VOLCANICLASTIC DEBRIS FLOW OCCURRENCES IN THE CAMPANIA REGION (SOUTHERN ITALY) AND THEIR RELATION TO HOLOCENE – LATE PLEISTOCENE PYROCLASTIC FALL DEPOSITS: IMPLICATIONS FOR LARGE SCALE HAZARD MAPPING

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Abstract

The Campania Region (Southern Italy) is characterized by the frequent occurrence of volcaniclastic debris flows that produce damage to property and loss of life (more than 170 deaths between 1996 and 1999). Historical investigation allowed the identification of more than 500 events during the last four centuries; in particular, more than half of these occurred in the last 100 years, causing hundreds of deaths. The aim of this paper is to identify debris flow proneness and to quantify hazard. To this end, we compared several elements such as the thickness distribution of pyroclastic fall deposits from the last 18 ka of the Vesuvius and Phlegrean Fields volcanoes, the slopes of relieves, and the historical record of volcaniclastic debris flows from AD 1500 to the present. Results show that flow occurrence is not only a function of the cumulative thickness of past pyroclastic fall deposits but also depends on the age of emplacement. Deposits younger than 10 ka (Holocene eruptions) apparently increase the risk of debris flows, while those older than 10 ka (Late Pleistocene eruptions) seem to play a less prominent role. This is probably in relation to different

climatic conditions, and therefore different rates of erosion of pyroclastic falls between the Holocene and the Late Pleistocene. Based on the above considerations, we compiled a large-scale debris flow hazard map of the study area in which five main hazard zones are identified: very low, low, moderate, high and very high.

Keywords: Debris flows; Explosive eruptions; Hazard mapping; Vesuvius volcano; Erosion; Campania Region; Southern Italy

1. Introduction

Debris flows are one of the most recurrent and dangerous natural hazards in volcanic terrains (e.g. Lowe et al. 1986; Newhall and Punongbayan 1996; Scott 1989; Scott et al. 1995, 2001; Pareschi et al. 2000a; Pierson 1985, 1995; Capra et al. 2004; Macías et al. 2004). The recurrence of volcanic debris flows usually increases during, and shortly after, an eruptive event (e.g. Waitt et al. 1983; Newhall and Punongbayan 1996; Capra et al. 2004). However, debris flows can also be generated by storms or earthquakes during volcanic quiescence (e.g. Scott et al. 2001; 2005; Pareschi et al. 2000a; Capra et al. 2004). Explosive eruptions disperse loose pyroclastic material over large areas, and volcaniclastic debris flows can potentially be triggered when the pyroclastic fall deposits have an appreciable thickness. One of the most striking examples of debris flows originated in volcanic terrains far from the volcanic edifice (15-20 km) is in the Campania Region (Southern Italy). Volcaniclastic debris flows occur frequently in this area, causing damage to property and loss of life. For instance, between 1996 and 1999 more than 170 people were killed by volcaniclastic debris flows in the areas bordering mountain slopes (Calcaterra et al. 2003a; Calcaterra and Santo 2004); the event of May 5-6, 1998 was responsible for 90% of injuries and fatalities (e.g. Pareschi et al. 2000a). Similar events have frequently occurred in the area in the last two centuries (Del Prete et al. 1998; De Riso et al. 1999; Migale and Milone 1998; Di Crescenzo and Santo 1999; Fiorillo et al. 2001; Calcaterra et al. 1999; 2003a, b). At least five events (1823, 1841, 1910, 1954 and 1998) killed more than 100 people (e.g. Migale and Milone 1998). Wide areas of the Campania Region have received pyroclastic deposits in the past (e.g. Cioni et al. 2003), and many sectors are potential sources of debris flows. However, to date no detailed analyses of the distribution of historical debris flows or of past pyroclastic falls have been completed. The relationship between debris-flow source areas and the age of the involved pyroclastic deposits is therefore unclear, as is the possible correlation with future hazards.

This paper analyses the distribution of recent/historical volcaniclastic debris and compares it with the dispersion of past pyroclastic fall deposits in order to gain insight on debris flow occurrence and hazard zonation.

2. Volcaniclastic debris flows in Campania

The volcaniclastic terrains which cover the Campanian Apennines derive from the explosive activity of the Somma-Vesuvius and Phlegrean Fields volcanoes (Santacroce 1987; Rosi and Sbrana 1987; Fig.1a,b; Table 1). The volcaniclastic cover of the hillslopes usually consists of alternating poorly- to well-preserved fallout beds, volcaniclastic colluvium and buried soils with variable amounts of bedrock material (e.g. Di Crescenzo and Santo 1999; Calcaterra et al. 1999, 2000; Zanchetta et al. 2004a, b). Volcaniclastic debris flows in the Campania Region are triggered by heavy or prolonged rainfalls (e.g. Onorati et al. 1999) on steep slopes (usually >25-30°, e.g. De Riso et al. 1999; Calcaterra et al. 1999; 2000; Pareschi et al. 2000a, 2002) that determine the formation of shallow landslides rapidly transforming into debris flows. This rapid transformation is driven by the high initial porosity and low bulk density of the volcaniclastic material deposited on the steep slopes (Zanchetta et al. 2004b). The high porosity and low density determine the initial contraction of soils after failure, thereby increasing the pore-water pressure and favouring liquefaction (Iverson et al. 2000). Destabilization of volcaniclastic terrains is usually favoured by progressive reduction of matrix suction, which plays an important role in increasing the stability of fine volcaniclastic material when it is moderately wet. However, the exact mechanism which leads to the destabilization of the fine-grained colluvial deposits and buried soil interbedded with coarser pyroclastic fall deposits is uncertain (Frattini et al. 2004). Moreover, local morphological conditions can increase the instability of the volcaniclastic terrain like the presence of man-made cuts, rock cliff or local topographic concavity. Once initiated, debris flows can increase their volume through channel scouring (bulking *sensu* Scott et al. 1995) and lateral collapse of soil on channel slopes (e.g. Calcaterra et al. 1999, 2000; Zanchetta et al. 2004b) and by the merging of different flows into a single slurry.

