

Pompei, Ercolano, Oplonti

Stefano Lugli



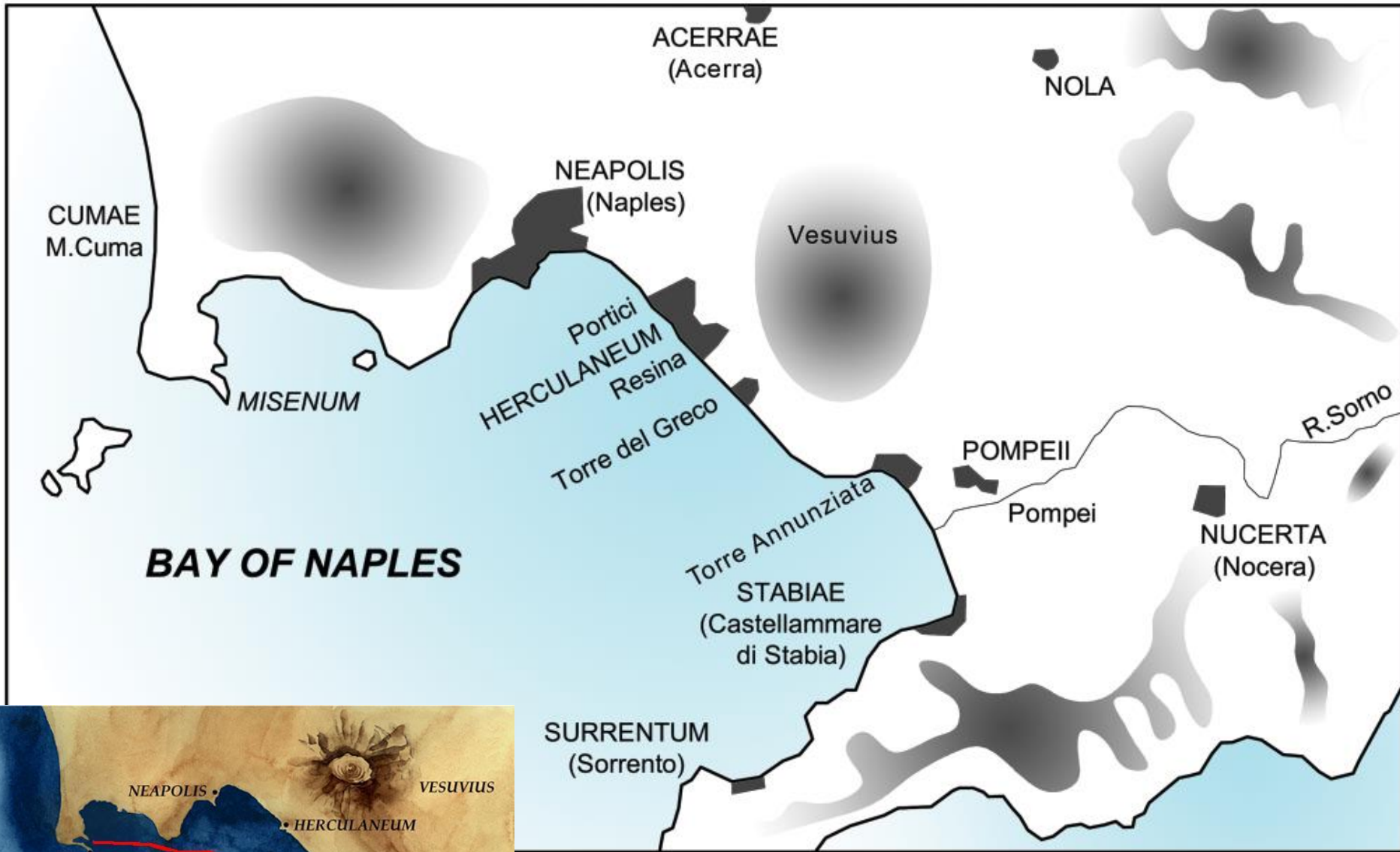


NO WARNING.
NO ESCAPE.

POMPEII IN 3D

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SCREENPLAY BY JEREMY BOLT PAUL W.S. ANDERSON ROBERT KULZER DON CARMOODY BASED UPON THE BOOK BY JANET SCOTT BATHCHLER & LEE BATHCHLER AND MICHAEL ROBERT JOHNSON WRITTEN BY PAUL W.S. ANDERSON
COLUMBIA TRISTAR PICTURES FILMDISTRICT
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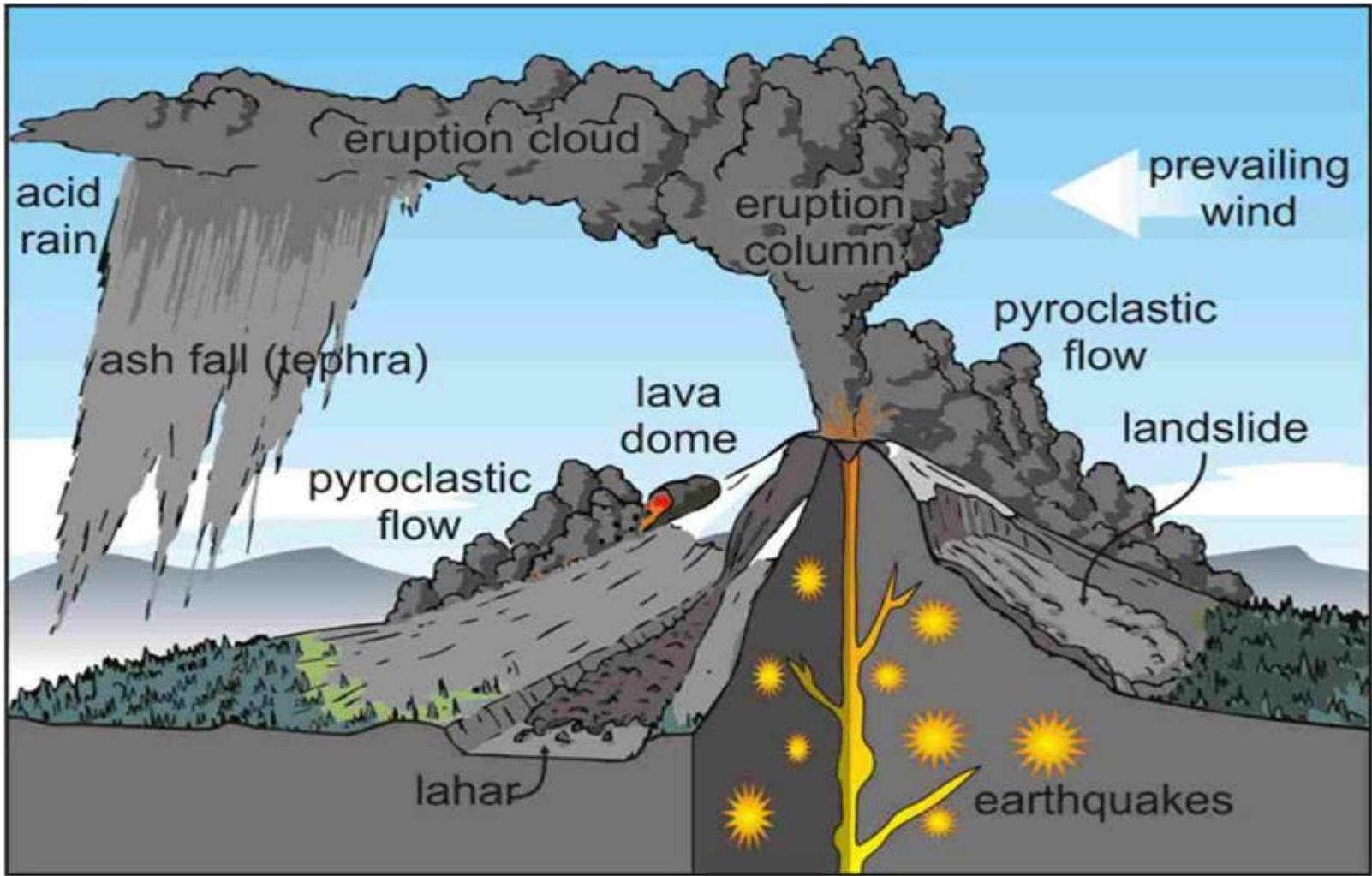
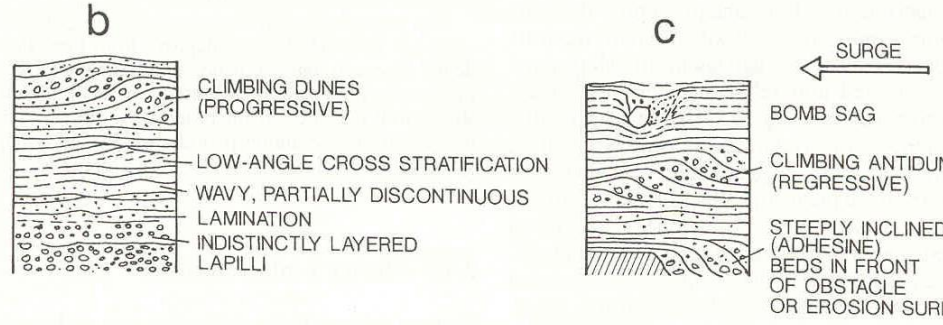
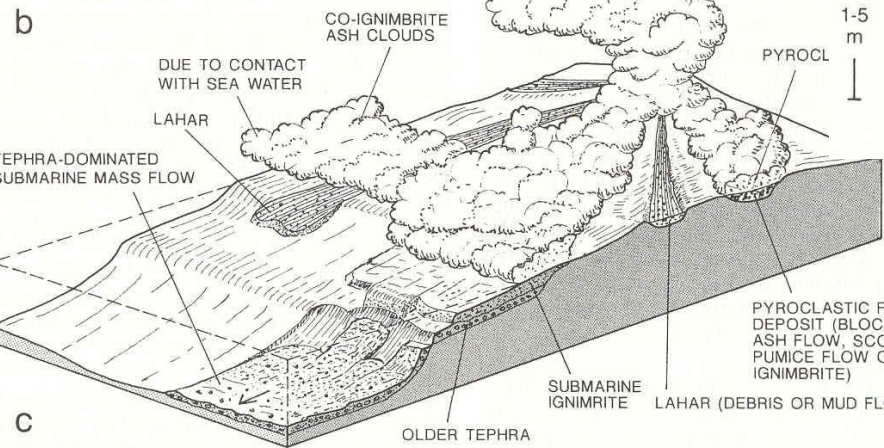
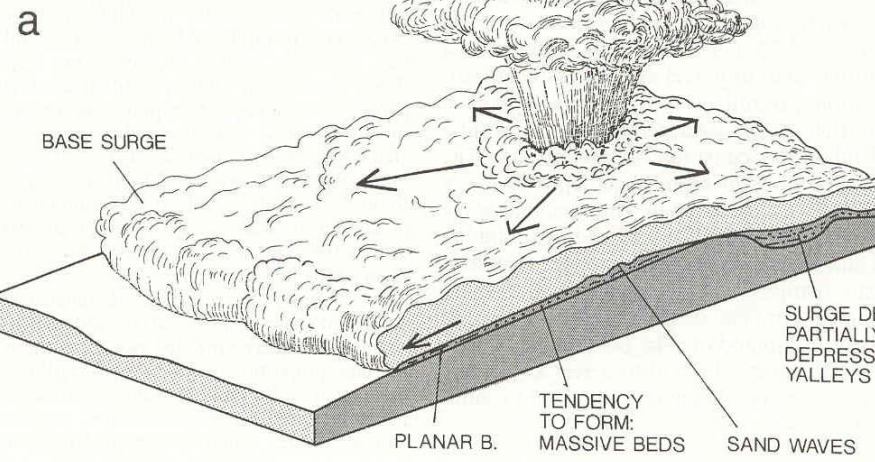
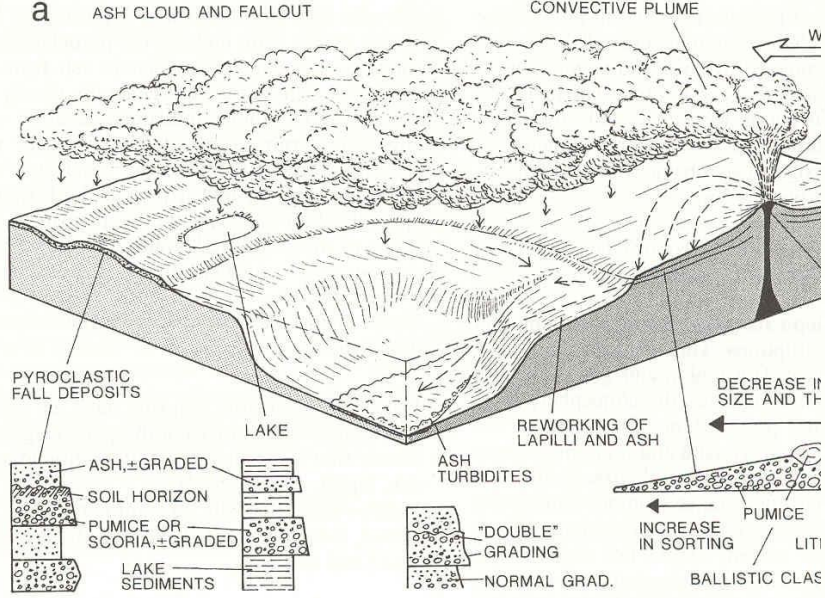


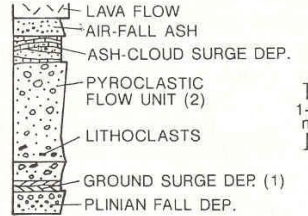
Table 3.6 *Classification of volcaniclastic grains and sediments on grain-size.*

	Volcaniclastic grains	Size	Volcaniclastic sediment terms (tephra)
64 mm	bombs – ejected fluid blocks – ejected solid	coarse – 256 mm – fine	agglomerate volcanic breccia
	lapilli	coarse – 16 mm – medium – 4 mm – fine	lapillistone
2 mm	ash	very coarse – 1 mm – coarse – 0.5 mm – medium – 0.06 mm – fine	tuff <ul style="list-style-type: none"> — vitric — lithic — crystal

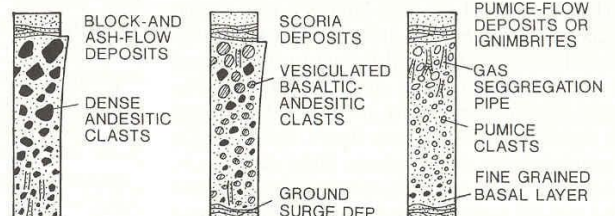
a ASH CLOUD AND FALLOUT

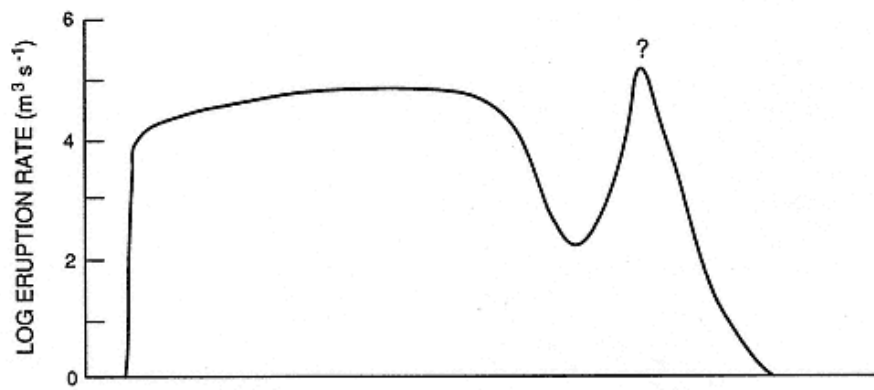
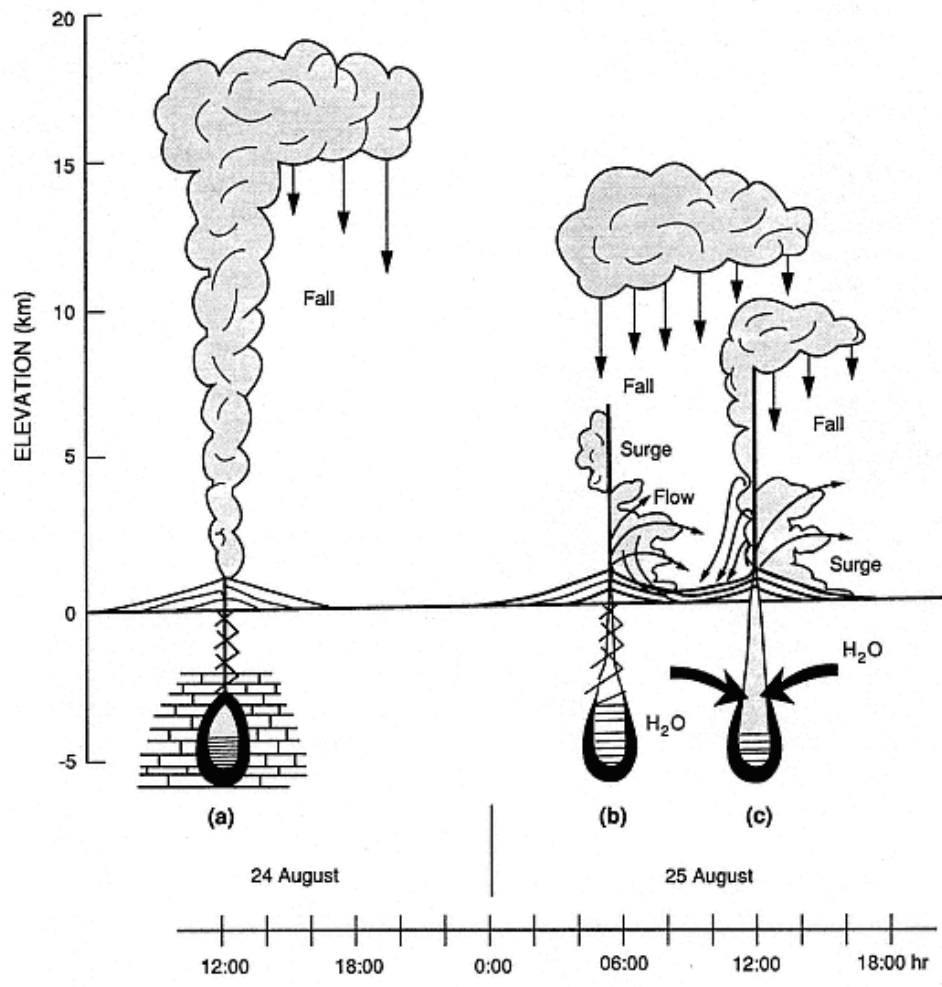


IDEALIZED COMPLETE SUCCESSION OF ONE ERUPTION EPISODE



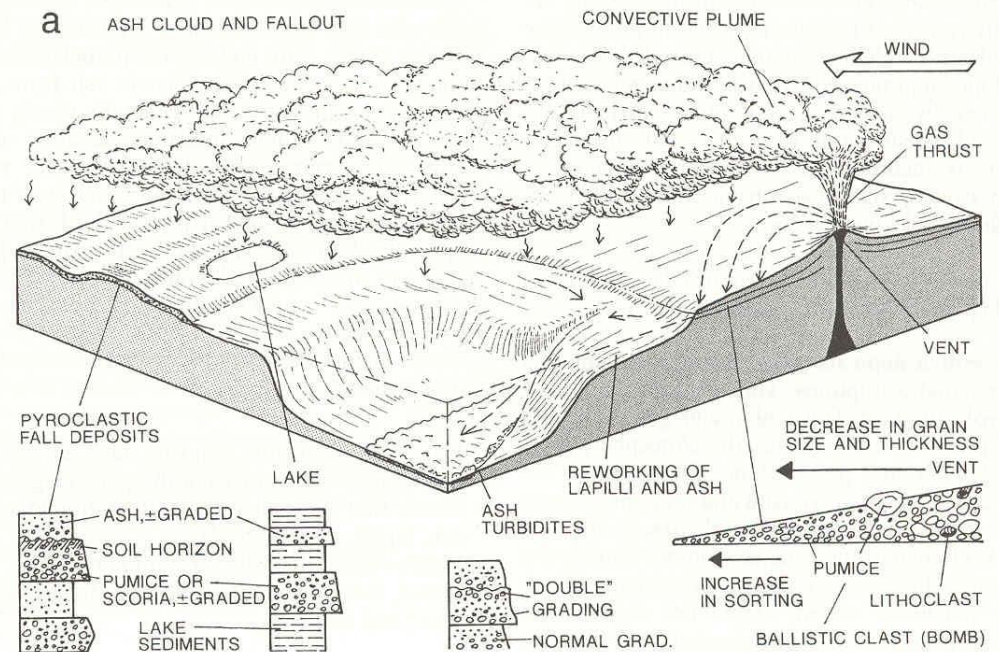
MAIN TYPES OF PYROCLASTIC FLOW DEPOSITS (PROXIMAL)





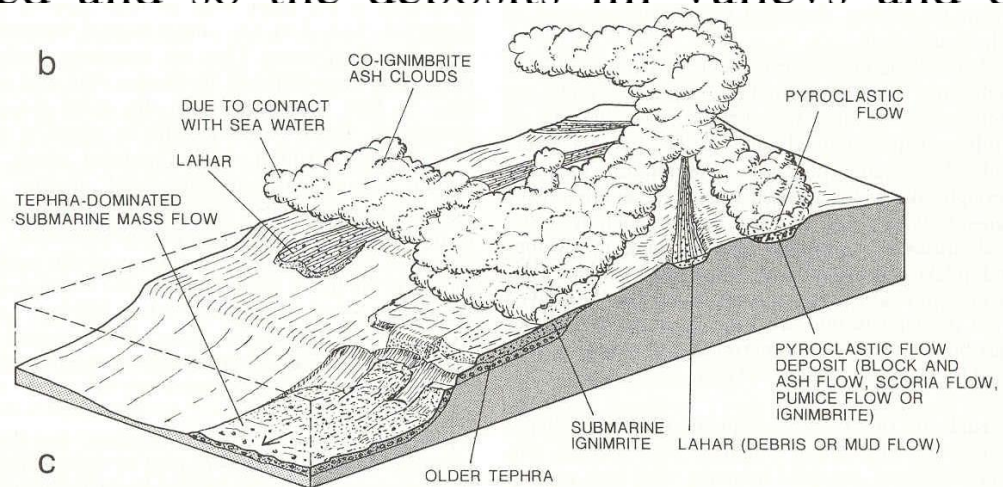
3.11.1.1 Pyroclastic fall deposits

These include subaerial and subaqueous (submarine or sublacustrine) fallout tephra. They are characterised by a gradual decrease in both bed thickness and grain-size away from the site of eruption. Beds are typically well sorted and normally graded. However, they are frequently reworked by currents and waves if deposited in water, or wind if subaerial, and thus may show cross- or planar lamination (strictly these would then be epiclastic deposits). Larger fragments of pumice may occur on top of the beds if they floated before being deposited. These deposits can be spread over wide areas and are useful for stratigraphic correlation, forming marker beds. Pyroclastic fall deposits mantle the topography, with layers of roughly constant thickness over both hills and valleys (Fig. 3.24).



