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Victims from volcanic eruptions: a revised database

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Abstract The number of victims from volcanism and the primary cause(s) of death reported in the literature show considerable uncertainty. We present the results of investigations carried out either in contemporary accounts or in specific studies of eruptions that occurred since A.D. 1783. More than 220000 people died because of volcanic activity during this period, which includes approximately 90% of the recorded deaths throughout history. Most of the fatalities resulted from post-eruption famine and epidemic disease (30.3%), nuées ardentes or pyroclastic flows and surges (26.8%), mudflows or lahars (17.1%), and volcanogenic tsunamis (16.9%). At present, however, international relief efforts might reduce the effects of post-eruption crop failure and disease, and at least some of the lahars could be anticipated in time by adequate scientific and social response. Thus, mitigation of hazards from pyroclastic flows and tsunamis will become of paramount importance to volcanologists and civil authorities.

Key words Natural disasters · Volcanic hazards · Society and eruptions · Volcanic risk

Introduction

Any close study of general volcano reference books reveals that they do not provide consistent data about the number of victims resulting from eruptions. Even in publications most directly concerned with volcanic hazards, the number and causes of death have often been compiled from such a variety of sources that uncertainties or misconceptions have arisen when drawing conclusions and interpreting them (e.g., Blong 1984; Latter 1989; Simkin and Siebert 1994; Scarpa and Tilling 1996). For instance, 15000 deaths have been cited as resulting from volcanogenic earthquakes at Mount Etna in 1169, and another 20000 in 1669, which account for 94% of the deaths quoted as resulting from such phenomena (Blong 1984, p. 114). In fact, the 1169 earthquake was tectonic, extending over a large part of Sicily and Calabria (Lombardo 1985), and the 1669 eruption caused no deaths directly, as various contemporary reports confirm (ref. in Tanguy 1996). Similarly, another authority notes that lava flows caused 18000 deaths at Vesuvius in 1631 and 10000 deaths at Etna in 1669, although he points out that these estimates are unreliable and probably too high (Tilling 1989). In fact, the 4000 victims generally acknowledged at Vesuvius in 1631 were almost entirely due to pyroclastic flows or surges (Rosi et al. 1993), and, as stated above, probably none occurred at all on Etna in 1669. Such misconceptions are clearly inevitable. The purpose of this paper is to make the best estimate of the number of victims from each major eruption of the past two centuries, in light of the most reliable contemporary and modern accounts presently available. Future compilers will undoubtedly bring further refinements to our conclusions. However, the fact that two dependable authorities have unwittingly propagated the errors noted above amply demonstrates the need for a critical selection among a mass of documents that display very different degrees of trustworthiness.

Selection of data

When gathering the data used in Table 1, we avoided catalogues of general interest that are often compilations whose sources cannot be verified. We found that