Debris-flow deposits comprise volcanic material in both the matrix and the coarse fraction, and contain variable amounts of bedrock clasts (e.g. Zanchetta et al. 2004b). The clay content is generally low (Zanchetta et al. 2003; 2004a, b; Sulpizio et al. 2006), and flows can be classified as non-cohesive debris flows (*sensu* Scott 1989; Vallance and Scott 1997).

3. Methods

3.1. Collection of historical data

In recent years many papers discuss available data on debris flow events in specific sectors of the Campania Region (e.g. Migale and Milone 1998; Del Prete et al. 1998; Cascini and Ferlisi 2003; Calcaterra et al. 2003b; Calcaterra and Santo 2004). All these data were collected, recompiled for this paper, then collated and checked to avoid incongruence and repetition. A debris flow database was created in which events were classified according to the municipality where they occurred, the date of occurrence and, when available (i.e. for the younger events only), cumulative rainfall at the time of occurrence. The database contains more than 500 debris flow events dating from AD 1540 to AD 1999 (Table 2). The database was inserted into an available geographical information system (GIS) of the area (Pareschi et al. 2000b; Bisson et al. 2002). The GIS contains a digital elevation model (DEM) derived from points and contour lines and calculated using a modified Delaunay approach (Favalli and Pareschi 2004).

3.2. Cumulative thickness of past pyroclastic fall deposits

Isopach data for the main explosive eruptions since 18 ka were obtained from literature and from georeferenced key geological sections (Table 1). These data were transformed into a digital format (point and line layers) containing information on the thickness (expressed in cm) of each eruption. A linear interpolation (TIN) and matrix elaboration were derived from these vector data. The final output was a grid with a cell size of 10 m containing the cumulative thickness of pyroclastic falls. Then, from this grid, the cumulative tephra isopachs were derived.

On the basis of the available literature data, the 0.1 m cumulative isopach was the thinnest considered isopach.

4. Results and discussion

Historical data is incomplete and the contemporary interpretations of the nature of past events are often faulty (e.g. Carrara et al. 2003). Only events of large magnitude and/or that produce great damage and loss of life have been recorded. Moreover, an event is not necessarily a single debris flow. An intense rainfall event can cause multiple debris flows over a large area or a number of slurries at different times in a single drainage basin as occurred during the May 1998 event. Such information can rarely be gleaned from historical sources. In this paper an event is defined as one or more debris flows if there is historical evidence in a certain municipality. This definition underestimates the actual number of individual debris flows.

Figure 1a shows the regional distribution of debris flow events over the last four centuries, while Figure 2 shows the distribution of events according to the year (Fig. 2a) and month of occurrence (Fig. 2b). The highest numbers of events occurred during the winter months, peaking in October, consistently with the distribution of rainfall for the area (Fig. 2c). Considering the whole data set, there has been about 1 event/yr, ranging from 0.2 events/yr in the 16th – 18th centuries to 2.3 events/yr in the 19th – 20th centuries. The increasing number of debris flow events from the 16th century to the first half of the 19th century can probably be mostly ascribed to the lack of information in the older portion of the record. However, this increase roughly occurs at the end of the Little Ice Age and after the unification of the Two Sicily Kingdom with the Italian Kingdom. Therefore the increased number of events may also in part be related to these environmental/ historical factors, implying changes of land use and/or climate conditions. In order to analyse the relationship between the distribution of debris flows events and that of pyroclastic fall deposits, the exact location of debris flow occurrences must be known. Such information is commonly not available from historical chronicles, however, so to overcome this problem and standardise analyses, the number of debris flow events for each municipality was attributed to the barycentre (centroid) of the polygon representing the municipality boundary and the tephra thickness considered was the average value computed in each municipality. Figure 3a shows the distribution of the number of debris flow events vs tephra thickness classes, obtained by this approach. This can introduce some bias, since a municipality can intersect different total thicknesses of pyroclastic fall deposits, and the debris flow distribution is obviously not homogeneous over each municipality. To assess the potential errors introduced through this simplification, we also considered the distribution of debris flows with respect to the mean thickness of pyroclastic fall deposits for each municipality, addressing areas with slopes $\geq 15°$ and $\geq 25°$ respectively. Figure 3b and 3c show the distribution of the number of debris flow events compared to classes of tephra thickness obtained by this approach. These slopes reasonably approximate the areas where debris flows occurred and/or expanded. The distribution of events with respect to the deposit thickness interval is fairly comparable in the three different cases (Fig. 3a,b,c), implying that the use of the average thickness over a municipality does not introduce significant errors during large-scale analysis. Negligible changes were infact observed in the distribution of the number of debris events as function of the average tephra thickness in each municipality as areas with different slopes are considered (Fig. 3a,b,c). When areas with thicknesses of pyroclastic fall are plotted against the percentage of events (Fig. 4), about 12% of events occurred below the cumulative isopach of 0.50 m, while only 4 events (about 1% of the total) occurred in areas <0.10 m. This indicates that areas characterised by very low pyroclastic fall accumulation since 18 ka do not contribute significantly to debris flows. More interestingly, ca. 60% of the events occurred within areas characterized by a cumulative thickness of ≤ 2.5 m, ca. 70% occurred in areas with a cumulative thickness of < 6 m, and 90% occurred in areas with cumulative thickness of < 7 m. This distribution indicates that debris flow occurrence is not just a function of the thickness of pyroclastic fall deposits in a certain area. This partly stems from the fact that the calculated thickness does not represent the total material currently available in the debris flow source areas, because part of this material was either removed by erosion or was only locally accumulated. Moreover, the distribution of Figure 4 can be affected by lack of historical data for certain areas. This could be the case for the apparent low occurrence of debris flow between 2.5 – 6 m of tephra thickness.

In Figure 5 the tephra thickness progressively accumulated since 18 ka on slopes ≥25° was plotted against the number of historical debris flow events. Interestingly, Figure 5 indicates that the areas covered by volcanic deposits older than the Mercato eruption (ca 8 ka, Fig. 1b, Table 1) did not contribute significantly to recent debris flows. Figure 5 also indicates that the areas recently affected by eruptions (e.g. since AD 1631 and AD 472) are not those with the highest number of debris flows events.