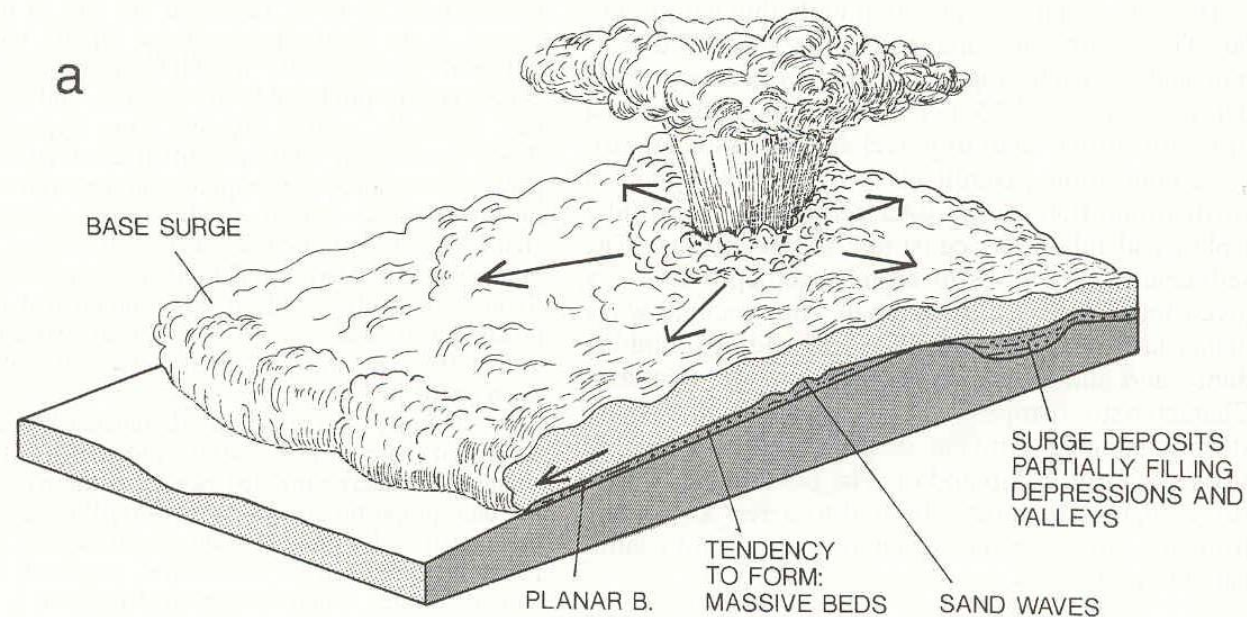
3.11.1.2 Pyroclastic flow deposits

These are the product of hot gas/solid high-concentration density currents, which may travel at velocities of $20\text{--}100\text{ m s}^{-1}$. One common pyroclastic flow deposit is an *ignimbrite*, produced by a violent plinian eruption, which generally occurs in subaerial situations, although the flows may continue into the sea or a lake. Ignimbrites are characterised by their homogeneous appearance with little sorting of the finer ash particles, so they lack internal stratification. Coarse lithic clasts in the bed may be normally graded (size decreasing upward) whereas large pumice clasts (which are very light at the time of eruption) may show reverse grading (size increasing upward), or glassy material is deformed around them. Some ignimbrites have a columnar jointing, also indicating that they were still hot on deposition. Typical thicknesses of an ignimbrite deposit are 1 m to 10 m or more. The flows are topographically controlled and so the deposits fill valleys and depressions (Fig. 3.24).



3.11.1.3 Pyroclastic surge deposits

These result from highly expanded turbulent gas–solid density currents with low particle concentrations. Phreatomagmatic and phreatic eruptions involve steam and generate base-surge deposits. They are characterised by well-developed unidirectional sedimentary bedforms (dunes) giving cross-stratification (Fig. 3.26), pinch-and-swell features and antidune cross-bedding (Section 5.3.3.15), since they are deposited by very fast-flowing ash-laden steam flows. Individual laminae are generally well sorted. These deposits tend to blanket the topography, although they do thicken into the depressions (Fig. 3.24). There is a complete gradation between high-particle concentration pyroclastic flows and low-particle concentration pyroclastic surges.



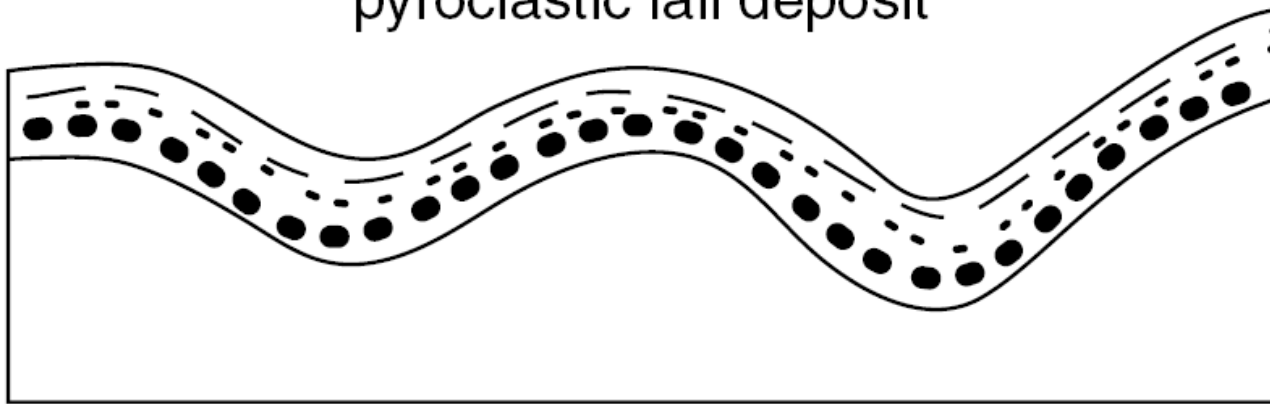
Pyroclastic flows are high-density mixtures of hot, dry rock fragments and hot gases that move away from the vent that erupted them at high speeds. They may result from the explosive eruption of molten or solid rock fragments, or both. They may also result from the nonexplosive eruption of lava when parts of dome or a thick lava flow collapses down a steep slope. Most pyroclastic flows consist of two parts: a basal flow of coarse fragments that moves along the ground, and a turbulent cloud of ash that rises above the basal flow. Ash may fall from this cloud over a wide area downwind from the pyroclastic flow.

A pyroclastic flow will destroy nearly everything in its path. With rock fragments ranging in size from ash to boulders traveling across the ground at speeds typically greater than 80 km per hour, pyroclastic flows knock down, shatter, bury or carry away nearly all objects and structures in their way. The extreme temperatures of rocks and gas inside pyroclastic flows, generally between 200°C and 700°C, can cause combustible material to burn, especially petroleum products, wood, vegetation, and houses.

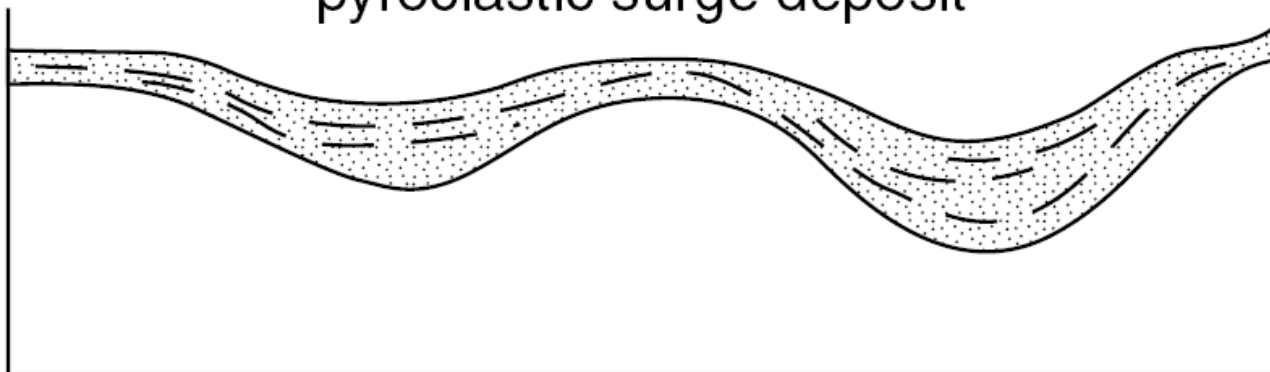
Pyroclastic flows vary considerably in size and speed, but even relatively small flows that move less than 5 km from a volcano can destroy buildings, forests, and farmland. And on the margins of pyroclastic flows, death and serious injury to people and animals may result from burns and inhalation of hot ash and gases.

Pyroclastic flows generally follow valleys or other low-lying areas and, depending on the volume of rock debris carried by the flow, they can deposit layers of loose rock fragments to depths ranging from less than one meter to more than 200 m.

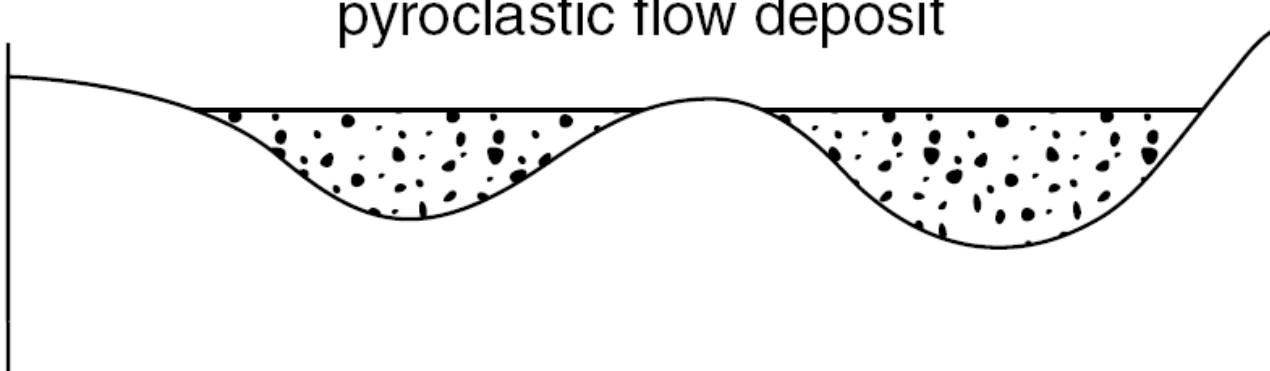
pyroclastic fall deposit

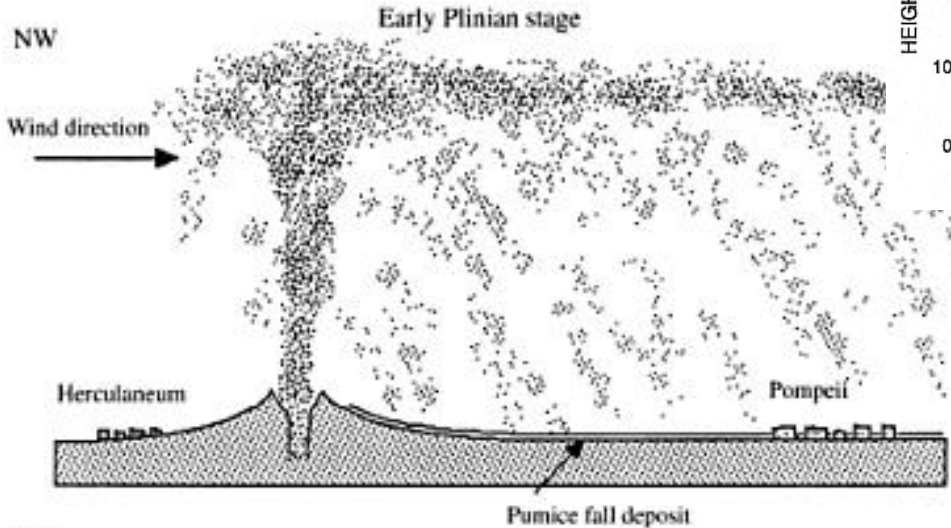


pyroclastic surge deposit

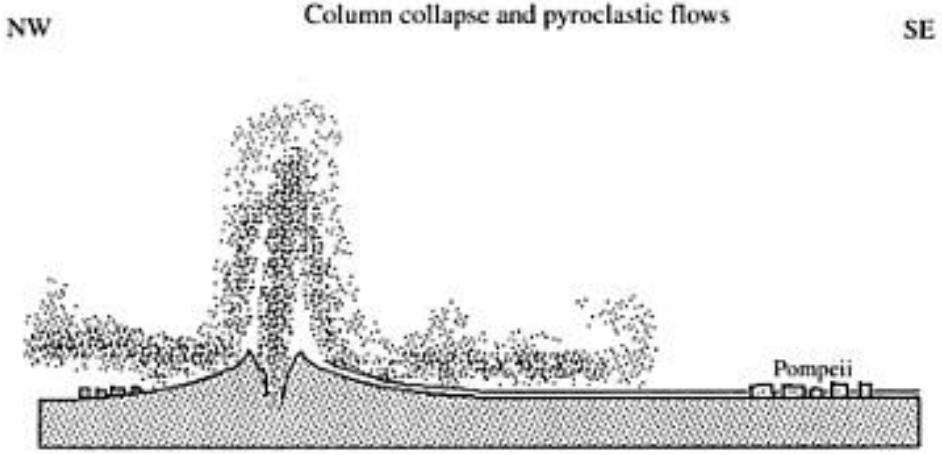


pyroclastic flow deposit

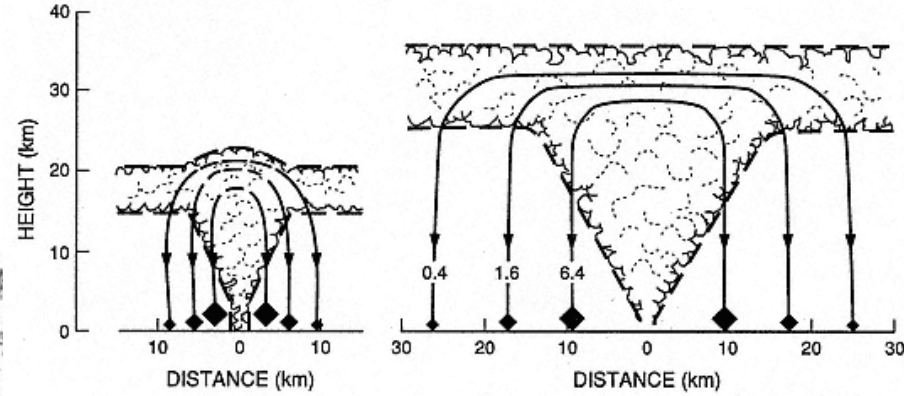




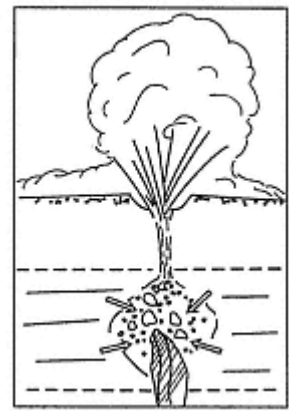
(A)

