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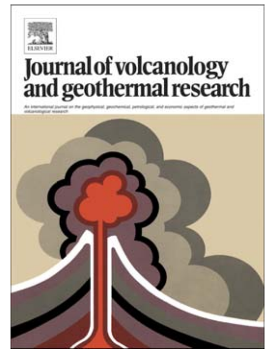

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Lava flow superposition: the reactivation of flow units in compound 'a'ā flows

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Abstract

Basaltic 'a'ā lava flows often demonstrate compound morphology, consisting of many juxtaposed and superposed flow units. Following observations made during the 2001 eruption of Mt. Etna, Sicily, we examine the processes that can result from the superposition of flow units, when the underlying units are sufficiently young to have immature crusts and deformable cores. During this eruption, we observed that the emplacement of new surface flow units may reactivate older, underlying units by squeezing the still-hot flow core away from the site of loading. Here, we illustrate three different styles of reactivation that depend on the time elapsed between the emplacement of the two flow units, hence the rheological contrast between them. For relatively long time intervals (2 to 15 days), and consequently significant rheological contrasts, superposition can pressurise the underlying flow unit, leading to crustal rupture and the subsequent extrusion of a small volume of high yield strength lava. Following shorter intervals (1 to 2 days), the increased pressure caused by superposition can result in renewed, slow advance of the underlying immature flow unit front. On timescales of < 1 day, where there is little rheological contrast between the two units, the thin intervening crust can be disrupted during superposition, allowing mixing of the flow cores, large-scale reactivation of both units, and widespread channel drainage. This mechanism may explain the presence of drained channels in flows that are known to have been cooling-limited, contrary to the usual interpretation of drainage as an indicator of volume-limited behaviour. Because the remobilisation of previously stagnant lava can occur swiftly and unexpectedly, it may pose a significant hazard during the emplacement of compound flows. Constant monitoring of flow development to identify areas where superposition is occurring is therefore recommended, as this may allow potentially hazardous rapid drainage events to be forecast. Reactivation processes should also be borne in mind when reconstructing the emplacement of old lava flow fields, as failure to recognise their effects may result in the misinterpretation of features such as drained channels.

Keywords

'a'ā lava, flow unit, compound flow, Etna, superposition, reactivation

1. Introduction

Basaltic lava flows may be classified as ‘simple’, if they consist of single cooling units, or ‘compound’, if they are constructed of many overlapping cooling units (Walker, 1967, 1971; Pinkerton and Sparks, 1976). Although basaltic 'a'ā flows are often less obviously compound than pāhoehoe flows (Walker, 1971), compound 'a'ā flows commonly develop on Mt. Etna, Sicily (e.g. Guest et al., 1987; Pinkerton and Sparks, 1976; Calvari and Pinkerton, 1998, 1999).

The development of compound flow morphology depends on many factors, including the mean effusion rate (Guest et al., 1987; Fink and Griffiths, 1990, 1992; Calvari et al., 2003), local topography (Hon et al., 1994; Polacci and Papale, 1999; Duncan et al., 2004) and eruption duration (Calvari et al., 2003). If magma supply to a flow ceases before it reaches its cooling-limited length (largely a function of effusion rate), a simple, volume-limited flow forms (Guest et al., 1987). If supply is maintained to a flow unit after it has attained its cooling-limited length, inflation of the unit may occur, and breakouts may develop around its margins, leading to widening and thickening of the flow (e.g. Guest et al., 1987; Kilburn and Lopes, 1988, 1991; Cashman et al., 1998; Kilburn and Guest, 1993). Longer-lived activity may result in the development of ephemeral vents and lava tubes, processes described in 'a'ā flows by Guest et al. (1987) and Calvari and Pinkerton (1998, 1999), who also consider potential hazards.

This paper examines the processes that can occur when a new flow unit is superposed on an older unit during compound flow emplacement. The time that elapses between the emplacement of the two flow units determines the fate of the underlying unit (Walker, 1971), because it controls the rheological contrast between the two units. If the time interval is long, the underlying flow unit has time to cool, degas and develop a rigid crust, so that it shows no significant response to loading, and the two flow units are easily discernable stratigraphically. If the interval is short, the underlying unit has little time to cool, so the two units may merge and cool as a single entity, forming a multiple flow (Walker, 1971). In this case the individual flow units are more difficult to distinguish post-eruption.

The effects of superposition in intermediate cases, when the underlying flows units have immature crusts, are less well understood and have received relatively little attention in the literature. One reason for this may be the paucity of direct observations, though two studies have documented possible examples of reactivation on Mt. Etna. During the 1989 eruption, Kilburn and Guest (1993) noted that ‘a superposed flow advances down the initial flow channel...and reactivates or overflows the original front...extending the flow field by 1.25 km’, but they did not describe how the possible reactivation may have occurred. Calvari and Pinkerton (1999) proposed that the lateral and vertical coalescence of lava flow units, observed from the study of transverse sections through lava tubes, may lead to the reactivation and consequent lengthening of earlier tubes. Here, we discuss the mechanisms by which reactivation may occur, considering the range of possible responses when flow units with immature crusts are overlain by new units, and illustrating these with examples from the 2001 eruption of Mt. Etna.

