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Perceptions of hazard and risk on Santorini

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Abstract

Santorini, Greece is a major explosive volcano. The Santorini volcanic complex is composed of two active volcanoes—Nea Kameni and Mt. Columbo. Holocene eruptions have generated a variety of processes and deposits and eruption mechanisms pose significant hazards of various types. It has been recognized that, for major European volcanoes, few studies have focused on the social aspects of volcanic activity and little work has been conducted on public perceptions of hazard, risk and vulnerability. Such assessments are an important element of establishing public education programmes and developing volcano disaster management plans. We investigate perceptions of volcanic hazards on Santorini. We find that most residents know that Nea Kameni is active, but only 60% know that Mt. Columbo is active. Forty percent of residents fear that negative impacts on tourism will have the greatest effect on their community. In the event of an eruption, 43% of residents would try to evacuate the island by plane/ferry. Residents aged >50 have retained a memory of the effects of the last eruption at the island, whereas younger residents have no such knowledge. We find that dignitaries and municipal officers (those responsible for planning and managing disaster response) are informed about the history, hazards and effects of the volcanoes. However, there is no "emergency plan" for the island and there is confusion between various departments (Civil Defense, Fire, Police, etc.) about the emergency decision-making process. The resident population of Santorini is at high risk from the hazards associated with a future eruption.

Keywords: volcanic hazard; risk; perception; santorini

1. Introduction and aims of the study

Humans have lived within the shadow of active volcanoes from the earliest periods of social and kinship organization. Volcanoes provide fertile soils, mineral riches, hydrothermal power and are hypnotically attractive in terms of their aesthetic beauty. However, an erupting volcano may be, at best, a cause of a short-lived inconvenience to normal activity and, at worst, a cause of massive loss of lives, destruction to rural and urban infrastructures and economies or to the destruction of entire communities or civilizations (Marinatos, 1939; McCoy and Heiken, 2000; Tor-

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rence and Grattan, 2002 and references therein; Vitaliano, 2002). It has even been argued that the human species came close to failing (total number of humans as low as 3000–10,000 individuals) due to the impacts of the massive Toba eruption circa 73,500 BP (Rampino and Ambrose, 2000).

Following the eruptions of Mt. St. Helens (1980), Nevado del Ruiz (1986) and Mt. Pinatubo (1991), scientists, policy makers and disaster/emergency planners and the public have become aware of the dangers that volcanoes may pose. Volcanologists working on a variety of projects during the 1990s International Decade for Natural Disaster Reduction (IDNDR) gained experience in the light of what Chester et al. (2002) referred to as "a paradigm shift" in the understanding of hazard assessment based upon changes in the social theory of natural hazards. The theoretical framework of hazard, risk and vulnerability is well explored by Alexander (2000 and references therein).

Until recently, the vast majority of volcano-related published work has been concerned with "pure research rooted in the earth sciences" (Chester et al., 2002). This is a pity since recent volcano-related emergencies demonstrate that there is a clear relationship between the success of dealing with an emergency and the degree to which policies focused on hazard reduction were already in place prior to that emergency (Paton et al., 1998; Kokelaar, 2002). European progress in addressing socially aware risk assessment and human vulnerability appears to have been disappointing. The proportion of published outputs concerned with applied volcanology and, in particular, that which relates to hazard, risk, vulnerability and hazard mitigation and disaster planning remains depressingly low. Much of what is available is referred to as "grey literature"—that is, official reports, conference papers and Web pages that are not widely disseminated. For an excellent discussion of these issues, interested readers are referred to Chester et al. (2002).

In spite of the lack of research into the social aspects of volcano-related hazards, interest has increased in undertaking risk assessments and in determining vulnerability of populations. From this research, it has been realized that risk, the interface between hazard (the probability of an area being affected by a hazardous eruption) and vulnerability (the susceptibility of the human and biophysical systems to a hazardous event), is increasing (i) as a consequence of the attractiveness of volcanoes and the draw of people to their environs but, more importantly, (ii) as a result of cultural, economic and social factors at work within individual countries' growth and development programmes coupled with the fact that development seldom incorporates civil protection measures with the same level of resource allocation that public education and health programmes receive (Alexander, 2000; Chester et al., 2002).

Hazard reduction will depend not just on an understanding of process per se, but also on the impacts these will have on: (1) the wider biophysical environment and (2) the fine detail of the socio-economic conditions and cultural milieu of the society in question.

Interestingly, it is frequently implied that developed countries have a lower intrinsic vulnerability to the impacts of natural hazards. That is, they will be less affected because: they have more resources; monitoring and warning systems are operational; that the political will and legislative frameworks to protect communities are in place; and citizens are more readily educated, informed and aware of the risks.

Santorini (a part of the Cyclades) is located within the Aegean Sea, Greece. Santorini is 75.8 km^2 and is a complex of five islands known as Thera, Therasia, Aspronisi, Palaea Kameni and Nea Kameni. Palaea Kameni and Nea Kameni constitute the active intra-caldera volcanic field. Mt. Columbo is a submarine volcanic centre located 6.5 km NE of the main island. Santorini was chosen as one of the European Union/European Science Foundation IVECO Laboratory volcanoes within the IDNDR.

Santorini has been the focus of significant volcanological research because of interest in its paroxysmal explosive eruption of circa 3500 BP that, according to some, had a terminal impact on the Minoan civilization (Marinatos, 1939; McCoy and Heiken, 2000). As a consequence of this interest, Santorini has some of the most complete and detailed geological, petrological and volcanological information of any European volcano. On the basis of much research, it has been demonstrated that

Santorini is potentially one of the most dangerous volcanoes in Europe (Druitt et al., 1999).

On the basis of the introduction provided above, our study aims:

(1) to note the range of volcanic hazards that might be expected to accompany a "most probable maximum" magnitude eruption;
(2) to investigate the existing provision of the "Xenocratis Emergency Plan" of the island and to determine its strengths and weaknesses;
(3) to use a questionnaire survey to investigate the vulnerability of the population by determining their level of awareness, perception and knowledge and;
(4) to make a series of recommendations to raise community awareness.

2. Santorini—an introduction

2.1. Tectonic and geological framework

Santorini, part of the Hellenic Volcanic Arc, is located in southern Greece (Fig. 1). The Hellenic Arc is the surface expression of the subduction of the African plate beneath the Eurasian plate. The arc is approximately 500 km long and 20–40 km wide and extends from the eastern coast of mainland Greece to western Turkey. The arc lies 250 km behind the trench system and includes the volcanic islands of Aegina, Methana, Poros, Milos, Santorini, Kos, Yali and Nisyros. Volcanic activity began approximately 3–4 million years ago (Keller et al., 1990) and the area is considered as a region of extensive Quaternary volcanism. However, the main explosive centres of the Upper Quaternary are Milos, Santoini, Kos and Nisyros. Santorini developed on the northern edge of a basement horst called the Santorini–Amorgos Ridge (Sparks et al., 1996; Druitt et al., 1999). Basement rocks consist of upper Mesozoic marbles and lower Tertiary phyllites and metasandstone (Druitt and Francaviglia, 1990). Santorini is a multicentre volcanic field and is a complex of islands arranged in a dissected ring around a flooded caldera (see Fig. 2 and Table 1 for a summary of the evolution of Santorini and place names referred to in the text). The volcanic field that probably extends beneath the sea includes the products of 12 major explosive eruptions and the dissected remains of several lava shields, stratovolcanoes and lava–dome complexes. The caldera is a composite structure resulting from several collapses (Druitt et al., 1999). The caldera walls reach 400 m above sea level and depths of 390 m below sea level and are breached by three channels. The outer islands of Thera, Therasia and Aspronisi are composed of rocks that predate the Late Bronze Age (LBA) or Late Minoan (LM) eruption of circa 3500 BP. Palaea and Nea Kameni are composed of dacitic lavas and post-date the LBA eruption. It is not the purpose of this paper to provide a summary of the volcanic history of Santorini. Very good summaries have been provided elsewhere. Interested readers are referred to Druitt et al. (1999 and references contained therein).

