the eruption column across the surrounding landscape (Fig. 7.20). A typical pumice fall bed is distinguished by an inversely-graded lower part, reflecting a waxing in column strength; a uniformly sorted middle section showing steady state column activity; a horizon of coarsest pumice clasts showing greatest intensity of eruption; and finally a normally graded upper part that represents post-climax weakening of the column

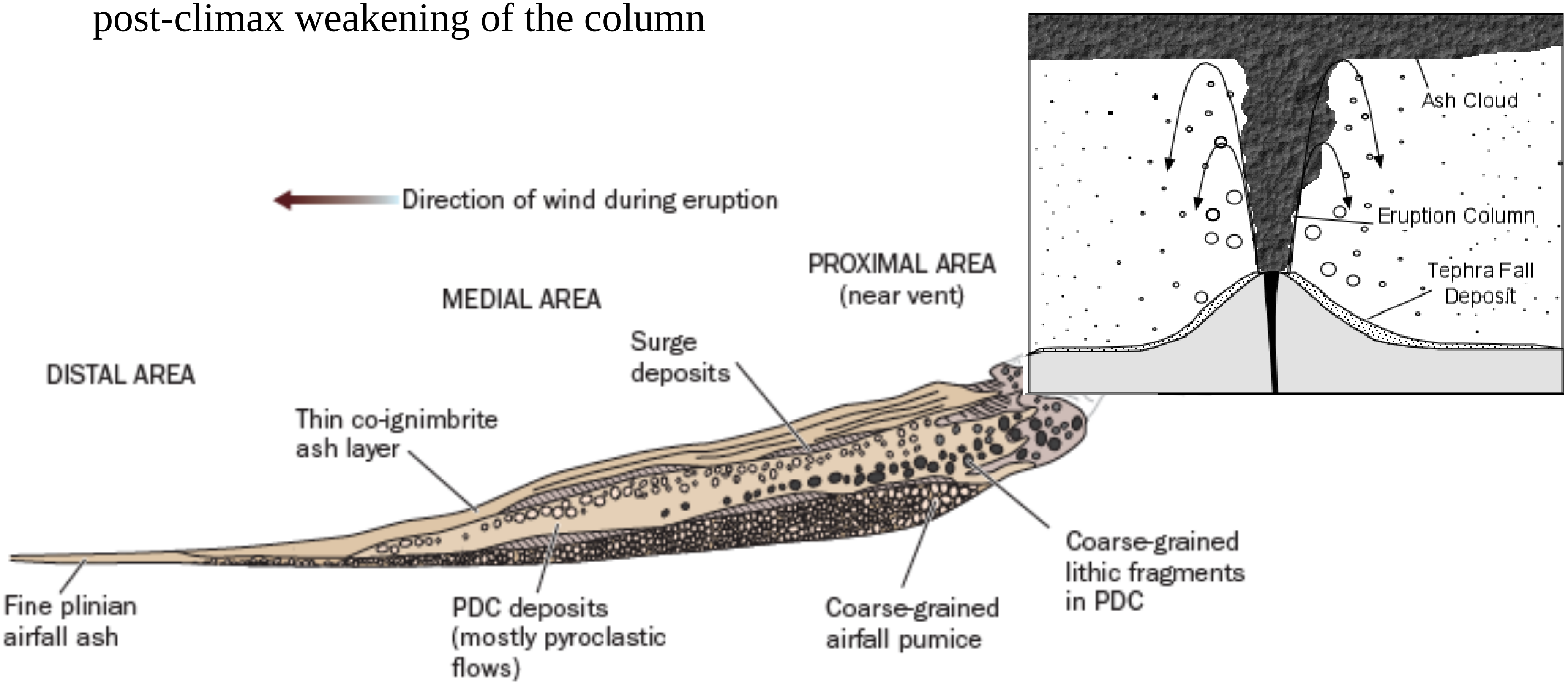
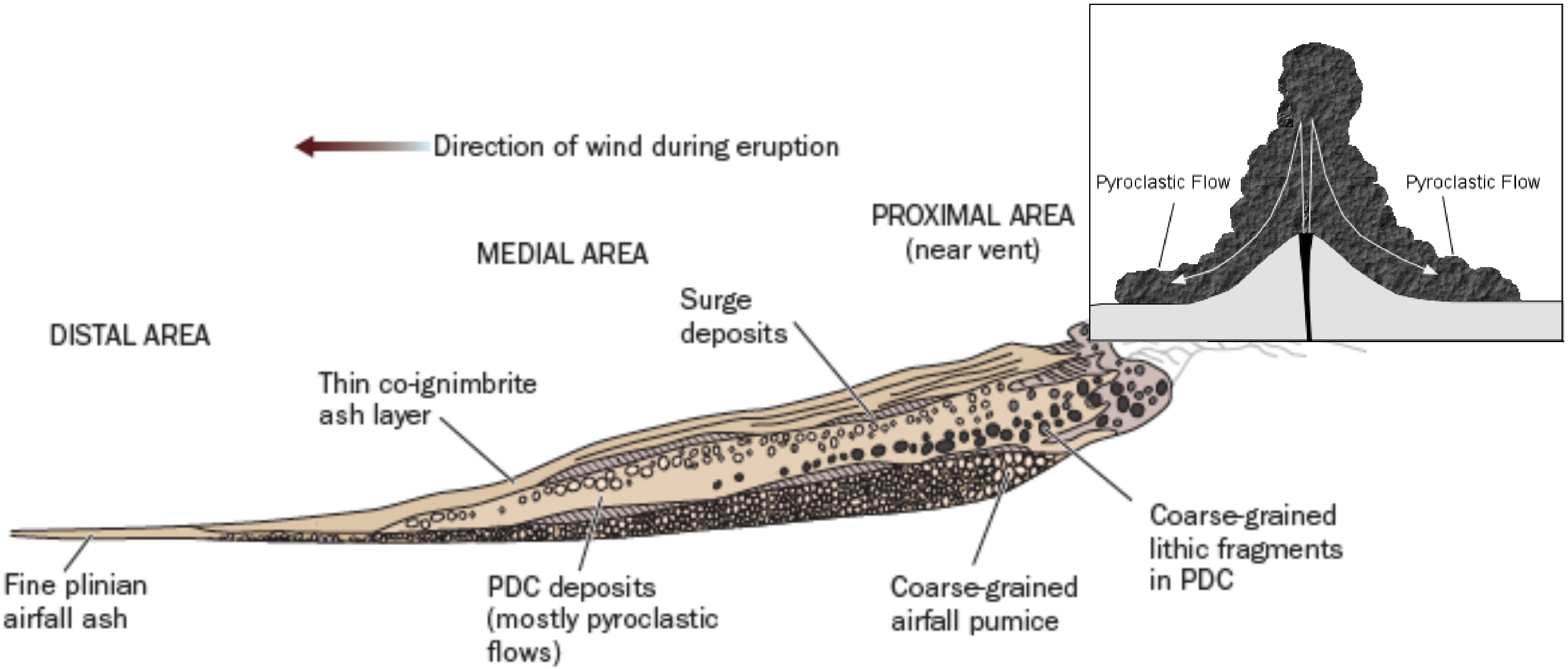


Fig. 7.20

The column then collapses or "boil-over" processes ensue forming PDCs that bury the pumice fall bed. Finally, as the eruption shuts down, the fine ash lingering in the air above the freshly veneered volcanic terrain settles out to develop the co-ignimbrite layer.