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Table 1

Eruption	Number of victims and cause(s) of death				References and Notes
	(1) Primary volcanic phenomena (P, A, D, L)	(2) Mudflow of Lahar (M)	(3) Volcanogenic Tsunami (T)	(4) Others (F, E, etc.)	
1783, Laki, Iceland	–	–	–	10521 (F, E)	Thorarinsson 1969; Thordarson & Self 1991;
	–	–	–	9367 (F, E)	Jackson 1982; environmental disturbances from a large basaltic eruption
1783, Asama, Japan	463 (P)	914	–	–	Aramaki 1956; (P) causing lahar
1790, Kilauea, U.S.A.	~ 80 (P)	–	–	–	Ellis, 1827; Dibble, 1843
	400–800 (P)	–	–	–	Desha,1922
	5405 (P)	–	–	–	Douglas, 1834
	≈ 100 (?)				Deaths caused by phreatomagmatic surges; data are quite uncertain, and 100 is a conservative number
1792, Unzen, Japan	9528 (D)	–	4996	–	Siebert et al. 1987
	9475 (D)	–	5843	–	Suzuki & Furuya 1992; collapse of old Mayuyama dome causing tsunami, no direct relation with the ongoing eruption at Mt. Unzen proper
1794, Vesuvius, Italy	3 (A) 15 (L)	–	–	1	Hamilton 1795, see text – one person killed by post-eruption CO_2 release
1812, Awu, Indonesia	–	963	–	–	Jansen 1856, and Wichmann 1893
1814, Mayon, Philippines	? (P)	1200	–	–	Punongbayan, pers. com. Part of the deaths probably resulted from (P)
1815, Tambora, Indonesia	12000 (A, P)	–	–	"many"	Raffles 1817, 1830
	10100 (A, P)	–	–	47825 (F, E)	Zollinger 1850, 1855; deaths from (F, E) in Sumbawa and Lombok alone
	≈ 11000 (A, P)	–	–	**≈ 49000 (F, E)**	see text
1822, Galunggung, Indonesia	4011 (P)	–	–	–	Roorda Van Eijsinga 1842, in Katili & Sudradjat 1984
1843, Etna, Sicily	–	–	–	59	Gemmellaro 1843; secondary phreatic explosion of a lava front
1845, Ruiz, Columbia	–	1000	–	–	Acosta 1846
1856, Awu, Indonesia	–	2806	–	–	Jansen 1856
1872, Vesuvius, Italy	12 (A?)	–	–	–	Two memorials at Vesuvius Observatory, and Franco 1872 + Palmieri 1872 (see text); some victims may have been asphyxiated by gas
1877, Cotopaxi, Ecuador	–	400	–	–	Wolf & Von Rath 1877

two kinds of documents were the most reliable: (a) reports from contemporary witnesses who were deeply involved in the event they describe; and (b) specific recent studies devoted to famous eruptions, and which make reference to the first type of data. This paper takes A.D. 1783 as its starting point for two reasons. Firstly, records more than two or three centuries old are either scarce or of low quality, and, moreover, in

Table 1 Continued

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	(1) Primary volcanic phenomena (P, A, D, L)	(2) Mudflow of Lahar (M)	(3) Volcanogenic Tsunami (T)	(4) Others (F, E, etc.)	
1883, Krakatau, Indonesia	?	–	36 417	–	Verbeek 1886, p. 79, including "a small part" of deaths from burns (P)
	3150 (P?)	–	–	–	Verbeek p. 104 (see text)
	1000 (P)	–	–	–	Furneaux, in Simkin & Fiske 1983 p. 84
	2000 (P)	–	–	–	Newspaper Java Bode, in Simkin & Fiske p. 127
	≈ **4600 (P)**	–	≈ **32 000**	–	see text
1886, Tarawera, New Zealand	153(A)	–	–	–	New Zealand Chronicle, 1886
1888, Bandai San, Japan	461(D)	–	–	–	Sekiya & Kikuchi 1890
1892, Awu, Indonesia	–	1532	–	–	Wichmann 1893
1902, Soufrière, St. Vincent	1565 (P)	–	–	–	Anderson & Flett 1903
	1680 (P)	–	–	–	HMSO, in Blong 1984, p. 97
1902, Montagne Pelée, Martinique	**28 600 (P)**	≈ **400**	–	–	Lacroix 1904, 1908; Chrétien & Brousse 1988, see text
1902, Santa Maria, Guatemala	2000 to 3000 (A?)	–	–	5000 to 10 000 (E)	Anderson 1908
	–	–	–	7000?	Anonymous 1902
	"hundreds"	–	–	?	Sapper 1903
1906, Vesuvius, Italy	213 (A) 3 (L)	–	–	2	Mercalli 1907; deaths mostly resulted from roof collapse, 2 people killed by post-eruption CO_2 release
1911, Taal, Philippines	1335 (P)	–	?	–	Pratt 1911; some victims from tsunamis
	1400 (P)	–	–	–	Worcester 1912
1919, Kelud, Indonesia	–	5110	–	–	Van Bemmelen 1949
1929, Santiaguito, Guatemala	5000? (P)	–	–	–	Mercado & Rose 1988
1930, Merapi, Indonesia	1369 (P)	–	–	–	Van Bemmelen 1949
1937, Rabaul, Papua N. Guinea	507 (A, P)	–	–	–	Johnson & Threlfall 1985
1944, Vesuvius, Italy	26(A)	–	–	2	Gasparini & Musella 1991; two children killed by steam explosion at the lava front
1951, Lamington, Papua N. Guinea	2942 (P)	–	–	–	Taylor 1958
1951, Hibok-Hibok, Philippines	500 (P)	–	–	–	Macdonald & Alcaraz 1956
1953, Ruapehu, New Zealand	–	151	–	–	Healy, in Thompson et al. 1965
1963, Agung, Bali, Indonesia	820 (P) 155 (A)	163	–	–	Suryo 1981