2. Mt. Etna: the 2001 eruption

During the 2001 eruption of Mt. Etna, seven effusive vents were active over a period of 24 days, between July 17th and August 9th (e.g. Calvari and INGV Catania staff 2001; Behncke and Neri, 2003; Coltelli et al., 2007). The southernmost vent, situated at 2100 m above sea level (a.s.l.) (figure 1), was active between July 18th and August 9th, and emplaced a compound 'a'ā flow that accounted for more than 50% of the total volume of lava erupted (Behncke and Neri, 2003; Coltelli et al., 2007). This flow, which was emplaced with an average effusion rate of ~10.7 $m^3 s^{-1}$ (Coltelli et al., 2007), reached its maximum length of 6.4 km on July 26th, at which time it consisted of a single channel. Thereafter the flow grew by the juxtaposition and superposition of new flow units, and two new flow branches developed due to levée breaching events on the eastern side of the channel below 1500 m a.s.l. (Behncke and Neri, 2003; Coltelli et al., 2007, Favalli et al., 2010; Applegarth et al., 2010). The three main flow branches, as observed post-eruption, are shaded in figure 1C.

An account of the 2001 eruption in its entirety may be found in Behncke and Neri (2003), while more detailed studies of the flow erupted from the 2100 m vent are presented in a number of other papers, including Coltelli et al. (2007), who calculated syn-eruption flow volumes and effusion rates for the flow, and Favalli et al. (2010), who used LIDAR data to examine the mechanisms of flow advance and channel development. The structural development of the flow after July 26th was reconstructed by Applegarth et al. (2010), who also examined the importance of late-stage and post-emplacement processes leading to 'squeeze-up' extrusions of high yield strength lava.

The reconstruction presented in Applegarth et al. (2010) invoked superposition-induced reactivation as an important element of flow development during the 2001 eruption. Here, we present the observations that support this hypothesis, and propose models for three different styles of reactivation, which are dependent on the time elapsed between the emplacement of the two flow units involved. This work is based on syn-eruption images and video footage, the daily online eruption reports published by the Istituto Nazionale di Geofisica e Vulcanologia (INGV) Catania (http://www.ct.ingv.it/Etna2001/Main.htm), post-eruption aerial photos, and field observations.

3. Observations and Interpretations

During the last few days of flow advance, leading up to cessation on July 26th, the flow front slowed progressively (figure 3 in Applegarth et al., 2010), and overflows and new surface units were observed behind the flow front. The fact that sufficient cooling of the front had occurred to result in cessation while lava was still being added to the active channel indicates that the flow was cooling-limited (Guest et al., 1987; Pinkerton and Wilson, 1994). On July 26th, the channel was full, but subsequent observations showed it to have drained between 1400 m and 1100 m a.s.l. (Applegarth et al., 2010). The drained region is shaded in black in figure 1C, and the transition from an undrained to a drained channel at 1400 m a.s.l. is shown in figure 2. Drained channels normally develop in lava flows that are volume-limited, that is flows that advance until the lava supply from the vent ceases. After this time, the flow front may continue to advance, as the relatively uncooled lava from the central part of the channel drains downslope (Borgia et al., 1983). Drained channels, which are easily recognised in the field, are often used as indicators of volume-limited behaviour in flows that were not observed during emplacement. However, their appearance in the 2001 flow, which clearly demonstrated cooling-limited behaviour, strongly suggests the action of processes that resulted in post-emplacement modification.

The presence of drained channels may be explained by superposition-induced reactivation of earlier flow units. On July 27th, a day after the flow front had ceased advancing, an active surface flow unit was documented overlying earlier units, the front of which was situated at 1400 m a.s.l. This unit was weakly supplied and stagnating (INGV internal report 27/07/01). The image shown in figure 3 shows the cross-cutting of earlier generations of levées by the new flow unit at 1400 m a.s.l., clearly demonstrating that superposition had occurred. The height of the 5th and final generation of levées shown in figure 3B is significantly greater than that of earlier levées, suggesting that inflation of the superposed unit had taken place. Between July 27th and 28th, the active front had advanced from 1400 m to 1180 m a.s.l. (Coltelli et al., 2007; Applegarth et al., 2010). As is demonstrated below, both the rapid advance of the front and the drainage of the channel below 1400 m a.s.l. can be attributed to superposition-induced reactivation of the underlying, cooling-limited flow unit.

Flow unit superposition was also observed in the distal channel at the beginning of August (figure 4; Applegarth et al., 2010). Post-eruption observations show that below the bifurcation at 1200 m a.s.l. (figure 1C), the eastern arm of the main channel is well defined by levées, and is drained (figure 4). The west side of the flow, however, comprises many overlapping units. Syn-eruption field observations on August 1st 2001 showed that the advance of new, superposed flow units had resulted in the remobilisation of the underlying units. This reactivation was manifested in the renewed advance of the underlying flow unit fronts, which had been stationary on July 31st.

Reactivation on a yet smaller scale, resulting from flow unit superposition at a late stage of activity, was observed to result in the extrusion of small volumes of high yield strength lava. Evidence for this process, dubbed the ‘toothpaste mechanism’ by Applegarth et al. (2010), is given in figure 5, which shows two views of the distal channel between ~1060 m and 1120 m a.s.l. The earlier image (figure 5A) was taken on August 1st 2001, and shows the channel to be full, with several marginal overflow lobes on the nearside of the levée, which had been emplaced on July 22nd (Favalli et al., 2010). The later image (figure 5B) was taken after the eruption, and shows the presence of new surface flows, which had advanced along this part of the channel on August 2nd, overtopping the levée and partially overlapping the overflow lobes. This superposition reactivated the overflow lobes, causing the small, dark-coloured squeeze-up extrusion seen at the front of the marginal lobes in figure 5B.