Worthy of mention is the last major eruption of the volcano. Around 1628 BC, a paroxysmal Plinian eruption of the Thera Volcanoes occurred and this eruption generated a caldera, the remains of which are still visible. This eruption has been extensively studied and is referred to as the Late Bronze Age (LBA) or Late Minoan (LM) eruption. The LBA eruption had four phases reflecting changing vent geometry's and eruption mechanisms (Heiken and McCoy, 1984; Druitt et al., 1999; McCoy and Heiken, 2000). The eruption began with phreatic and phreatomagmatic explosions that produced 4×10^{12} kg (or 2 km^3) of ash. Phase 1 was characterised by sub-aerial plinian ejection of tephra and pumice that reach depths of 6 m. It is probable that the eruption column attained a height of ~36 km. The intensity of the eruption then increased. Phase 2 associated with violent phreatomagmatic explosions led to the deposition of high-temperature base surge deposits up to 12 m deep. Phase 3 consists of massive, white, poorly sorted low-temperature pyroclastic flows up to 55 m thick. Phase 4 of the eruption is characterised by the deposition of high-temperature fine-grained ignimbrite laid down by pyroclastic flows. Phase 4 deposits reach 40 m in depth. Phases 1–4 produced a volume of (DRE) 8.4×10^{13} kg (or 39 km^3) (Sigurdsson et al., 1990). Peak mass eruption rate was estimated as 2.5×10^{8} kg s^{-1} and lasted about 4 days (Sigurdsson et al., 1990). Heiken and McCoy

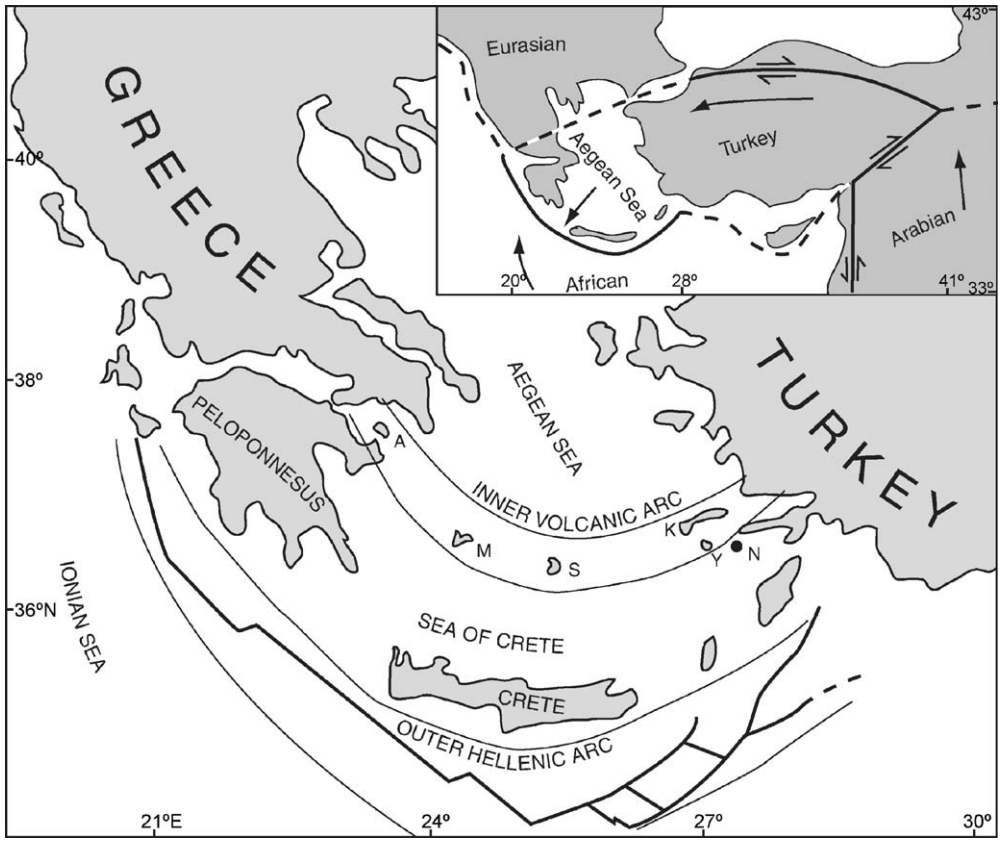

Fig. 1. The major tectonic components of the Aegean Sea region: the Inner Hellenic Volcanic Arc with the principal centres of explosive volcanism and the Outer Hellenic Arc (with subducting trench system) shown by heavy black lines south of Crete. Abbreviations of volcanoes: A, Aegina; M, Milos; S, Santorini; K, Kos; Y, Yali; N, Nisyros). Inset shows the principal (African, Arabian, Eurasian) and minor (Aegean, Anatolian/Turkey) crustal plates. Arrows indicate directions of plate motion. Adapted from Jackson (1994, p. 242) and Le Pichon and Angelier (1979, 1981, p. 140).

(1984) state collapse began during Phase 3, whereas Pichler and Friedrich (1980) and Sparks and Wilson (1990) suggest collapse occurred after Phase 4. Caldera collapse is estimated at ~25 km^3. The LBA eruption was violent and during successive phases, numerous hazardous processes occurred.

Historic volcanism has resulted in the present-day islands of Palaea and Nea Kameni. Post-LBA volcanism broke the water surface in 197 BC and all sub-aerial products are dacitic (Fytikas et al., 1990). Approximately 6.5 km NE of the main island, a new volcanic centre broke the water surface in 1650 AD. This volcanic field is referred to as the Columbo Volcanic Reef (hereafter referred to as Mt. Columbo) and is considered to be active today.

Fig. 2. Summary diagram of the volcanic evolution of Santorini and the distribution of the volcanic products: Akrotiri Volcanics (stages 1 and 2); Micros Profitis Ilias Volcanics (Peristeria volcano) (stage 3); Cape Balos (products of the first eruptive cycle) (these are actually hidden beneath the Thera Pyroclastic Formation) (stage 4); Megalo Vouno Volcanics, Skaros Volcanics and Thera Pyroclastic Formation (stage 5); Kameni Islands (stage 6). Adapted from Druitt et al. (1999, p. 15).

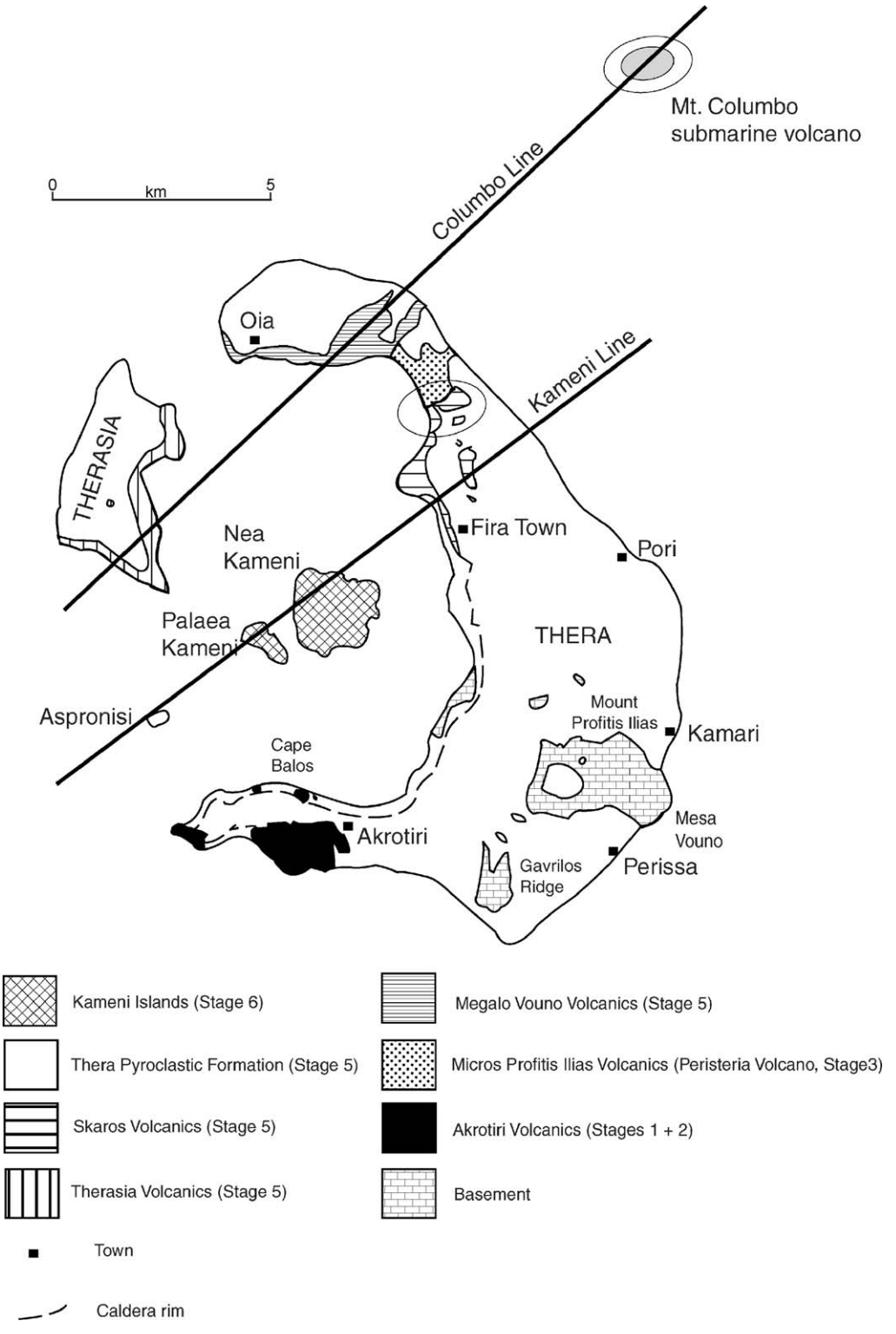
Mt. Columbo
submarine volcano
0
km
5
Columbo Line
Kameni Line
Oia
THERASIA
Nea
Kameni
Palaea
Kameni
Fira Town
Pori
THERA
Aspronisi
Mount
Profitis Ilias
Kamari
Cape
Balos
Akrotiri
Mesa
Vouno
Gavrilos
Ridge
Perissa
Kameni Islands (Stage 6)
Thera Pyroclastic Formation (Stage 5)
Skaros Volcanics (Stage 5)
Therasia Volcanics (Stage 5)
Town
Caldera rim
Megalo Vouno Volcanics (Stage 5)
Micros Profitis Ilias Volcanics (Peristeria Volcano, Stage3)
Akrotiri Volcanics (Stages 1 + 2)
Basement

