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Reply to comment by Ferlito et al. on "Complex magma dynamics at Mount Etna revealed by seismic, thermal and volcanological data"

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[1] The eruptive episode of Mount Etna's Southeast Crater (SEC) on 16 November 2006, which culminated with phreatomagmatic explosions and a peculiar volcaniclastic flowage event, is the subject of different interpretations. *Behncke* [2009] and *Behncke et al.* [2008, 2009] interpret the explosions as resulting from mixing of flowing lava with fluid-saturated, hydrothermally altered rock and describe the resulting flow as a low-temperature (but potentially deadly) pyroclastic density current (PDC). *Norini et al.* [2009] speak of gravity-induced flank collapse affecting the SEC cone, leading to the emplacement of a landslide (or debris avalanche) deposit. Finally, *Ferlito et al.* [2009], commenting our recent work [*Behncke et al.*, 2009], repropose their earlier [*Ferlito et al.*, 2007] scenario of a shallow intrusion from the SEC conduit, caused by unloading and decompression when a part of the SEC cone flank was removed ("sector collapse"), leading to the explosive opening of an eruptive fissure, which discharged a pyroclastic flow. An outstanding feature of this event is that it was not accompanied by any significant change in the seismic signal, which led us [*Behncke et al.*, 2009] to exclude the opening of an eruptive fissure. However, Ferlito et al. point out that seismic evidence alone does not rule out their scenario and cite the lack of seismic signals accompanying the start of the (rather voluminous, in terms of lava discharge, but purely effusive) 2004–2005 Etna eruption as support for their hypothesis. Finally, they describe what they interpret as the source fissure for the phreatomagmatic explosions and PDCs, which was the site of minor lava extrusion toward the end of the 16 November 2006 event.

[2] On their Web site, Ferlito et al. host a short (<2 min) clip excerpted from a 40:54 min long video recorded by G. Tomarchio, cameraman of the Italian public television RAI, featuring only the 1425 UT explosion and PDC. The integral, original version of that video (which was made available to INGV-CT immediately after the event) documents, among others, the presence of B. Behncke and INGV colleagues on site and shows a number of extremely similar explosions and PDCs over several hours prior to 1425 UT, only on a smaller scale. As for the 1425 UT event, the video spectacularly shows explosive activity but nothing proving the opening of an eruptive fissure, neither does it show any landsliding as surmised by *Norini et al.* [2009]. Our careful viewing of 1500 still photographs taken of the activity on that day, including nearly 1000 taken by INGV staff, plus other videos taken from different viewpoints (e.g., Movie S3 in the auxiliary material to our article) leads us to analogous conclusions. Videos and photographs document dozens of minor explosive, PDC-generating events before the major phreatomagmatic explosions and PDCs at 1425 UT. The mechanisms of these events were virtually the same throughout, differing only in their magnitude. All were caused by hot, flowing lava mixing with wet, hydrothermally altered rocks making up the SEC cone's flank that the lava was burrowing through.

[3] The "eruptive fracture" that *Ferlito et al.* [2009] refer to is a secondary feature, formed at the toe of a lava flow, which had flowed down the ESE side of the cone early on 16 November 2006 and was severed around noon by the progressive enlargement of the large scar eroded into the cone's flank. Draining of the lava within the active channel of the severed flow led to accumulation of lava at the cone's base, developing into a sort of bubble. For reasons unknown, this bubble drained during the late afternoon, yielding an extremely small flow. The pocket evacuated by this outflow subsided to become what Ferlito et al. interpret as an eruptive fissure, a single slightly elongate collapse depression, lying ~150 m northeast of the locus of the 1425 UT phreatomagmatic explosions, which is well visible in aerial photographs taken after the events under discussion (Figure 1). The lava flow that *Ferlito et al.* [2009] claim to have sampled is the secondary flow formed by the draining of the pocket. It has no whatsoever genetic relationship with the phreatomagmatic explosions and PDCs of 1425 UT.

[4] Another fundamental argument lies in the seismic record, and it is here that Ferlito et al. miss two major points. First, unlike the seismic scenario usually observed at Etna in more than three decades of monitoring [e.g., *Patanè et al.*, 2004], the start of the 2004–2005 lava effusion was *exceptionally* silent as many authors noted [e.g., *Burton et al.*, 2005; *Di Grazia et al.*, 2006; *Corsaro et al.*, 2009]. The onset of lava emission was indeed completely and unusually aseismic (in terms of volcano-tectonic seismicity, volcanic tremor changes, etc.), but it was also totally nonexplosive, due to the nearly complete depletion in gas of the magma. Therefore, this effusive episode stands in marked contrast with the 16 November 2006 activity. It should be noted that when new, gas-rich magma moved toward the surface at a later stage of the 2004–2005 lava effusion, the volcanic tremor amplitude markedly increased [*Di Grazia et al.*,