Despite the fact that the total calculated thickness of fallout does not represent the real thickness of volcaniclastic cover on steep slopes, these data indicate that the distribution of deposits from past eruptions can still provide some general indications useful for hazard assessment. As would be expected, the areas where the total thickness of past eruptions fall deposits is less than 0.1 m have mostly not been involved in the generation of debris flows (Fig. 4) in the recent past. These areas do not contain enough volcaniclastic deposits to generate debris flows. The lack of historical data for these areas also indicates that bedrock material (i.e. carbonates) does not have a relevant role in debris flow formation. The areas affected by the emplacement of pyroclastic fall from eruptions older than ca 10 ka play no particular role in driving historical debris flow recurrence, nor do they represent a future hazard. This because older deposits were substantially eroded from the source areas or stabilised. Stratigraphic analyses performed by Zanchetta et al. (2004a, b) on selected areas of the Campania Region indicate the absence of pyroclastic fall deposits older than Holocene on the slopes recently affected by debris flows (i.e. May 1998). In these areas, Holocene succession directly covers the carbonate bedrock. This corroborates the thesis that the pre-Holocene pyroclastic fall were almost completely eroded. According to the relationship observed in Figure 5, this conclusion may be extended to the entire Campania Region. Pyroclastic fall deposits younger than 10 ka (Table 1) are, instead, still partially stored in the source areas of debris flows, and their presence is a prerequisite for triggering future debris flows. The recurrence of explosive volcanic eruptions and their magnitude has produced a situation in which the source areas can be considered transport-limited basins according to the definition of Bovis and Jakob (1999). None of the debris-flow source material in these basins derives from local weathering of bedrock; it consists only of large volumes of potentially mobilized volcanic material. According to Jakob et al. (2005), basin channels have high sediment recharge rates, an important factor in controlling debris flow activity. The considered data indicate that this situation may have lasted throughout the Holocene. A very well documented example comes from the mainly dispersed southward (Sidgurdsson et al. 1985) pyroclastic fall deposits of the Pompei Plinian eruption (AD 79, Table 1). Those deposits largely cover the Sorrentina Peninsula (Fig. 1). The AD 79 pyroclastic fall dispersed to an area with no significant deposition from others eruptions. According to Di Crescenzo and Santo (1999), the deposits of the AD 79 eruption are still the main source of debris flows in the area. This indicates that after ca. 2 k.y. there is still enough material stored on the slopes.

A tentative large-scale hazard zonation was completed taking into account the following factors: the cumulative thickness of pyroclastic deposits, the age of eruption (younger or older than 10 ka) and slope. The latter factor is important in distinguishing between debris flow source areas and potential areas of inundation. For instance, areas with slopes greater than 25° can be reasonably considered to have the highest probability of initiating debris flows. Similarly, geological data on past debris flow events (e.g. Zanchetta et al. 2004a, Sulpizio et al. 2006), analysis of recent debris inundation areas, and geomorphological considerations (e.g. the presence of alluvial fans) can be useful in defining past inundation areas.

Figure 6 shows an example of a possible zonation map of the debris flow source areas. In this map, by: i) the 0.1 m inferred deposit isopach and ii) slopes greater/smaller than 25°, it is possible to distinguish: 1) Very Low hazard: areas with cumulative isopach tephra thicknesses of less than 0.1 m, or areas with thicker deposits but having slope of less than 6°. These show very low recurrence of debris flows; 2) Low hazard: areas with cumulative isopach tephra thicknesses ≥ 0.1 m containing only deposits older than 10 ka (i.e. Pomici di Base eruption); 3) Moderate hazard: areas with cumulative isopach tephra thicknesses ≥ 0.1 m containing only deposits younger than 10 ka and with slopes of less than 25°. These show occurrences of debris flows; 4) High hazard: areas with cumulative isopach tephra thicknesses ≥ 0.1 m containing deposits of both old and young eruptions and with slopes of less than 25°. These show occurrences of several debris flows; 5) Very high: areas with cumulative isopach tephra thicknesses ≥ 0.1 m containing Holocene or Holocene to Late Pleistocene deposits but with slopes > 25°. In this class, slope is the main factor differing from classes 3 and 4. Although this classification is only a preliminary hazard zonation, it demonstrates that volcanologic data on tephra dispersion from past eruptions can be useful in defining debris flow hazard zonation.

Concluding remarks

The large scale identification of debris flow hazard in volcanic areas can be achieved by collecting historical data and defining the cumulative dispersion of pyroclastic fall deposits. It is important to note that because of past erosion and redeposition, the cumulative thickness of original fall deposits revealed by isopachs mapping does not necessarily match the present-day thickness of volcaniclastic cover on slopes. There is no simple correlation between the cumulative thickness of tephra and recent debris flow events. The age of pyroclastic fall is an important factor controlling debris flow hazard. The main conclusions for the Campania Region are summarised as follows:

1) Areas in which cumulative deposition of pyroclastic fallout was less than of 0.10 m have a low probability of generating volcaniclastic debris flows.
2) Areas with thick pyroclastic fall deposits are not necessarily those in which debris flows are most common.
3) The role of pyroclastic fall deposits in determining the debris flow hazard seems to markedly decreases where deposits just older than 10 ka (Holocene eruptions) occur. Deposits older than 10 ka (Late Pleistocene eruptions) apparently play a marginal role in generating historical debris flows.
4) Since debris flow source areas in the Campania Region are well constrained, a simple slope-analysis can rapidly suggests areas where debris flows may occur.

The link between the age of pyroclastic fall deposits, their cumulative thickness and the historical occurrence of debris flows is useful in defining debris flow hazard areas. These analyses can also be useful in defining large areas of debris flow hazard when historical data are lacking.