Table 1
Summary of the history of the Santorini Volcanic Complex (after Druitt et al., 1999, p. 50)

Event	Magma [1]	Age
Mt. Columbo eruption	?	1650 AD
Formation of the Kameni Volcano	D	197 BC to 1950 AD
Caldera collapse (possible tsunamigenesis)		
Minoan eruption	R	3.6 ka [3]
Caldera collapse (possible tsunamigenesis)		
Cape Riva eruption	R	21 ka [4]
Eruption of the Andesites of Oia	A	
Construction of Therasia dome complex	R	
Upper Scoriae 2 eruption	A	79±8; 54±3 ka [5]
Construction of Skaros lava shield	B, A, D	67±9 ka [5]
Caldera collapse (incremental?) (possible tsunamigenesis)		
Upper Scoriae 1 eruption	A	
Vourvoulos eruption	A, D	
Eruption of Megalo Vouno; Columbos tuff ring	A	76±28; 54±23 ka [4]
Middle Pumice eruption	A, D	*c.* 100 ka [6]
Cape Thera eruption	A	
Construction of Simandiri lava shield	A	172±33; 172±4 ka [5]
Caldera collapse (possible tsunamigenesis)		
Lower Pumice 2 eruption	R	
Lower Pumice 1 eruption	R	203±24 ka [5]
Cape Therma 3 eruption	A	
Extrusion of Rhyodacites of Cape Alonaki and NE Thera	R	257±31; 224±5 ka [5]
Cape Therma 2 eruption	R	
Cape Therma 1 eruption	A	
Extrusion of Cape Alia andesites	A	456±138; 364±62; 345±88 ka [5]
Eruption of Akrotiri Cinder Cones	B, A	522±104; 451±27; 344±24 ka [5]
Construction of Peristeria 3	B, A, D	480±5; 478±3; 464±8; 433±8; 308±10 ka [5]
Extrusion of Peristeria 2 lavas	A	496±16 ka [5]
Caldera collapse (possible tsunamigenesis)		
Construction of Peristeria 1	A	528±23 ka [5]
Eruption of the Early Centres of Akrotiri Peninsula	D, R	645±92; 619±35; 586±15; 582±24; 553±10 ka [5]

[1] B, basalt; A, andesite; D, dacite; R, rhyodacite.
[2] Historic records.
[3] Mean of radiocarbon ages on plant remains in tuffs (Friedrich et al., 1990).
[4] Mean of radiocarbon ages on plant remains in tuff (Pichler and Friedrich, 1976), correlated using the data of Bard et al. (1990).
[5] K–Ar or $^{40}Ar/^{39}Ar$ age of this study.
[6] Tentative correlation by Federman and Carey (1980) with W-2 deep-sea ash.

2.2. Present-day demography and economy

The 1991 census showed that Santorini had a resident population of 8000 [though this figure is likely to be slightly higher now—the 2001 census data are not available in sufficient detail from the Greek Government (National Statistical Service Department, 2003; www.statistics.gr)]. Some 3000–4000 people live in Fira and approximately 1500 people live in Oia (see Fig. 2 for locations). The remainder of the population is distributed among 11 larger villages. However, during the summer months, Santorini's population rises significantly in response to the arrival of tourists. According to the Epic Travel Agency in Kamari, during the summer of 1999, 900,000 domestic and foreign tourists visited the island. At any one time, there may be more than 50,000 people on Santorini.

The islands' economy is principally supported by tourism and most income is generated during the summer. The majority of the permanent population is employed within the tourist sector. Many own hotels or rent rooms and camping grounds. Others own and run tourist shops, art and craft establishments, shops, bars and restaurants. Thirty percent of all hotels, bars and tourist-related businesses and outlets are centred in Kamari and Perissa on the SE coast of the island (Fytikas et al., 1998). The remaining 70% are located in Fira and Oia. A minority of the population is involved in traditional occupations of fishing and viniculture.

While the island is popular with young budget travelers, it is also rather expensive and is frequented by wealthier more discerning travelers.

2.3. Previous hazard and risk assessment, identification of a worse case scenario and civil defense planning

Fritzalas and Papadopoulos (1988) were the first to present an assessment of hazard type, magnitude and distribution and risk for Santorini. Their study noted the high vulnerability of the island, its residents, visitors and infrastructure to the impacts of a post-LBA type eruption. They considered (in descending order of importance) the principal hazard types likely associated with such an eruption as volcanogenic earthquakes, tsunami, toxic gases, ashfall and ballistic ejecta. The exact areas affected by these hazards and their magnitude would likely be determined by the specific location of the eruption, time of day and year and the effect of secondary factors such as wind speed and direction. Fritzalas and Papadopoulos (1988) stated that as early as 1986, a Greek group of scientists and specialists recommended to the Earthquake Planning Protection Organisation (EPPO) that Santorini should be continuously monitored and that a specialist emergency management plan should be developed, which at the time did not exist.

In an important report, Fytikas et al. (1998) provide a summary of work on hazard and risk assessment for Santorini together with an outline of completed programmes concerned with hazard reduction, mitigation and education on the island between 1992 and 1998.

Fytikas et al. (1998) identify those hazards likely associated with what they refer to as a "Maximum Probable Event" eruption. Such an event would be similar to a LBA eruption. No hazard zone maps have been constructed for such an event since it is widely held that the magnitude of any hazards associated with such an eruption would, in fact, blanket the entire island. Such eruptions have recurrence periods of c. 15–20 ka and may therefore be considered not relevant to the present time period (and disaster planning cycle). More significant is the identification of a "Most Probable Event" eruption (i.e., a worse-case scenario). Such an event would be similar to historical post-LBA eruptions and have recurrence periods of c. 900 years (the last being in 1650 AD). Fytikas et al. (1998) hold that such a post-LBA eruption would be characterised by a similar suite of hazardous processes whose magnitudes and distribution of effects reflect previous eruptions of this type. In either case, these authors believe that an eruption of LBA or post-LBA type will be centred on either the Kameni and/or Columbo lines (see Fig. 2 for locations). These lines represent volcanotectonic zones of weakness that are likely to act as conduits through which magma may ascend.

For a "post-LBA worse-case scenario eruption," the following hazards and hazard zones are proposed: (1) phreatic explosions zone—posing a relatively high localized hazard zone depending on where the eruption begins; (2) ballistic ejecta zone—posing a relatively high localized hazard zone; historical data suggest trajectories for ballistics reach little more than 1 km from the vent (but may be up to 5 km; Fritzalas and Papadopoulos, 1988) and may therefore pose a significant hazard within the intra-caldera area if the eruption were centred on the Kameni line. (3) tsunami zone—may pose a relatively high localized hazard to parts of the eastern and southeastern coastline (e.g., Kamari and Perissa) to a distance of 200 m from the shoreline; (4) toxic gas/ashfall zone—depending on wind speed and direction, may present a major hazard effecting all areas of the islands; and (5) landslide zone—considered to be a especially high hazard in the intra-caldera area where slopes are extremely steep.

For a post-LBA worse-case scenario eruption, the risk to people is considered highest in the peak summer period of July and August reflecting the high number and density of people on the island at this time of year (Fytikas et al., 1998). The risk to fixed infrastructural units (buildings, bridges, roads, the airport, etc.) is broadly constant throughout the year. Actual variations in risk (the probability of a certain level of loss) will occur according to the magnitude of specific hazards affecting that unit (e.g., the size of a tsunami wave, volume of ashfall, etc.) and their proximity to the eruption location (Blong, 2003).

For Greece as a whole and Santorini specifically, there are *no* civil protection planning guidelines for volcanic eruptions of any magnitude (Fytikas et al., 1998). This issue and its implications for Santorini are discussed in Section 5.2 below. It is worth noting

at this point that for any major eruption at Santorini that required rapid and controlled evacuation, officials would need to undertake such evacuation according to an as yet, unwritten plan!

Fytikas et al. (1998) report that a number of important geological, geochemical and volcanological projects were conducted on Santorini during the IDNDR, many of which were funded by the European Commission. Additionally, monitoring of the volcanic complex together with the establishment of an operational surveillance system was a principal objective of the European Laboratory Volcanoes Project. At the time of writing of Fytikas et al.'s report, the Civil Protection team and several scientific monitoring teams were in constant contact and the results of their work were stored at what was nominally identified as the "Santorini Volcano Observatory" in Fira. By the close of the IDNDR, funding to support this work and the "observatory" had declined significantly.