Prima Lettera di Plinio il Giovane a Tacito
Da “Lettere a Tacito, 104 d.C.”
Caro Tacito,
mi chiedi di narrarti la morte di mio zio per poterla tramandare ai posteri con maggiore esattezza.
(…)
Egli si trovava a Miseno e comandava la flotta. Il nono giorno prima delle calende di Settembre verso l’ora settima (24 Agosto ore 13), mia madre gli indicò una nube insolita per grandezza ed aspetto. Egli, dopo avere preso un bagno di sole e poi di acqua fredda, aveva preso a letto un piccolo pasto a stava ora studiando; chiese i calzari e salì ad un luogo dal quale si poteva veder bene quel fenomeno. Una nube si innalzava (non appariva bene da quale monte avesse origine, si seppe poi dal Vesuvio), il cui aspetto e la cui forma nessun albero avrebbe meglio espressi di un pino. Giacché, protesasi verso l’alto con un altissimo tronco, si allargava a guisa di rami perché ritengo, sollevata dapprima da una corrente d’aria e poi abbandonata a se stessa per il cessare di quella o cedendo al proprio peso, si allargava pigramente. Talora bianca, talora sporca e chiazzata a causa del terriccio e della cenere trasportata.
(…)

The classic Plinian eruption of 79 CE was mostly over in less than a day. The initial pumice fall put down a layer as much as 1.4 meters thick across the small city of Pompeii over a period of about 18 hours, enabling most of the population (about 90 percent of some 20,000 residents) to escape by foot and cart, though how many eventually reached safety is unknown. Many evacuees carried mattresses, pillows, or other protection on their heads to escape injury from pelting, though from archaeological remains it is clear that some were felled horribly in their tracks. Some 12 hours after the development of the eruptive column, PDCs were already underway, initially directed toward the port of Herculaneum a few kilometers west of Pompeii (De Carolis & Patricelli 2003). When the first pyroclastic current finally reached Pompeii itself, the city’s defensive wall managed to restrain it, but the accumulating ash and pumice provided a ramp on the upslope side of the wall for subsequent currents to overtop with ease. Magnetic studies of the PDC deposits indi-

HYDROVOLCANIC ERUPTIONS

Hydroexplosions result from the sudden generation of steam where water comes in contact with hot rock or melt, as when molten lava rises through water-saturated rocks or is extruded into a lake or the ocean. **Phreatic** and **phreatomagmatic eruptions** are both end-member types of hydroexplosions, the former involving steam only, and the latter steam + magma.

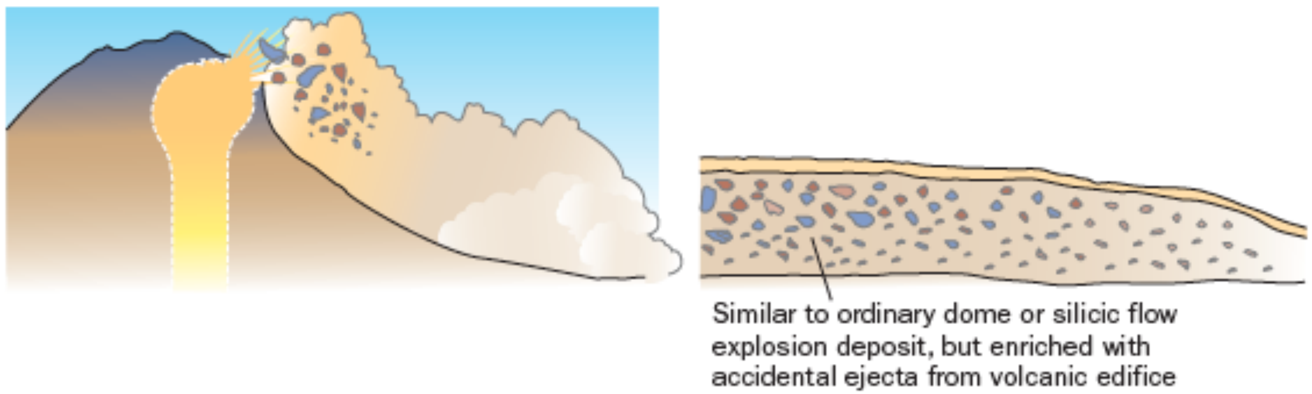
Fig. 7.22 Hydrovolcanic eruption that is burying the (fortunately uninhabited) island of Hunga Ha`apai, northwest of Nuku`alofa, Tonga, with tephra and blocks on March 18, 2009. The island represents the subaerial rim of a large submarine caldera in the very active Tonga volcanic belt, on the western margin of the Tonga trench. Large blocks falling from the 500 m-high cloud can be seen impacting on the sea. Photo by Lothat Slabo/AFP/Getty Images.

Peleean-Merapi type eruptions

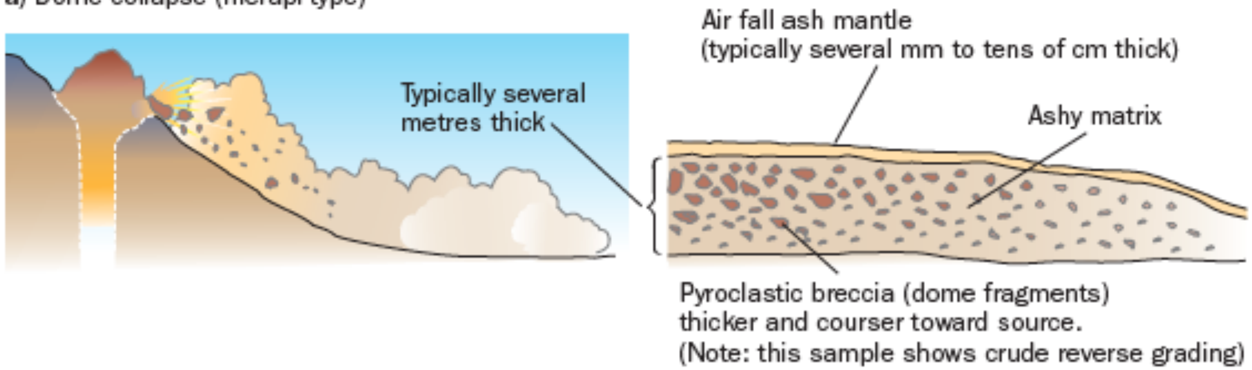
repetitive collapse or explosion of growing volcanic domes, which are circular mound-shaped protrusions resulting from the slow extrusion of viscous lava from a volcano.

If the gas pressure inside the magma is directed outward instead of upward, a lateral blast can occur. When this occurs on the flanks of a lava dome, a pyroclastic flows called nuée ardentes can also result. Directed blasts often result from sudden exposure of the magma by a landslide or collapse of a lava dome.

e) Cryptodome explosion



a) Dome collapse (merapi-type)



Plinian, phreatic, phreatomagmatic and peleean eruptions are characterized by **pyroclastic surges or flows, which are** deadly torrents of hot ejecta and gases that pour down volcano flanks.