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FIGURE

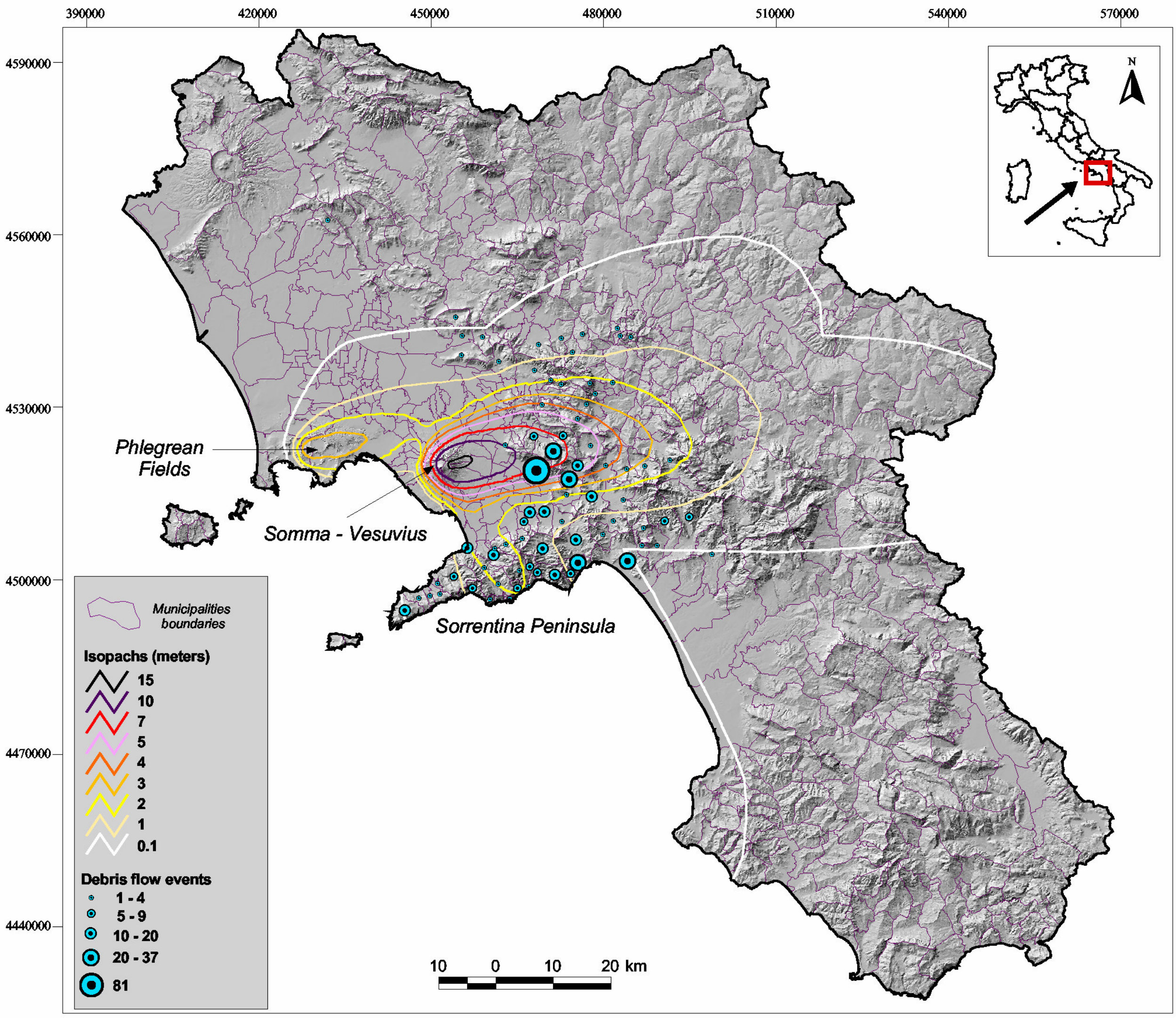

Fig.1- a) Location map. Thin violet lines are municipality boundaries. Coloured lines indicate the cumulative thickness of pyroclastic fall deposits produced by eruptions since 18 ka calculated through a matrix obtained from literature data. Blue points indicate the number of debris flows events for each municipality

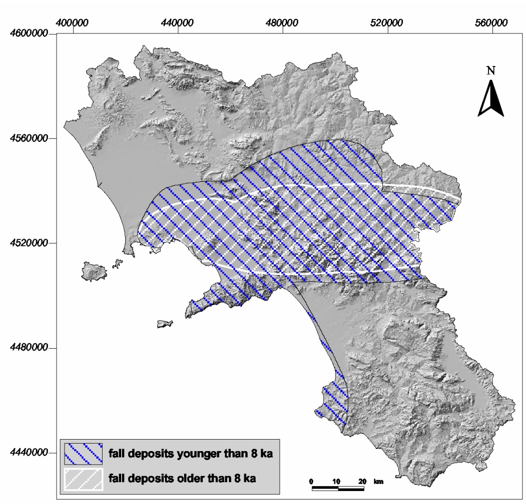

Fig.1- b) Areas covered by pyroclastic fall deposits younger and older than 8 ka (Mercato eruption), respectively