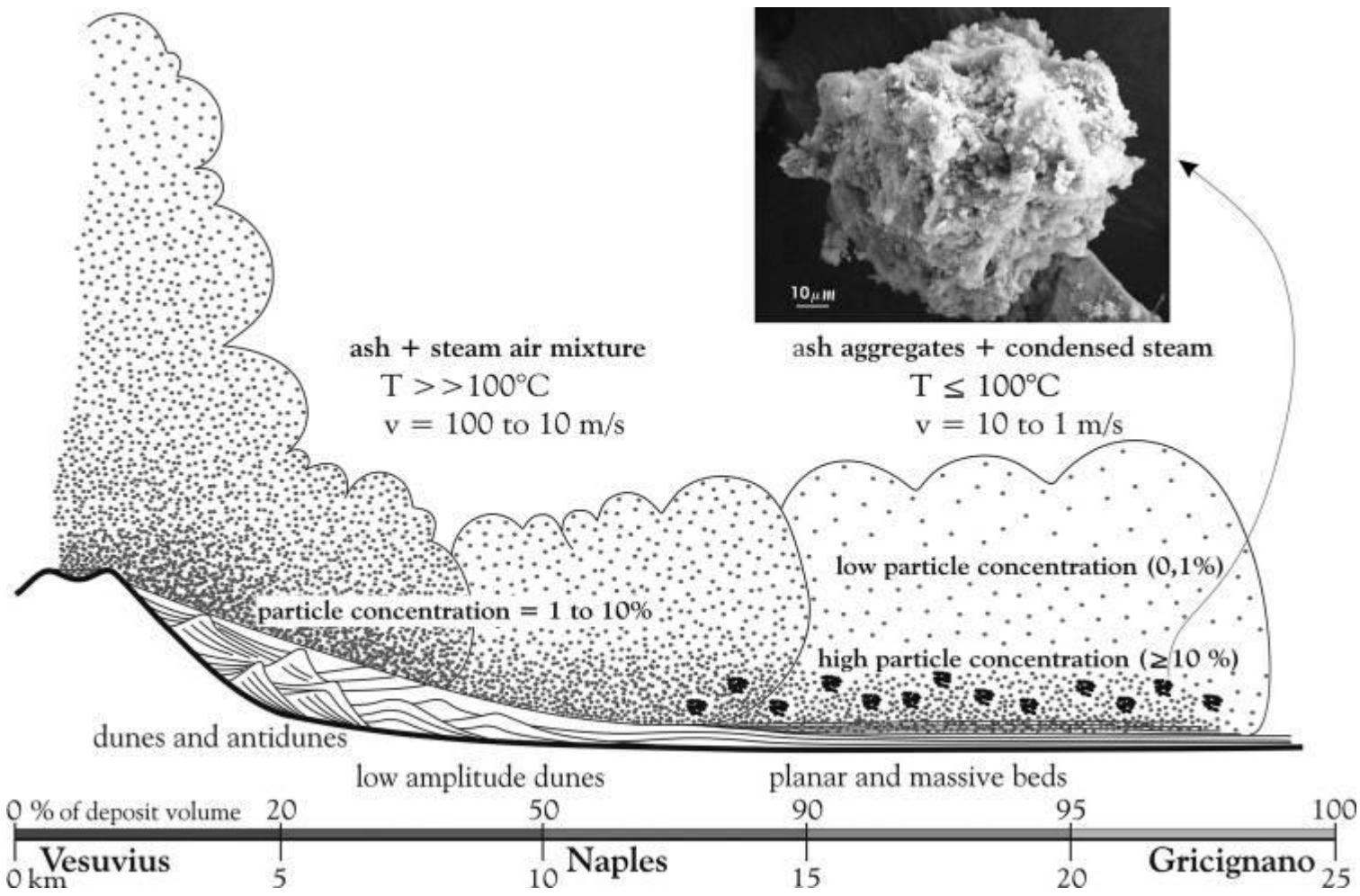


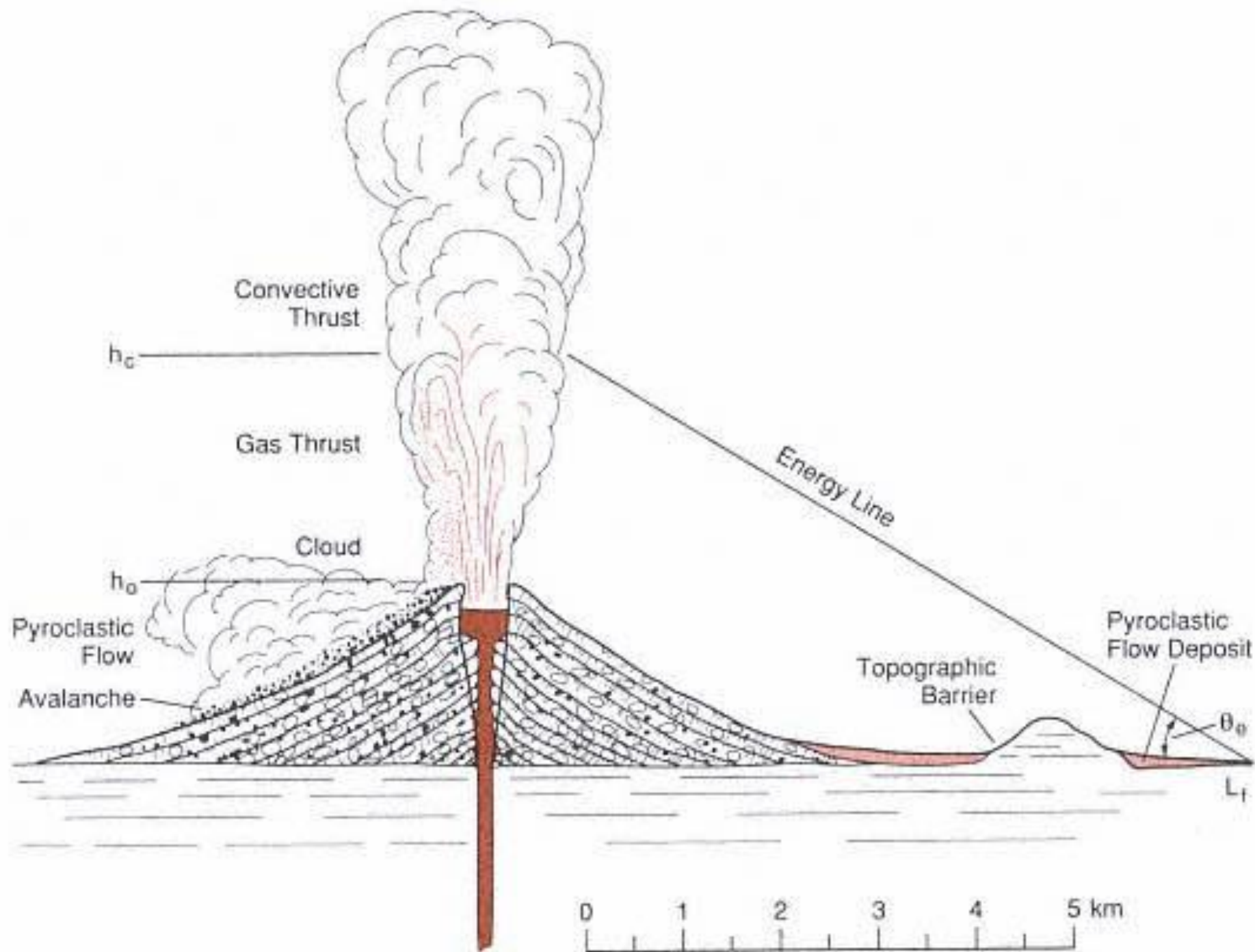
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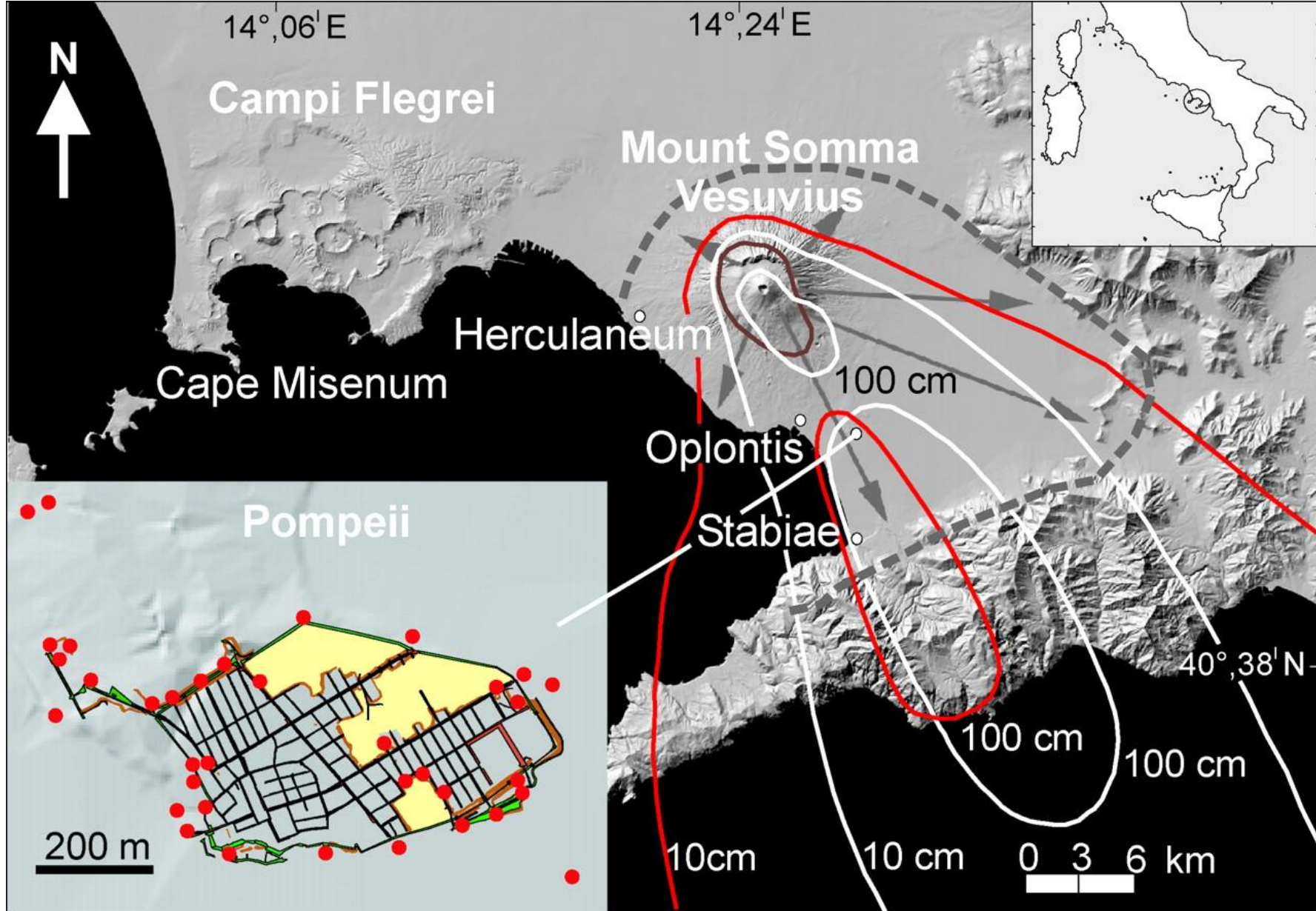


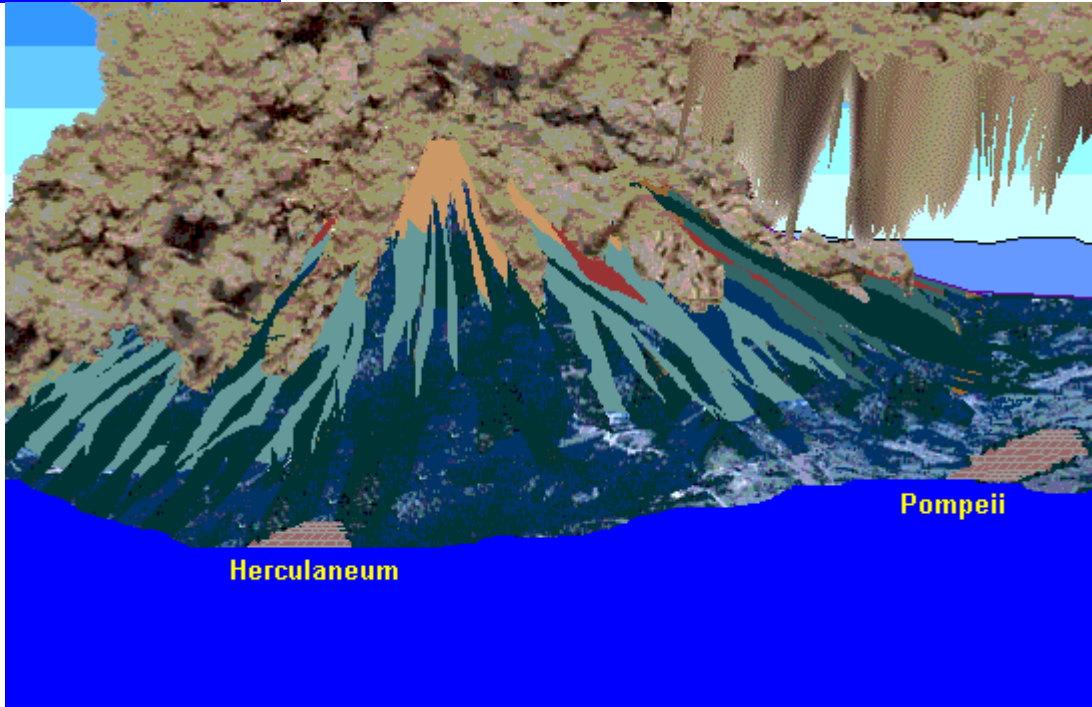
Clast trajectories from the umbrella region of a Plinian eruption column; clast sizes are given in centimeters. Note that the dispersal is greater for the 35-km-high column than for the 21-km-high column. (Adapted from Carey and Sparks, 1986.)

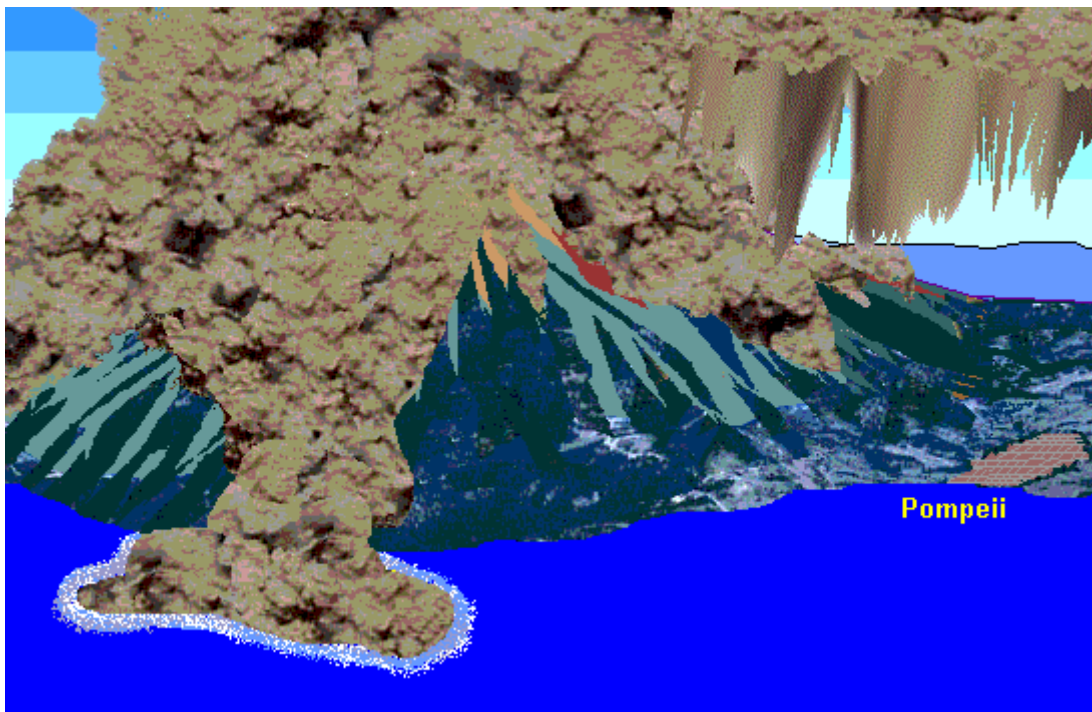
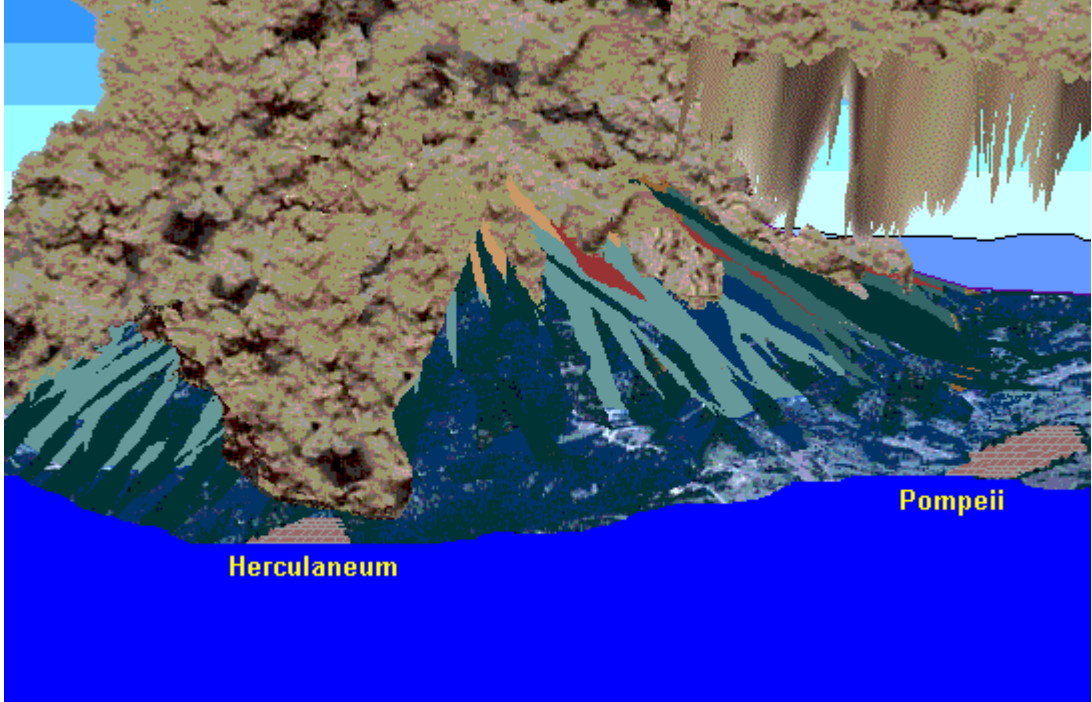




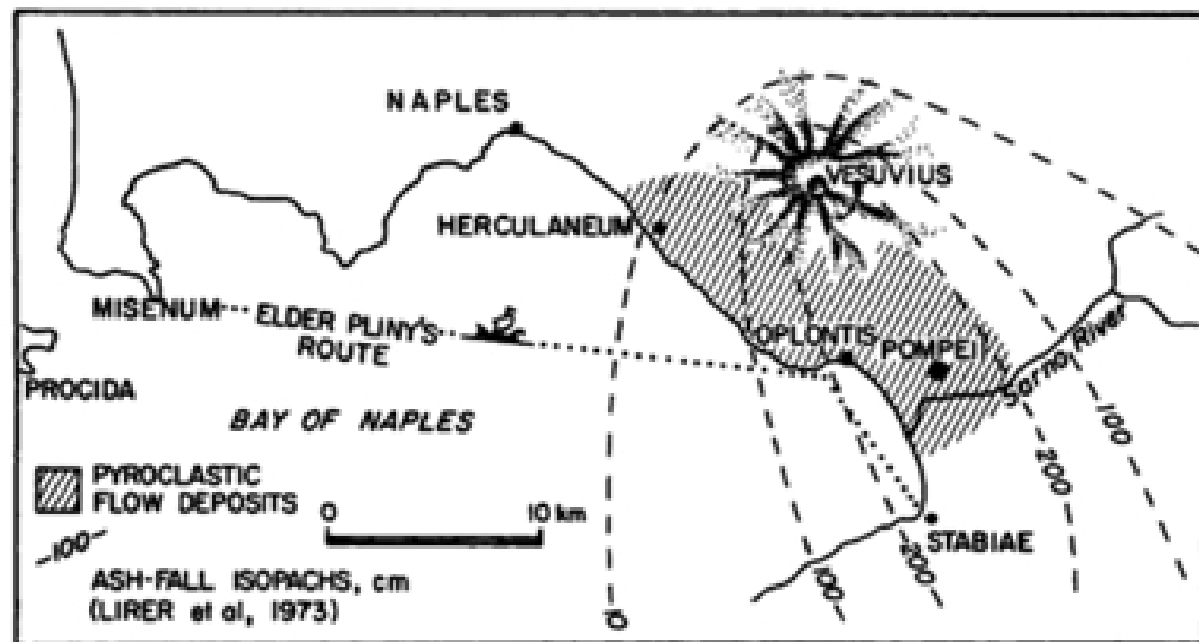
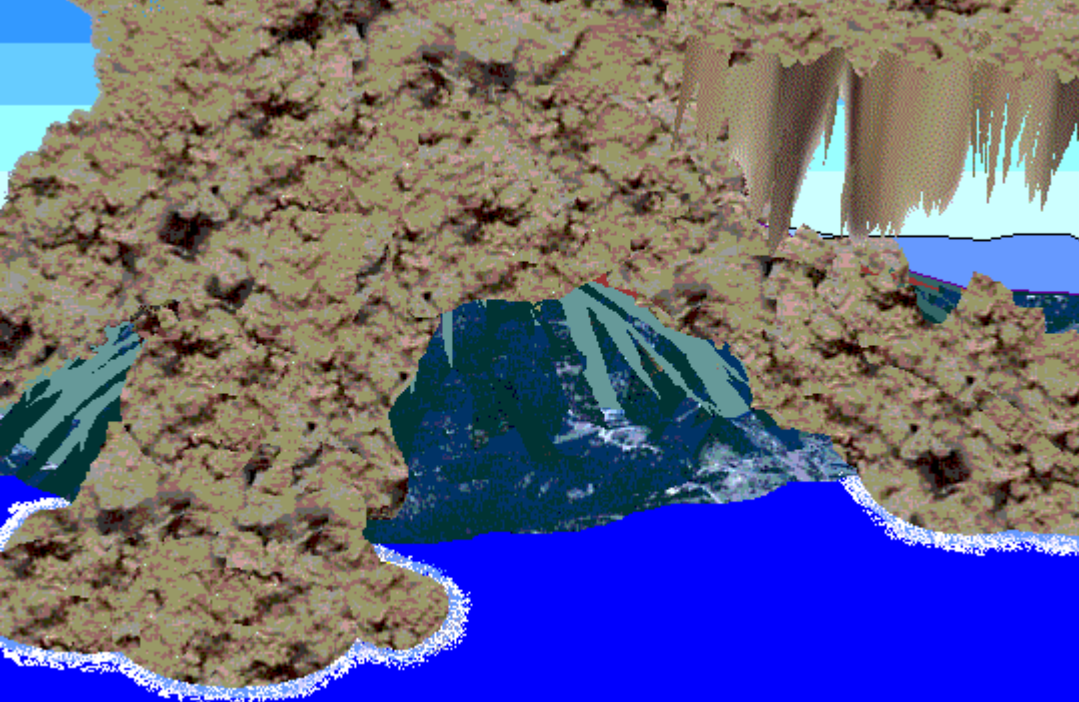








S. Dutch



VESUVIUS



Areas of ash-fall and pyroclastic flow in Naples bay area.

Wind direction determined the ash-fall pattern.