On the basis of the above observations, we present models for three different reactivation processes resulting from flow unit superposition involving different degrees of rheological contrast. These models can explain the appearance of drained channels in a cooling-limited flow, the renewed advance of stationary flow fronts, and the origin of some of the squeeze-up extrusions found in the 2001 lava flow.

4. Flow reactivation styles

4.1 Large rheological contrast: late-stage extrusions

If the time interval separating the emplacement of two stacked units is sufficient, then the underlying flow will be able to cool and degas sufficiently to resist significant deformation upon superposition (figure 6A; Walker, 1971). However, if the crust is capable of yielding under the applied load, the increased pressure in the underlying flow core may result in crustal rupture and the subsequent extrusion of some of the core material. This process, dubbed the ‘toothpaste mechanism’ because is similar to the squeezing of toothpaste from a tube (Applegarth et al., 2010), is shown schematically in figure 6B. The example shown in figure 5B involves the reactivation of units after a period of at least 11 days (July 22nd to August 2nd, assuming the extrusion developed on August 2nd), though the time interval during which reactivation is possible is likely to depend on the history of the underlying flow unit.

Because the core of the underlying unit may cool and degas significantly in this time, the resulting extrusion may have a high yield strength, but it does not necessarily consist of the coincidentally named toothpaste lava described by Rowland and Walker (1987), which is inferred to be an intermediate product between pāhoehoe and 'a'ā lava. Figure 5B shows that the toothpaste reactivation mechanism may result in extrusions of squeeze-up lava, which are inferred to have viscosities and/or yield strengths that are even higher than those of toothpaste and 'a'ā lava (Applegarth et al., 2010). The length of the time interval may influence the nature of the extrusion, with shorter intervals producing toothpaste lava extrusions, and longer intervals squeeze-up extrusions. The squeeze-up shown in figure 5B occurred through the surface of the flow unit, which indicates that the surface crust was weaker than the flow front. This may perhaps be due to either accumulated rollover material resulting in greater carapace thickness at the front, or fracturing of the surface crust. Failure through the flow unit surface is shown in figure 6B.

4.2 Intermediate rheological contrast: renewed advance of flow fronts

On shorter timescales (1 to 2 days), when the front of the underlying flow unit has not cooled and thickened significantly, the increased pressure in the core of this unit due to superposition may result in renewed flow unit advance (figure 6C). This was observed in the area shown in figure 4, where flow unit superposition on August 1st caused the renewed advance of underlying units that had been stationary on July 31st.

4.3 Small rheological contrast: large-scale channel drainage

We suggest that the occurrence of drained channels between 1400 m and 1100 m a.s.l., and the rapid advance of the active fronts between July 27th and 28th (figure 3 in Applegarth et al., 2010) may be explained by the superposition of a new, hot, thick surface flow unit that reactivated older, stationary units in the channel. This process, illustrated in figure 6D, occurs if there is only a small rheological contrast between the underlying and superposed units.

On July 26th, the main channel flow ceased to advance when the basal shear stress equalled its yield strength. According to Hulme (1974), the critical depth, h_c, at which this occurs can be estimated from:

$h_c = \tau_y / g \rho \sin\alpha$, (1)

where τ_y is the yield strength of the lava at the flow front, ρ, the lava density, g, the gravitational acceleration, and α, the ground slope.

By July 27th, a new surface flow unit had been emplaced in the channel, the front of which had stagnated at 1400 m a.s.l. This superposed unit, which can be seen cross cutting earlier units in figure 3, was thicker than the earlier, underlying units (figures 2 and 3) suggesting that it had inflated. Due to the short time interval (< 1 day) between the emplacement of the two flow units, the upper crust of the underlying unit was thin and weak, and its core was rheologically similar to that of the overlying unit. Consequently, superposition resulted in wholesale disruption of the intervening crust, and mixing of the flow unit cores (figure 6D). The flow depth thus increased to exceed the critical depth, and the basal shear stress overcame the yield strength. A deep wave of lava is inferred to have then propagated rapidly downflow, reactivating the flow units downslope.

Using Jeffrey's equation (Jeffreys, 1925):

$u_{max} = \rho\, g\, h^2 \sin\alpha / 3\, \eta$, (2)

where u_{max} is the surface velocity at the centre of the channel and η is the fluid viscosity, it can be shown that doubling the flow depth can increase the surface velocity fourfold. Although this is a simplification, as Jeffrey's equation assumes Newtonian rheology, it may point to the reason behind the rapid advance of the active fronts between July 27th and 28th.

This remobilisation of earlier units resulted in the drainage of the main channel below 1400 m a.s.l. Some of the drained material may have used the eastern arm of the main channel below the bifurcation at 1200 m a.s.l., but the early generations of overflows to the west of the flow field at this altitude (figure 4) probably account for the majority of this material. The reactivated units themselves were effectively volume-limited, as the discharge rate dropped rapidly following the depletion of the material stored in the channel below 1400 m a.s.l., meaning that once formed, the drained channel was preserved.