Table 1 Continued

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	(1) Primary volcanic phenomena (P, A, D, L)	(2) Mudflow of Lahar (M)	(3) Volcanogenic Tsunami (T)	(4) Others (F, E, etc.)	
1966, Kelud, Indonesia	1 (P)	211	–	–	Suryo 1985
1968, Arenal, Costa Rica	78 (P)	–	–	–	Melson & Saenz 1968
1977, Nyiragongo Zaïre	600? (L)	–	–	–	Tedesco, pers. com.
1980, Mt St. Helens, U.S.A.	57 (P)	–	–	–	Peterson 1988
1982, El Chichon Mexico	> 2000 (P)	–	–	–	Sigurdsson et al. 1984; Tilling 1989
1985, Ruiz, Columbia	–	21100 22000 25000 **≈23000**	–	–	Voight 1990 Herd et al. 1986 Naranjo et al. 1986 Voight, in Scarpa & Tilling 1996, p. 719 (see text)
1990, Kelud, Indonesia	35 (A)	–	–	–	GVN Bull. 1990, and VSI internal report
1991, Unzen, Japan	43 (P)	–	–	–	Yanagi et al. 1992
1991, Pinatubo, Phillipines	359 (A)	143	–	700 (E)	Pinatubo Obs. Team 1991, and GVN Bull. 1991, 1992; most of the deaths by (A) resulted from roof collapse
1993, Mayon, Philippines	75 (P)	–	–	–	GVN Bull. 1993
1994, Merapi, Indonesia	64 (P)	–	–	–	Mas Atje et al., 1997
1996, Manam, Papua N. Guinea	13 (P)	–	–	–	GVN Bull. 1996
1997, Soufriere Hills, Montserrat	19 (P)	–	–	–	Montserrat Volcano Observatory scientific report 68, July 1997

Total : 59500 (P) + 9962 (D) + 9,206 (A) + 618 (L) + 37993 (M) + 37420 (T) + 67,144 (F, E) + 64 (others) = 221907
%: 26.8 (P) + 4.5 (D) + 4.1 (A) + 0.3 (L) + 17.1 (M) + 16.9 (T) + 30.3 (F, E) + 0.03 (others) = 100.03

(A) = Ashfall, including ballistic projectiles
(P) = Pyroclastic flows or surges ("nuées ardentes"), and magma-generated sector collapse
(D) = Debris avalanche (non-magmatic sector collapse)
(L) = Lava flow
(M) = volcanic Mudflow ("lahar")
(T) = volcanogenic Tsunami
(F, E) = post-eruption Famine and Epidemie disease
The data of various authors have been averaged for general totals and percentage calculations. **Bold characters,** however, indicate the most probable numbers of victims for the cases discussed in the text

many countries the "historical period" does not encompass a larger span of time. Secondly, 1783 is the date of the Laki eruption in Iceland, the greatest witnessed outpouring of basaltic lava and the only one that resulted in, albeit indirectly, a large number of victims (e.g., Thorarinsson 1969). The same year, furthermore, a lethal eruption of Asama Volcano occurred in Japan (Aramaki 1956).