TABLE 7.3 CHARACTERISTICS OF PRINCIPAL PYROCLASTIC DEPOSITS.

Pyroclastic deposit Type	Origin	Deposition mechanism	Deposit characteristics
Fall ejecta	Gravity settling from overhead ash clouds	Accumulation by gravity settling through air or water, potentially affected by prevailing winds or water currents.	Typically poorly consolidated layers of uniform thickness that drape pre-existing topography. Size sorting is moderate to good.
Pyroclastic surge	Ash column collapse, phreatic or phreatomagmatic eruption	Deposition from low concentration, relatively low-temperature mixtures of ash, broken rock fragments and gases. Surges are characterized by turbulent flow.	Usually poorly sorted and poorly consolidated. Dune and internal erosion structures are typical and result in irregular thicknesses over short distances. Commonly contain ballistically emplaced blocks – bomb sags are common in proximal areas. Accretionary lapilli common.
Pyroclastic flow	Boiling of magma chambers, ash column or dome collapse. Most commonly associated with caldera-forming eruptions	Deposition from high-concentration, high-temperature clouds of mixed ash, gas, and juvenile magma fragments. Characterized by laminar flow.	Poorly stratified, with thicker deposits filling valleys and thinner or absent deposits on highlands. Commonly shows poor grading, with denser fragments near bases. Evidence of high-temperature origin include welding, deformation of glassy pumice fragments, pink-oxidized tops and gas pipes.

lahar Volcanic mudflows are known as lahars, some of which have killed tens of thousands of people in single events. When pyroclastic flows and nuée ardentes move into large rivers, they quickly cool and mix with water, becoming fast-moving mudflows. Lahars may also result from the extremely rapid melting of icecaps on volcanoes

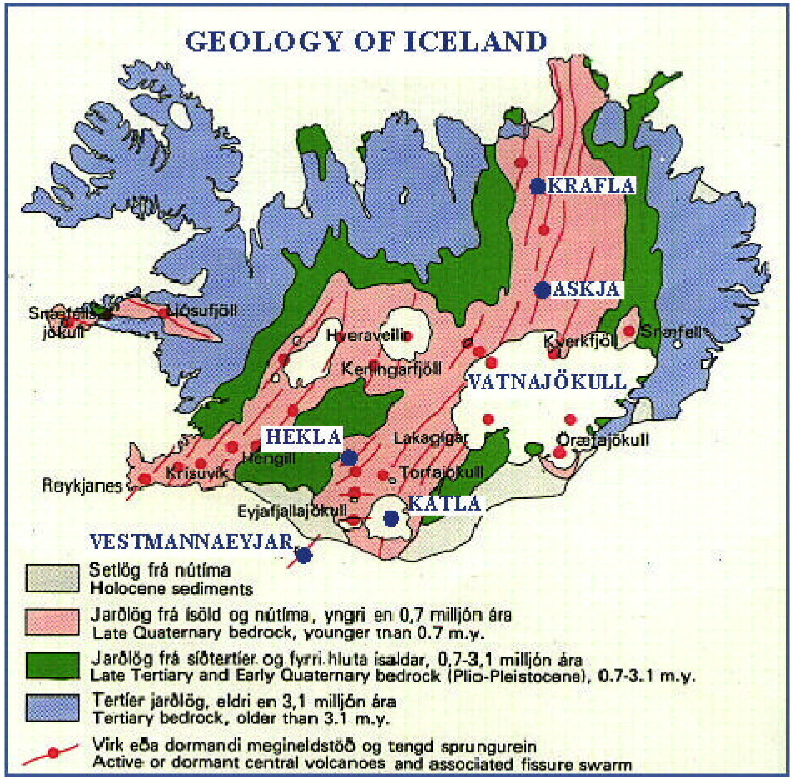
One of the greatest volcanic disasters of the 20th century resulted from the generation of a huge lahar when the icecap on the volcano Nevado del Ruiz in Colombia catastrophically melted during the 1985 eruption. Nevado del Ruiz entered an active phase in November 1984 and began to show harmonic tremors on November 10, 1985. At 9:37 P.M. that night, a large Plinian eruption sent an ash cloud several miles into the atmosphere, and this ash settled onto the ice cap on top of the mountain. This ash, together with volcanic steam, quickly melted large amounts of the ice, which mixed with the ash and formed giant lahars down the east side of the mountain into the village of Chinchina, killing 1,800 people. The eruption continued and melted more ice that mixed with more ash and sent additional larger lahars westward. Some of these lahars moved nearly 30 miles (48 km) at nearly 30 miles per hour (48 km/hr) and buried the town of Armero under 26 feet (8 m) of mud, killing 23,000 people in Armero and surrounding communities.

Nevado del Ruiz

Subglacial Eruptions and Jokulhlaups

Vatnajokull, Iceland

- Third largest ice sheet on earth
- 8400 km^2, up to 1000m thick
- Covers centers of Eastern Volcanic Zone