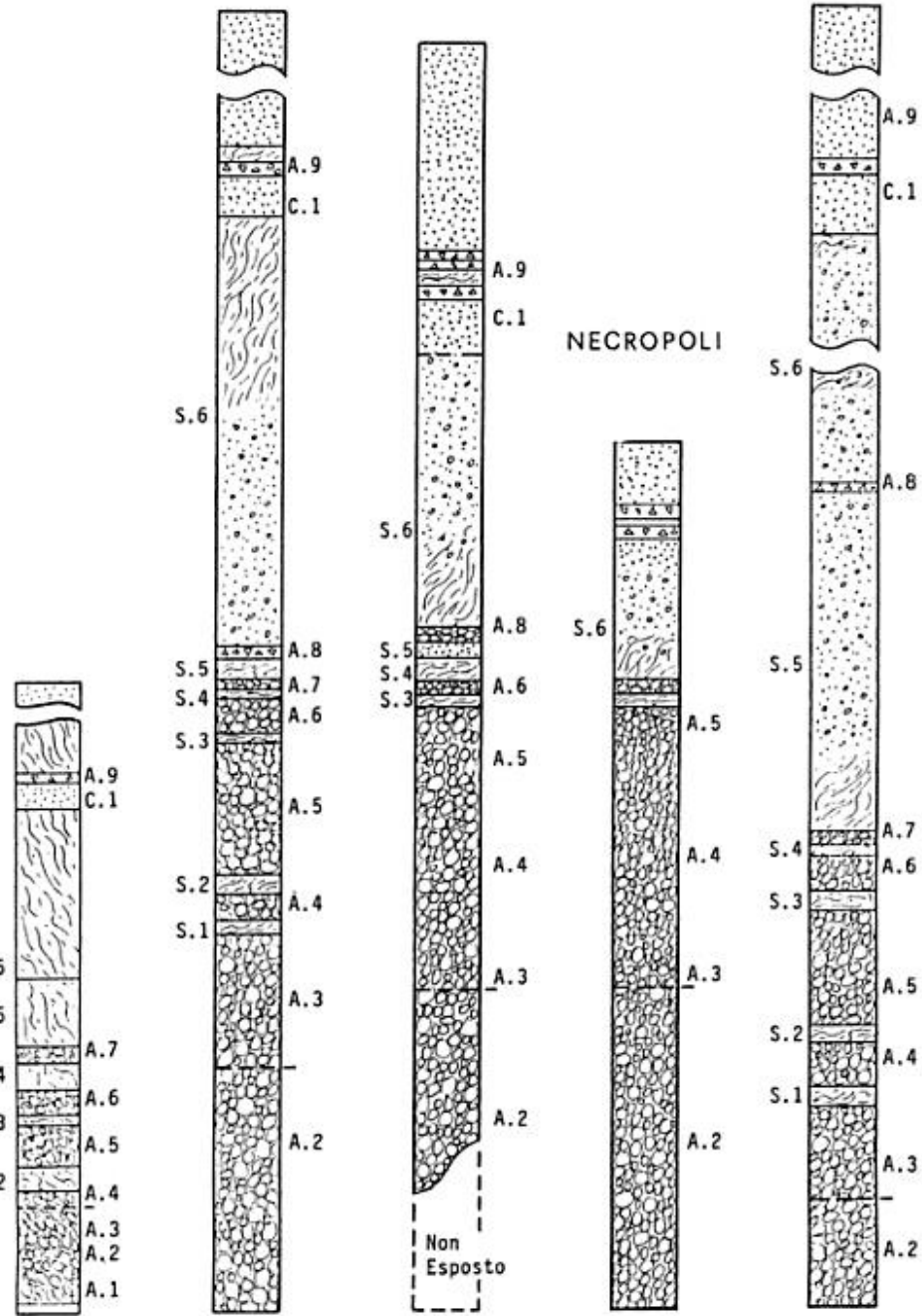
The direction of the pyroclastic flows supports the "two peak" theory of how Vesuvius looked before the 79 AD eruption.

TERZIGNO

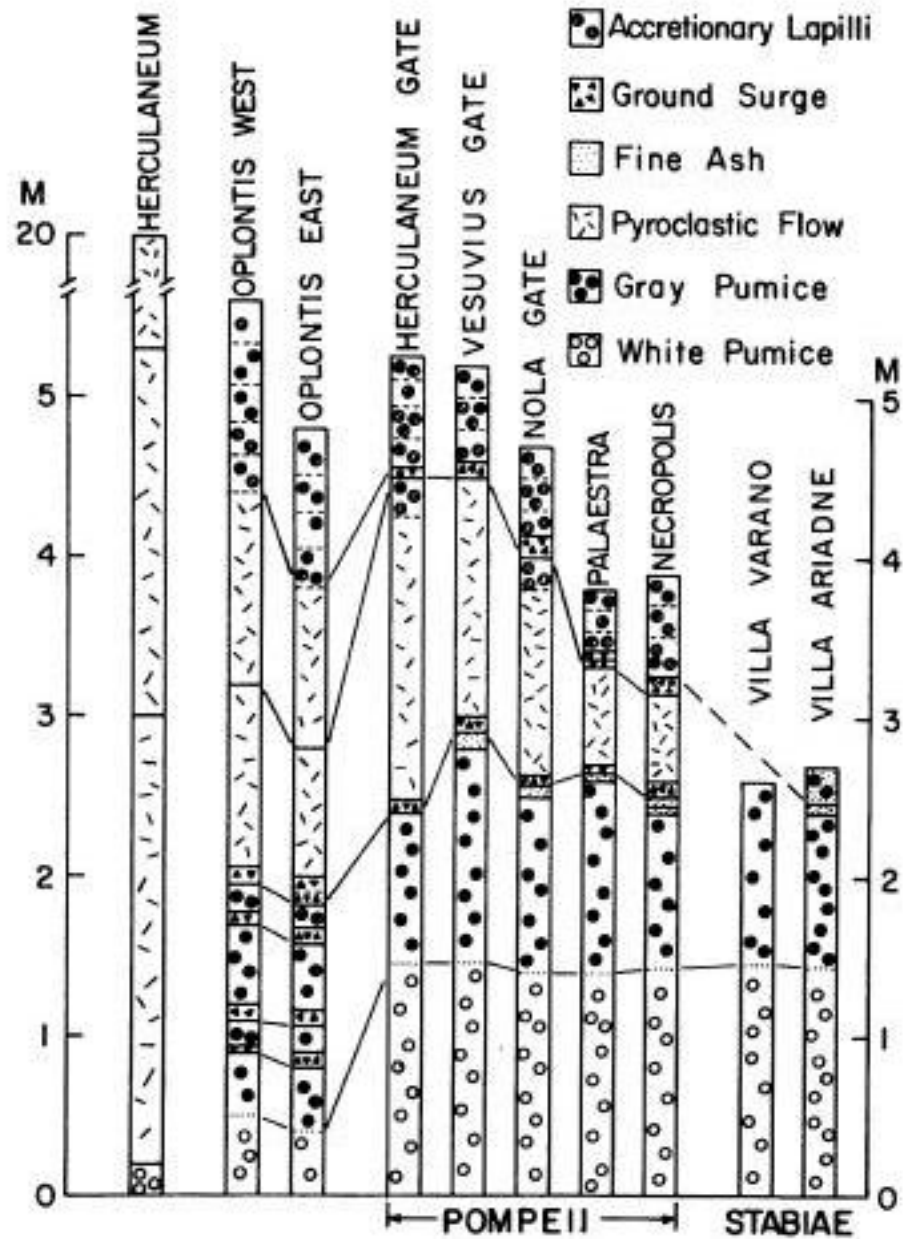
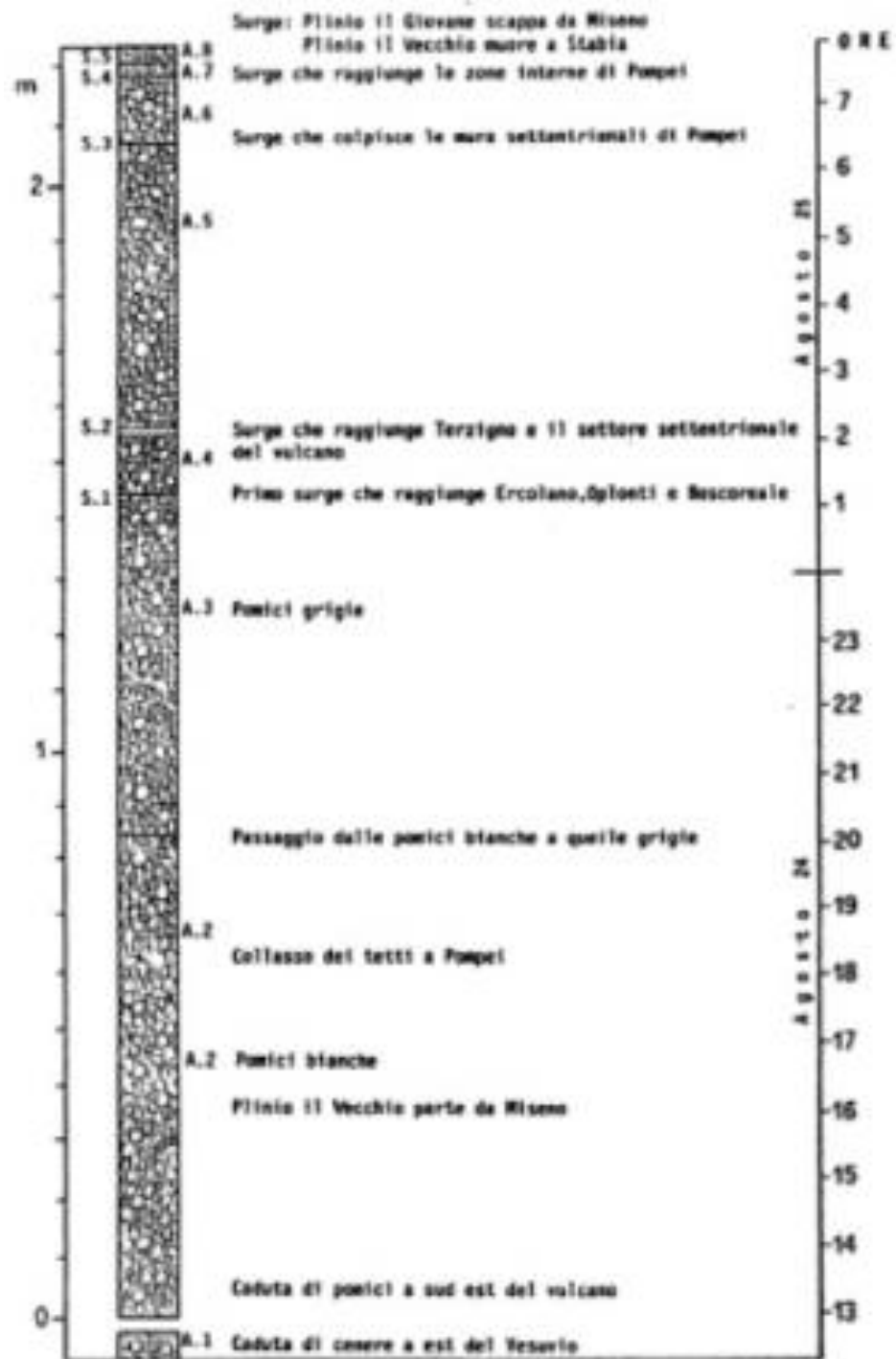
VILLA REGINA,
BOSCOREALE

POMPEI
PORTA ERCOLANO

OPLONTI



NECROPOLI



Ill. 2. Stratigraphy of the deposits of A.D. 79 in excavations west and south of Vesuvius

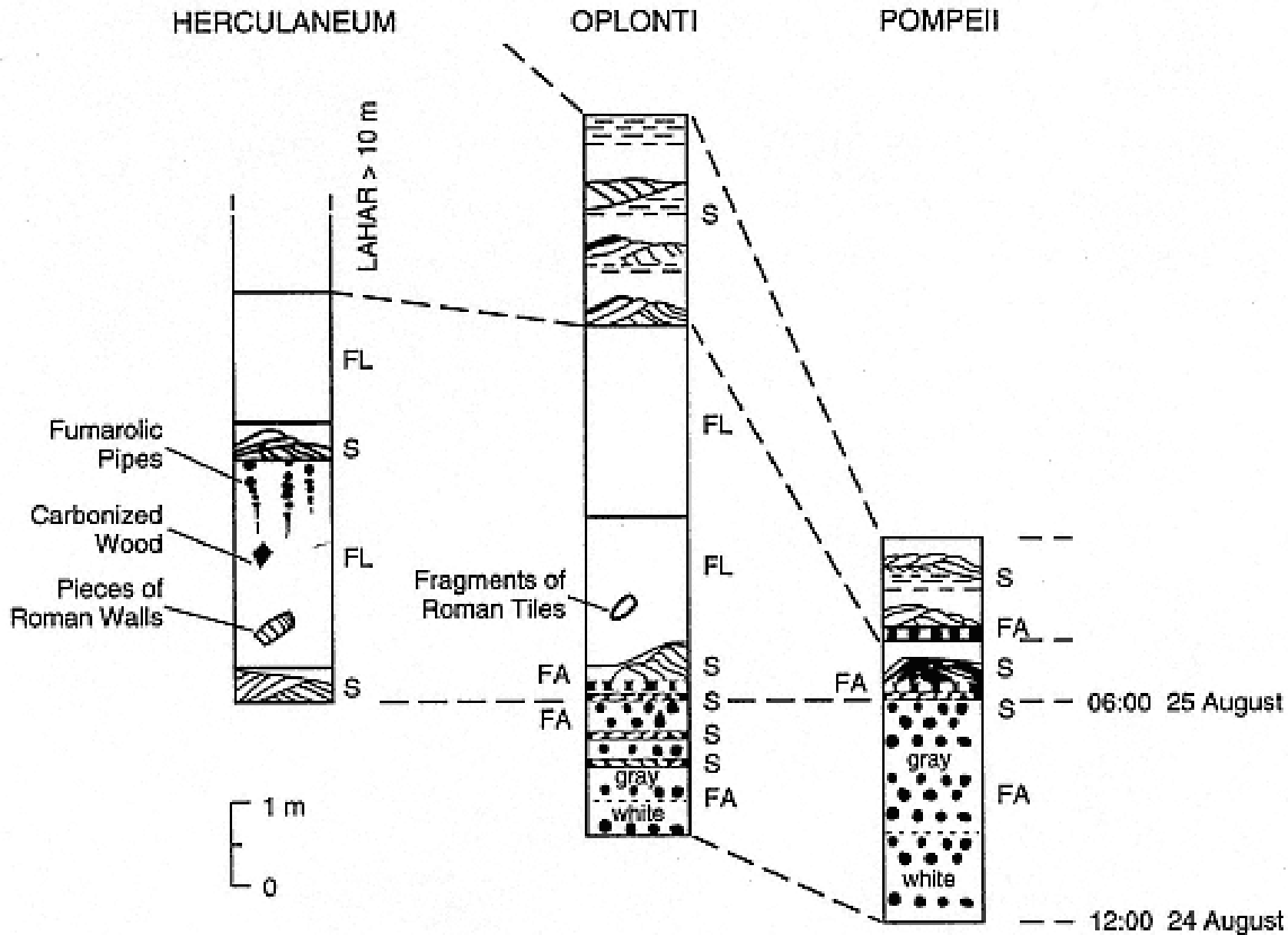
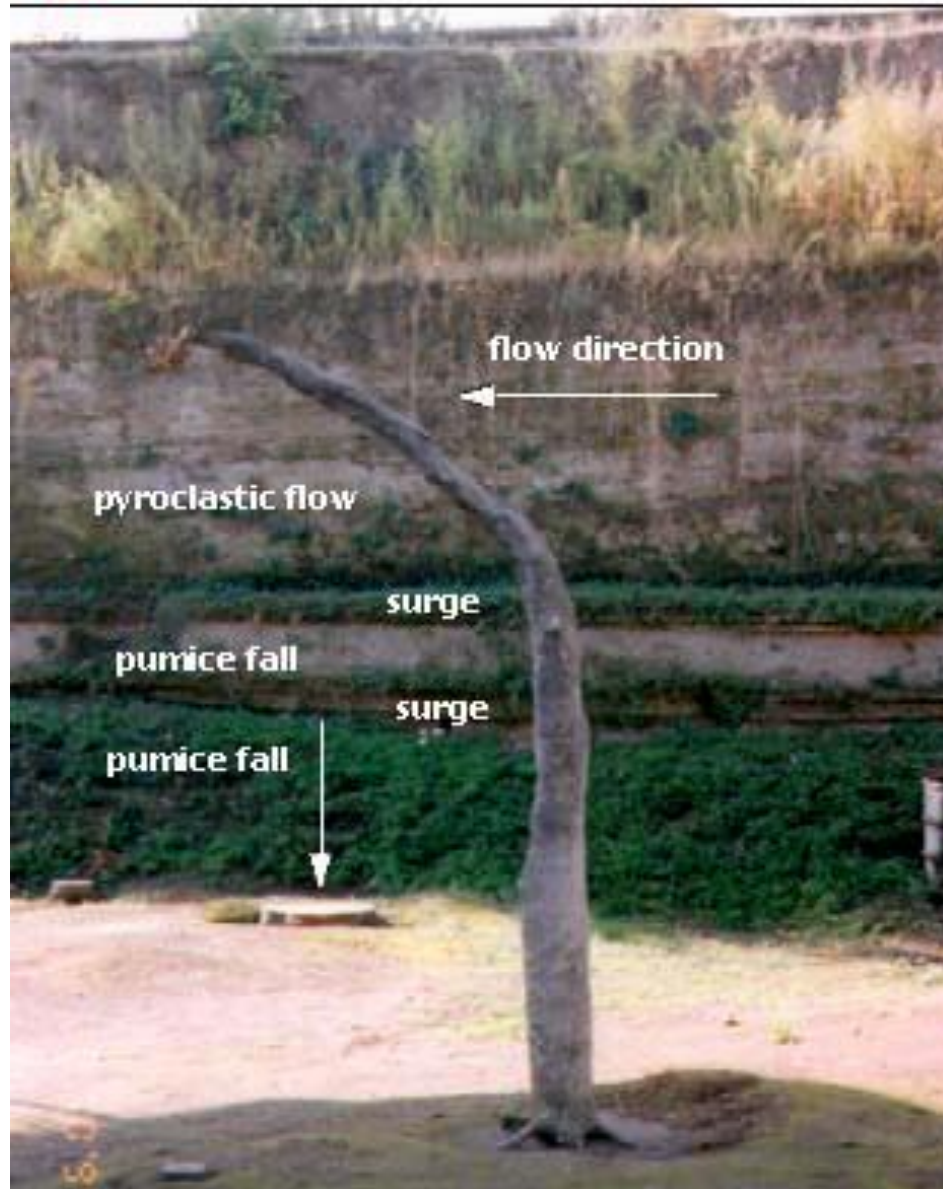


Fig. 2.18 Representative stratigraphy of AD 79 pyroclastic deposits exposed in archaeological excavations along the coastal side of Vesuvius; FA = pumice fallout, FL = pyroclastic flows, and S = surges. The basal white and gray pumice fallout was from early

Villa Regina (Bosc coreale)

The tree was partially buried by the fall of pumice and then was bent by the pyroclastic flow







HERCULANEUM

20 metres

Pyroclastic flow (hot ash, pumice and rock)

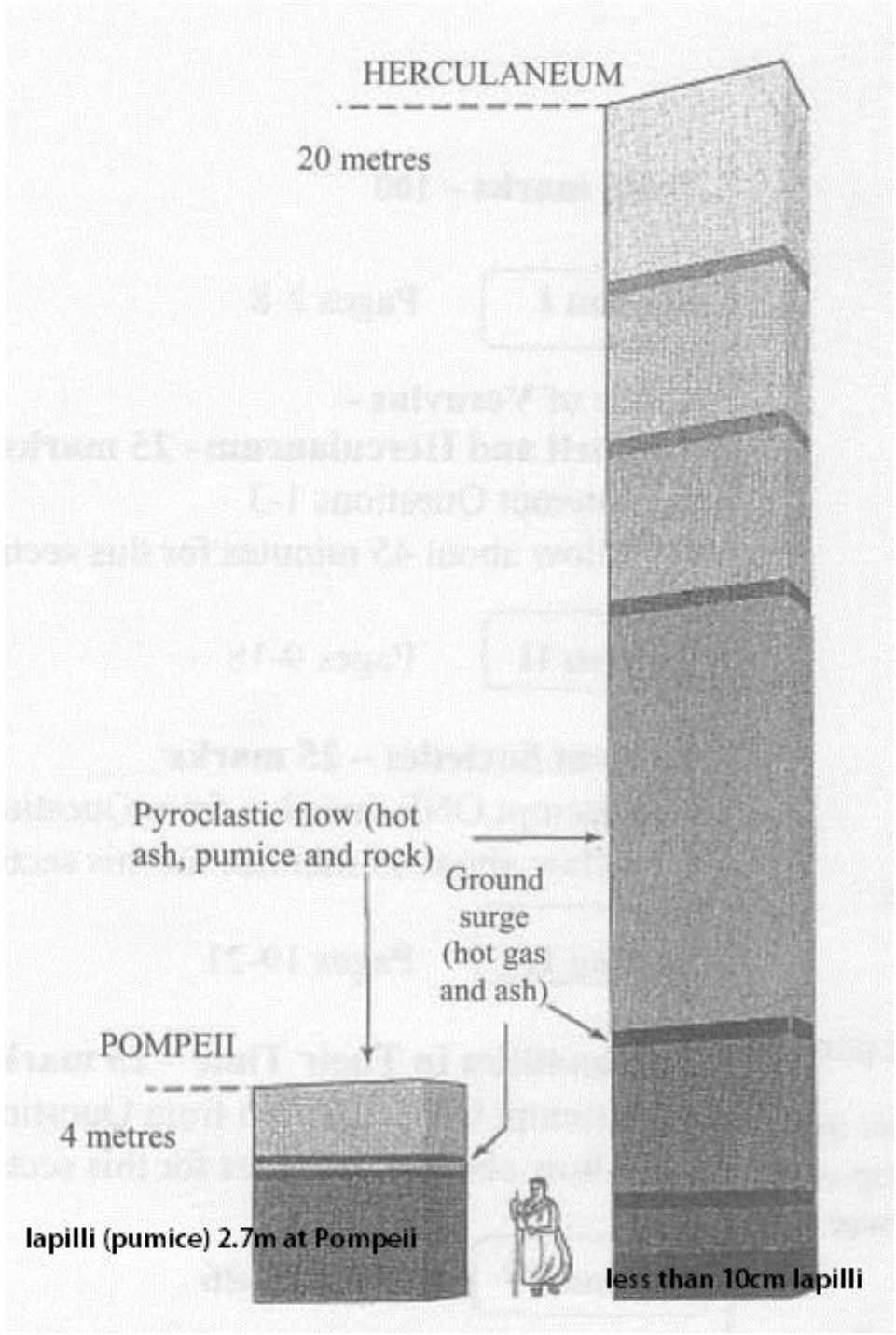
Ground surge (hot gas and ash)