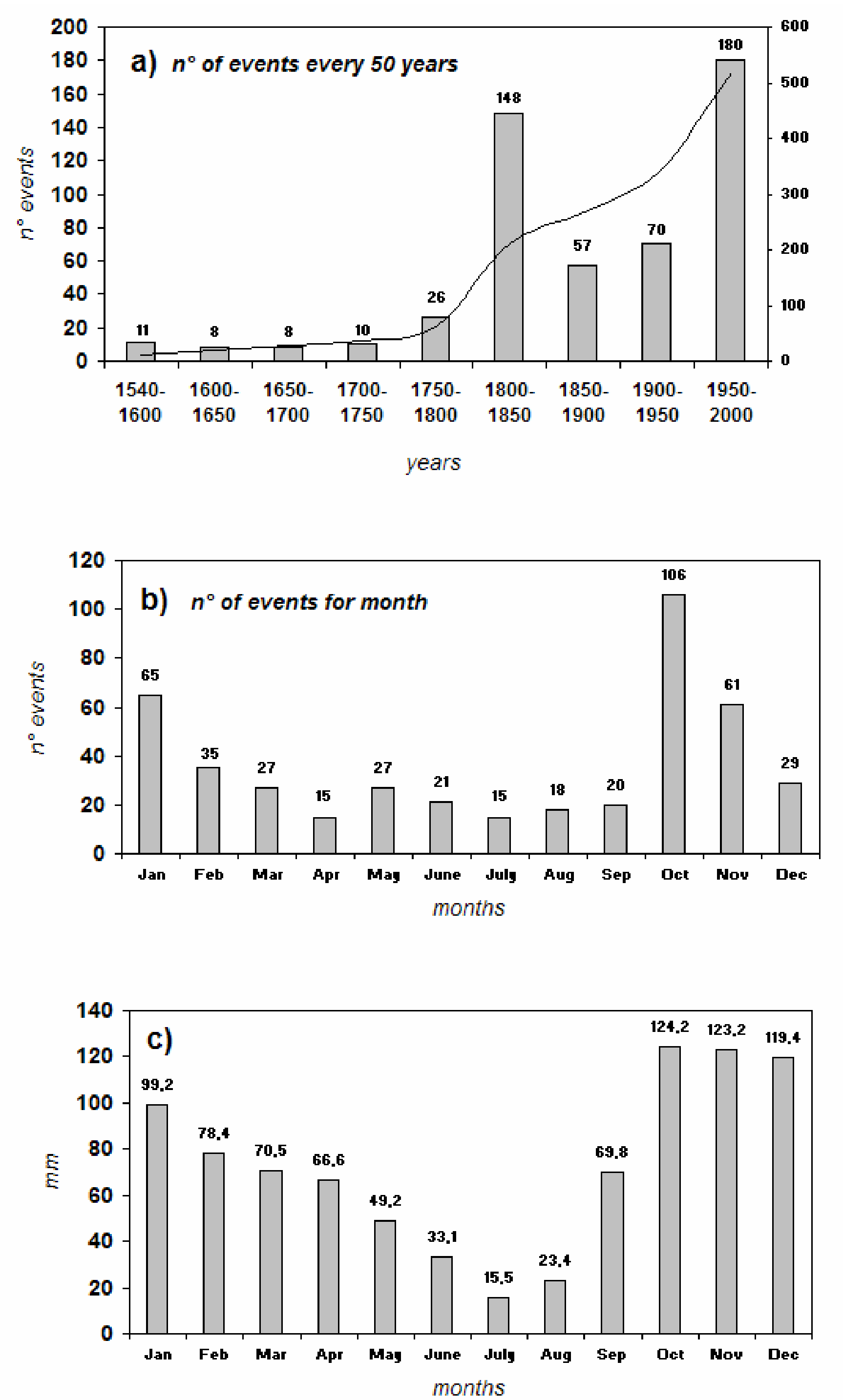

Figure 2 - a) Distribution of debris flow events in the last four centuries (left y-axes). Cumulative curve (right y-axes); b) Distribution of debris flow events with respect to the month of occurrence; c) Monthly mean precipitation (mm) for the period 1872-1966 from Napoli station (Palumbo and Pisano, 1966). The data are indicative because rainfall is locally strongly affected by orography.

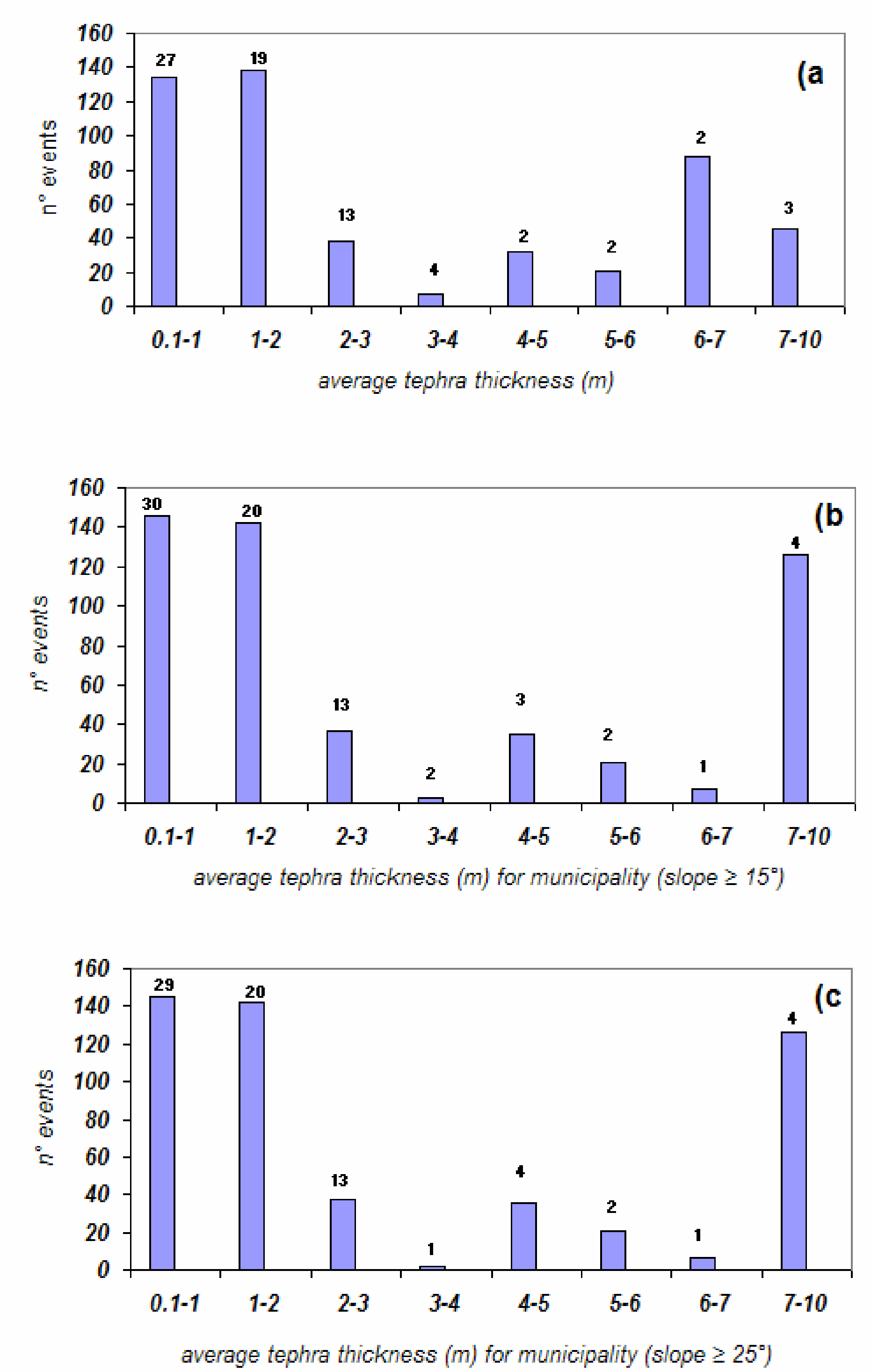

Fig. 3 - Distribution of debris flow events with respect to classes of pyroclastic fall thickness (meters). The pyroclastic fall thickness refers to a reference value calculated for each municipality where debris flow events occurred. In more details the reference value is:

a) The average tephra thickness referred to the whole area of each municipality

b) The average tephra thickness referred to slopes ≥ 15° of each municipality

c) The average tephra thickness referred to slopes ≥ 25° of each municipality

In all figures, the small black number at the top of the bars refers to the total number of municipalities affected by the considered debris flows. The greater number of debris flow events in the class 0.1-1 m, reported in Fig. 3b and 3c respect to Fig. 3a, is due to the presence of 4 municipalities with average pyroclastic fall thickness <0.1 m, but with higher average thickness (0.1 – 1 m) on slopes ≥ 15°.

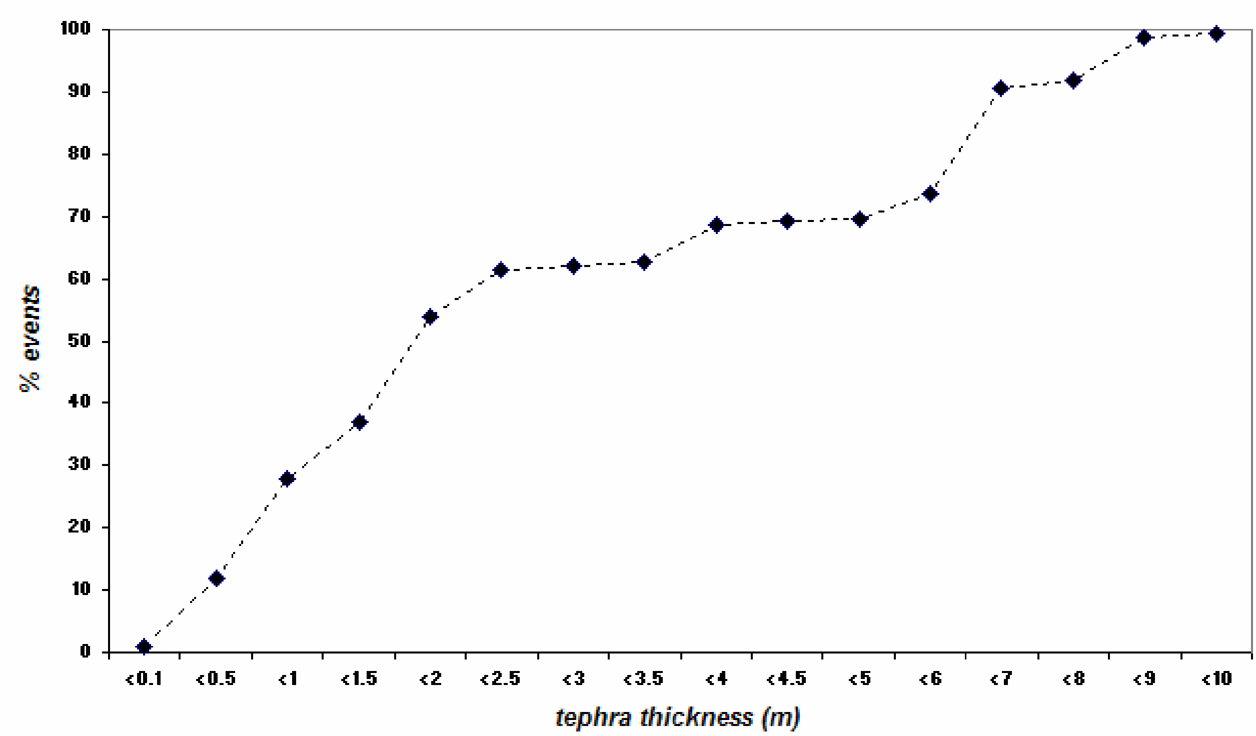

Fig. 4 - Distribution of events (percent of total) according to areas defined by the thickness of pyroclastic fall deposits