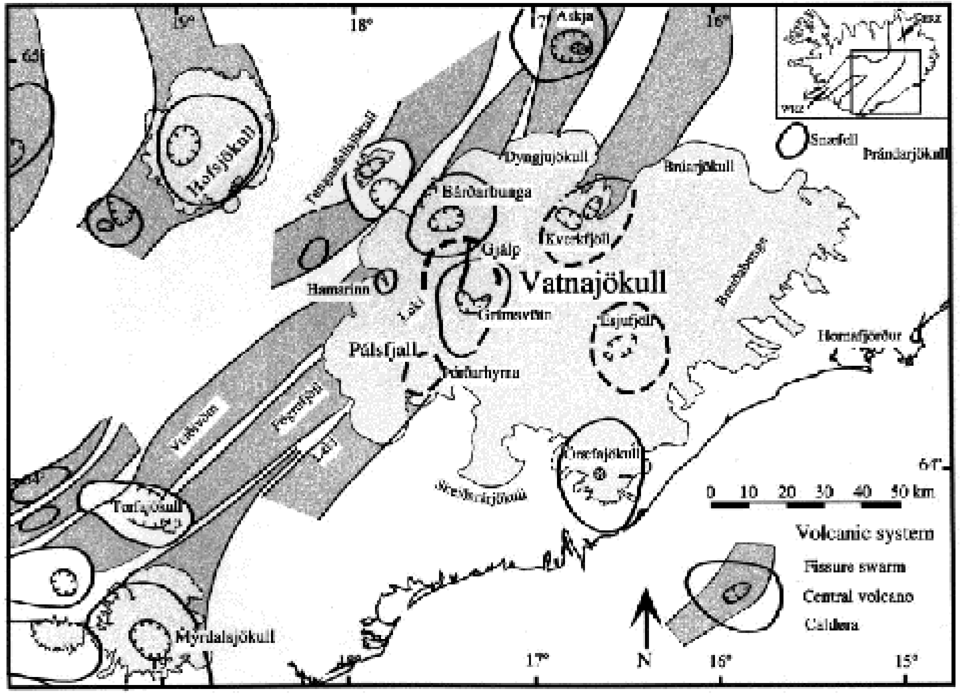
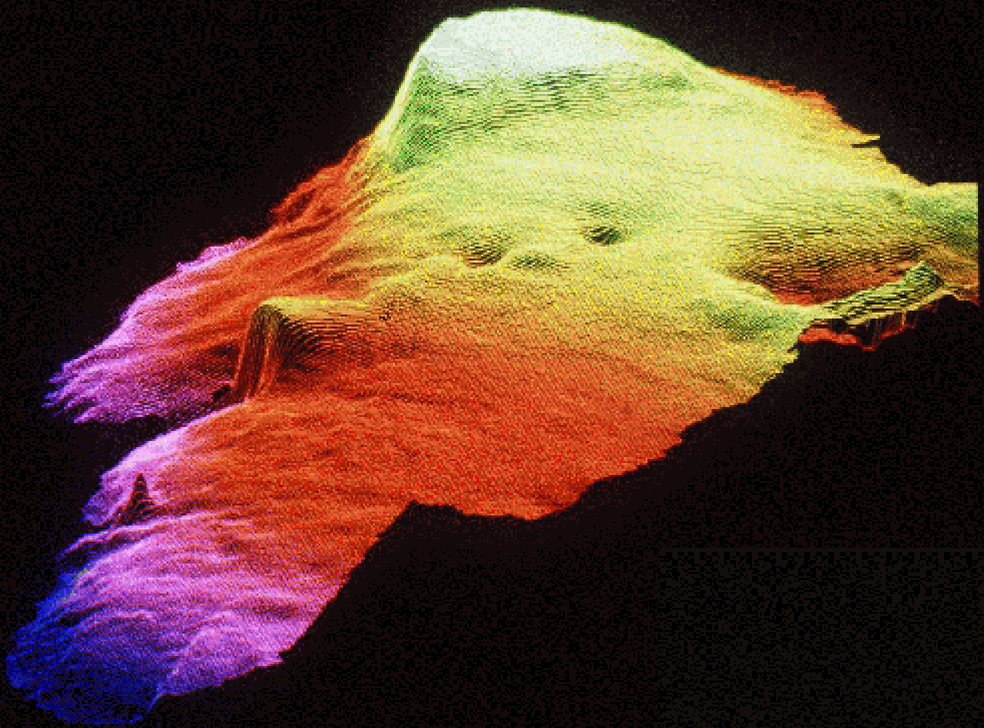
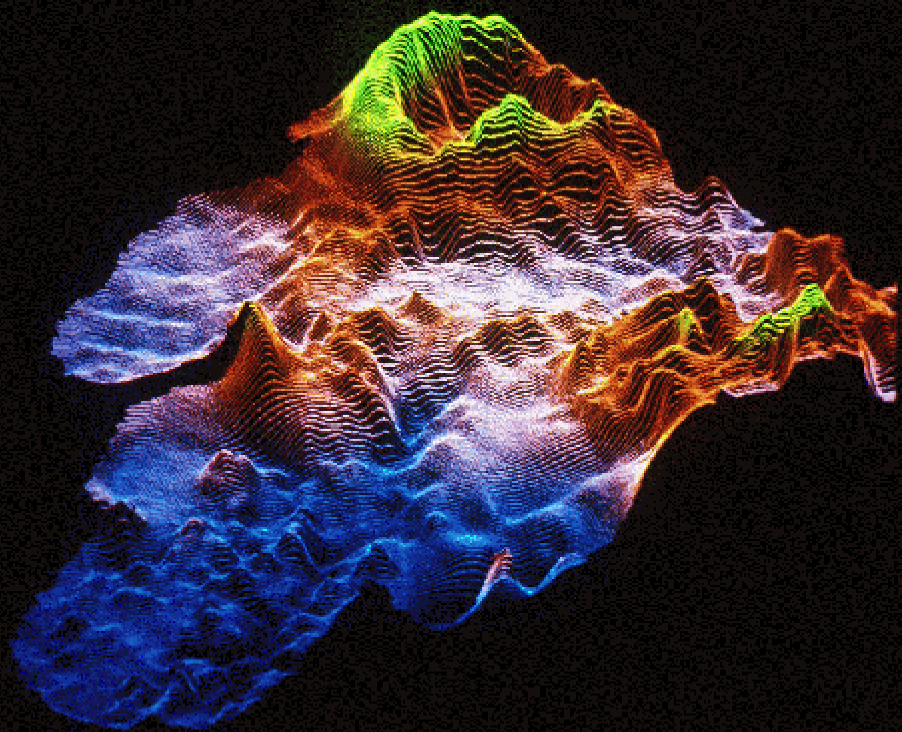


Fig. 1. Map of SE Iceland showing volcanic centres in W Vatnajökull and associated fissure swarms (after Björnsson and Einarsson, 1990). The Vatnajökull-1996 fissure (Gjálp) and the suggestion of a caldera are seen in centre field. Inset shows the volcanic zones.