5. Hazard implications

The possibility of flow unit superposition causing reactivation was suggested by Kilburn and Guest (1993) and Calvari and Pinkerton (1999), but observations of the processes involved were not made in those studies. Our study of the 2001 Etna flow shows that reactivation may occur on a range of spatial and temporal scales, with varying hazard implications.

The effects of superposition depend on the time elapsed between the emplacement of the two flow units. Following an interval of more than 1 day, core remobilisation can result in renewed advance of flow unit fronts, or in the extrusion of squeeze-ups. If the interval is shorter, (< 1 day), reactivation may lead to large-scale channel drainage. During the 2001 eruption of Etna, drainage produced overflows that did not extend as far as the cooling-limited flow front (figure 4), and which were laterally confined by old cinder cones (figure 1C), so flowed parallel to the original channel. Superposition elsewhere in the flow field may have resulted in the newly reactivated flows breaking out of the original channel and forging a new path, thus threatening different areas, as was the case with the second of the breakouts from the main channel to develop into a new flow branch during the eruption (figure 1C).

Post-eruption observations of three-dimensional braided tube systems have been used to discuss the hazards that may be posed by the merging and reactivation of lava tubes, as opposed to lava flow units, on Etna (Calvari and Pinkerton, 1999) and Hawai‘i (Peterson and Swanson, 1974; Mattox et al., 1993). The consequences in both cases may be similar. Tube coalescence usually occurs vertically and close to the vent, when the weight of lava in the upper tube causes failure of the lower tube roof, which has not thickened significantly (Peterson and Swanson, 1974; Calvari and Pinkerton, 1999). Following coalescence, the lower tube may be reused (if drained), or its contents may be reactivated in a process similar to that shown in figure 6D. Either scenario may lead to unexpected breakouts of insulated lava far from source. This consequence has parallels with the toothpaste reactivation mechanism, in that breakouts occur at localities some distance removed from the site of superposition/coalescence.

Although the action of the toothpaste mechanism in the 2001 Etna flow produced only small squeeze-up extrusions, observations from Parícutin, Mexico, indicate that such activity could be a precursor of more significant reactivation. The eruption of Parícutin (1943-1952) involved the emplacement of many lava flows with life spans of several months (Luhr and Simkin, 1993). Following a pause in the episodic advance of the San Juan Parangaricutiro flow, the resumption of supply first caused renewed advance of the flow front, and then forced drainage of the flow, producing large volumes of squeeze-up material (Krauskopf, 1948; Applegarth et al., 2010). Drainage resulted in a tube system that channelled fresh lava to the flow front, inundating an area of 350,000 m^2 overnight (Luhr and Simkin, 1993). Although no superposition of flow units was reported in contemporary accounts of the eruption, similar enforced drainage could occur as a result of superposition, possibly leading to the development of tubes that could be exploited by later flows.

These examples illustrate that flow reactivation by the mechanisms described above could result in the rapid resumption of lava flow advance without significant warning.

6. Conclusions

Lava flow unit reactivation increases the complexity of compound flow fields, and can produce morphologies that confuse post-eruption interpretations. Lava flow lengths are often used to make first order estimations of effusion rates, and failure to recognise the effects of flow reactivation, which may cause flow lengthening, could result in erroneous reconstructions.

Flow unit superposition may also result in the reactivation of previously quiescent parts of a flow field, leading to renewed hazard, and we have outlined three ways in which such reactivation may occur. In general, the degree of reactivation, and consequently the risk posed, depends on the time elapsed between the emplacement of the two units, hence the rheological contrast. The shorter the timescale, hence the smaller the rheological contrast, the greater the potential for significant levels of reactivation. However, even late-stage reactivation could produce new pathways for the transport of fresh lava, as observed at Parícutin. Reactivation therefore does not necessarily need to result in large volumes of earlier lava being remobilised and transported significant distances in order to pose significant threat. Constant monitoring of the structural development of compound flows is recommended to distinguish areas where new units are being superposed, and hence to identify sites of potentially dangerous reactivation events.

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Figure captions

Figure 1. (A) Sicily and the location of the Etna National Park. (B) The location of the 2001 flow on the southern flank of the volcano. SP indicates the location of the Sapienza tourist complex. (C) Simplified sketch showing the post-eruption structure of the 2001 flow. Historic cinder cones are shaded in pale gray. The outline of the entire flow field is given, with the paths of the three principal channels shaded. The earliest channel, extending from the vent to the flow front down the west side of the flow, ceased advancing on July 26th. Two new branches developed sequentially to the east after this date, following levée breaches just below 1500 m a.s.l. Undrained channels are shaded in mid grey, and drained channels in black. The locations of figures 2 to 5 are boxed. Contour interval is 100 m.

Figure 2. Post eruption image (A) and sketch (B) showing the channel between ~1450 m and 1350 m a.s.l. An abrupt change in the level of lava in the channel occurs at 1400 m a.s.l. The upflow, undrained part of the channel is the unit that was emplaced over earlier flows on July 27th. Below 1400 m a.s.l., the drainage of the channel is seen from the relatively high relief of the far levées and the dagalas. The depth of lava in the undrained part of the channel is at least 15 m, as this is the magnitude of the sudden vertical drop between the surface of the flows in the undrained and drained parts of the channel. Image: INGV Catania.