POMPEII

4 metres

lapilli (pumice) 2.7m at Pompeii

less than 10cm lapilli



Oplonti (Torre Annunziata)













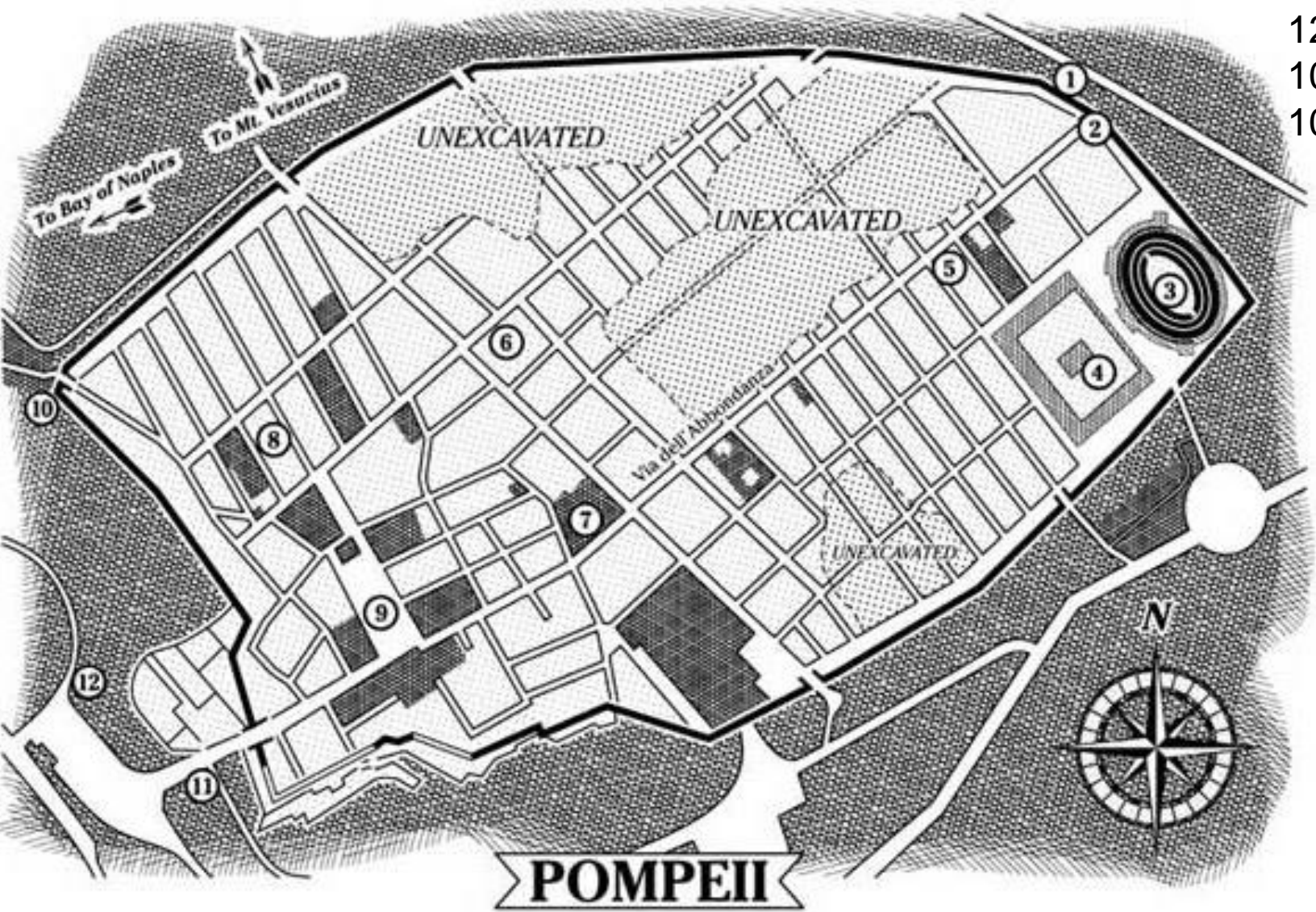




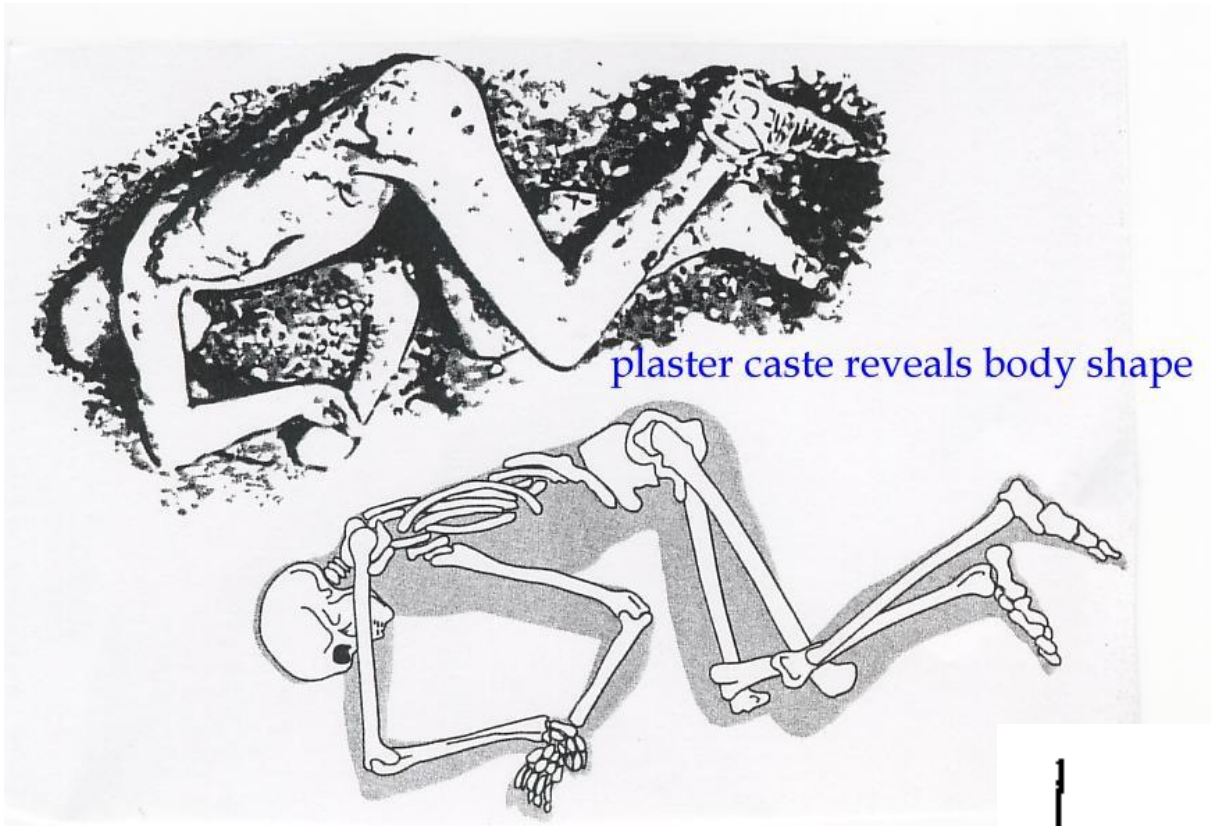




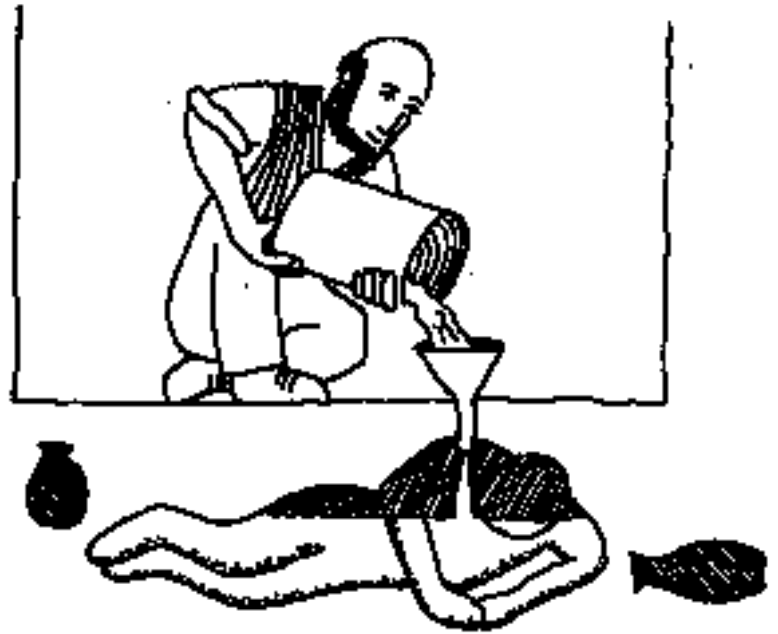
12000 abitanti
1047 vittime
103 calchi



- | | | | | | |
|---|-----------------|---|---------------------------------------|----|----------------|
| 1 | VILLA DEIDAMIA | 5 | HOUSE OF OCTAVIUS QUARTUS | 9 | FORUM |
| 2 | PORTA DI SARNO | 6 | HOUSE OF JULIA FELIX | 10 | PORTA ERCOLANO |
| 3 | AMPHITHEATRE | 7 | STABIAN BATHS | 11 | PORTA MARINA |
| 4 | GRAND PALAESTRA | 8 | HOUSE OF THE TRAGIC POET - Cave Canem | 12 | UMBERTO'S CAFE |



plaster caste reveals body shape





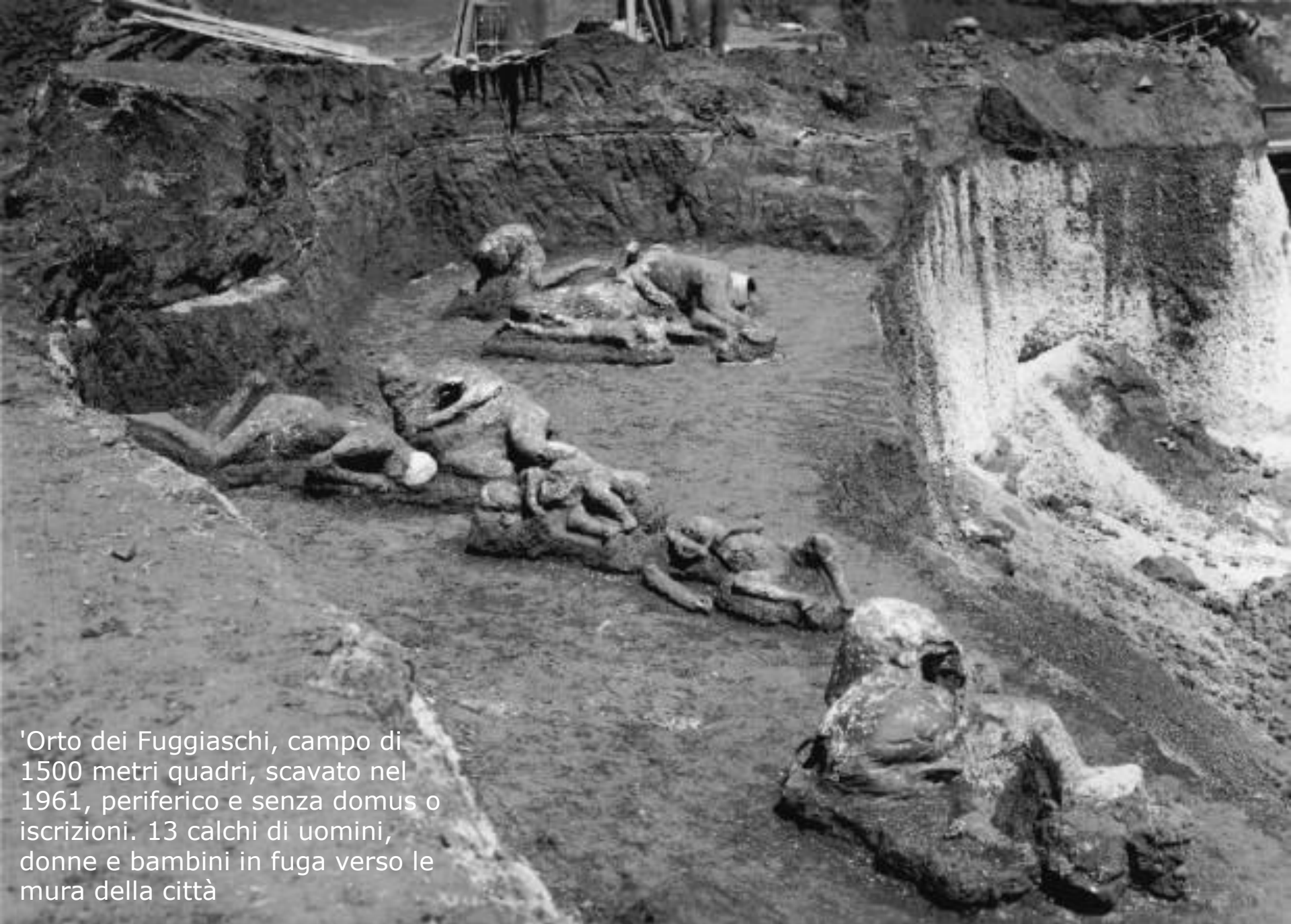


P. 1103

Group of corpses (casts and skeletons) near the Casa del Criptoportico 1914. They were encountered in the ash and pumice PDCs deposit above a thick, white^grey, lapilli pumice fall deposit. Below the human cast on the right side the stratigraphic sequence from unit B to E1 is well exposed. (Soprintendenza Archeologica di Pompei) Luongo et al., 2003

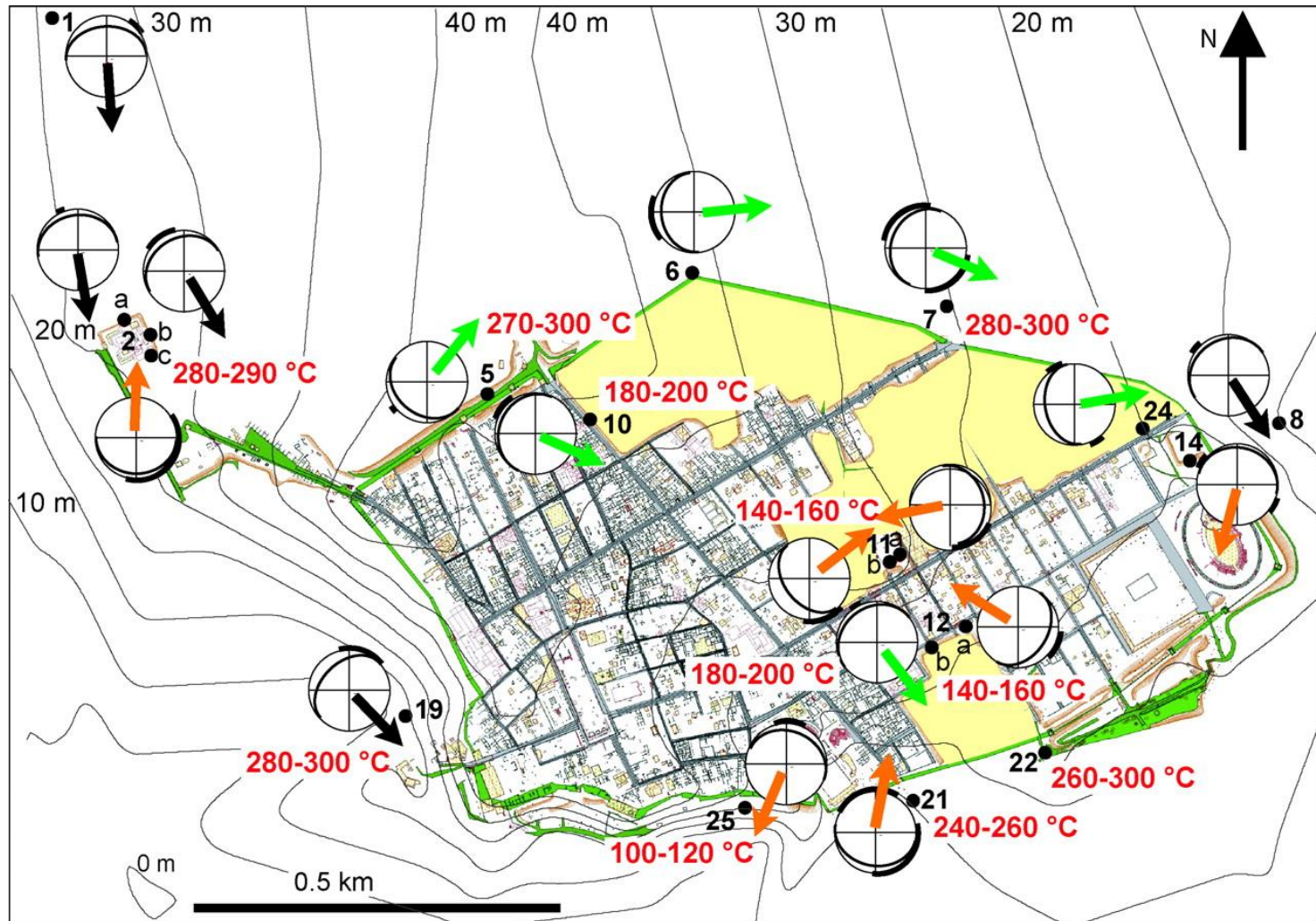


Casa del Criptoportico

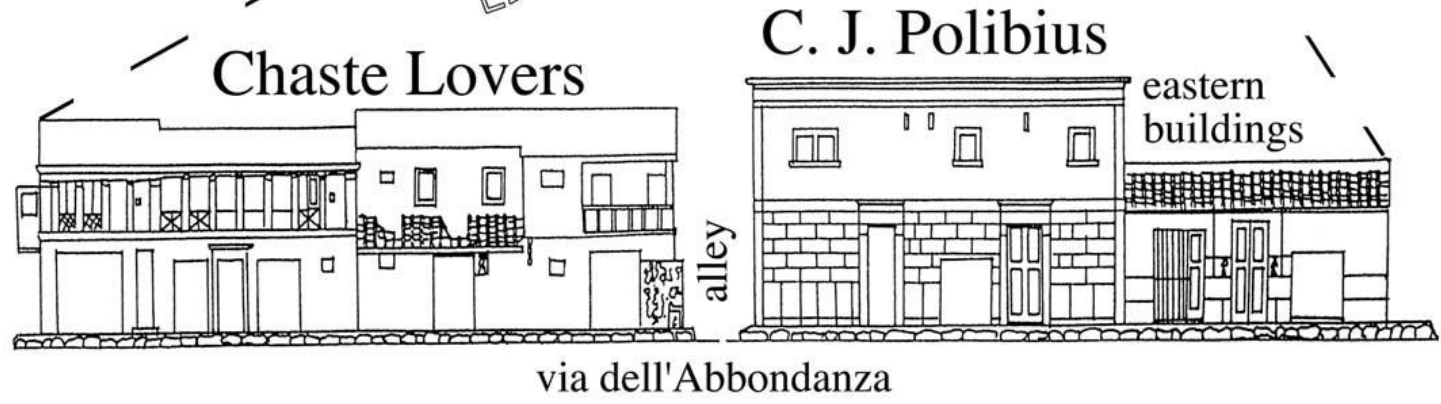
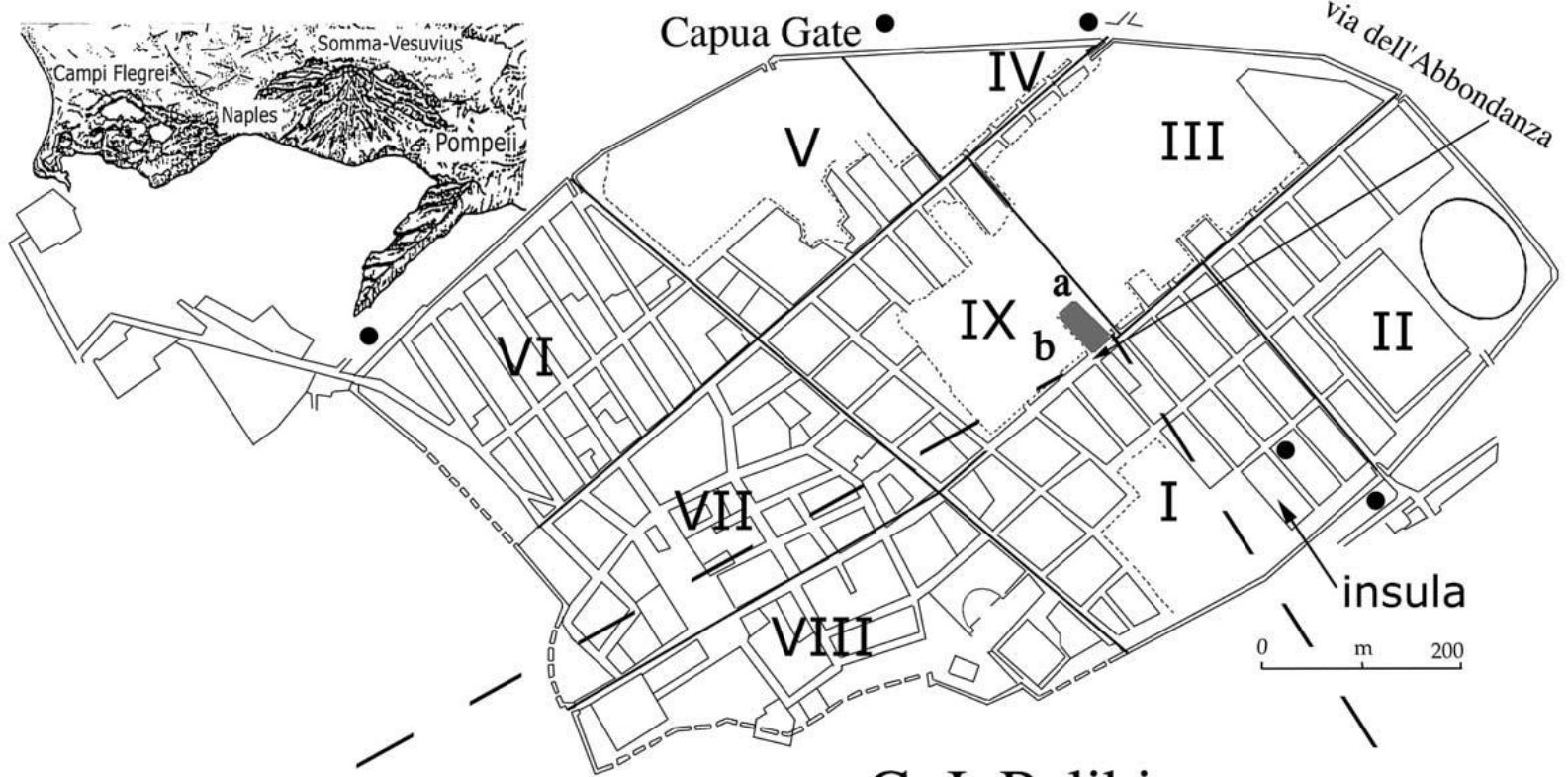


'Orto dei Fuggiaschi, campo di 1500 metri quadri, scavato nel 1961, periferico e senza domus o iscrizioni. 13 calchi di uomini, donne e bambini in fuga verso le mura della città

Variations in EU4pf flow direction (anisotropy of magnetic susceptibility [AMS] data) and temperature (thermal remanent magnetization [TRM] data).