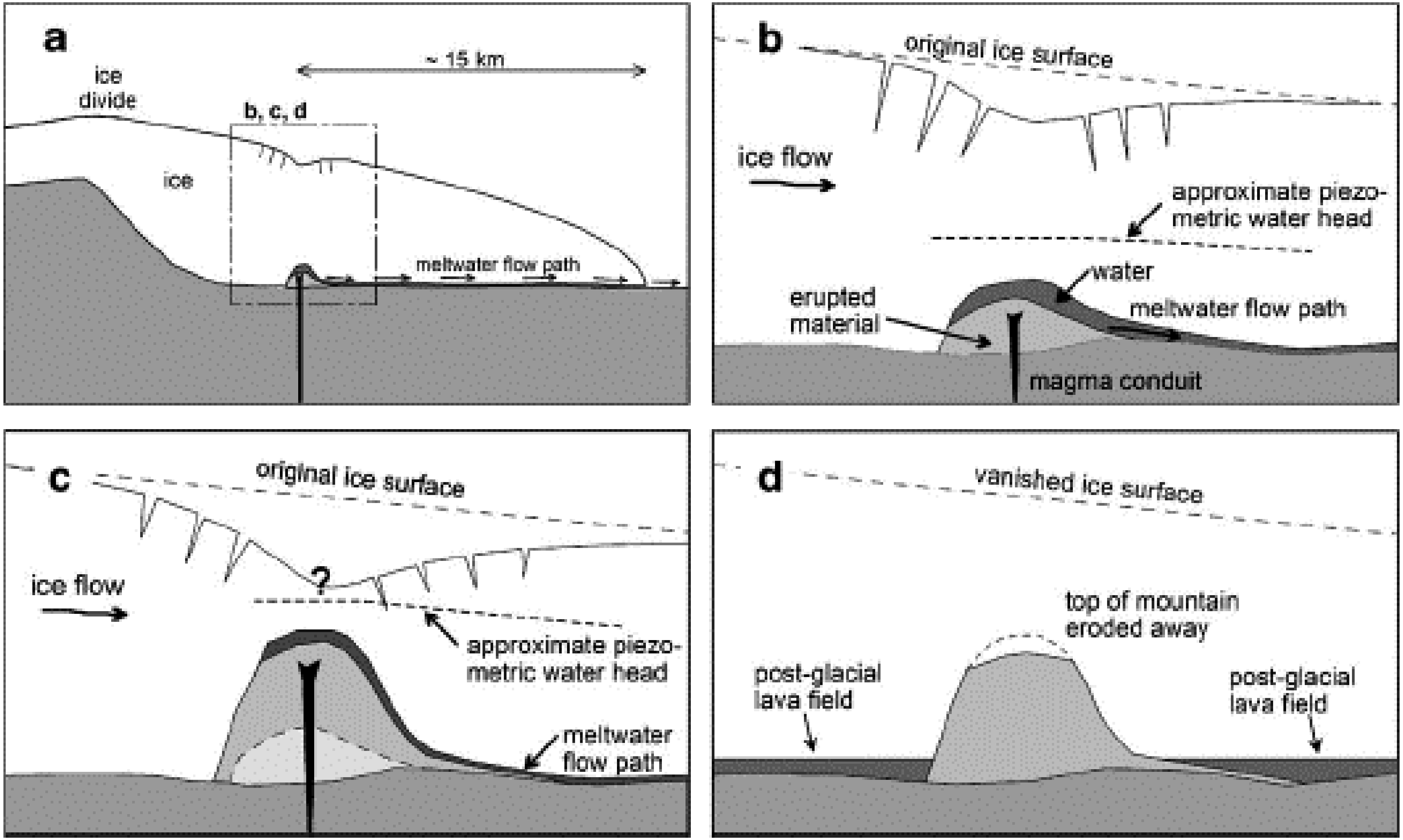


Vatnajokull Ice Surface

Vatnajokull Bedrock map

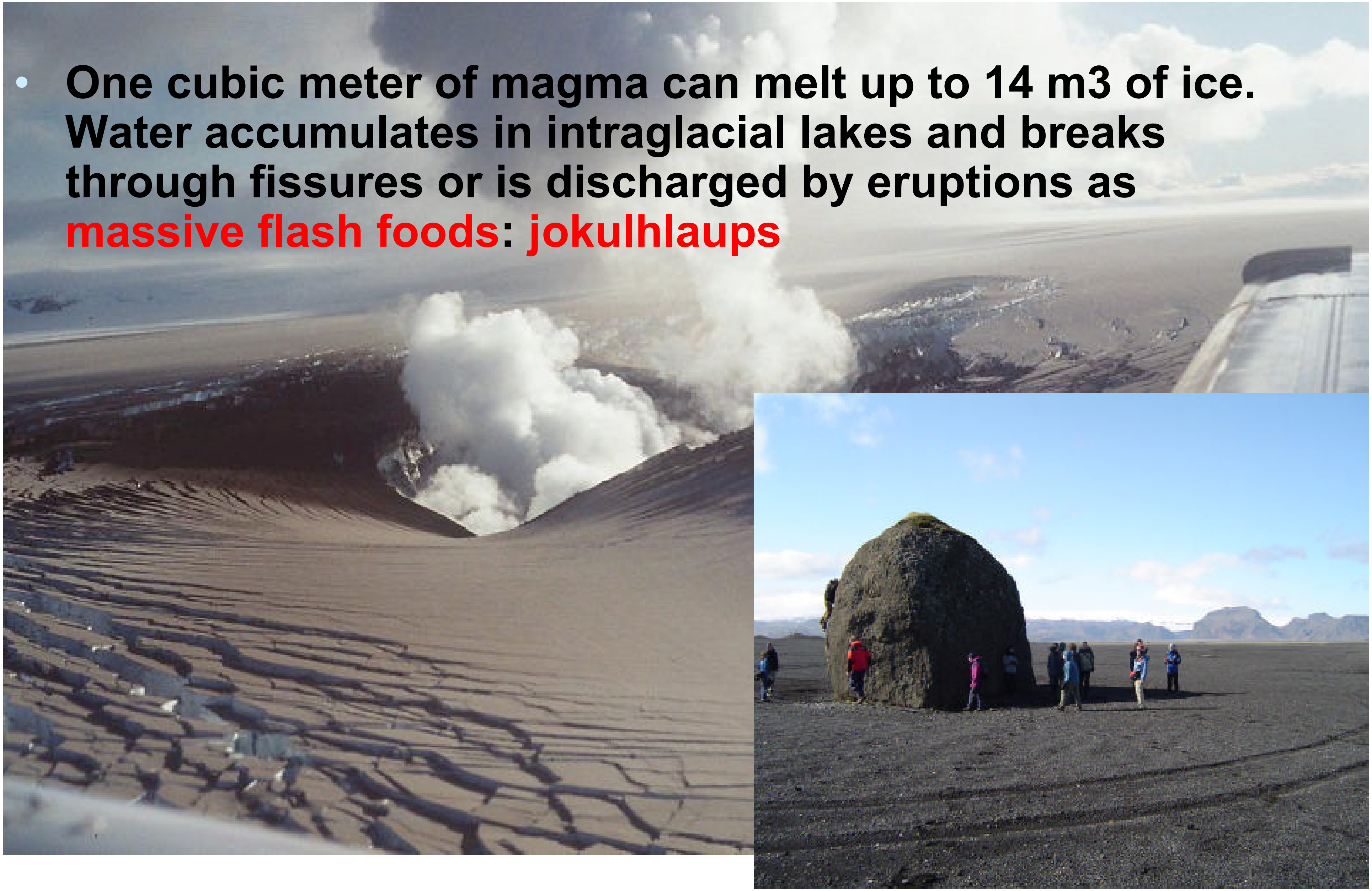


Subglacial Eruptions



Subglacial Eruptions and Jokulhlaups

- **One cubic meter of magma can melt up to 14 m3 of ice. Water accumulates in intraglacial lakes and breaks through fissures or is discharged by eruptions as massive flash foods: jokulhlaups**



Volcanic eruptions and climate

Abstract: The primary effect of a volcanic eruption is to alter the composition of the stratosphere by the direct injection of ash and gases. On average, there is a stratospherically significant volcanic eruption about every 5.5 years. The principal effect of such an eruption is the enhancement of stratospheric sulphuric acid aerosol through the oxidation and condensation of the oxidation product H_2SO_4. Following the formation of the enhanced aerosol layer, observations have shown a reduction in the amount of direct radiation reaching the ground and a concomitant increase in diffuse radiation