Figure 3. Syn-eruption image (A) and sketch (B) of the front of the superposed unit on August 6th, looking upflow from ~1375 m a.s.l. Several generations of levées can be seen. Generations 1 to 4 represent waning flow early in the eruption, as progressively lower flux resulted in narrowing of the active channel to produce nested levées. Overflows of lava from these earlier channels are also seen. The 5th generation of levées belong to the superposed unit, and cross cuts the earlier generations. These levées are considerably higher than the earlier sets (see also figure 2), suggesting that inflation of the new unit had occurred. The step change in surface relief in the channel can again be seen. Image: INGV Catania.

Figure 4. Post-eruption image of the distal main channel, looking upflow from ~1100 m a.s.l. The channel bifurcates at ~1200 m a.s.l. Below this altitude, the eastern arm of the channel is well defined by levées, and is drained. In contrast, the western side of the flow field is made up of a number of overlapping flow units. The superposition of units in this region resulted in the renewed advance of underlying flows at the beginning of August. Image: INGV Catania.

Figure 5. Syn- and post-eruption views of the distal main channel between ~1060 m and 1120 m a.s.l., looking west. (A) August 1st. Marginal overflow lobes, emplaced on July 22nd (Favalli et al., 2010), are visible on the near-side of the channel-levée boundary. The main channel is full, and its surface is uneven. The overflow lobe front that is ringed appears similar to the surrounding lobe fronts. (B) Post-eruption. Several surface flows are visible along the axis of the main channel, resulting in stacked flow fronts. These flows were emplaced on August 2nd, and partially overlap the marginal overflow lobes. A dark squeeze-up has developed at the front of the ringed lobe since August 1st, due to loading of the lobe by the new surface flows. Images: INGV, Catania.

Figure 6. The possible outcomes of flow unit superposition. In all cases, a stationary flow unit is overlain by a new unit which itself then ceases to advance. (A) Time >> 15 days. Sufficient cooling and degassing before superposition means that the underlying flow unit does not respond to the newly emplaced load (Walker, 1971). (B-D) The three reactivation styles observed to result from flow unit superposition when the underlying flows were sufficiently young to have immature crusts and deformable cores. The response of the underlying unit depends on the time interval between the emplacement of the two units. (B) Time: 2 to 15 days. The 'toothpaste mechanism'. Loading deforms the crust and squeezes the underlying flow core forwards, generating an increased pressure in the underlying unit. Rupturing of the crust, perhaps at the surface as in figure 5B, results in the extrusion of a small volume of cooled, degassed core material. The extrusion may consist of toothpaste or squeeze-up lava. (C) Time: 1 to 2 days. The crust of the underlying flow is still relatively thin, so the increased pressure due to loading causes renewed flow front advance. (D) Time < 1 day. Loading disrupts the young, thin flow crust, allowing mixing of the flow cores. This creates a new, deep flow, which propagates as a wave, reactivating the earlier flow units ahead of it in the channel and eventually causing large-scale drainage.

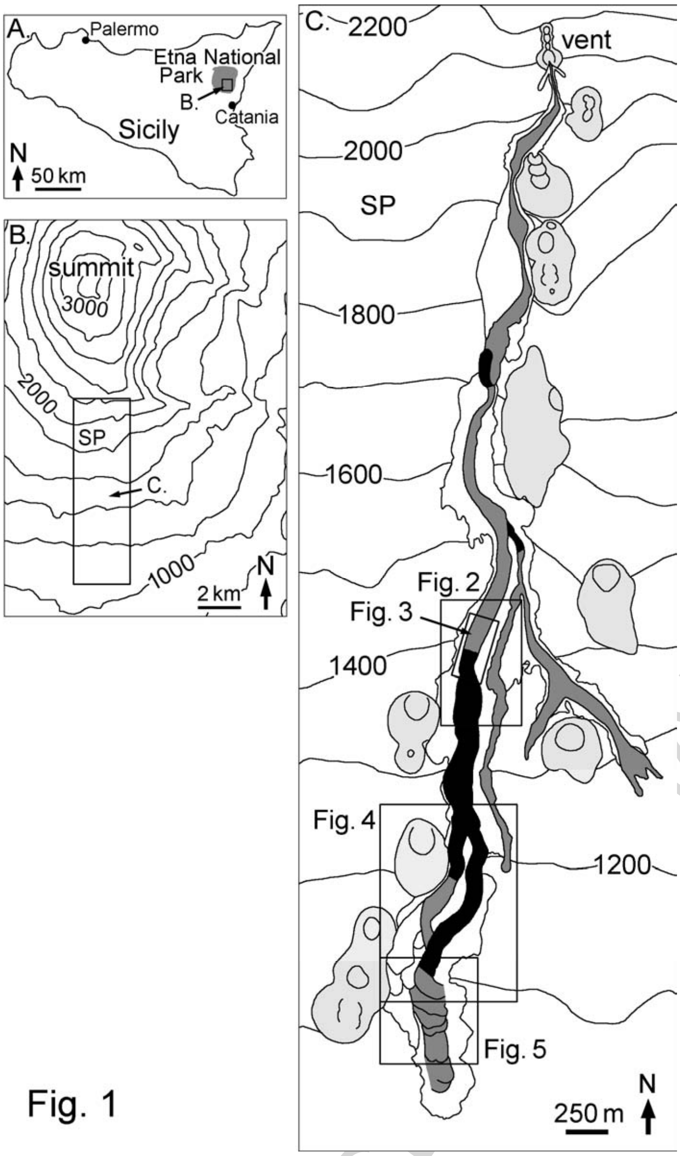

A.
Palermo
Etna National
Park
B.
Catania
Sicily
N
50 km
B.
summit
3000
2000
SP
C.
1000
2 km
N
C.
2200
vent
2000
SP
1800
1600
Fig. 2
Fig. 3
1400
Fig. 4
1200
Fig. 5
250 m
N