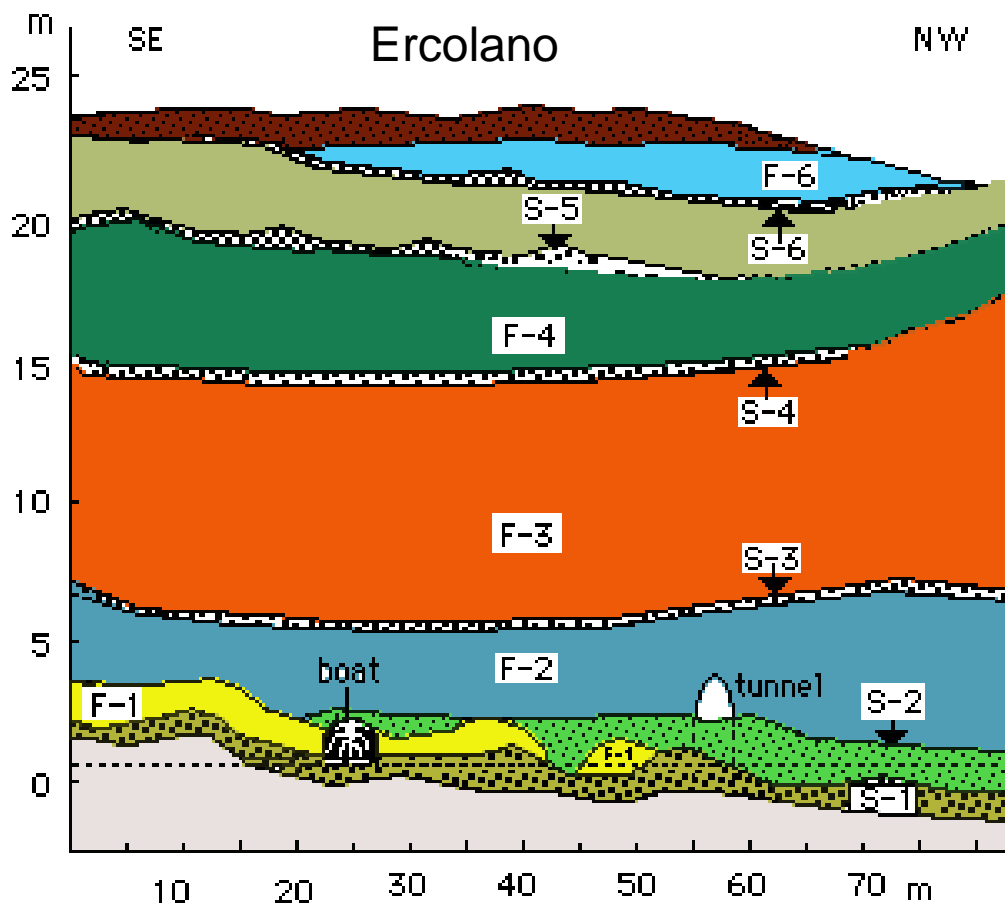


Lucia Gurioli et al. *Geology* 2005;33:441-444

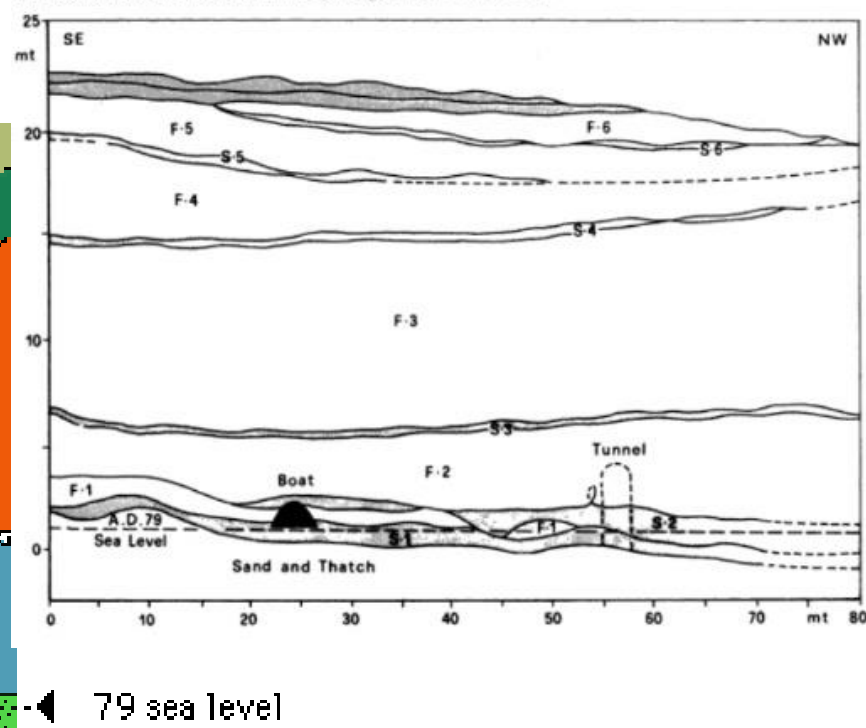


Ercolano





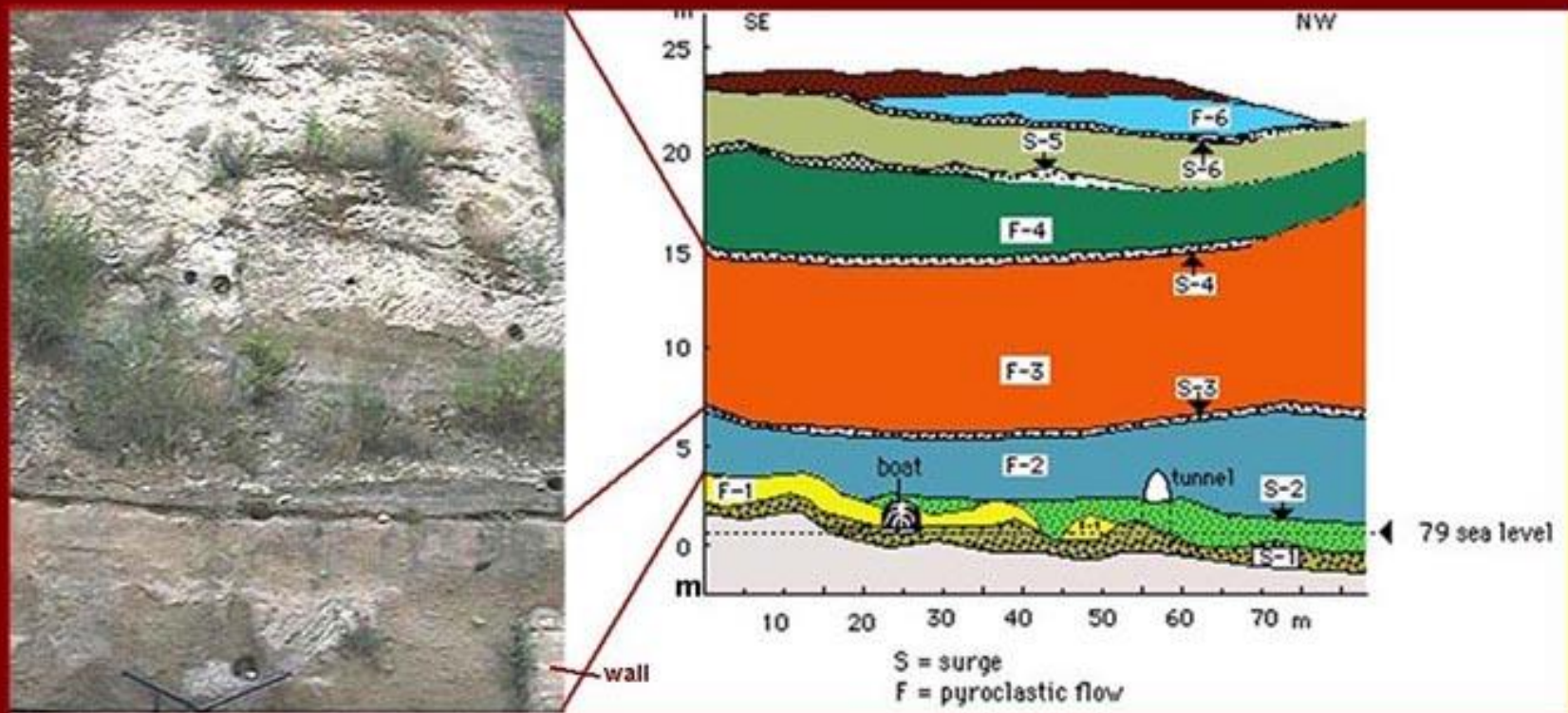
XCV, 2. Stratigrafia dei depositi vulcanici del 79 d.C. a Ercolano. La scala verticale inizia a 5 m al di sotto dell'attuale livello del mare (da Sigurdsson et al., 1985).



S = surge
F = pyroclastic flow

Pyroclastic Flow: A hot, chaotic avalanche of pumice, ash, and gasses. Pyroclastic flows can move at high speeds along the ground and pass over substantial objects. Their distribution is strongly controlled by topography.

Pyroclastic Surge: A turbulent cloud of volcanic ash and hot gasses, which hugs the ground and travels at speeds often exceeding 100 km per hour. Surge deposits are more widely distributed than pyroclastic flow deposits though not as widespread as air fall pumice layers.



At Herculaneum, there were six surge/flow pairs, and, although they may have contained moisture, none of them could be characterized as “mud flows” (lahars). Because Herculaneum was so close to the crater, the flow deposits were much hotter than those at Pompeii -- hot enough to fuse together into the much harder overlay than the deposits at Pompeii. The flows did act as a liquid, however: Solid particles were suspended in a gas (mostly just hot air) and fluid mechanics determined how the flows spread.

Stratigraphy of the AD 79 Eruption Deposits seen at Herculaneum

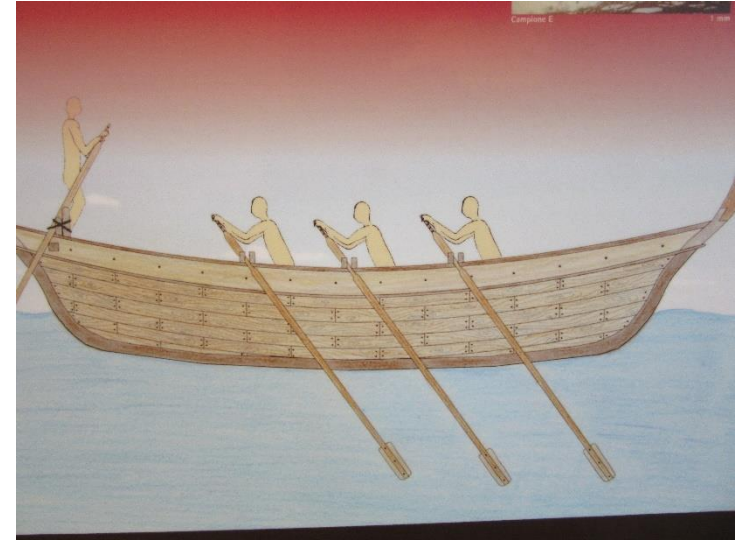
The diagram (by Roberto Scandone)above shows the stratigraphy at Herculaneum, as identified by Haraldur Sigurdsson in 1985. (The **upper flow units** F4 etc can also be identified in Pompeii). There is a very thin base lapilli layer of a few centimetres. The first broad deposit shown immediately above the ancient coast is an ashy layer interpreted as a surge. It is 20-40 cm thick and is a result of a surge of gaseous material. The majority of the skeletons found in this area lie within this deposit. Above this layer is a deposit of a pyroclastic flow containing carbonized wood and fragments of tiles. The thickness of this deposit is less than 1.5 m. Above this layer are several alternating surge and pyroclastic flow layers resulting in a 20 to 23 metre thick cover. Flow 3 is particularly strong. According to some authors (Mike Sheridan, for example) the topmost layers are related to mudflows.

In many houses there is abundant evidence of processes of carbonization of wood due to the high temperature of the first surge and flow. On this profile, the extension of the coastline is identifiable. Also notice the location of the boatshed.

Surge 3 reached the walls of Pompeii. The next three surges covered Pompeii, S-4, S-5 and S-6. The first of these surges would have been most damaging to people, whereas the last surge would have been most damaging to buildings. S-4 may have had temperatures around 400°C upon its arrival at Pompeii. (Martini *et al.* 1995)

The key basis for distinction is the amount and nature of the pyroclastic material included in the mixture of volcanic solids and gas. Denser mixtures which include larger fragments at higher solid concentrations are typically categorized as pyroclastic flow, while less dense mixtures where the pyroclasts are primarily fine dust and ash are categorized as pyroclastic surge. The term "glowing avalanche" is sometimes used to describe pyroclastic flow, while the terms "glowing cloud" and "ground surge", are sometimes used to describe pyroclastic surge. The French term "nuée ardente" is often used to describe a common phenomenon where an avalanche of coarse material, a pyroclastic flow, is accompanied by an overriding ash cloud of fine material, a pyroclastic surge. The diagram below shows how the ash cloud (surge) layer of a nuée ardente separates from the ash-and-block (flow) layer. The surge layer may separate from the flow layer climbing hills and travelling greater distances

Fisher 1995



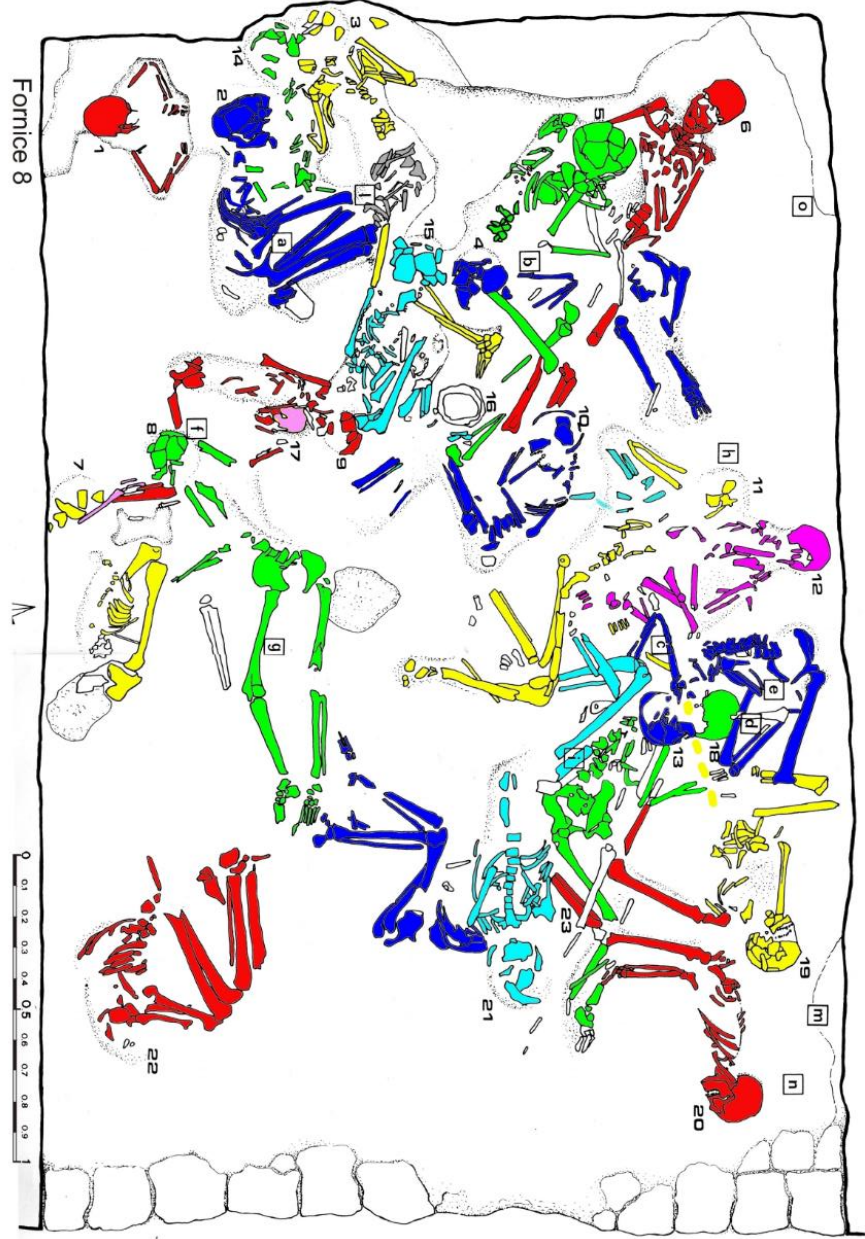


Ercolano

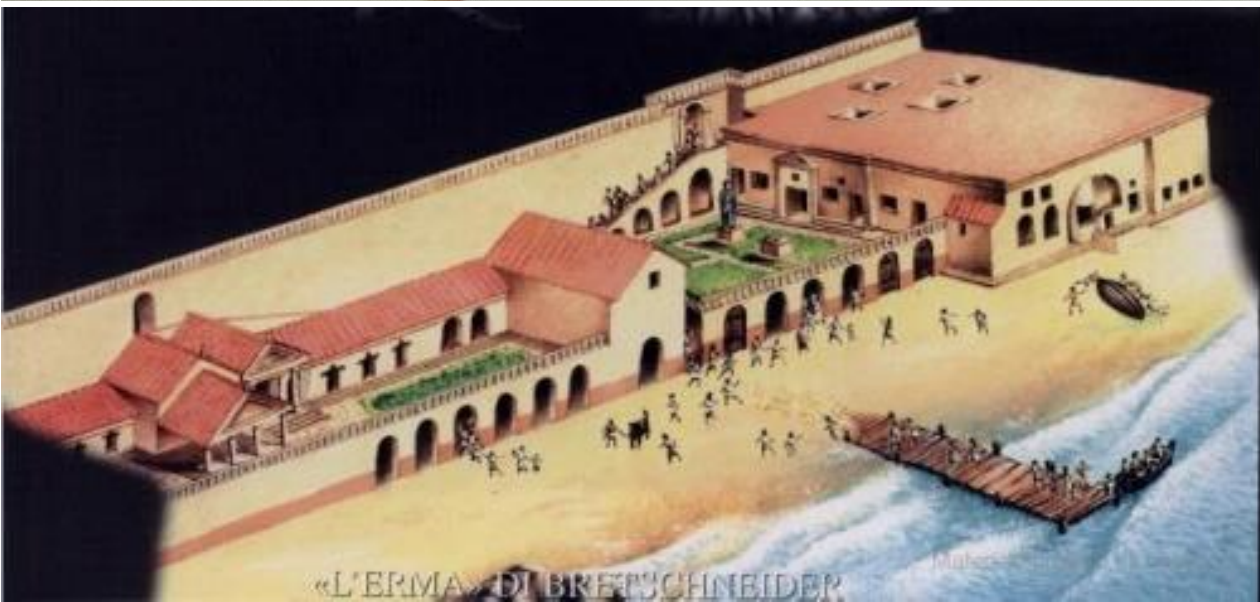
Scoperta 1738
Spoliata attraverso cunicoli fino al 1828
Pochi resti umani
Città evacuata?
1981 scavo dei fornici sulla spiaggia
160 scheletri di cui 12 bambini
Popolazione stimata: 5000