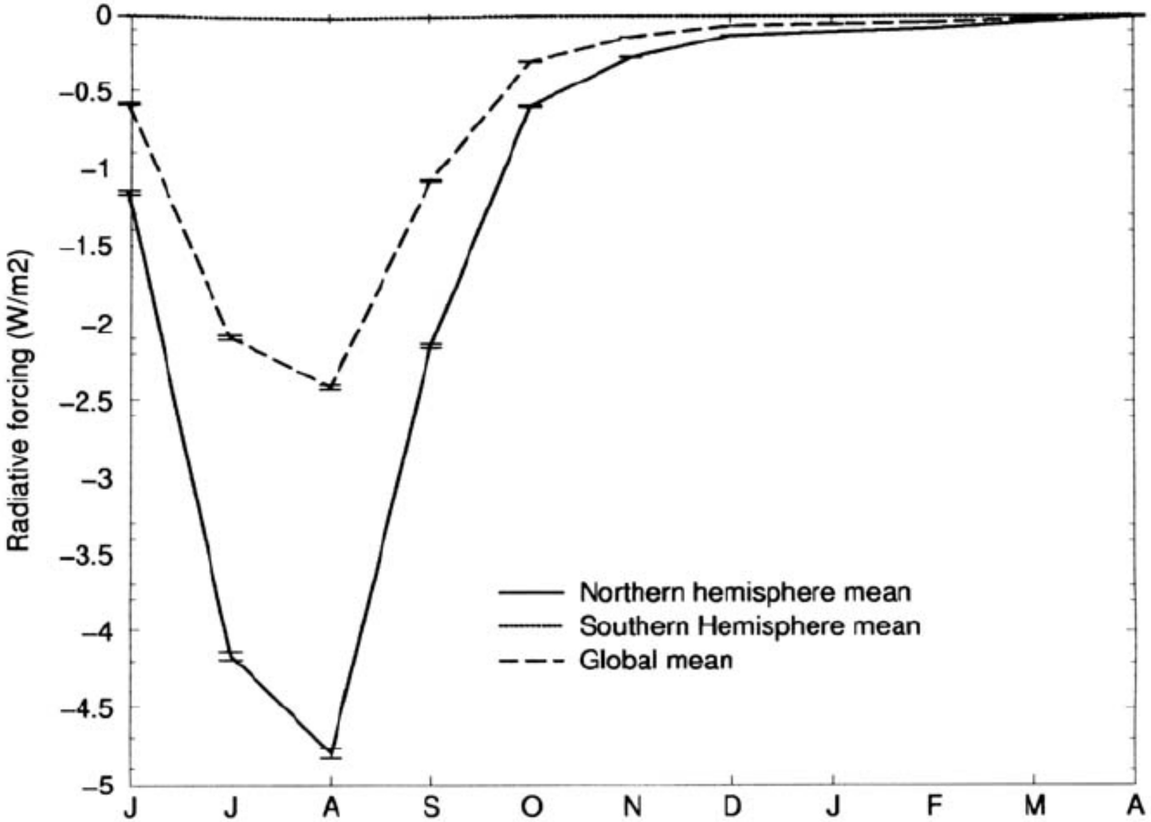


Fig. 7. Global and hemispheric mean radiative forcing due to sulphate aerosols from the eruption of Laki in 1783. The aerosol distribution has been simulated using the chemical transport model STOCHEM as in

Grainger & Highwood, 2003

This is associated with an increase in stratospheric temperature and a decrease in global mean surface temperature (although the spatial pattern of temperature changes is complex).

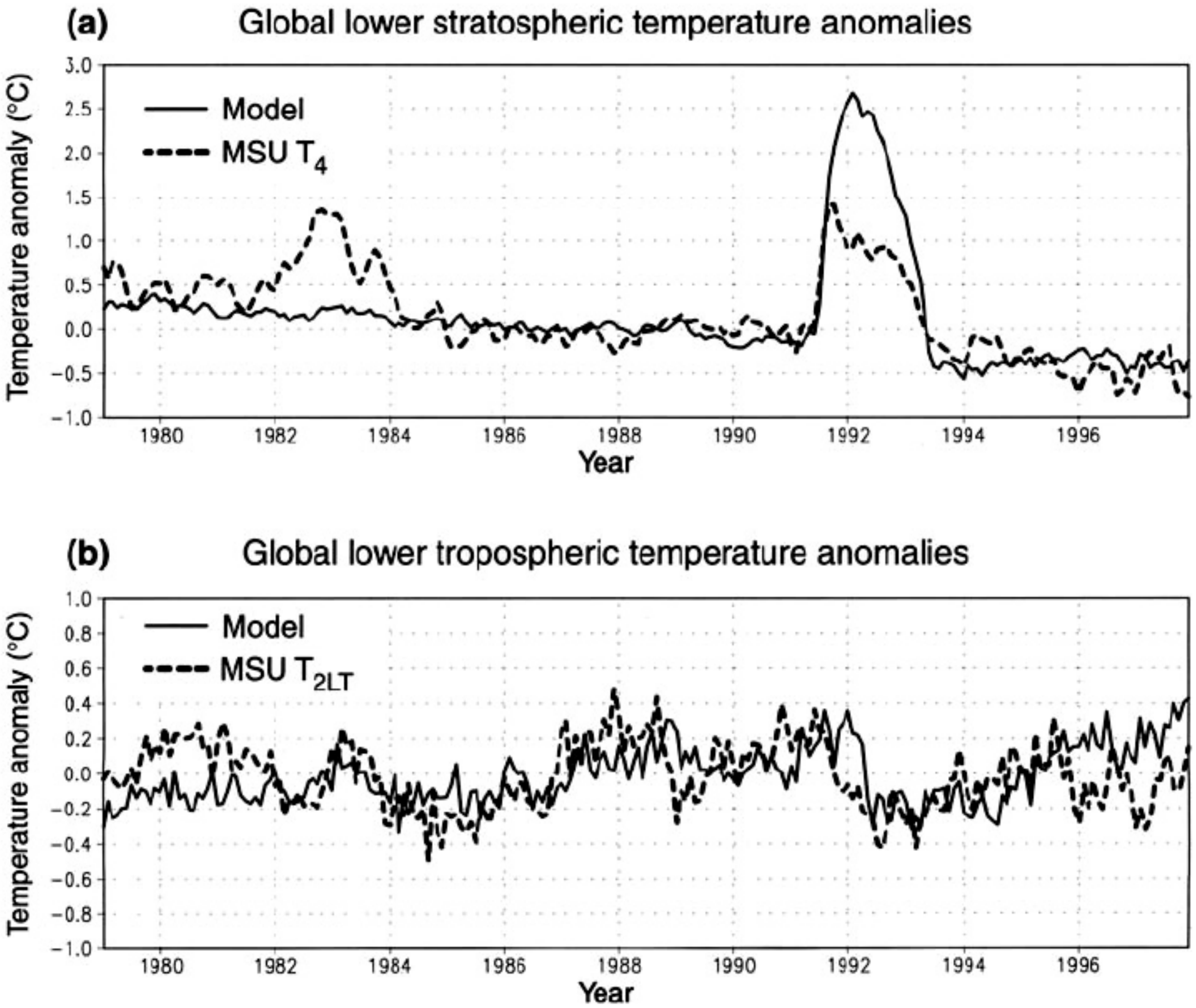
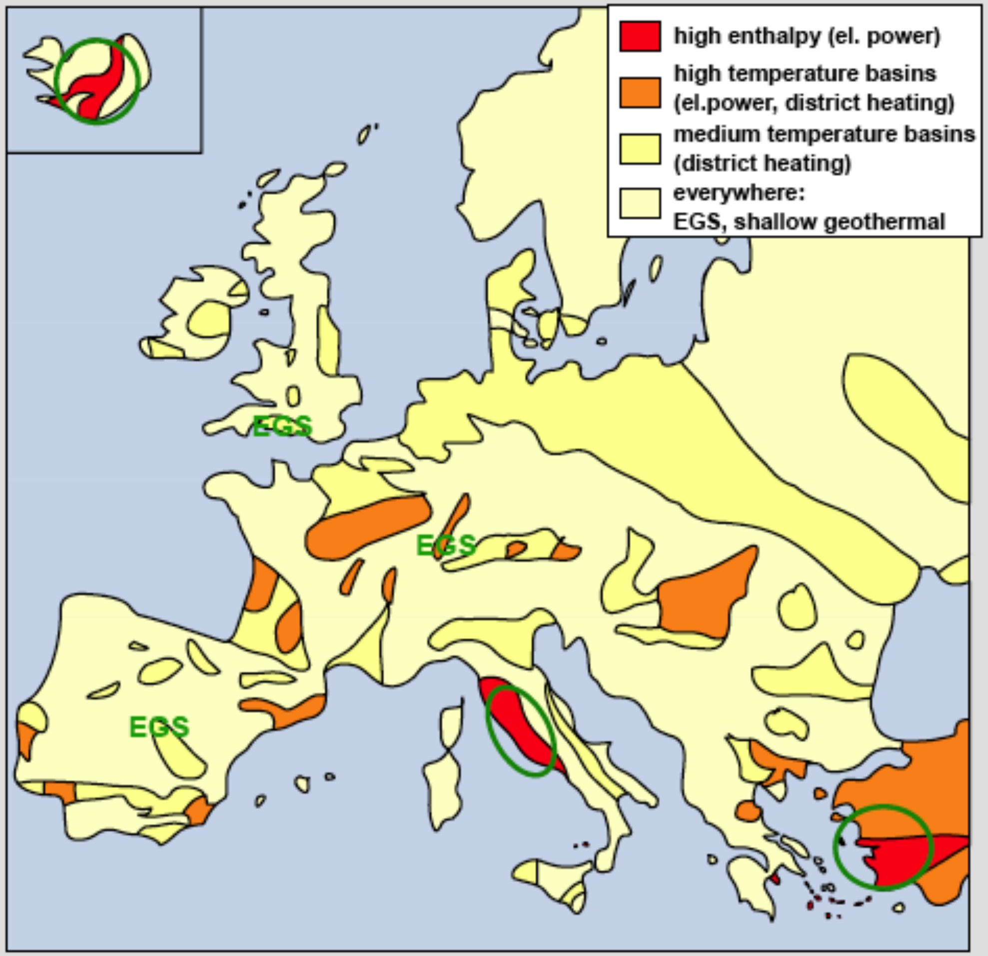