3. Method

It has already been noted that successful volcano disaster management is often affected by pre-event public awareness and perception. As such, we conduct a pilot survey in which we interview a range of people to determine their general level of awareness and knowledge of volcanoic hazards and risks. This is considered important because more than 50 years have elapsed since the last eruption, and the resident population has had the time to "forget" the impacts of an eruption.

A questionnaire was constructed and the questions specifically relate to the history of the volcanic field, its past products and likely future behaviour, likely human response to a future eruption and the measures taken by the local authorities. Two groups were targeted for the questionnaire: the first group includes permanent residents and the second group includes representatives of the local authorities (hereafter referred to as "dignitaries").

3.1. Criteria for the selection of interviewees

We interviewed two broad sample groups. The first group was permanent residents of the island. Temporary residents, visitors or tourists were not interviewed since they are not part of the local community, are not related to the island's history and may have views about the volcano not appropriate or relevant to this study. Interviews were conducted with people of different ages in order to investigate how different generations understand and interpret the existence of a volcanic complex in the area in which they live and how they would react in an emergency. Furthermore, we were interested in knowing to what extent the experiences of elder members of the community had been passed to younger generations. Interview answers were recorded anonymously since it was realized that some answers would only be given if interviewee anonymity were guaranteed. Part of this target group includes school children, which may be regarded as a "captive" sample and as such, an independent target group. We focused on this group because we wanted to determine whether the education system had included some information on the history of the volcano and the hazards that it poses.

The second group that we targeted was quite different. With the second group, anonymity could only be kept in certain circumstances where the interviewee did not have a managing position within the local authority. For example, the mayor and the sub-prefecture are specific people and therefore anonymity is impossible to ensure. While in the case of the local representative of the Civil Emergency Design Office (PSEA), anonymity was easier to ensure. Furthermore, with this group, it was impossible to limit the interviews to permanent residents of the island since individual interviewees were people on the island for a specific time period after which they would be transferred as part of their official duties. However, we did not consider this a problem since these individuals are actually tasked with the responsibility of management of a volcano-related emergency. Therefore, their knowledge and perceptions were considered quite relevant.

3.2. Development of questionnaire

3.2.1. Initial survey—March 2000

An initial survey was carried out in order to test the questionnaire in terms of structure, wording, content and results. The wording of the questions was tested in order to ensure that no misinterpretation occurred and no further explanation was needed. Finally, the

structure of some questions was tested in order to ensure that they were not restricting or guiding the interviewee's response. The final version of the questionnaire includes a combination of closed (checklist) and open (free answer) questions. It has two sections (Appendix A). The first section was answered by both target groups and included questions on the history of the volcanic complex, the hazards that a future eruption might pose and how people expected they would react. The second section of the questionnaire applied only to the local dignitaries. In this section, the dignitaries had to answer questions regarding the existence of an evacuation plan and the structure of the local council in the case of an emergency. At the end of this section, the interviewee could add any information that they considered useful.

3.2.2. Main study—November 2000

The main research phase was carried out on Santorini in November 2000 after the tourist season had ended, schools had returned and the holiday period for officials of the municipality had ceased. Finally, authorities such as the mayor's office, the port service and the police and the health services were less busy, something that made the interviews less time-consuming.

3.3. Meetings with the local dignitaries

For meetings with the local dignitaries, no appointments needed to be made since they were available at the time they were approached. We regard this as an advantage since an appointment would have indicated the purpose of the interview on matters regarding the volcanic complex and could either have resulted in refusal to give an interview and/or resulted in false statements being made. For example, if a member of the local dignitaries knew that they were going to be interviewed, we were concerned that they might try to collect information on the subject in order to appear more informed and up to date.

It could be argued that if the local authorities knew about the interview and the content of the questionnaire, it might have been better for the research since more data could have been collected. However, an important element of this process was surprise, just like a possible eruption. The only interview for which an appointment had to be arranged was with the mayor of Santorini. Fortunately, the option to conceal the subject of the meeting was retained by us. The 14 members of the local authorities (dignitaries) interviewed were the mayor of Santorini (1), the president of Oia community (1), the sub-prefecture representative on the island (1), the local PSEA representatives (3), the port authority director and a port employee (2), the fire brigade chief officer and employees (3), the health centre doctors (2) and a police station officer (1).

4. Results

4.1. The questionnaire results

In total, 57 people were questioned of whom 14 were local dignitaries and 43 were island residents. The results are presented in the following subsections. For the purpose of brevity, the results of interviews with local residents are summed as percentages. It should be noted that for some questions, responses may total more than 100% since respondents were permitted to select several answers. The results are also presented as a series of bar charts in Figs. 3–11. The results of interviews with local dignitaries are given as full text answers. This is because we consider the knowledge and opinions of these people particularly important since these officers include those charged with the responsibility of protecting the community.

4.2. Questionnaire responses from local residents

- Ninety-five percent of the interviewees were permanent residents.
- Twenty-one percent of the respondents lived in Fira, 4% lived in Oia and 75% lived in other areas close to Fira.
- Ninety-three percent of respondents know that Nea Kameni is active.
- With regard to when Nea Kameni last erupted, 34% of respondents said 1950 AD, 20% said 1500 BC and the remaining 46% gave a variety of dates between 1840 AD and 1960 AD (Fig. 3).
- Sixty percent of respondents know that Mt. Columbo is active, while 27% believed that the volcano is inactive (Fig. 4).
- Only 7% knew that the last eruption of Mt. Columbo was in 1650 AD (Fig. 5).

- With respect to which volcanic products were associated with Nea Kameni, 35% of respondents said volcanic ash, 62% said lava flows, 28% said poisonous gases, 28% said pumice, 18% said volcanic bombs and 16% said sulphur.
- Regarding the main volcanic products of Mt. Columbo, 40% of respondents identified poisonous gases, 18% lava flows and 12% identified tsunami.
- Respondents were asked to rank those hazard types that they believed are of greatest threat to Fira and Oia. Forty-four percent of respondents answered poisonous gases, 27% said tephra fall, 21% said earthquake, 12% said volcanic bombs and 9% said tsunami.
- Forty-one percent of respondents believe that a future eruption could result in loss of human life, 69% believe that an eruption will result in building damage, 44% believe land damage will occur and 67% believe damage will occur to tourism (Fig. 6).
- Forty percent believed that damage to tourism would have a serious impact on the island. By contrast, 23% believe that loss of life would affect the island's community the most (Fig. 7).
- Sixteen percent believed that Nea Kameni will erupt in the next 10–20 years, 21% in 21–50 years, 14% in 51–100 years and 19% in more than 100 years (Fig. 8).
- Twelve percent of residents said that there is an evacuation plan for the island (here, they refer to the general Xenokratis emergency plan), 44% said that an evacuation plan for the island did not exist and a further 44% did not know whether such a plan exists (Fig. 9).
- However, 76% of respondents believe that there is a need for an evacuation plan for the island.
- When asked whom residents thought would inform them of the current situation in the event of an eruption, 44% said the mayor, 23% said the police, 23% said the government, 20% said the military and 12% said the mass media (Fig. 10).
- If nobody informed them about the situation, then 41% of respondents would attempt to leave the island by plane, 28% would move to areas further away from the volcano, 9% would leave the island by ferry, 9% would stay indoors and wait for somebody to inform them about what to do and 5% would see what other people were doing and act accordingly (Fig. 11).
- If Nea Kameni suddenly erupted, 46% of respondents said that they would stay calm and examine

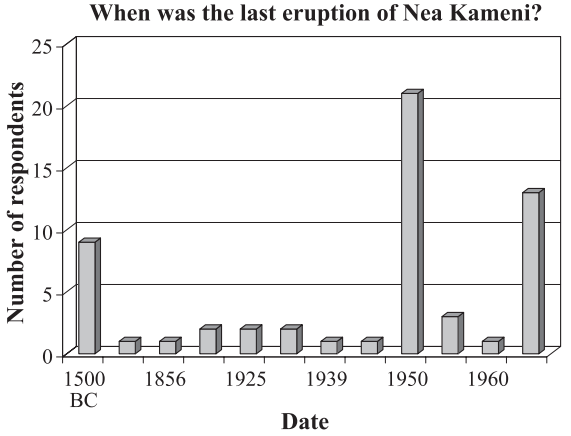

Fig. 3. Number of respondents that identified a particular year as the date when Nea Kameni last erupted.

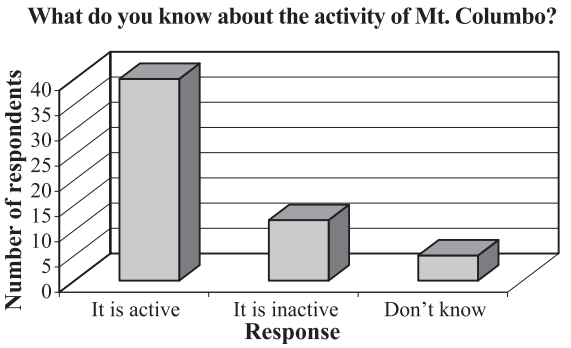

Fig. 4. Number of local residents who believe Mt. Columbo is active, inactive or do not know.