Fig. 1

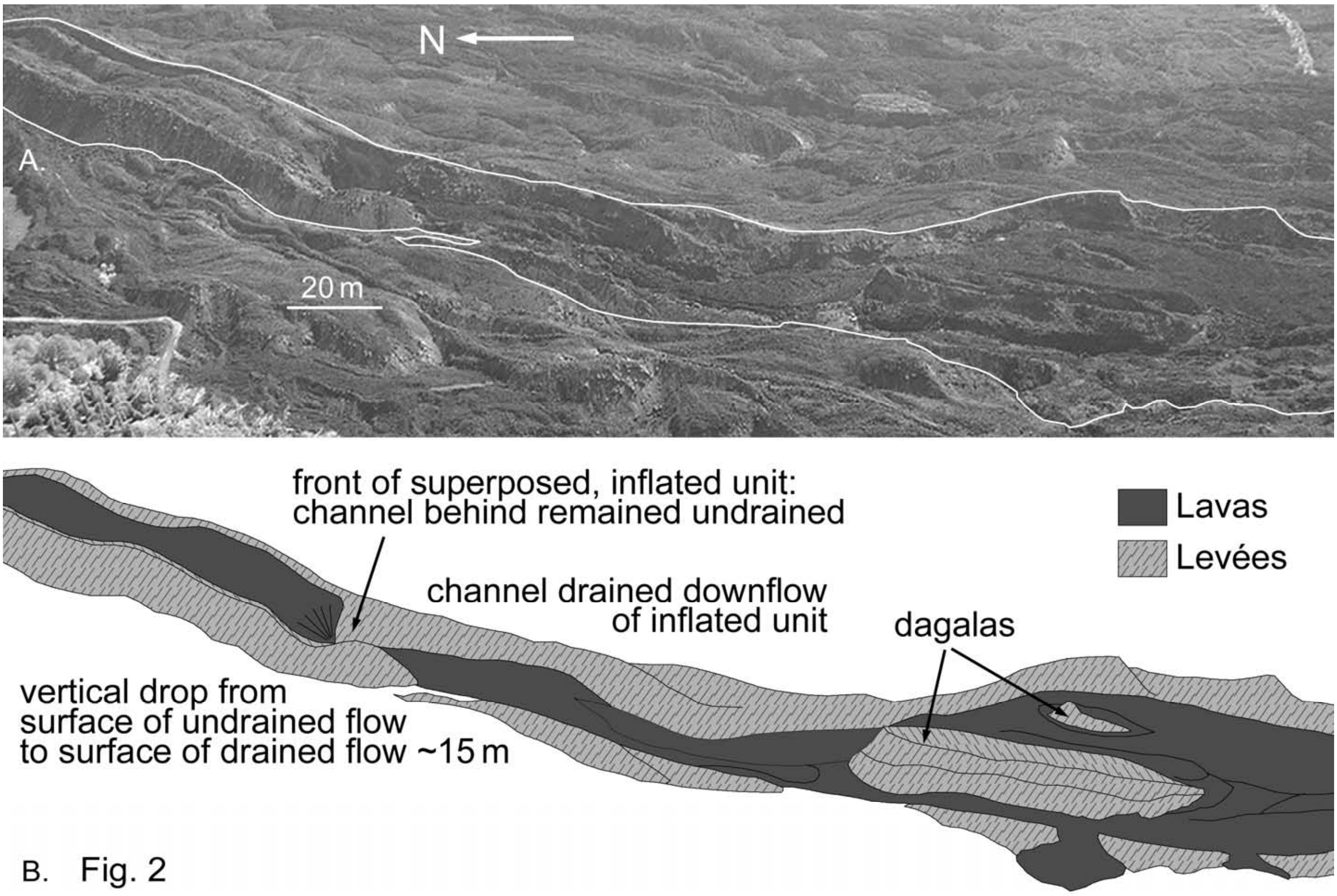
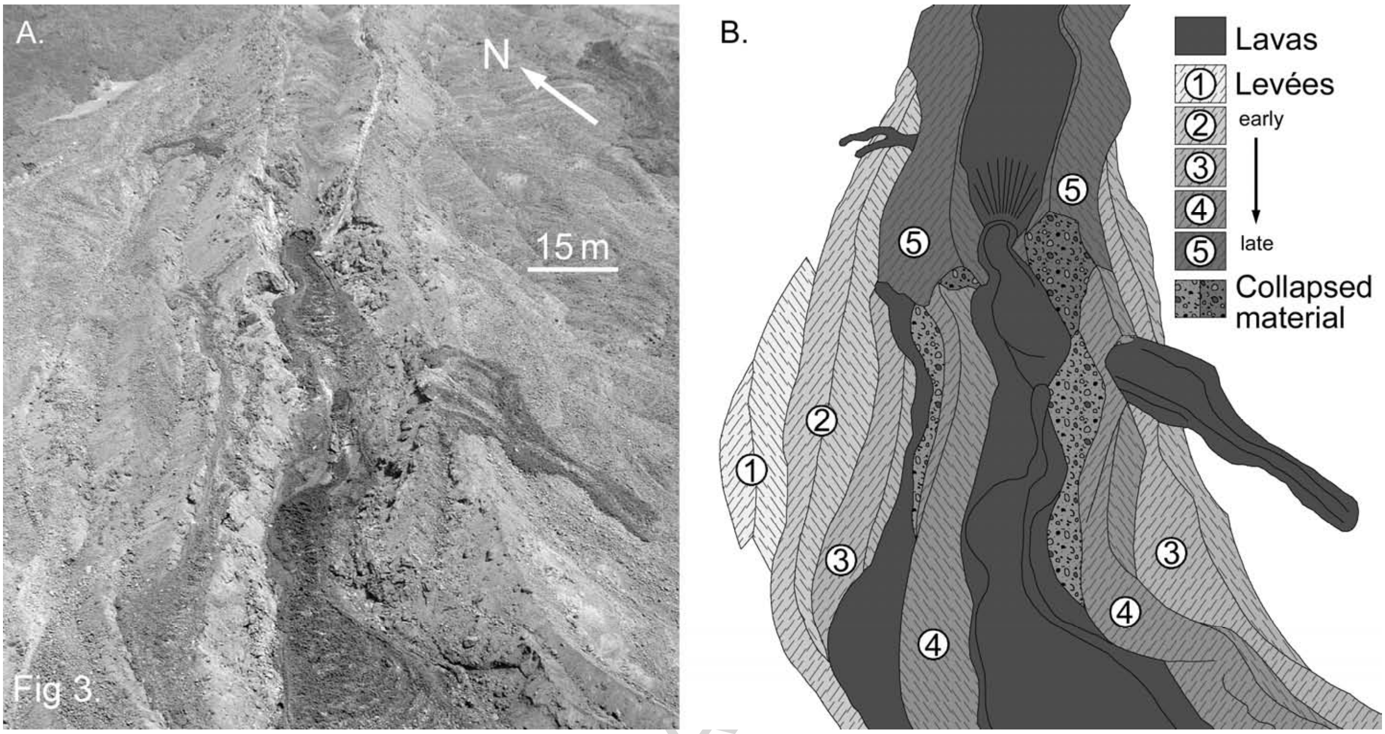