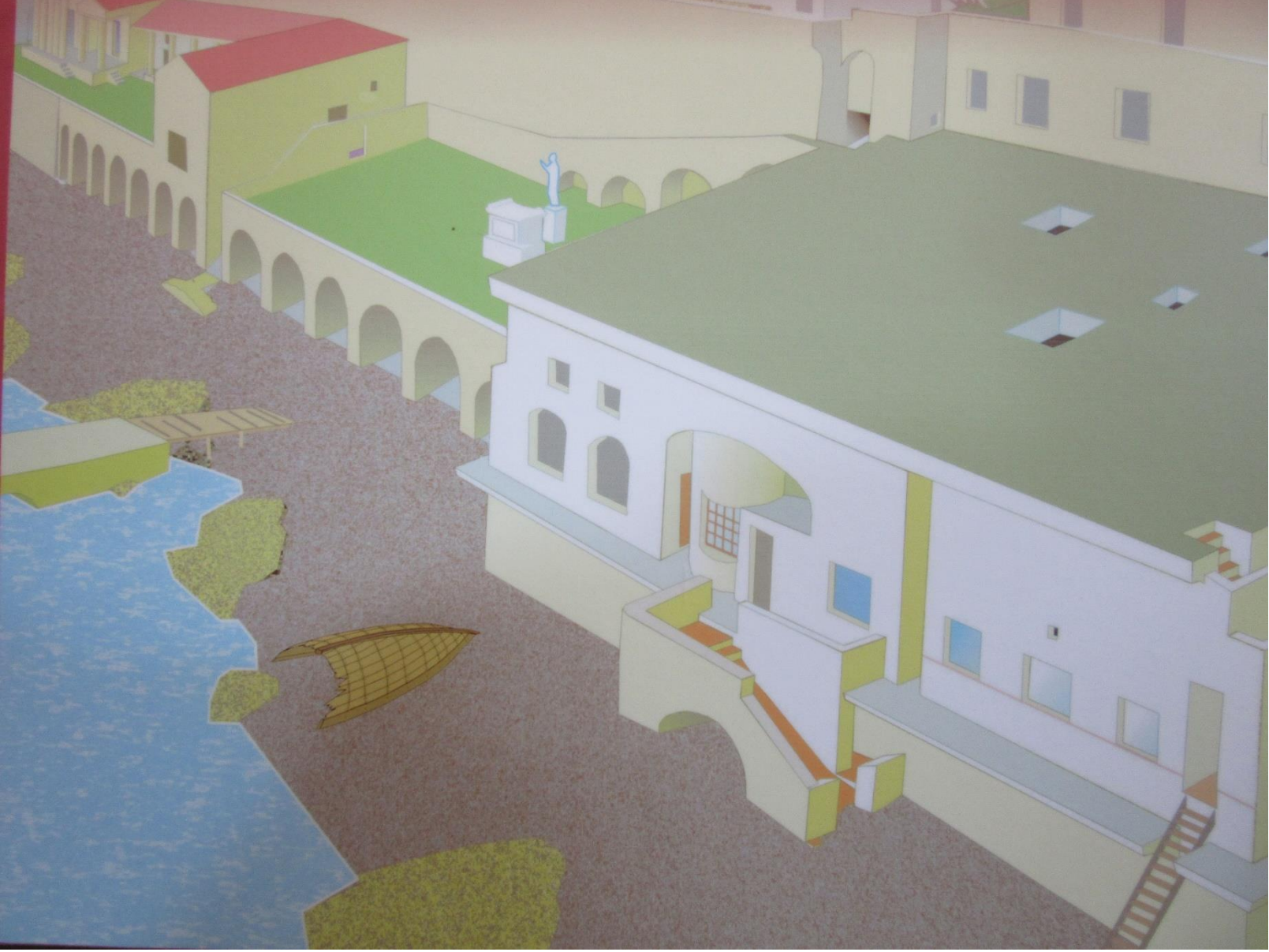






Formice 8







«L'ERMA» DI BRETSCHNEIDER

ORE 01:00



Fig. 29 - Ricostruzione degli effetti dell'impatto del *surge I* sulla antica spiaggia di Ercolano circa all'1 di notte del 25 agosto del 79 d.C.

ORE 01:00 - 02:00



Fig. 32 - Ricostruzione della situazione sull'antica spiaggia di Ercolano nella notte fra il 24 ed il 25 agosto 79 d.C. dopo la deposizione del primo flusso piroclastico.

ORE 02:00

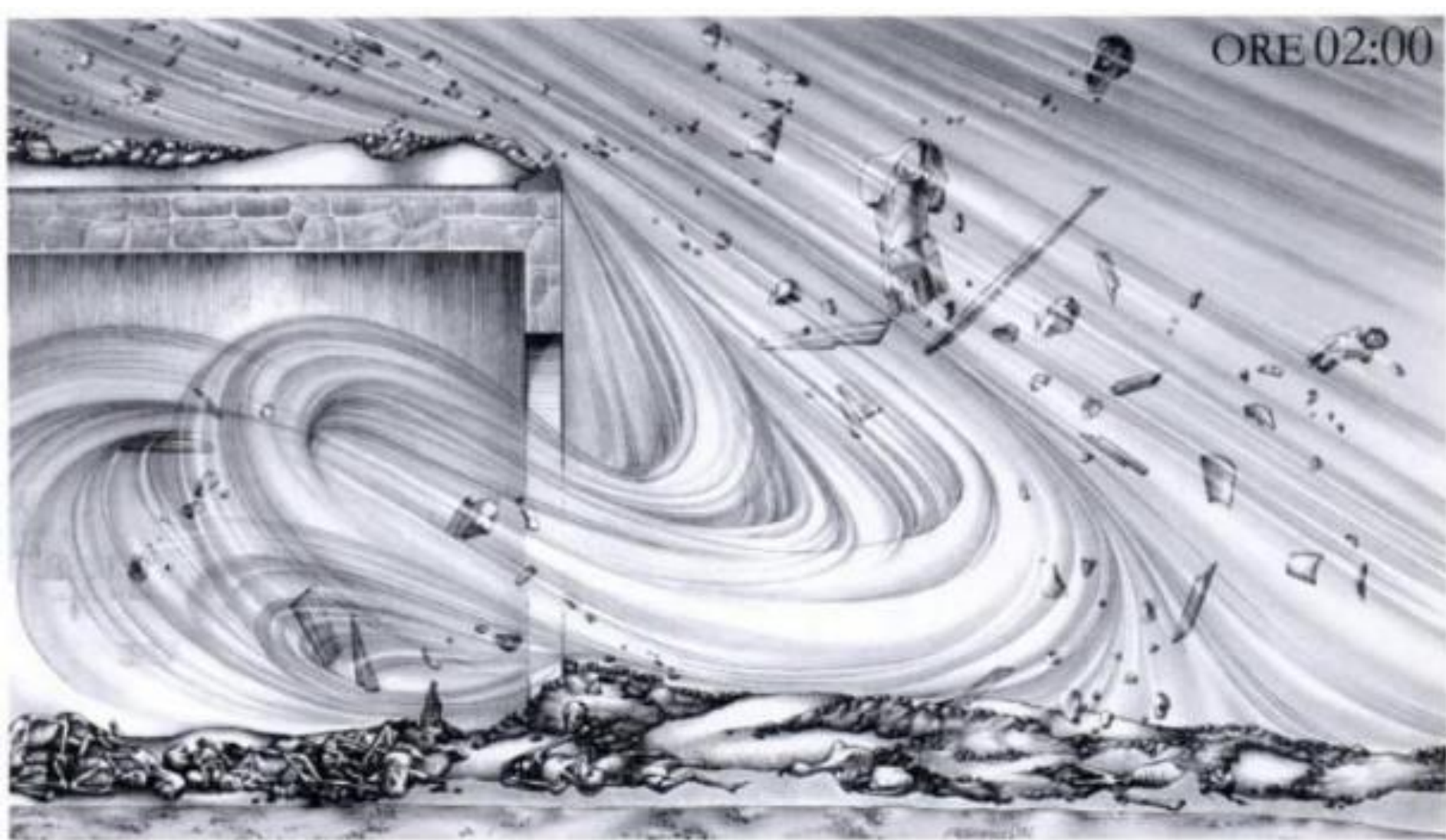


Fig. 33 - Ricostruzione degli effetti dell'impatto del *surge 2* sull'antica spiaggia di Ercolano circa alle ore 2 del 25 agosto 79 d.C.

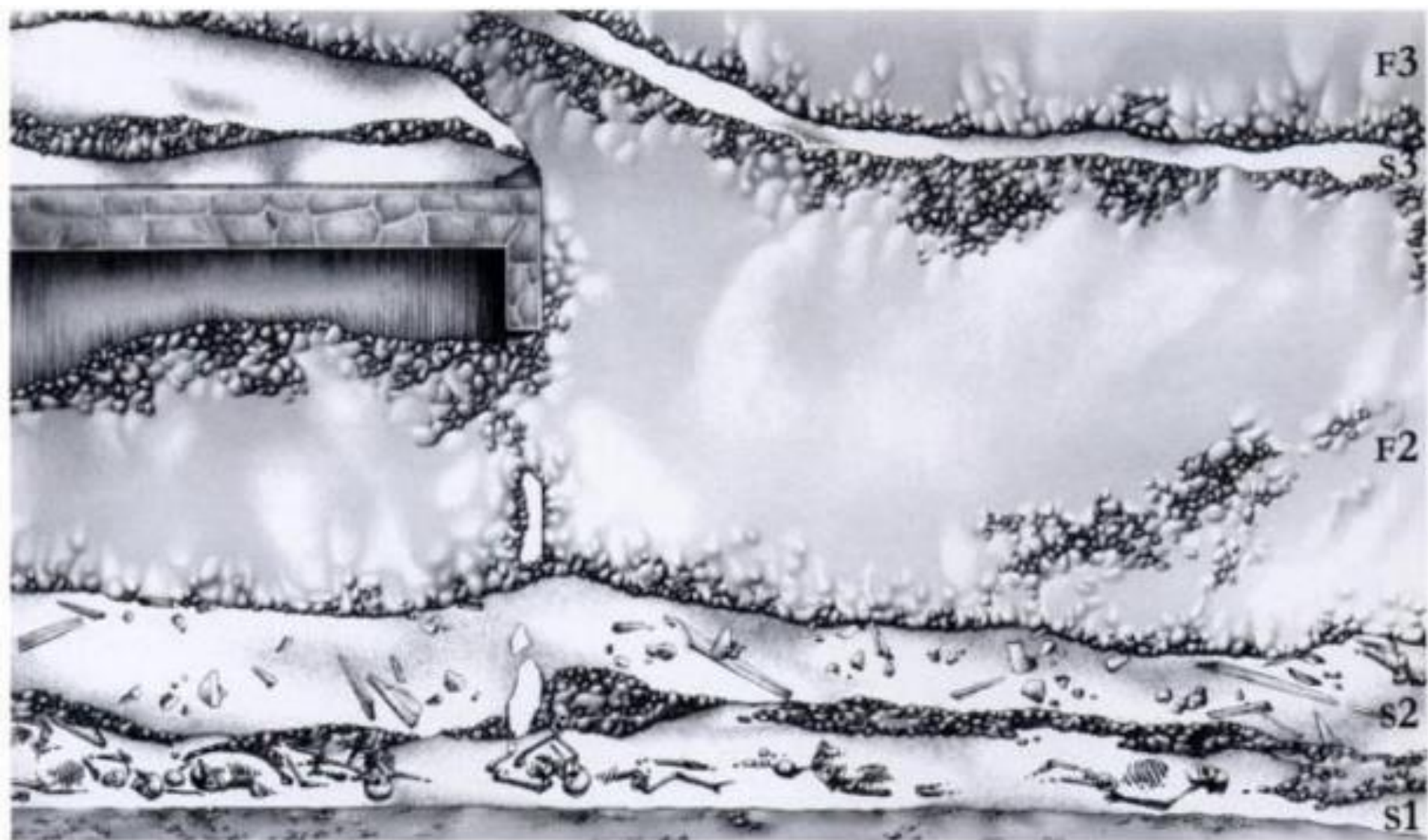


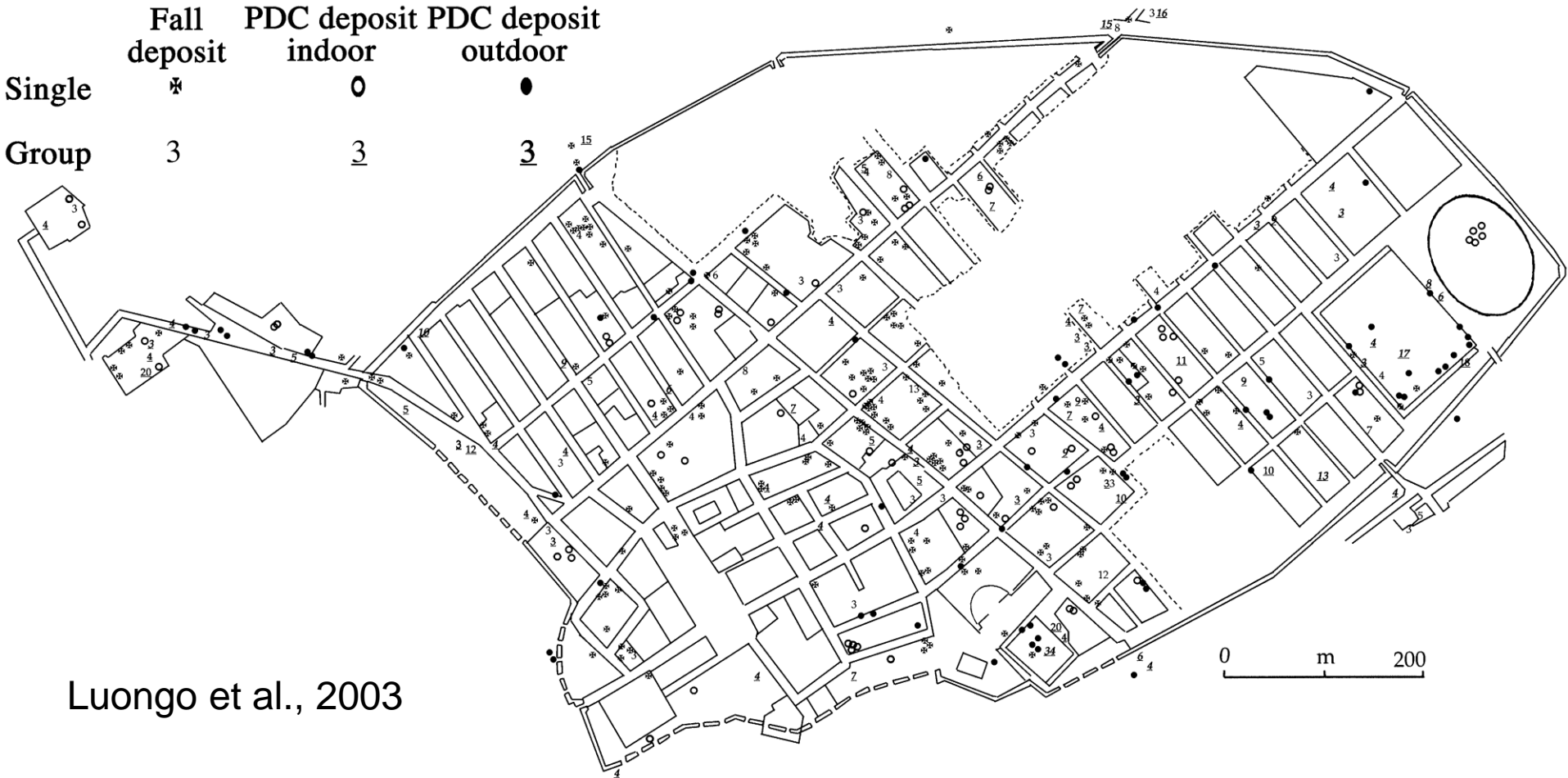
Fig. 34 - Ricostruzione della situazione sull'antica spiaggia di Ercolano dopo la deposizione dei vari flussi piroclastici e *surges* che si susseguirono nel corso della giornata del 25 agosto 79 d.C.



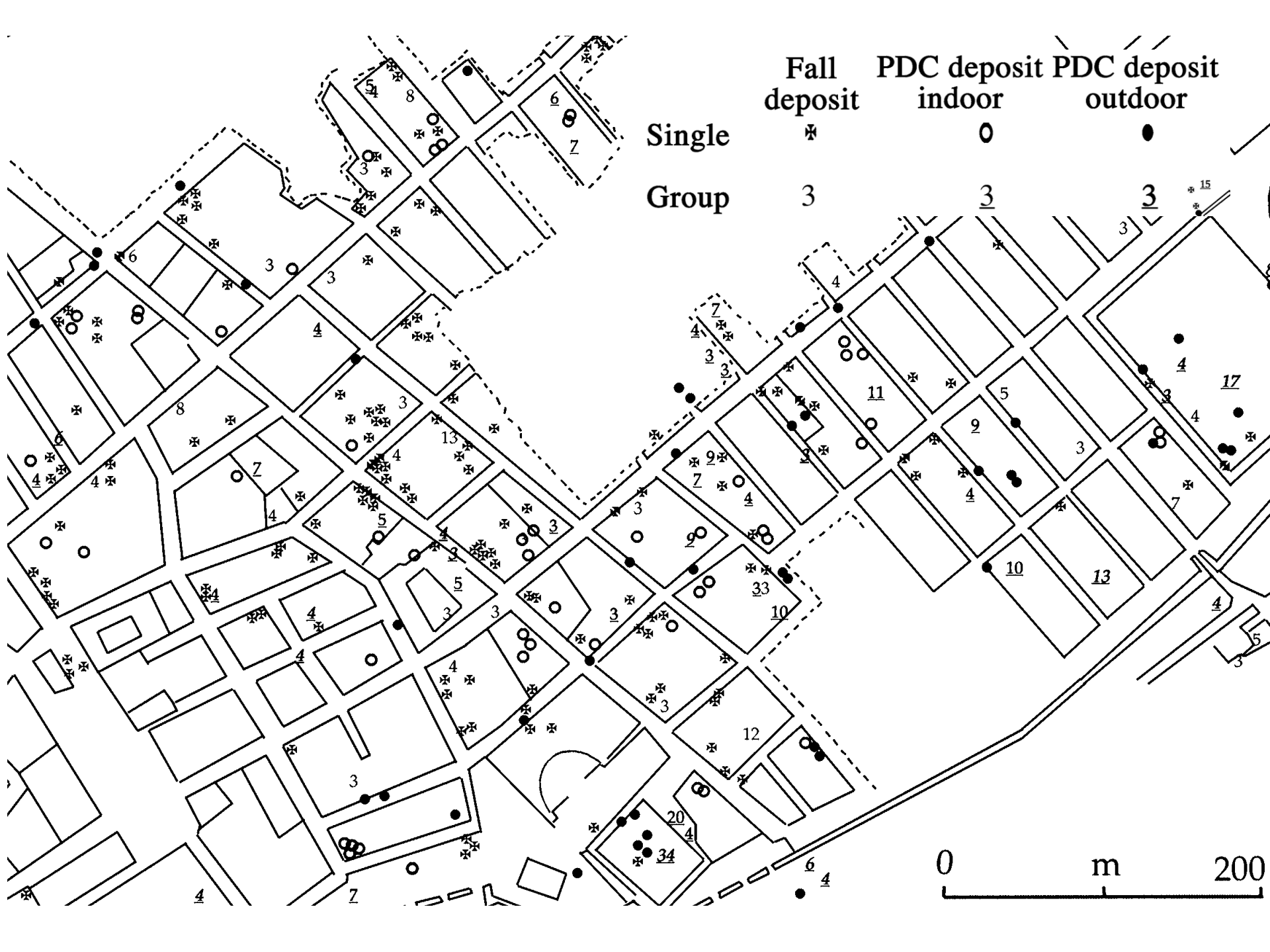








Of the 394 intact corpses within the pumice lapilli deposit, 200 were found isolated and 194 in groups; 345 were inside buildings or houses and 49 in outdoor places. Of the 650 corpses recovered from the PDCs deposit, 152 were isolated and 498 grouped. 334 were found inside buildings, of which 168 were on the upper floors, 166 on the ground floors and 316 outdoors



falling pumice

accumulation rate 15 cm/h ([Sigurdsson et al., 1985](#))

average density 650 kg/m₃

incremental load of 100 kg/m₂ per hour

No data on the yield strength of the Pompeii roofs available in the literature, the critical thickness causing the collapse?