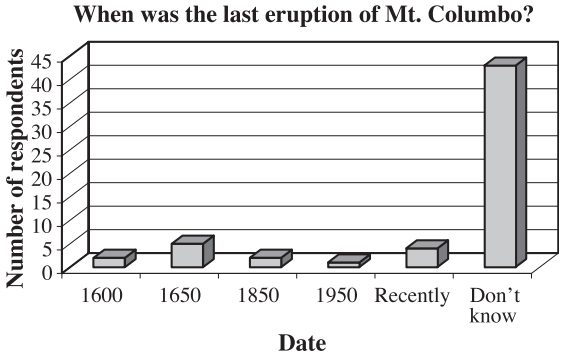

Fig. 5. Number of respondents that identified a particular year as the date when Mt. Columbo last erupted.

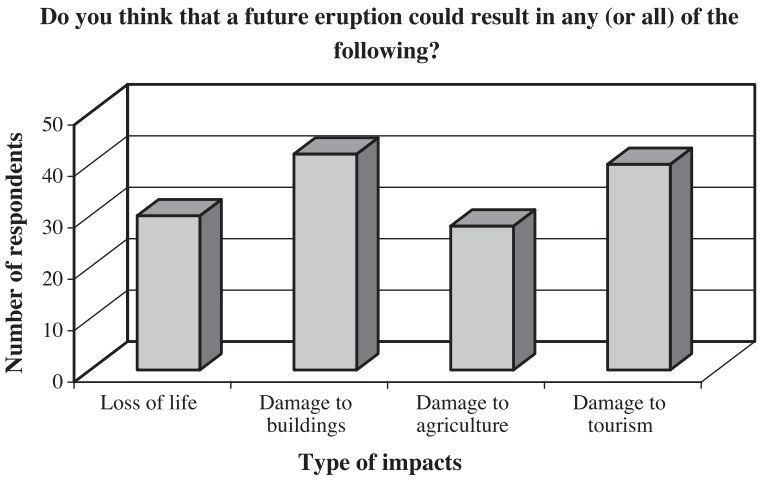

Fig. 6. What respondents believe a future eruption may result in.

the situation, 37% said that they would leave the island immediately and 12% said that they would simply panic.

- Eighty-eight percent of respondents said that they had never been educated or informed on issues regarding the evolution of Nea Kameni or Mt. Columbo by either the municipality or the local council.
- Seventy-six percent of respondents believe that education on such issues is the responsibility of the local authorities.
- Eighty-one percent of respondents believe that Nea Kameni is being monitored.
- Finally, 99% of respondents would like to be informed on issues regarding the history and evolution of Nea Kameni and Mt. Columbo.

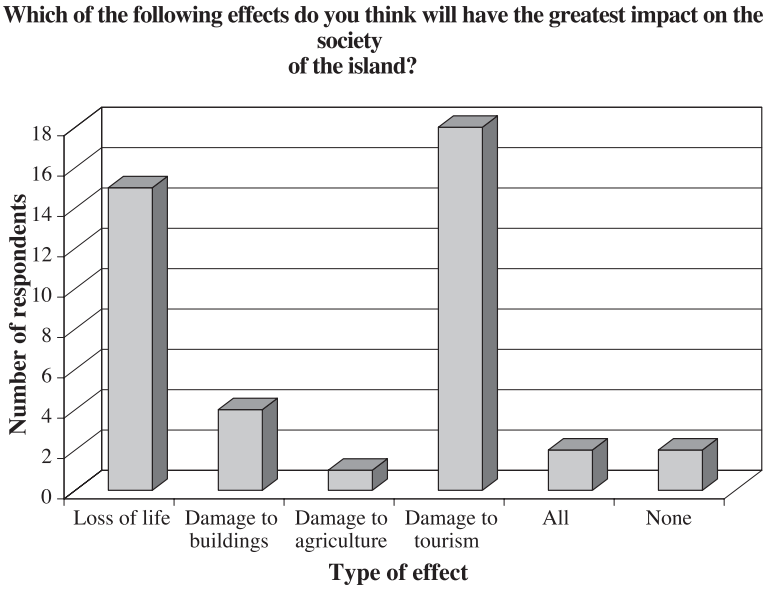

Fig. 7. Type of effects most respondents think a future eruption would have the greatest impact on society.

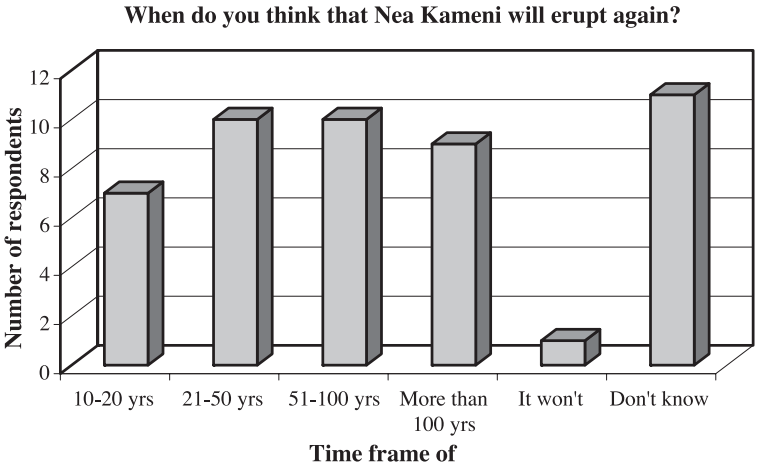

Fig. 8. When respondents think the next eruption of Nea Kameni will be.

4.3. Questionnaire responses from local dignitaries

4.3.1. Interview with the mayor

The mayor knew the history of Nea Kameni and Mt. Columbo and their main volcanic products. However, he was not aware of the potential hazards that each posed to Fira and Oia. He supposed that if a volcanic eruption occurred, it would be *advantageous* for the island since it would *attract more tourists*. Regarding his knowledge of the existence of an evacuation plan, he confirmed that there is no plan for the island in the event of an eruption. He believed that there is *no need for one*. In the case of an eruption, he expected to be informed by scientists and claimed that he was constantly updated on the state of activity of Nea Kameni and Mt. Columbo.

In the questionnaire section for the local dignitaries, he confirmed the following:

- that there is a team on the island that would deal with an emergency such an eruption;
- that this team was the local council;
- that it includes representatives of the local police, health and fire departments and;
- that the municipality spent 11,700 euros annually (US$13,400) for the maintenance of the monitoring equipment (seismographs, etc.) installed on the island.

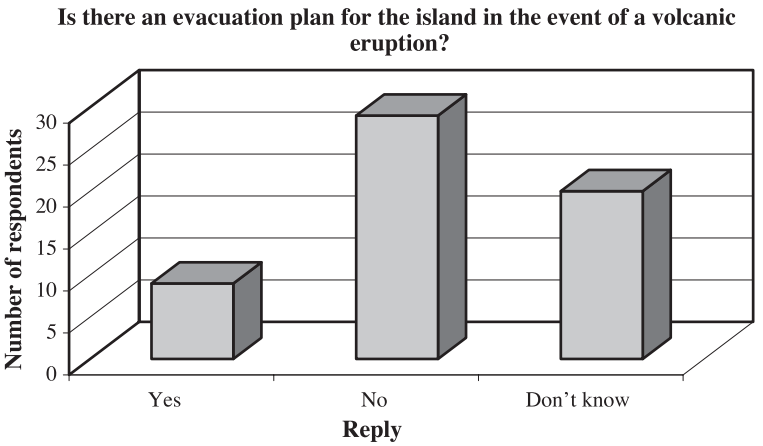

Fig. 9. Respondents knowledge about the existence of an evacuation plan.

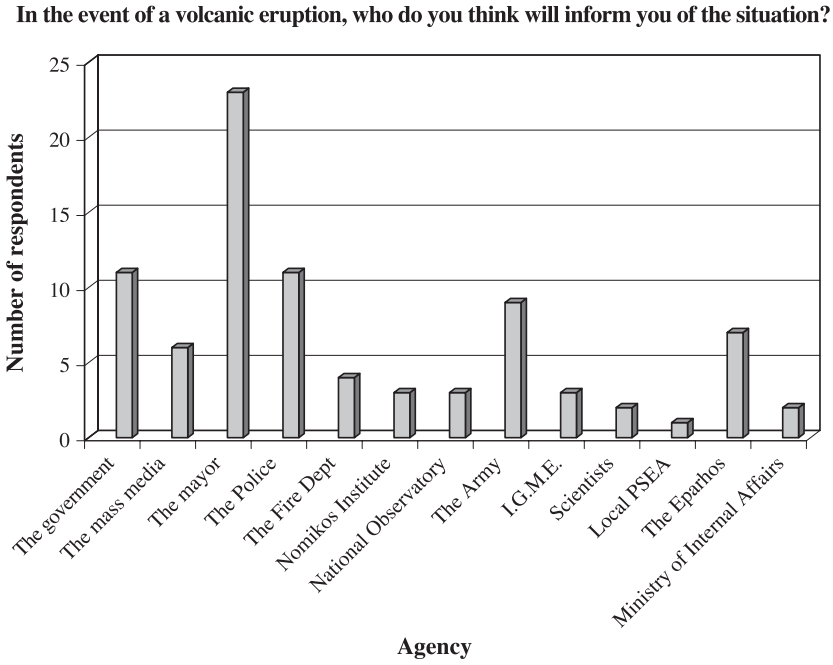

Fig. 10. Whom respondents believe will inform them regarding the situation during a future eruption.