From 1783 onward, Table 1 is probably complete for recorded eruptions involving 400 or more fatalities. It was clearly impossible to include every historical eruption since 1783 that caused a smaller number of victims, but such cases would have very little influence on the general conclusions. However, we have included those eruptions responsible for more than ten deaths in the past decade and, also, some other previous outbursts for which misconceptions have arisen, although they caused relatively few casualties. For instance, the 59 deaths of the 1843 Etna eruption – the most deadly event thus far reported for this volcano – are commonly attributed to a "lava flow," whereas they actually resulted from a secondary phreatic explosion when a lava snout slowly advanced over wet ground (Gemmellaro 1843; no evidence supports the other popular belief that the steam explosion might have been caused when the lava boiled the water of a cistern).

Fatalities caused by lava flows themselves, i.e., persons burned alive and overwhelmed by the lava, are very few. Sir William Hamilton (1795) reports that the 1794 lava flow of Vesuvius killed 15 bed-ridden people at Torre del Greco. At Vesuvius again, in 1872, it is often said that 22 young people were engulfed in the lava. In fact, the contemporary reports (Franco 1872; Palmieri 1872) show that they were surprised by the opening of an eruptive fissure and at least a dozen of them, whose names appear on two memorials near the Observatory, were killed by ballistic projectiles or asphyxiated by gas. According to Diego Franco, the only scientist who witnessed this event, there was no lava flow at the time of the accident, and the outpouring of liquid lava began more than 4 h later (those lava flows may have buried, however, some of the corpses that were abandoned when the badly injured survivors hastily retreated). The only example in which lava flows killed more than a few persons could be that of Nyiragongo in 1977, when exceptionally fluid nephelinitic flows might have burned to death as many as 600 people (D. Tedesco, pers. commun.). In this context, it must also be recalled that lava flows have often been confused with pyroclastic flows at many volcanoes in older eruptions.

Discussion

Particular efforts were focused on three of the most lethal volcanic disasters in human history, i.e., Tambora (1815), Krakatau (1883) and Montagne Pelée (1902), for which the available documents were re-examined. Thus, the figure commonly cited in modern literature of 92 000 deaths at Tambora (Sumbawa Island, Indonesia) comes from an inaccurate interpretation by Petroechevsky (1949) of data from Zollinger (1855) and Junghuhn (1854). Petroechevsky did not take into account the 10 000 deaths from starvation estimated by Zollinger on the neighboring island of Lombok and merely replaced them by approximately 44 000 indicated on this same island by Junghuhn. However, Junghuhn did not make any specific study himself and relied on Van den Broeck (1834), who alludes in general terms to the eruption and does not give any precise number of victims. This figure of 44 000 deaths in Lombok thus appears to be entirely unfounded. The only reliable data, therefore, remain those published by Raffles (1817, 1830) and especially by Zollinger (1850, 1855), who himself spent several months in Sumbawa and was able to make the best estimates. It is quite possible that the actual number of victims from famine and disease may have exceeded the total of 47 825 calculated by Zollinger (1850, 1855) in Sumbawa and Lombok alone, because evidence of disease and crop failure linked to the eruption was reported in Bali and even Java, but we have no means of evaluating them. In Table 1, however, we tentatively suggest a round number of 11 000 deaths from direct volcanic effects and approximately 49 000 others because of post-eruption famine and epidemic disease.

The 1883 Krakatau disaster is famous for its giant tsunamis, which are thought to have claimed 36 417 lives (Verbeek 1886). However, there is evidence that 1000–2000 of the victims died from burns inflicted by "nuées ardentes" (pyroclastic flows or surges) in southeast Sumatra (Simkin and Fiske 1983; Carey et al. 1996). Moreover, the islands of Sebesi and Sebuku lay between Krakatau and southeast Sumatra, directly in the path of these very nuées ardentes and tsunamis. Nobody survived out of the population of 3150 on these islands (Verbeek 1886, p. 104). It is thus impossible to estimate the proportion of deaths attributable to either tsunamis or nuées ardentes. However, as in southeast Sumatra, the islanders were probably able to take refuge in the hills from the tsunamis. All things considered, we suggest that 4000–5000 deaths should best be ascribed to pyroclastic flows or surges and approximately 32 000 to the tsunamis themselves (Table 1).