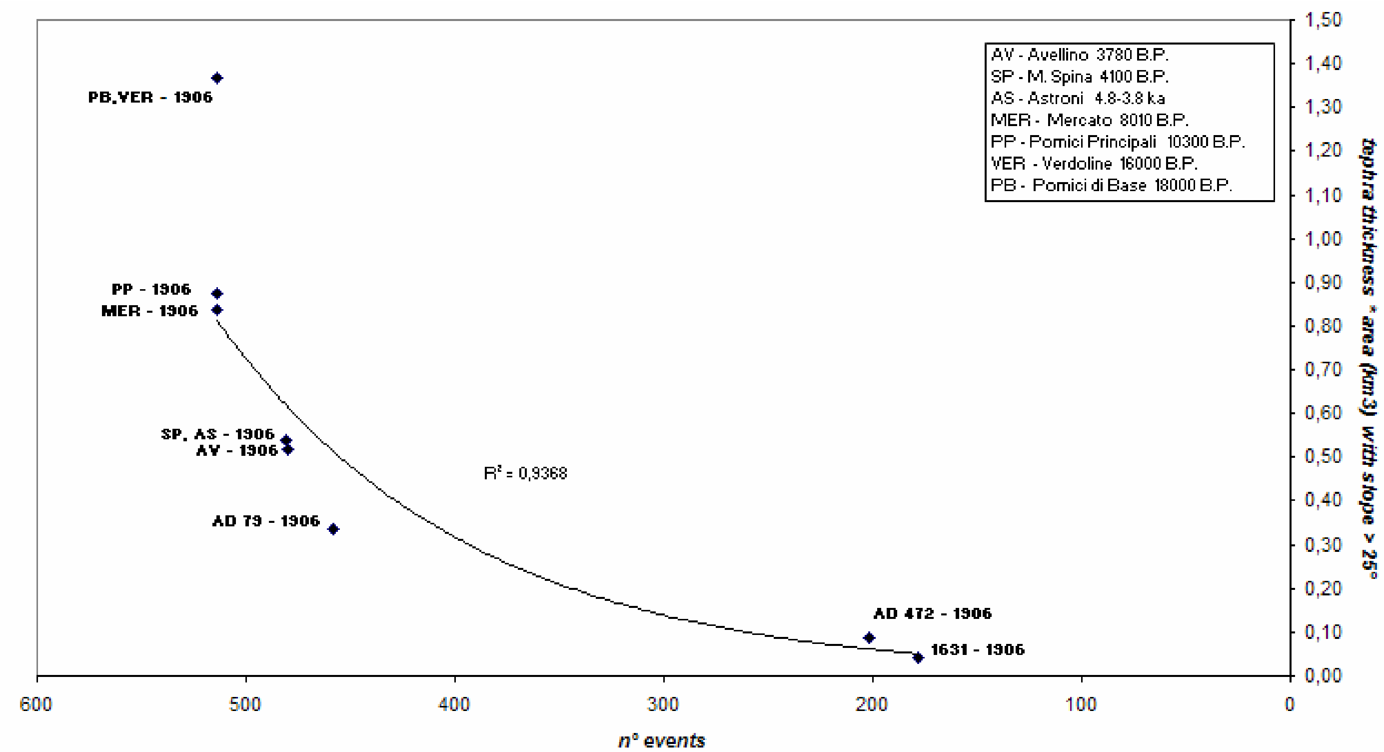

Fig. 5 - Relationship between the number of historical debris flow events and the volume of tephra progressively accumulated since 18 ka on areas with slopes >25°. Inset provides key to labelled diamonds. Each point, e.g. AV - 1906, plots the thickness accumulated against the number of events, for the period between the indicated eruption (AV=Avellino) and the year 1906

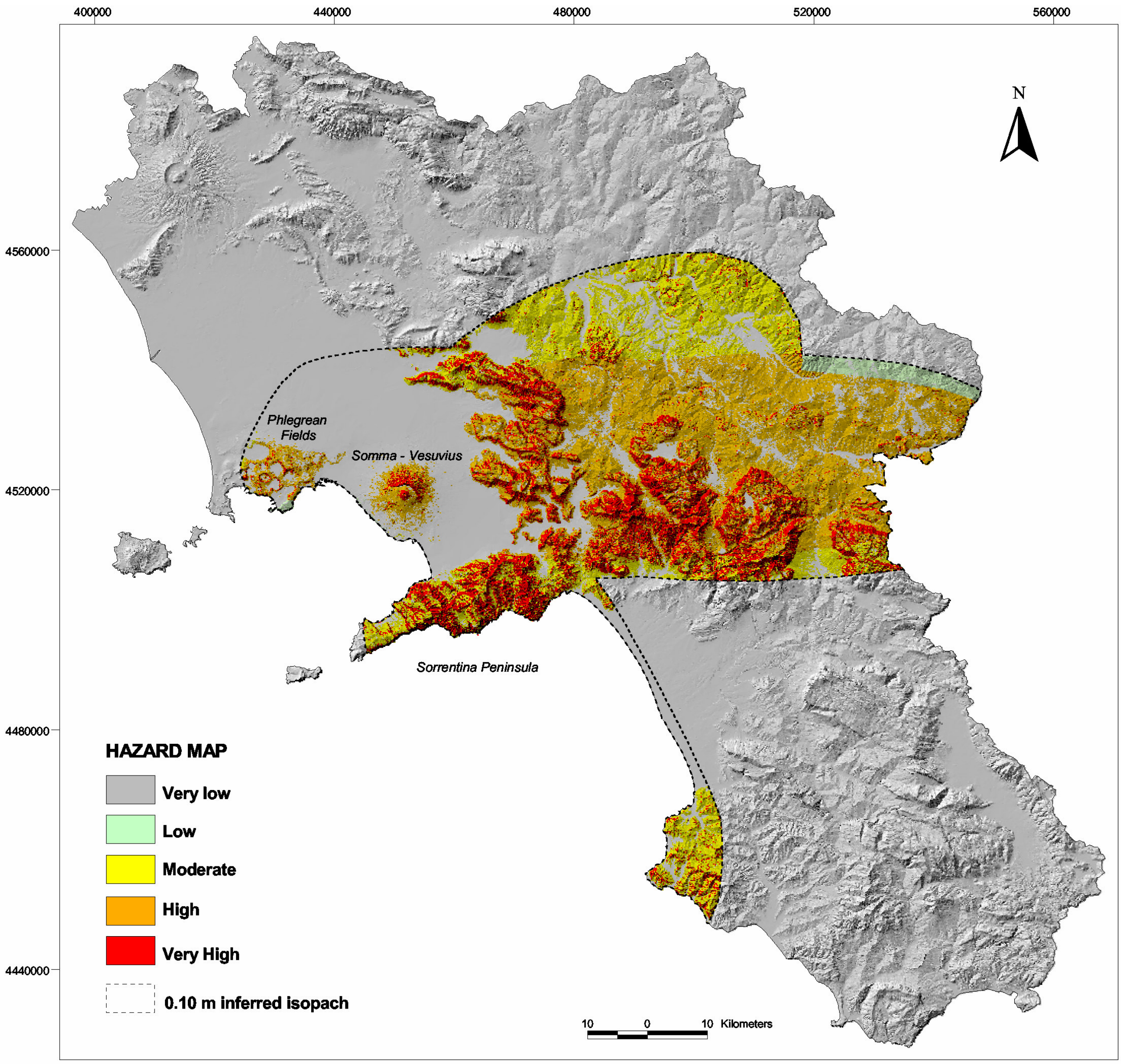

Fig. 6 – Proposed debris flow hazard map using slope, historical debris flow occurrence, the dispersion of fall deposits from Late Pleistocene-Holocene eruptions, and age of pyroclastic fall deposits