N
A.
20 m
front of superposed, inflated unit:
channel behind remained undrained
Lavas
Levées
channel drained downflow
of inflated unit
dagalas
vertical drop from
surface of undrained flow
to surface of drained flow ~15 m
B.

Fig. 2


A.
N
15 m
Fig 3.
B.
Lavas
1 Levées
2 early
3
4
5 late
Collapsed material
1
2
3
4
5
3
4
5

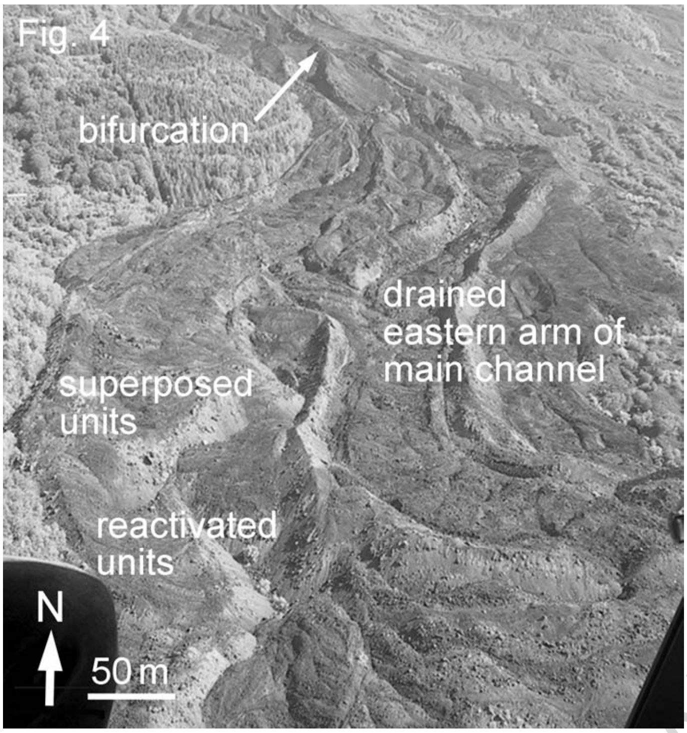


Fig. 4
bifurcation
drained
eastern arm of
main channel
superposed
units
reactivated
units
N
50 m