Fig. 8. Satellite observations and model predictions of lower-stratospheric and tropospheric temperature anomalies after the eruptions of El Chichón and Pinatubo (from Houghton *et al.* 2001).

Grainger & Highwood, 2003

Volcanism and geothermy

The geothermal development – high enthalpy



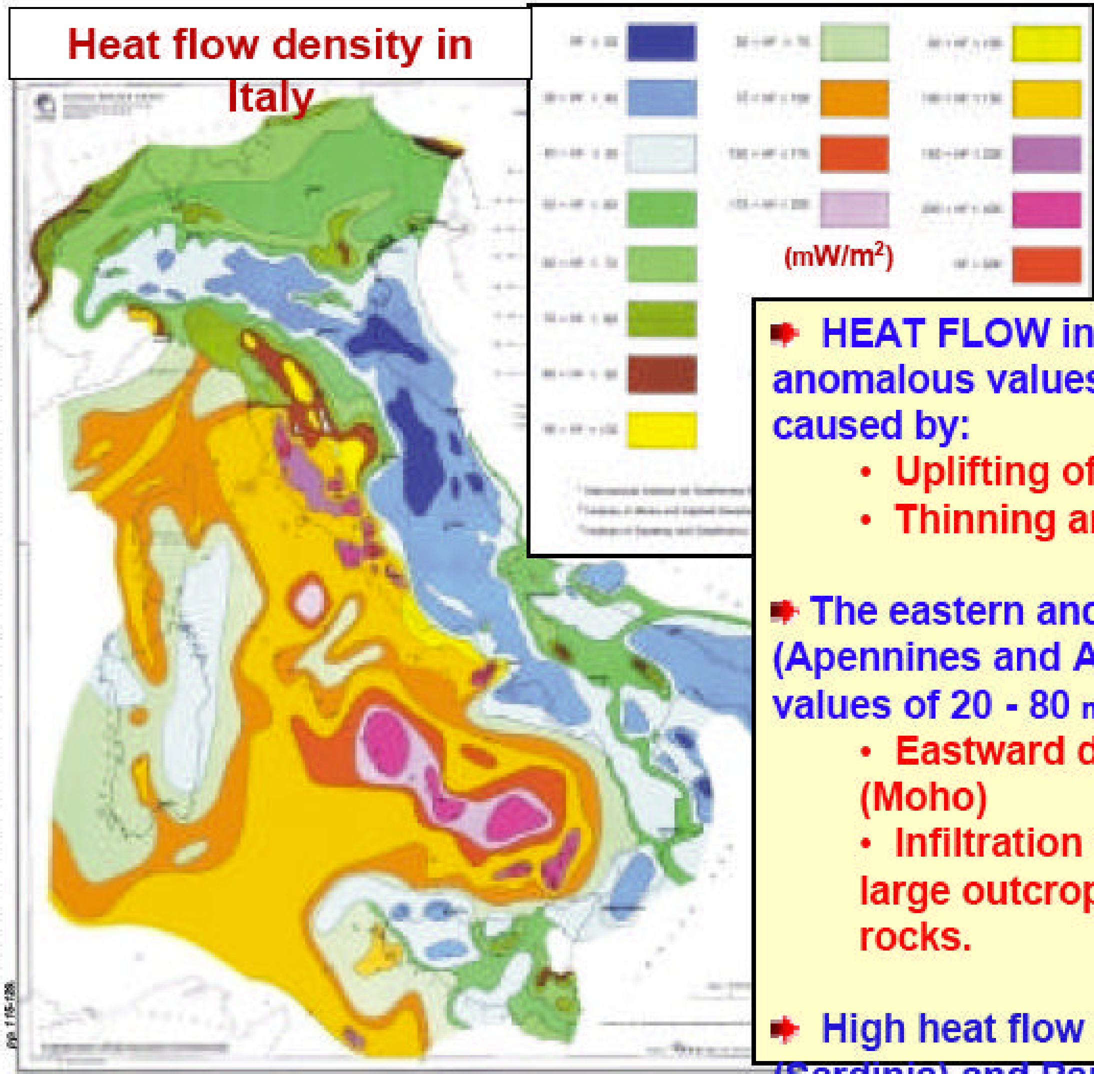
Map showing main basins and high-enthalpy geothermal areas