The mayor added that (in his opinion) if a volcanic eruption did occur, it would be such as to allow enough time for the evacuation of the island and that he would be counting on immediate assistance from Athens. Interestingly, when asked what would happen if a volcanic eruption took place today, his answer was "Then God help us!"

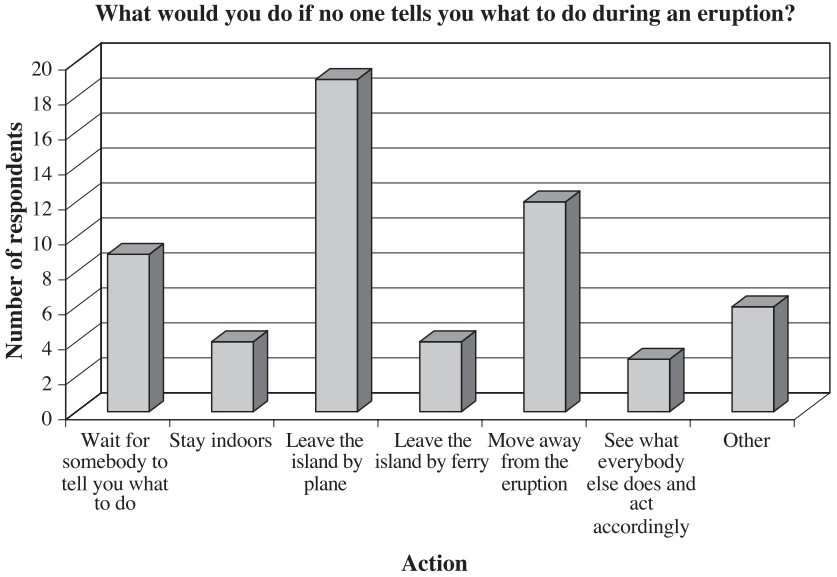

Fig. 11. What respondents would do during an eruption if no one informed them about appropriate procedure.

4.3.2. Interview with the president of Oia community

The president of Oia community knew the history of the volcanoes and their products. He believed that a future eruption could result in a loss of life, damage to buildings and negative impacts on the land and to tourism. He confirmed that there was no evacuation plan for Santorini or the towns of Fira and Oia specifically. He also confirmed that the only emergency plan that existed is the Xenokratis for earthquakes for the Eastern Cyclades. He was aware of the procedures that he is required to follow in the case of an emergency (according to the Xenokratis), but he believed that there is a need for an appropriate evacuation plan for the whole island.

In the event of an eruption, he expected to be informed by the Ministry of Internal Affairs. However, if nobody informed him, he was obligated to apply the Xenokratis Emergency Plan. He knew that Nea Kameni is being monitored and he wished to be informed of the evolution and behaviour of the volcanoes. He added that there is no team on the island that has the responsibility to deal with emergencies such as eruptions and he stressed the need for the formation of such a team.

With regard to the range of mitigation measures, he said that it was the responsibility of the community to:

- establish a local building code for the area and to ensure that all construction applications had conducted a geological survey;
- develop a micro-zonation map for the town of Oia and;
- to collaborate with the University of Athens to create a substratum map of the area of Oia to provide useful information on the slope stability of the local area.

4.3.3. Interview with the sub-prefecture representative on the island

The sub-prefecture representative only had a partial knowledge of the history of the volcanoes. However, he was well aware of their potential products. He believed that a future eruption could result in loss of life, damage to buildings, land and to tourism. He also estimated that a future eruption could happen in the following 50–100 years. He confirmed that there is no evacuation plan for Santorini apart from the Xenokratis Emergency Plan whose procedures he knew. He believed that there was a need for a volcano evacuation plan. In the case of an eruption, he expected to be informed by the local PSEA office and, if nobody informed him, he would apply the defined emergency procedures from the Xenokratis Emergency Plan. He had never been educated by the municipality or anyone else on the possible future behaviour of the volcanoes, and he believed that it was his responsibility to be informed on such issues. He knew that Nea Kameni is being monitored and he expressed the desire to be informed on issues regarding the activity of the volcanoes. The sub-prefecture representative also confirmed that there was no micro-zonation map for the town of Fira and surrounding areas near to, or on, the caldera rim.

4.3.4. Interview with the PSEA representative

The Chief PSEA (Civil Emergency Design Office) representative knew that both volcanoes are active but he did not recall when the volcanoes last erupted. The volcanic products that he knew relative to the Nea Kameni volcano were pumice and lava, while he was not aware of the products of Mt. Columbo. He believed that both the aforementioned products could be a threat to the towns of Fira and Oia. He also thought that a future eruption could result in loss of life, damage to buildings, land and tourism. He confirmed that there is no evacuation plan for the towns on the island and that there was a need for one. In the case of a volcanic eruption, he expected to be informed by the Prefecture of Eastern Cyclades and by the local sub-prefecture. He had never been educated on issues regarding the volcano and he believed that this was the responsibility of the local authorities. The PSEA representative confirmed that even the Xenokratis Emergency Plan for earthquakes had not been adjusted specifically for Santorini. He also confirmed that there is no micro-zonation map for Fira and that a geological survey was not compulsory for construction licenses for proposed developments on the caldera rim.

4.3.5. Interview with the port authority

The officer of the port authority was not a local resident of the island. However, he had spent 1 year on the island by the time of the interview. He knew

the history of the volcanoes and he was aware of the main products of Nea Kameni but he did not know those associated with Mt. Columbo. He thought that none of the products of the Nea Kameni volcano would threaten the towns of Fira and Oia and he imagined any future eruption would be mild causing little damage. He confirmed that there is no evacuation plan for the island and he agreed that there is a need for one. In the case of a volcanic eruption, he expected to be informed by nobody. He said that he had not been educated on the activity of the volcano and that it was his responsibility to educate himself. However, he would appreciate it if the municipality organized seminars about the volcano. He confirmed that there is a specialised team on the island to deal with emergencies or disasters.

4.3.6. Interview with the fire authority

Five firemen, 10 volunteers and four vehicles compose the entire Fire Brigade Service on Santorini. The chief fireman of the Fire Brigade together with the remaining fire service personnel are not permanent residents of the island. The chief fireman knew the history of the volcanoes and their products. He said that tephra fall and volcanic bombs could be a threat to the towns of Fira and Oia and that a future eruption (in 50–100 years time) could result in a loss of human life, damage to buildings, land and tourism. He confirmed that there is no evacuation plan for the island and he stressed the need for one. In the case of a volcanic eruption, he expected to be informed by the government, media and the mayor of the island. However, if nobody informed him about the situation, then he would leave the island as soon as possible and preferably by plane. He had never been educated by the municipality on issues regarding the evolution of the volcanoes, and he regarded it as the responsibility of the local authority to organize such education. He stated that there is no specialised team on the island to deal with emergencies or disasters.

4.3.7. Interview with the police authority

There is only one police department on Santorini and it comprises 30 police officers during the winter and 60 during the summer. The non-commissioned officer who was interviewed on behalf of the police department knew that the volcanoes were active, but he did not know when their last eruptions were. He knew the main volcanic products of Nea Kameni but he could not name any for Mt. Columbo. He considered rocks, landslides and volcanic ash as the most dangerous volcanic products that might threaten Fira and Oia. He believed that a future volcanic eruption could result in a loss of human life, damage to buildings and tourism, but not to the land. He confirmed that there is no evacuation plan and that the only emergency plan existing was the general Xenokratis Emergency Plan for earthquakes. In the event of a volcanic eruption, he expected to be informed by the sub-prefecture, and in the situation where nobody informed him, he would get in touch with the mayor of the island, the Prefecture of Cyclades and the Ministry of Internal Affairs. He had never been informed by the municipality of the activity of the volcano, and he believed that community education on this issue is the responsibility of the municipality.

4.3.8. Interview with the health authority

The Health Care Centre of Santorini comprises 17 permanent doctors, which rises during the summer to 20. The health centre also has two permanent ambulances. Unfortunately, the chief of the health authority was not on the island during our research so one of the doctors on duty was questioned instead. He knew the history of the volcanoes very well, although he was not from the island and he knew the main products of both volcanoes. He regarded tephra fall and volcanic gasses as the most hazardous products and that a future eruption could result in a loss of life and damage to buildings, land and tourism. He also confirmed the lack of an evacuation plan for the island. In the case of an eruption, he expected to be informed by the Ministry of Health and the Ministry of Internal Affairs. He had never been educated by the municipality on the activity of the volcanoes, although he regarded it as their responsibility. He further added that in the case of an emergency, the health centre could only be used as a first aid centre since it lacked basic hospital equipment. He noted that the closest island with a hospital is Crete. He also mentioned that in the case of an emergency, the health centre would ask for assistance from the military units on the island. The military service has three doctors and three ambulances.