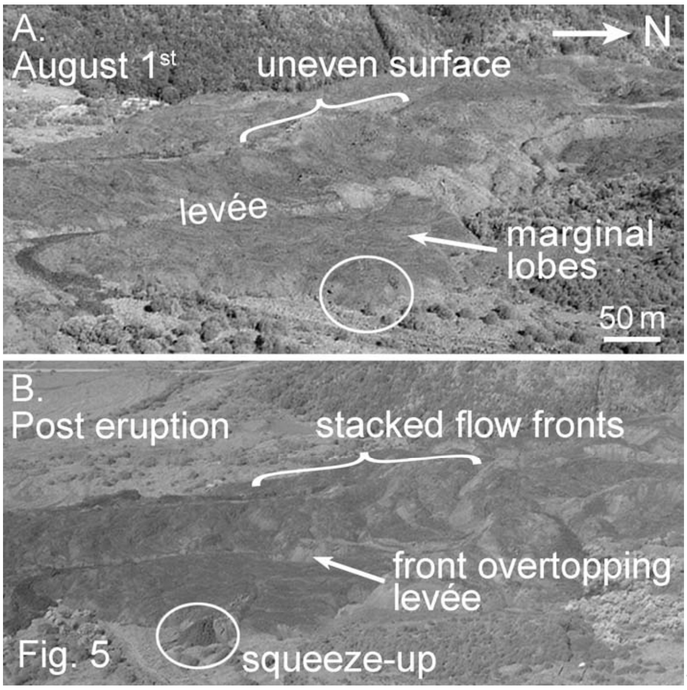
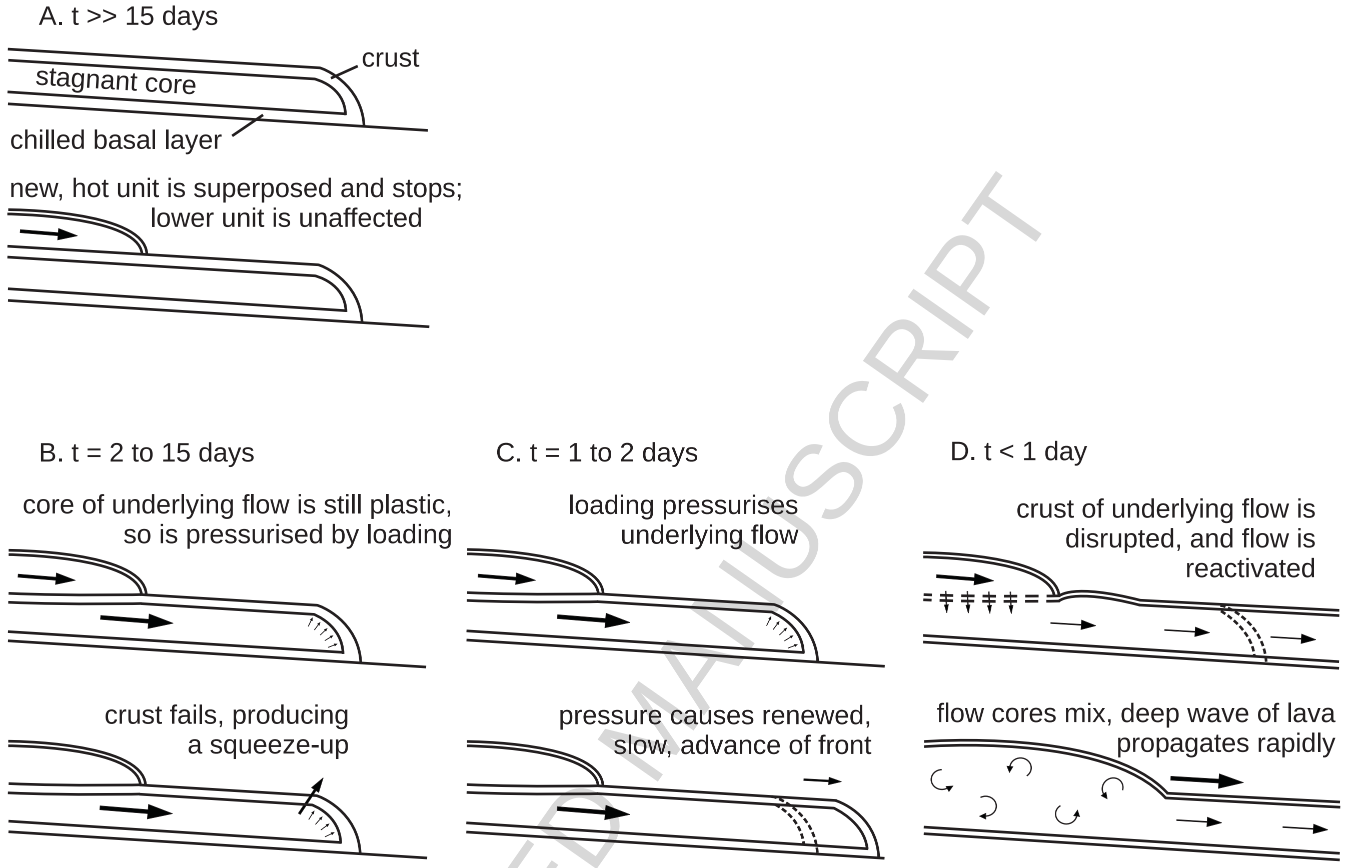

A.
August 1st
uneven surface
N
levée
marginal
lobes
50 m
B.
Post eruption
stacked flow fronts
front overtopping
levée
squeeze-up

Fig. 5

Fig. 6



A. t >> 15 days
crust
stagnant core
chilled basal layer
new, hot unit is superposed and stops;
lower unit is unaffected
B. t = 2 to 15 days
core of underlying flow is still plastic,
so is pressurised by loading
crust fails, producing
a squeeze-up
C. t = 1 to 2 days
loading pressurises
underlying flow
pressure causes renewed,
slow, advance of front
D. t < 1 day
crust of underlying flow is
disrupted, and flow is
reactivated
flow cores mix, deep wave of lava
propagates rapidly