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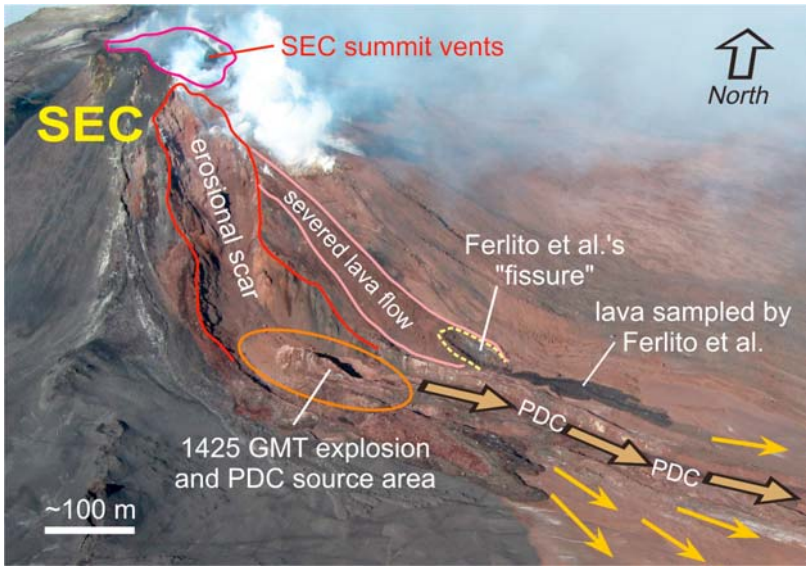

Figure 1. Aerial photograph taken on 18 November 2006, showing the discussed features: the large scar eroded into the southeast flank of the Southeast Crater cone by lava interacting with the wet rocks making up that flank, the site where the major explosions occurred at 1425 UT and the path of the resulting pyroclastic density current, and the location inferred by Ferlito et al. to be the source fissure of the explosions. This is actually a collapse feature formed in a lava flow emitted early on 16 November and later diverted into the growing erosional scar. The small dark lava flow emitted from this collapse depression is the lava sampled by Ferlito et al., in a location clearly different to that of the explosions that generated the pyroclastic density current. Photo courtesy of M. Neri and S. Calvari.

2006]. Second, *Ferlito et al.* [2009] refer to papers [e.g., *Cardaci et al.*, 1993; *Patanè et al.*, 2004] which deal with the relationship between volcano-tectonic (VT) seismicity and the triggering of eruptive activity at Etna. VT seismicity covers just a part of the information contained in a seismic record [e.g., *Chouet*, 1996; *McNutt*, 2000]), a detail which can be easily missed by nonexperts in seismology. There is indeed a variety of signals (e.g., long-period events, hybrid events, volcanic tremor, explosion quakes) related to the movement of fluids and/or magma, which can herald and accompany the opening of eruptive fractures. We did extensive cross-checking of the seismic record of the entire 2006 eruptive sequence, paying particular attention to episodes of new eruptive fissures opening. Each single event marked by the opening of new vents displaying some sort of explosive activity (this occurred during at least four of the paroxysms during the August–December 2006 eruptive sequence) shows conspicuous changes not only in the amplitude of the seismic (tremor) signal but also in the location of the centroid of the tremor source and frequency content, features amply discussed in our paper [*Behncke et al.*, 2009]. The migration of subsurface magma can thus be well documented if it is accompanied by degassing. We would also like to point out that the phreatomagmatic explosions and PDCs of 1425 UT occurred shortly after a conspicuous *drop* in the volcanic tremor amplitude [see *Behncke et al.*, 2009, Figure 8] and at the time of the explosions the amplitude remained low, contrary to the statements made by *Ferlito et al.* [2009]. The lack of changes in the seismic signals concurrent with the PDC is also evident in the spectrograms (in which the frequency content excludes the occurrence of any seismic signals associated with fracturing [see *Behncke et al.*, 2009, Figure 9]) and in the records of all the broadband stations considered by *Behncke et al.* [2009], notwithstanding their vicinity to the site of the PDC-generating explosions (EBEL and ECPN are located ~1 km from the SEC, at 2899 and 3050 m elevation above sea level, respectively).

[5] Finally, the hypothesis of magma uprise at the base of the SEC cone caused by unloading related to the removal of a major portion of the cone's flank, has been vested by *Ferlito et al.* [2007] in a volcanic sector collapse scenario similar to the catastrophic 1980 debris avalanche at Mount St. Helens. Volcanic sector collapse commonly takes place instantaneously, which is the contrary of what happened at the SEC on 16 November 2006. Thanks to our presence on site from the early morning onward, we were able to document how the removal of a portion of the flank of the cone occurred extremely slowly, over at least 5 h [cf. *Behncke et al.*, 2008, Figure 5]. The material involved in this displacement moved at best at 50–80 m h^{-1}, which is rather unlike the speed of volcanic debris avalanches. There was no such thing as a major landslide, and no such thing as a new eruptive fissure opening; what did happen was a very hazardous sequence of events, including phreatomagmatic explosions and quite low temperature but fast moving, dense pyroclastic density currents. Such volcanic phenomena deserve in-depth multidisciplinary studies, and the ongoing discussion underscores how much work is still necessary to better understand the dynamics of a versatile volcano such as Mount Etna.

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