4.4. Comparison of responses by age and comparison of responses between local residents and dignitaries

Having presented the general results, firstly, we analyse the "resident interviewees" by age. This is undertaken since we are interested in knowing whether older residents who may have experienced a volcanic crisis have a greater awareness and perception of hazard and risk than younger residents who have not. Secondly, we make a comparison of responses between local residents and dignitaries. The purpose of this analysis is to determine to what extent, if any, there is variation in perception between the general public and elected or appointed officials. The results are also shown as a series of bar charts in Figs. 12–17.

4.4.1. Responses by age distribution (local residents)

For the purposes of this comparison, the ages of the interviewees have been separated into three groups: <18 years of age, 18–50 years of age and >51 years. The results are summarised as follows:

- All three age distribution classes agreed that Nea Kameni is active.
- Nearly 80% of the <18 knew that Mt. Columbo is active. By contrast, the majority of respondents aged 18–50 and >51 said that Mt. Columbo is inactive (Fig. 12).
- For the <18 class, respondents cited lava flows only as the main volcanic product of Nea Kameni. Respondents aged 18–50 cited lava flows and volcanic bombs. Respondents aged >51 cited tephra, lava flows and volcanic bombs as the main products.
- All age classes cited poisonous gases as the main hazard type associated with Mt. Columbo. Interestingly, age class 18–50 also cited lava flows and tsunami as major hazard types for Mt. Columbo.
- One hundred percent of age class >51 and 88% of age class 18–50 regarded tephra fall as the most hazardous volcanic product for the towns of Fira and Oia. Age class <18 said that poisonous gases are the most hazardous product. Age class 18–50 also stated that tephra fall and earthquakes are also hazardous products which could threaten Fira and Oia.
- The majority of age classes 18–50 and >51 stated that damage to buildings would be the main result of a future eruption. However, the majority of age class <18 stated that loss of life would be the main result of an eruption. All age classes agreed that there would be damage to tourism.
- Sixty-six percent of age class 18–50 said that loss of life from a future eruption would have an impact on society, while all age classes agreed that damage to the tourist sector would have a definite impact on the island (Fig. 13).
- In the event of an eruption where the population received no information, the majority of respondents in the age class >51 said that they would move to areas away from the volcano. However, the majority of age classes <18 and 18–50 said that they would abandon the island by plane (Fig. 14).

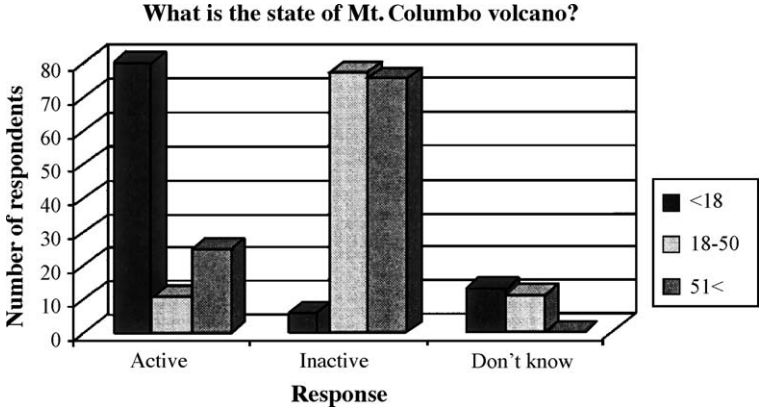

Fig. 12. Respondents' knowledge about the state of Mt. Columbo (by age).

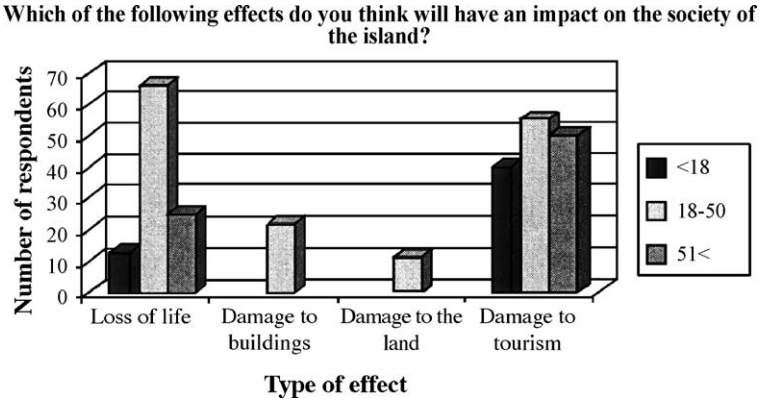

Fig. 13. Type of effects of a future eruption most respondents think would have the greatest impact on society (by age).

- In the case of an unexpected eruption, the reactions of the majority of all three age classes would be to stay calm and examine the situation, while approximately 40% of the respondents within age classes <18 and 18–50 stated that they would leave the island as soon as possible.

4.4.2. Comparison of responses between residents and dignitaries

The main findings of this analysis may be summarised as:

- Although 100% of dignitaries agreed that Nea Kameni is active, only 80% of the residents knew

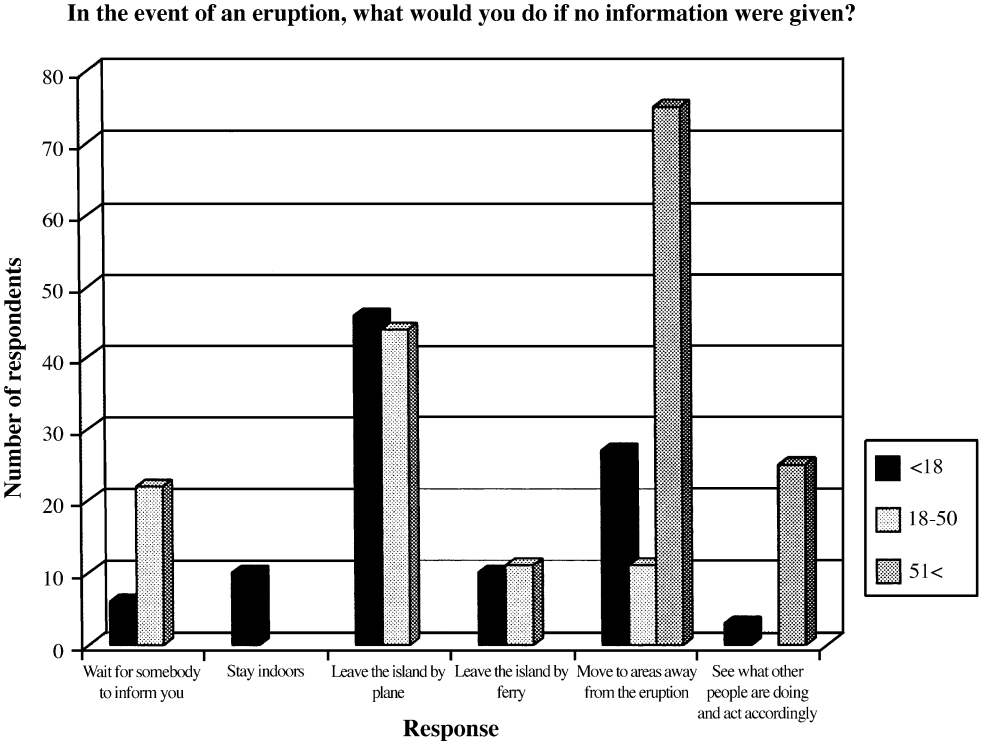

Fig. 14. What respondents would do during an eruption if no one informed them about appropriate procedure (by age).

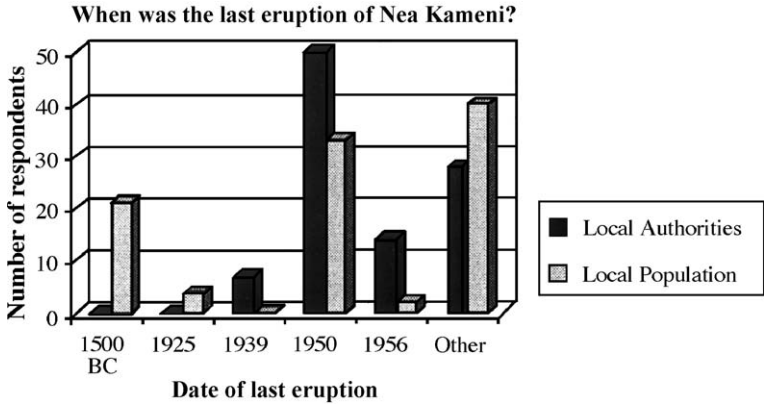

Fig. 15. When the local dignitaries and residents believe Nea Kameni last erupted.

this. Ten percent of residents did not know the current state of Nea Kameni.