At Montagne Pelée, Lacroix deduced that all the 1902 eruptions caused approximately 29 000 victims by comparing official reports and census returns before and after these events (Lacroix 1904, 1908). This figure is often misinterpreted in two ways. It is taken as the death toll in Saint-Pierre itself, and it is attributed solely to the great nuée ardente of 8 May 1902. However, Lacroix included in his figure those killed by mudflows (lahars), which caused 23 casualties on 5 May at the Guérin factory and approximately 400 others early on 8 May at Le Précheur (Chrétien and Brousse 1988). Then, on 8 May, the great nuée ardente killed approximately 300 inhabitants of Le Précheur who had taken refuge on a hill 1 km nearer Saint-Pierre (Ariès et al. 1981) and an unknown number of people at Sainte-Philomène, just to the north, and at Le Carbet, just to the south of Saint-Pierre. Finally, on 30 August, at least 1000 people were killed in the Morne Rouge by the last lethal nuée ardente. Thus, it must be concluded that (a) the fatalities in Saint-Pierre and its suburbs scarcely reached 27 000, and (b) the nuées ardentes themselves claimed a maximum of approximately 28 600 lives.

Even where the estimates given by individual authors are not rounded off, it is important to recognize that the precision of the numbers of fatalities is more apparent than real. In most eruptions, in most countries, for most of the period under consideration, reliable population statistics before and after disasters were not available, and there was no legal requirement to register births and deaths. This was the case, for example, in the Dutch East Indies during the nineteenth century, where so many lethal eruptions occurred. Even when basic statistics were available, as in Martinique, problems have still arisen. Thus, in the absence of reliable data, the stated numbers of victims can only be crude estimates – and the greater this number, the wider the margin of possible error. Another difficulty lies in the fact that early estimates have subsequently been repeated by various authors, and we have reported only what we feel to be the primary reliable reference, although some hasty and unfounded exaggerations have been omitted. Despite these precautions, it remains difficult to decide between different data, even for recent eruptions. For example, in his comprehensive article on the 1985 Nevado del Ruiz catastrophe, Voight (1990) cites 21 100 victims, whereas other works (Herd et al. 1986; Naranjo et al. 1986) indicate a range between 22 000 and 25 000. Although Voight acknowledges the round number of 23 000 in a subsequent publication (Voigt, in Scarpa and Tilling 1996, p. 719), a great uncertainty still remains. For calculations shown at the bottom of Table 1, therefore, and except for the few cases reviewed above, where our best estimates are indicated in bold characters, we have averaged data from conflicting sources for each volcanic event.

Column 1 of Table 1 shows that deaths resulting from primary eruptive phenomena are mainly caused by pyroclastic flows (P) and ashfall (A). It is not always easy to distinguish between them, and, for some eruptions (e.g., Tambora, 1815), we have had to assign arbitrarily an equal number of those killed either by (A) or (P). In the same column are reported the deaths from debris avalanches (D), this figure being here restricted to non-magmatic sector collapse, such as occurred at Mount Unzen in 1792 or Bandaï San in 1888. Fatalities resulting from magma-generated debris avalanches (e.g., Mount St. Helens, 1980) are reported as (P), although there is often a very low magmatic component in such avalanches. In our opinion, the distinction between magmatic and non-magmatic debris avalanches is important in terms of prediction, because (D) does not involve the usual volcanic precursors and may be better ascribed to mere landslides. For the same reasons it would be useful to distinguish between primary lahars (M, column 2), i.e., those directly generated by a volcanic event (crater lake eruption, melting of glacier by hot materials, pyroclastic flow entering the drainage system, etc.), and secondary lahars due to heavy rainfall, which may occur for years after the eruption. However, the secondary lahars are generally not recorded in accounts written just after the eruptions, and many lahars produced during eruptive periods themselves may be merely caused by rainfall, so that distinction between primary and secondary lahars could be a matter of debate. For the same reason we have not reported steam explosions occurring in geothermal areas, nor poisonous gas release from crater lakes, because they do not result from true volcanic phenomena (e.g., Ladbury 1996).