TABLE

Age	Dir. of Disp. Axis	VEI	section map
Vesuvius			
1906	50° NE	2-3	Arrighi et al. 2001
1822	140° SE	2-3	Arrighi et al. 2001
1730	110° E	1-2	Arrighi et al. 2001
1723	100° E	2-3	Arrighi et al. 2001
1707	110° E	1-2	Arrighi et al. 2001
1682	65° NE	2	Arrighi et al. 2001
1631	85° E	5	Rosi et al. 1993
AD 472	75° E	5	Sulpizio et al. 2005
AD 79	140° SE	6	Sigurdsson et al. 1985
AP	80° E	4-5	Andronico et al. 2002
Avellino 3780 B.P. (AV)	60° E	5-6	Cioni et al. 2002
Mercato 8010 B.P. (MER)	85° E	6	Zanchetta et al. 2004b
Verdoline 16.000 B.P. (VER)	70° E	5	Cioni et al. 2003
Pomici di Base 18.000 B.P. (PB)	80° E	6	Bertagnini et al. 1998
Phlegrean Fields			
M. Spina 4100 B.P. (SP)	70° E	5	De Vita et al. 1999
Astroni 4.8 - 3.8 ka (AS)	95° E	5	Isaia et al. 2004
Pomici Principali 10300 B.P. (PP)	80° E	5	Civetta et al.1998

Table 1 – Summary of eruptions in the last 18,000 years discussed in this paper. In the brackets are the abbreviations used to describe the eruptions

munycipality	n° events	years	bibliography	munycipality	n° events	years	bibliography
AGEROLA	1	1969-1998	1,2	MOSCHIANO	7	1841-1998	1,2,6
AMALFI	8	1751-1998	1,2	NOCERA INFERIORE	20	1607-1998	1,2
ARIENZO	1	1830-1998	1	NOCERA SUPERIORE	1	1935-1998	2
ATRANI	4	1540-1998	1	OSPEDALETTO D'ALPINOLO	1	1985-1998	1
AVELLA	1	1998	1,2,3	PAGANI	11	1674-1998	1,2,5
BAIANO	1	1973-1998	1	PALMA CAMPANIA	2	1962-1998	1,2
BARONISSI	2	1896-1998	1	PANNARANO	3	1960-1998	1
BRACIGLIANO	20	1813-1998	1,2,3	PELLEZZANO	3	1963-1998	1
CAPRIGLIA IRPINA	2	1976-1998	1	PETRURO IRPINO	1	1986-1998	1
CASOLA DI NAPOLI	1	1997-1998	1	PIANO DI SORRENTO	3	1934-1998	1,2
CASTEL SAN GIORGIO	1	1935-1998	1	PIMONTE	3	1963-1998	1,5
CASTELLAMMARE DI STABIA	14	1931-1998	1,2,5,7	POSITANO	7	1812-1998	1,2
CASTIGLIONE DEL GENOVESI	3	1582-1998	1	PRAIANO	4	1823-1998	1,2
CAVA DE' TIRRENI	13	1733-1998	1,2	QUADRELLE	3	1977-1998	1,2,3
CERVINARA	2	1903-1998	1,4	QUINDICI	37	1632-1998	1,2,3,6,7
CETARA	5	1762-1998	1,2	RAVELLO	8	1815-1998	1,2
CHIANCHE	1	1969-1998	1	ROCCABASCERANA	4	1938-1998	1
CONCA DEI MARINI	4	1896-1998	1,2	ROCCARAINOLA	2	1986-1998	1,2,3
CORBARA	4	1822-1998	1,5	SALERNO	32	1580-1998	1,2
DURAZZANO	1	1985-1998	1	SAN CIPRIANO PICENTINO	3	1580-1998	1
FISCIANO	1	1934-1998	1	SAN FELICE A CANCELLO	3	1830-1998	1,2,3
FORINO	1	1853-1998	6	SAN MANGO PIEMONTE	1	1899-1998	1
GIANO VETUSTO	1	1974-1998	1	SAN MARTINO VALLE CAUDINA	1	1991-1999	1
GIFFONI SEI CASALI	5	1580-1998	1	SANTA MARIA A VICO	1	1830-1998	1
GIFFONI VALLE PIANA	7	1580-1998	1	SANT'AGNELLO	2	1986-1998	1
GRAGNANO	13	1540-1998	1,2,5	SANT'EGIDIO DEL MONTE ALBINO	6	1823-1998	1
LAURO	6	1660-1998	1,6	SARNO	81	1625-1998	1,2,3
LETTERE	1	1997-1998	1	SCALA	3	1764-1998	1
MAIORI	20	1540-1998	1,2	SERINO	1	1993-1998	1
MASSA LUBRENSE	11	1939-1998	1,2	SIANO	31	1794-1998	1,3
MERCATO SAN SEVERINO	10	1607-1998	1	SIRIGNANO	2	1977-1998	1,2,3
MERCOGLIANO	2	1985-1998	1	SOLOFRA	1	1993-1998	1
META	1	1986-1998	7	SORRENTO	4	1900-1998	1
MINORI	7	1696-1998	1,2	SUMMONTE	1	1985-1998	1
MONTECORVINO ROVELLA	2	1935-1998	1	TORRIONI	1	1963-1998	1
MONTEFORTE IRPINO	1	1985-1998	1	TRAMONTI	12	1812-1998	1,2
MONTORO INFERIORE	3	1974-1998	1,2,3	VICO EQUENSE	8	1910-1998	1,2,5
MONTORO SUPERIORE	1	1992-1998	1	VIETRI SUL MARE	22	1773-1998	1,2

Table 2 – List of debris flow events organised according to municipalities. The main references are also reported: 1) Migale and Milone, 1998; 2) Del Prete and Del Prete, 1999; 3) Cascini and Ferlisi, 2003; 4) Fiorillo et al., 2001; 5) Calcaterra and Santo, 2004; 6) Calcaterra et al., 2003b; 7) www.sicimaps.irpi.cnr.it.