Studies carried out on several recent eruptive events ([Blong, 1984](#)) report roof collapses to occur with thicknesses ranging 0.1-1 m, 40 cm calculated by [Sigurdsson et al. \(1985\)](#).

roof collapses in Polibius' house might have taken place 1-6 h after the beginning of the eruption.

A significant number of victims has been found in the fall deposit: 38% of the total of Pompeii victims. They probably died as a consequence of the building's collapse.

Accumulation rate in outdoor areas about 15 cm/h.

In the zones of the buildings where material sloughed from roofs, the accumulation rate reached values as high as 25-30 cm/h. Within 6 h the roofs and part of the walls of the buildings had collapsed under the pumice load.

On the morning of August 25, many buildings had been destroyed almost completely and only some edifices were still standing.

1-5 m of pumice lapilli, had filled the impluvia and the rooms the roofs of which had collapsed. Also, the peristyles and the alleys had been filled to these depths.

The lapilli pumice fall deposit, about 3 m thick, buried the lower part of the buildings, partly protecting them from the impact of the later pyroclastic currents.

Human casts frozen in the attempt to support their heads from the aggrading deposit. (a) Human cast in the Garden of Fugitives. (b) Human cast in the Casa di Stabianus.



Examination of the corpses' posture suggests the complete absence of any mechanical effect and an instantaneous death followed by sudden muscles contraction (cadaveric spasm) due to the heat-shock induced by the PDC, as also testified by hyperflexion of hands and feet toes (flexor reflex)

The primary postures include:

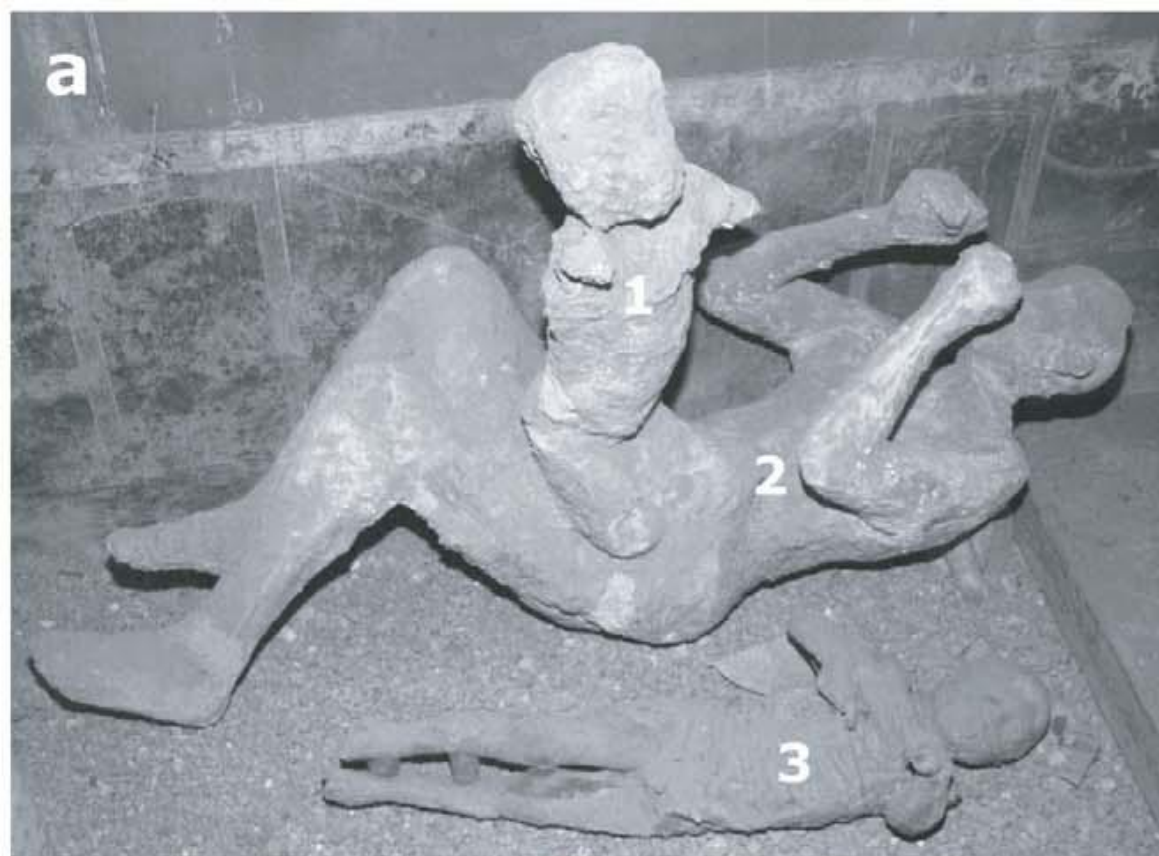
- a) "life-like" stance: victims that appear in suspended action
- b) "sleep-like" stance: victims laying on their back, on their right or left side in an apparent relaxed posture
- c) "impact-like" stance: victims showing corpse displacement and/or rupture of body elements

The secondary postures include:

- d) "limb contraction" stance: hyperflexion of hands and feet
- e) "pugilistic attitude" stance: limb flexures that result from dehydration and shortening of tendons and muscles.

Postures types e. and f. are generally observed as secondary effects in victims exposed to extreme heat (at least 200–300°C).

The pugilistic attitude was erroneously thought to be the victim's attempt for self-defence by previous authors



Typical body postures assumed by human victims in PDCs at Pompeii.

“Life-like” stance:

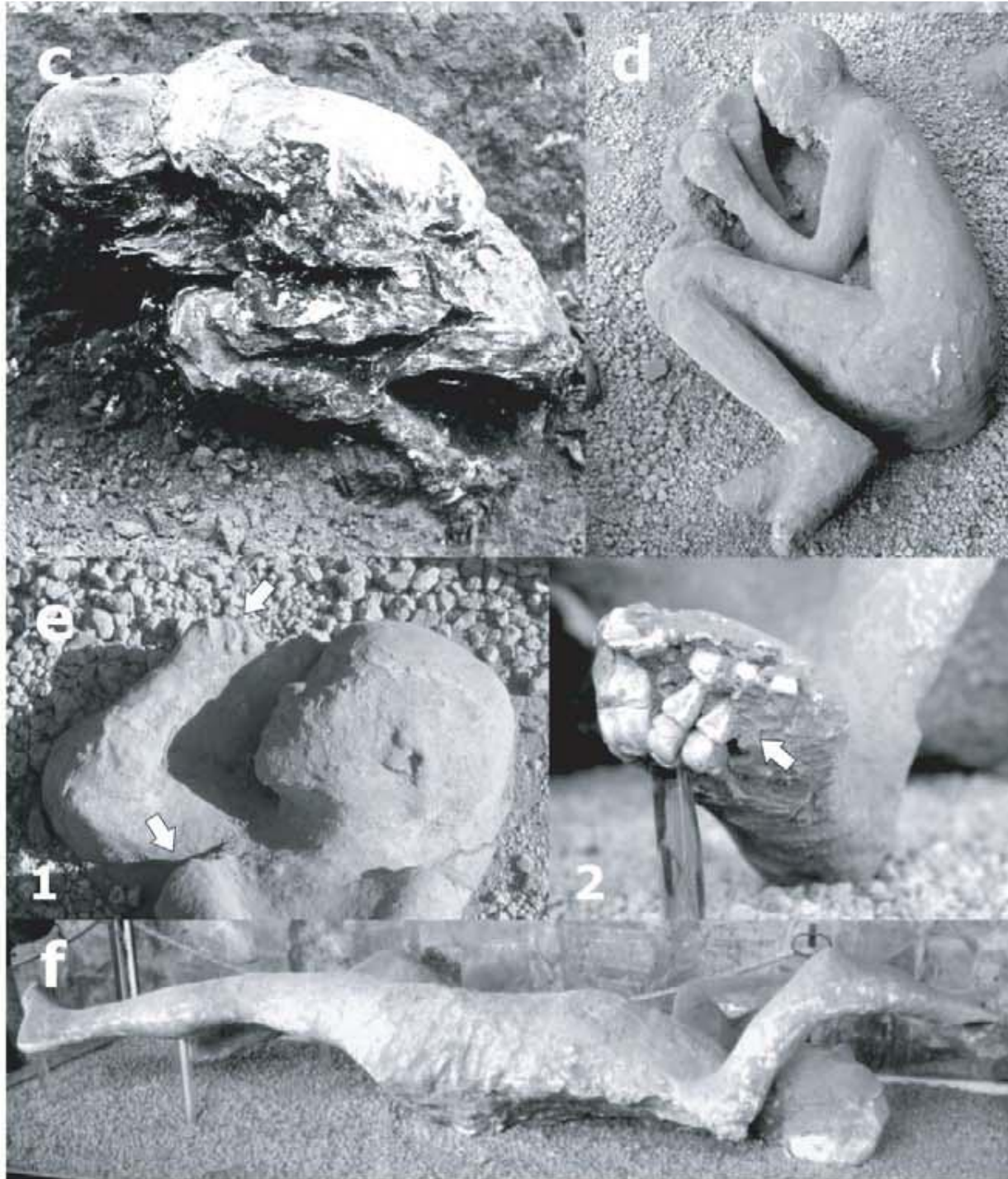
a₁. infant and a₂. adult female

“pugilistic attitude” stance: a₃.

child (House of the gold bracelet, Regio VI, Insula 17 [Insula Occidentalis], 42),



b. adult male (The garden of the fugitives, Regio I, Insula 21),



“Life-like” stance: c. Adult male (The Great Palaestra, Regio II, Insula 7);
“sleep-like” stance: d. adult male (The garden of the fugitives, Regio I, Insula 21);
“limb contraction” stance: e₁. child (The garden of the fugitives, Regio I, Insula 21) and e₂. left foot adult male (outdoor victim, XIX sec. findings);
“pugilistic attitude” stance: f. adult male (outdoor victim, XIX sec. findings).

Pompeii and surroundings

most of the victims are typically frozen in suspended actions (73% life-like stance, 27% sleep-like stance), showing as well as limb contraction (76%) and a large number of corpses presenting the pugilistic attitude (64%).

Different postures often coexist in the same victims group, but the prevalence of people frozen in suspended actions (life-like stance) is univocally indicative of a condition known as cadaveric spasm.

In contrast, postures indicative of mechanical impact effects on victims both inside and outside buildings are extremely rare (2.1%). These evidence confirm that dynamic overpressure was generally below the human lethal threshold as well as their partial or total entrapment into the current (about 2000 Pa), according with the results of our numerical modeling of PDC.

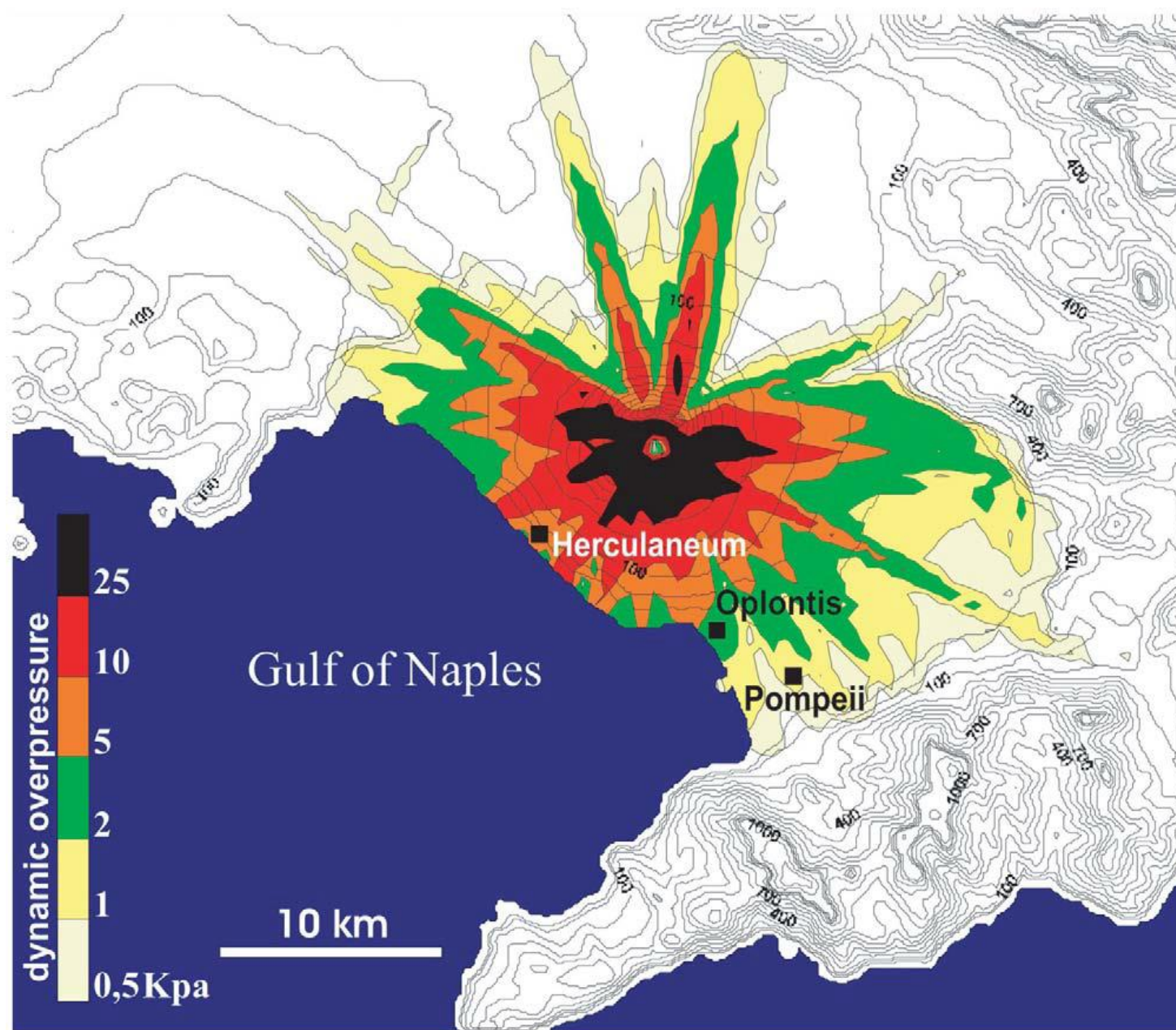
Cadaveric spasm is a rare but diagnostic form of instantaneous muscular stiffening associated with instant violent death, which crystallizes the last activity one did prior to death. Such instant rigor prevents the ordinary onset of muscular relaxation immediately after death, thus avoiding any further substantial body posture modification.

The presence of this stance is indicative that people was alive at the time of posture arrest and its widespread occurrence is a key evidence that all victims groups were exposed to the same lethal conditions.

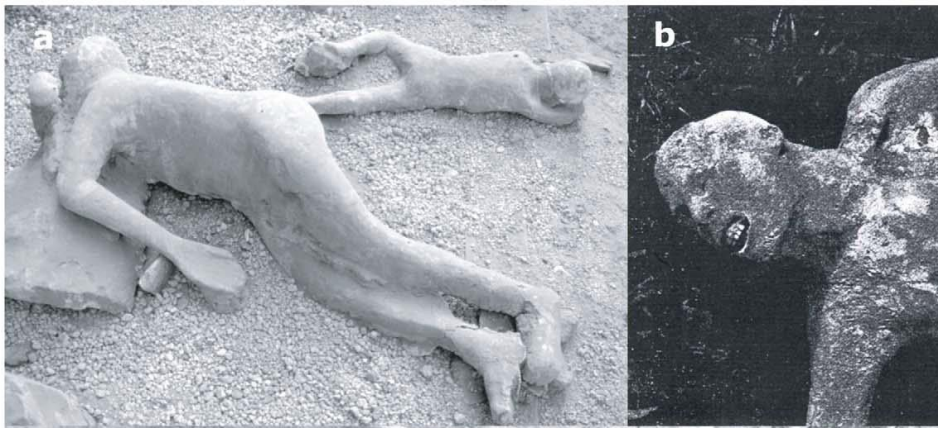
Cadaveric spasm commonly involves groups of muscles and only exceptionally the entire body. This last condition is described in battle situations, due to the exposure of victims to extreme heat. The predominance of this rare feature in Pompeii victims points

Numerical simulation of S4 PDC

The pyroclastic surge advanced as a dilute turbulent poorly-energetic deflating cloud and emplaced suddenly, also lead by town buildings and walls and trench barrier effect. Such behavior accounts for the lack of evidence of mechanical impact on structures and of engulfment and transport in the S4 deposit of tiles and bricks.



velocity at the vent of 50-100 m/s, front thickness of 30-130 m, density of 1.5450 kg/m^3 and average run-out within 10 km passage time of PDC cloud between 30 and $1.5 \cdot 10^2$ seconds.



Human victims of the 79 AD eruption at Pompeii and Oplontis.

- a. Cast of adult woman, part of 13 human victims died outdoor (Pompeii, Garden of Fugitives), possibly showing some evidence of minor mechanical impact;
- b. cast of adult male, part of a group of 21 victims found outdoor (Pompeii, Porta Nola), with evidence of exposure to high temperature typical of fire victims or lethality in PDCs;
- c. the group of human victims found in the Villa B at Oplontis, partially just skeletons and to some extent casts.

at high velocities the body is constantly in contact with the heated air. The other reason is that the PDC contains solids with a higher heat capacity than air. For these reasons, while it is possible to tolerate exposure to hot dry air at temperature up to temperatures of 200°C and above for several minutes, even a brief exposure to a surge cloud in the 200–300°C range, or even as low as 100–150°C, is capable of causing severe burns to unprotected skin

In fires it is considered that exposure to hot smoke at temperatures in excess of 200°C (a total heat flux of more than approximately 12kW) is likely to be fatal within a few minutes.

Survival in the open without protection from the intense heat is virtually impossible. The heat flux is so great that the burns may extend below the dermis into the subcutaneous tissues and the muscles (“fourth degree burns”), giving rise to contractions of the limbs and spine to produce the pugilistic attitude, a post mortem finding normally seen in victims of building or other common fires, but which is also in evidence in many of the numerous plaster casts of victims at Pompeii. The body is fixed in its position, which is not due to the rigor mortis found in deaths from other causes and which will typically pass off in 36h. In contrast, the body in the pugilistic attitude can be straightened only by a pathologist cutting apart the contracted muscle tendons. The most recent volcanic settings in which the pugilistic attitude has been observed, namely in the present study of Merapi in 2010, and Soufrière Hills, Montserrat in 1997, suggest exposure to surge temperatures in excess of 200°C around the time of death.

The time required for thermal radiation to cause deep burns is always shorter than that for auto-ignition of clothing materials, so clothing can be left intact even though a person has died from burns, as evidenced at Pompeii where some of the plaster casts in pugilistic attitudes still retain the forms of togas and sandals worn by the victims when they died. In surges the radiant heat comes from the combined contribution of the individual hot particles in the enveloping hot cloud.



An independent verification that PDC temperatures in Pompeii exceeded 250°C is the melting of silverware solder. In Roman times this material was made with a lead/tin alloy like Tertiarium (Pb-Sn 2:1), which has a melting point of ca 250°C. A temperature of 250°–300°C was also high enough to char wood objects, vegetal material and food but was unable to affect glass, that is preserved intact in the ash deposits.

The exposure time of the victims to high temperature and dusty gas was very short as resulting from lasting passage of S4 surge in the range of 30-1.5x10² seconds. This result is crucial being the capability of PDCs to cause death and injury not only depending on their physical conditions but also on the exposure time. The passage time is consistent with the inferred lethal time for temperatures in the range of 250°–600°C evaluated from ca 10 to ca 10² seconds.

Notably, such a time lapse is insufficient to cause asphyxia that would require an exposure time of several minutes, thus indicating that people would be able to survive to suffocation in 0.5 to 2.5 minutes of the S4 surge cloud passage.

Nevertheless, the calculated concentration of inhalable ash in the PDC approached the survival condition in the order of ca. 0.1 kg/m³. Consistently, the widespread occurrence of primary life-like postures (cadaveric spasm) in the victims is only compatible with an instantaneous death, while exclude the longer agony and the final floppy posture that characterize suffocation.

while impact force and exposure time to dusty gas dropped below lethal conditions, the pyroclastic cloud retained its high temperature thus being the main cause of instantaneous mortality for the Vesuvius area inhabitants, including people who were sheltered within buildings as far as in Pompeii. Definitely, a group of indoor victims found at Muregine, within the S4 PDC limit about half kilometer south-east of Pompeii walls, suggests that even an extremely short exposure to the pyroclastic surge in the order of seconds to a few tenths of seconds was lethal. These facts and the evidence that the late, most powerful 79 AD PDCs reached distance exceeding 20 kilometres from the vent and the findings of several scattered groups of victims in Roman villas even as far as at least 15 kilometres in Stabiae highlight the need to strengthen the emergency plans for Vesuvius and other similar