The indirect effects of eruptions in general, although they are sometimes well constrained as in Iceland in 1783, still remain the subject of gross approximations in many other cases. We have noted the large uncertainty regarding the famine and disease around Tambora, and an even greater degree of imprecision should be noted for the Santa Maria eruption in Guatemala in October 1902. Similarly, Ritter Island (Papua New Guinea) collapsed in 1888, causing a tsunami that produced a large, though virtually unknown, number of victims (Johnson 1987). It is likely that in many countries with a short modern history, deaths ascribed to eruptions and their aftermaths were unknown or unrecorded. A further example is given by the 1790 phreatomagmatic surges of Kilauea (Hawaii), which are thought to have caused between 80 and several hundred deaths (D. Swanson, pers. commun.) at a volcano noted for its generally quiet behavior. The uncertainty in this figure comes from the fact that there is no contemporary written record of this event.

Conclusion

For all these reasons the total of 221 907 deaths in the volcanic eruptions cited here certainly represents a minimum. Of these, most have resulted from famine and epidemic disease (30.3%) followed by pyroclastic flows (26.8%), lahars (17.1%), and tsunamis (16.9%), these four causes accounting for 91.1% of the deaths. On the other hand, only four eruptions (Tambora, 1815; Krakatau, 1883; Montagne Pelée, 1902; and Ruiz, 1985) account for more than 66% of the deaths, and each event involved a different main cause: famine, tsunami, pyroclastic flow, and lahar. These facts suggest at least two conclusions:

1. The span of little more than 200 years is dramatically short when compared with the geologic timescale. However, even if the records of millenia of human history were available, it would be unlikely to encompass the effects of huge eruptions comparable to that of Toba (Sumatra, Indonesia), which happened approximately 75 000 years ago, or to the basalt floods millions of years ago.
2. Humanity itself is rapidly growing and becoming more sophisticated, thereby increasing its vulnerability to volcanic hazards. For instance, had the Montagne Pelée eruption been delayed for only 50 years, Saint-Pierre would have continued to grow and the death toll could have reached 100 000. An ordinary ignimbrite eruption, such as that of Taupo (New Zealand, ca. 186 A.D.), could produce millions of casualties if it were to take place today in a densely populated urban area. Several authors (Peterson 1986; Tilling and Lipman 1993) estimate that 350–500 million people now live in volcanic zones and will be at risk during future eruptions.

Conversely, some causes of death from volcanoes that had a major impact only two centuries ago, such as famine and epidemic disease, would be considerably reduced at present by international relief and assistance. The lethal effects of lahars could perhaps be anticipated by developing warning systems, and the risk itself could be reduced by long-term urban planning that would avoid concentrating dense populations in valleys and deltas or at least provide shelters on higher ground. Similar means might also be used against tsunamis, though with greater difficulty because of the much larger areas that would have to be protected. The effects of the less energetic nuées ardentes could be mitigated, and loss of life reduced, by using the same precautions of long-term urban planning (strong buildings, subways, etc.), rather than developing evacuation plans that are usually difficult to implement. We must recognize, however, that people easily forget the threat and that society is not ready to pay the price for protection against geologic events which have very long recurrence intervals. Whatever the effective response, pyroclastic flows and tsunamis will become in the future the two most lethal volcanic agents, especially during cataclysmic, ignimbrite eruptions, for which geophysical precursors have yet to be observed.

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