Current main growth regions for high enthalpy geothermal in Europe

European Geothermal Energy Council

EGEC

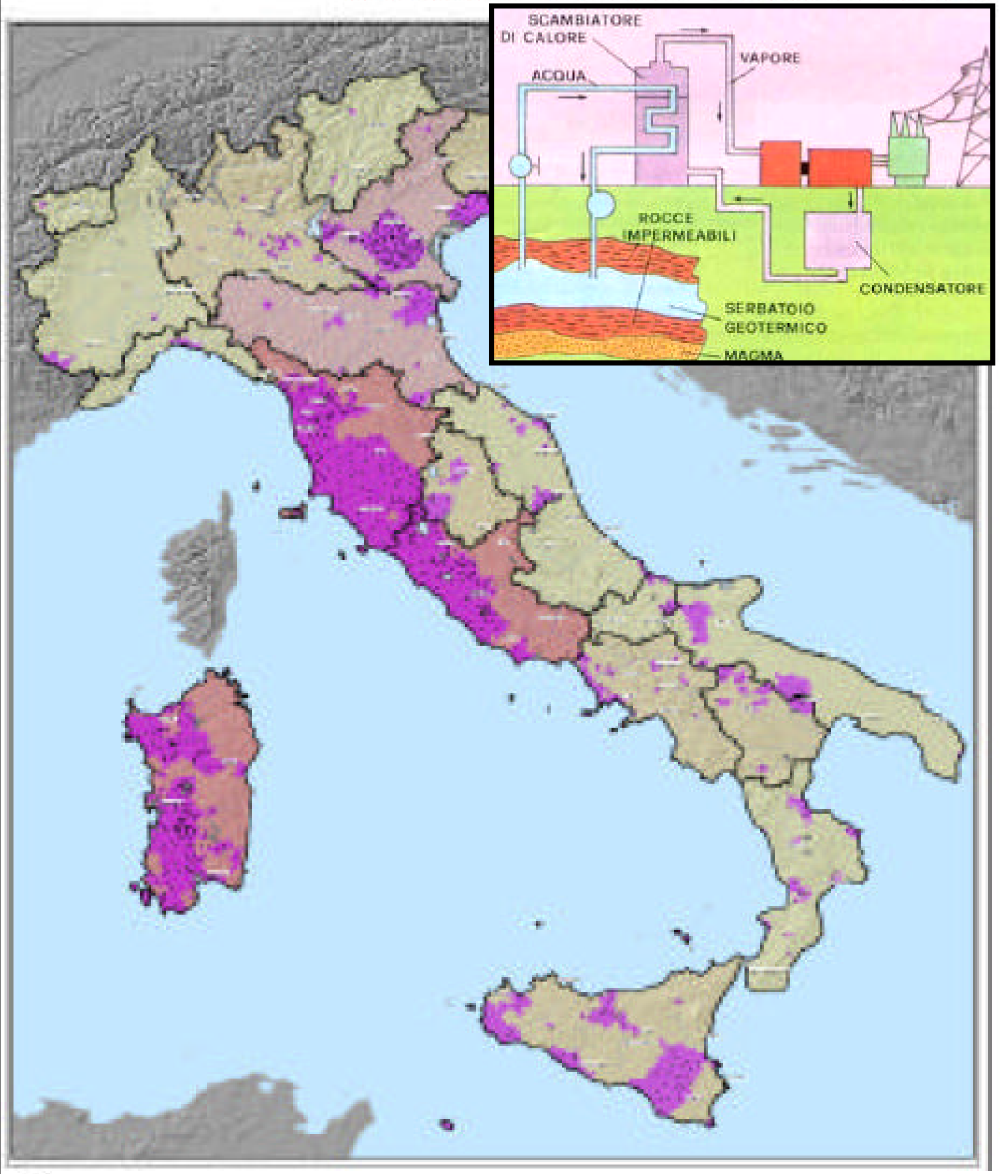
Heat flow density in Italy



- HEAT FLOW in the Tyrrhenian sector has anomalous values (from 100 to 450 mWatt/m^2), caused by:
  - Uplifting of the mantle
  - Thinning and spreading of the crust.
- The eastern and southern sectors of Italy (Apennines and Adriatic-Ionian areas) display values of 20 - 80 mWatt/m^2 due to:
  - Eastward deepening of the crust base (Moho)
  - Infiltration of meteoric waters through large outcrops of permeable carbonate rocks.
- High heat flow values in Campidano (Sardinia) and Pantelleria (Sicily) areas are due to the opening of rift structures.

Average heat flow of world's continents = 55 mWatt/m2

GEOTHERMAL ENERGY IN ITALY: A GENERAL



- ***Huge hydrothermal resources exist in Italy within 3 km depth. They are mostly located in the fuchsia-colored areas).***
- ***High temperature resources (> 150 °C) suitable for power generation are present at economically-accessible depth in restricted areas of peninsular Italy, covering some 1500 km^2 altogether.***
- ***More than 1000 Municipalities are classified priority areas for short term development of hot water at T > 60 °C.***
- ***However, by using heat pumps, low-to-very low temperature resources could also be utilized, almost everywhere***

THEREFORE, ITALY AS A WHOLE PRESENTS A MARKED GEOTHERMAL VOCA...

GEOTHERMAL vs. TOTAL NATIONAL ENERGY CONSUMPTION 2006

TOTAL GROSS ENERGY CONSUMPTION: 200.000.000 OET

- Fossil fuels (altogether) 87 %
- Hydro. and other renewables 7 %
- Imported Electricity 6 %

GEOTHERMAL OUTPUT 1,292,000 OET(0.65%of the total)

including:

- Electric generation : 1.1 million OET(0.55 % of the total)
- Direct uses (all) : 192,000 OET(0.10 % of the total)

Therefore, geothermal development in Italy (especially for direct uses) is very limited if compared to the huge country' potential

WHY TO GEOTHERMAL SHOULD BE GIVEN FIRST PRIORITY AMONG NON-CONVENTIONAL ENERGY SOURCES

To curb energy-supply shortage in Italy, all non-conventional energy sources should be developed fastly.

However, first priority should be given to natural heat due to:

- its sizeable targets in production of both electrical energy and heat for direct uses
- its notable contribution to the reduction of CO_2 emissions
- its mature technology
- possibility of direct applications over 50% of national territory with hot waters, and everywhere by using heat pumps
- its continuous and constant availability the whole year round.

NECESSARY MEASURES

- Strong commitment of all political parties and institutions involved in energy matters
- New National Energy Plan
- Incentives to develop all non-conventional energy sources, with priority for the Earth's heat
- Energy Plans in all Italian Region and main Provinces
- Involvement of professionals in exploration, exploitation, transport, distribution and use of geothermal resources
- Public information campaigns on the advantages to use geothermal energy.

http://www.egec.org/

How a geothermal power plant works

Volcanic hazard

- **<u>Gas</u>**:
  - e.g. Lake Nyos (Cameroon), 1984
- **<u>ashfalls:</u>**
  - e.g. Mt Pinatubo, 1991
- **<u>Pyroclastic flows</u>**:
  - e.g. Mt Pelee, 1902
- **<u>Lahars</u>** (mudflows):
  - e.g. Nevado del Ruiz, 1985