- Approximately 50% of the dignitaries knew that the last eruption of Nea Kameni was in 1950 AD. Only 33% of the residents answered this question correctly. It is noteworthy that dignitaries did not recall the eruptions before 1939 AD (Fig. 15).
- There was more-or-less agreement between both sets of interviewees that the main volcanic products of Nea Kameni are poisonous gasses, lava flows, tephra and pumice.
- One hundred percent of the dignitaries know that Mt. Columbo is active; only 60% of residents know.
- Seventy percent of residents and 60% of dignitaries did not know when the last eruption of Mt. Columbo occurred. Only 10% of dignitaries and 4% of residents knew that it was in 1650 AD.
- Both groups considered poisonous gasses, lavas and tsunami as the main hazards of Mt. Columbo.
- The majority of the residents and dignitaries are of the opinion that poisonous gasses and tephra are the main hazards for Fira and Oia.
- According to residents, an eruption is expected to cause most damage to buildings and would affect tourism negatively. However, the dignitaries are of the opinion that a future eruption is most likely to result in loss of life and damage to buildings (Fig. 16).
- Residents believe that damage to tourism would have the greater impact on the community. The

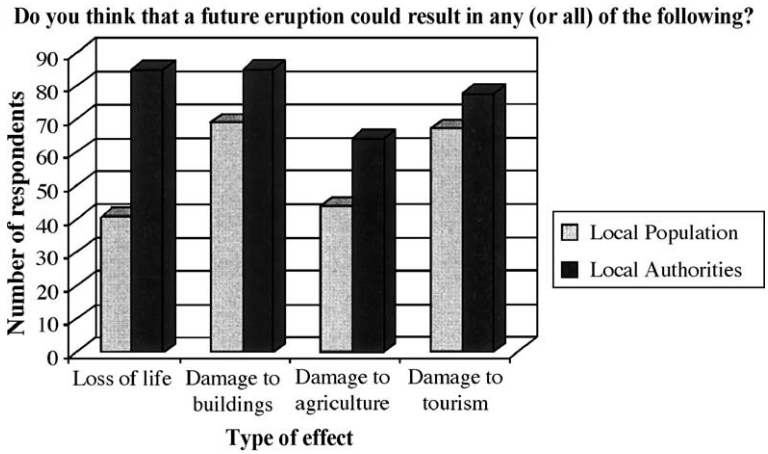

Fig. 16. What local dignitaries and residents believe may be the consequences of a future eruption.

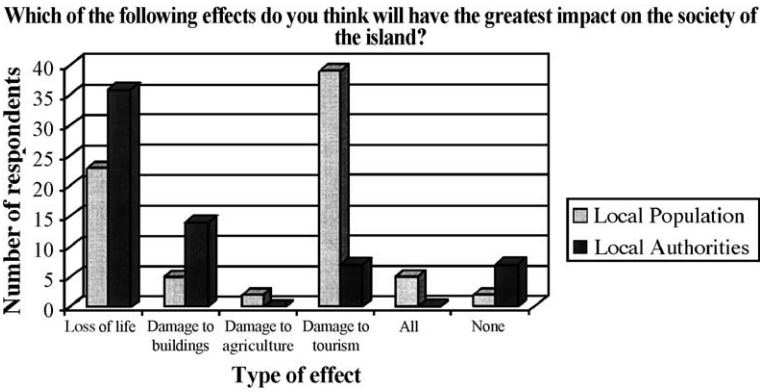

Fig. 17. Which type of effects of a future eruption would have the greatest impact on society (local dignitaries compared to residents).

dignitaries are concerned that loss of life would have the greater impact (Fig. 17).

- The residents have no clear consensus on when the next eruption will occur. The dignitaries agree that the next eruption is likely to take place in the next 50–100 years.
- Finally, the majority of residents know that there is no emergency plan, although 40% do not know if such a plan exists. Seventy percent of the dignitaries know that there is no emergency plan for the island. Alarmingly, 20% of dignitaries think there is an emergency plan and 10% do not know. Both groups agreed that there was a need for an evacuation plan, at least for the towns of Fira and Oia, if not for the whole island.

5. Discussion

Our discussion is structured to reflect the aims of this investigation. We begin by discussing the worse-case scenario and the range and magnitude of likely hazards. We then discuss the "Xenocratis Emergency Plan" (or lack thereof) and finally the results of our survey.

5.1. Discussion of hazard, risk and worse-case scenario

The Santorini volcanoes are currently experiencing a phase of quiescence that will give way to a period of intense activity. Nea Kameni has been active many times. Mt. Columbo, however, has only had one notable eruption [that of 1650 AD] that had a devastating effect on the island's community.

The main hazards of Nea Kameni and Mt. Columbo that may be considered as dangerous and which put the community at risk include phreatic and phreatomagmatic explosions (that include base surges and pyroclastic flows), ballistic projectiles, tsunami, toxic gas/ashfall and landslides.

It is our view that these hazards represent accurately the range of potential hazards associated with a post-LBA eruption. However, further research should be undertaken to determine the likely maximum magnitude for each of these hazard types on Santorini. For example, recent work indicates that the impacts and effects of past volcanogenic tsunami on Santorini may have been significantly overestimated (Dominey-Howes, 1998, 2002, 2004; Dominey-Howes et al., 2000). Also, the magnitude of the "most probable event" (and that which is likely to inform disaster and emergency planning) is volcanologically reasonable and is well constrained by historical data. However, those eruption scenarios that have been identified (e.g., LBA and post-LBA type) all assume and depend upon the premise that the volcanoes will exhibit identifiable precursory warning signs that permit a full assessment of the impending eruption, its magnitude and effects and allow sufficient time to undertake evacuation of the islands. We believe that such an assumption is, at best, unwise and, at worse, catastrophic.

5.2. Discussion concerning the "*Xenocratis*" or Emergency Plan for Santorini

No evacuation or volcano emergency plan specifically exists for Santorini. Therefore, in the event of a volcanic emergency, the authorities would have to utilise the more general "Xenocratis National Emergency Plan." The main features of the Xenokratis National Emergency Plan may be summarised as the following:

- It has the character of a guidebook. It defines terms such as "disaster" and "emergency"; it names the Civil Protection Authorities in terms of governmental authorities, prefectures, local authorities and so forth and the required actions that should be taken for the management of an emergency. It sets the conditions for an effective response and management of an emergency by means of mitigation strategies in order to manage a disaster effectively.
- It sets the duties and responsibilities of the authorities from national to local level and how these should be cooperating with each other.
- It is required to be adjusted to a local level by the local authorities and the local office of civil emergency planning according to the specific hazards and risks relevant to that area.

Since the dignitaries confirm that the National Emergency Plan has not been modified for local needs, we believe that the Xenokratis National Emergency Plan should be considered far too general to serve the needs of the community in the event of an eruption. Furthermore, the previously identified worse-case scenario and the recommendations made by the Santorini Volcano Observatory team and reported in Fytikas et al. (1998) should have been adopted and utilised by the local municipality and by the Civil Protection Authorities in order to produce an effective Local Emergency and Evacuation Plan for the island. Unfortunately, this has not happened yet.

5.3. Discussion concerning the questionnaire results

The purpose of this pilot study is to determine the general level of awareness and knowledge of volcano-related hazards and risks. This is considered important because more than 50 years have elapsed since the last eruption, and the resident population has had the time to "forget" the effects of an eruption.

A criticism of our study is that the number of respondents is low (57 in total) which, of course, cannot be considered as truly representative. However, of those 57 people, 14 were members of the local authorities, and in this case, the results can be considered as significant. Furthermore, to our knowledge, this is the first time that a survey of local perception has been conducted. Therefore, even a pilot investigation provides a valuable insight into endemic levels of awareness, knowledge and perception.

5.3.1. Discussion of responses from local dignitaries

We believe that the local dignitaries are reasonably well informed of the history of Nea Kameni and Mt. Columbo. They identified the hazardous products of the volcanoes together with those that may pose serious risk to the island. However, we were surprised that the only authorities that seemed really concerned about a future eruption are the fire, police and health representatives and the president of Oia community. They agreed that the National Xenokratis Emergency Plan is too general to cover the islands' needs and that the construction of a local evacuation and emergency plan is necessary. Significantly, it is not in their hands to make that decision, but all officers stated they are willing to assist and provide their knowledge, if such a decision is taken by the municipality of Santorini.

The views of the mayor and members of the prefecture (sub-prefecture, PSEA representatives) were not encouraging. In our view, the response of the mayor to the potential problem seemed depressingly inappropriate. The mayor was of the opinion that most eruption scenarios were far fetched. Consequently, there has been no effort to regulate construction of buildings, create an emergency and evacuation plan or form a scientific team to provide continuous information on the volcanoes. Furthermore, the mayor stated such actions were not within his future plans. To the mayor's credit, he had agreed that the municipality was responsible for the maintenance of the seismometers that are located on the

island and to pay for the annual maintenance of the geological monitoring equipment.

Interviews with the sub-prefecture representatives showed a rather typical communications gap. The sub-prefecture representative presented a passive impression towards the issue and, in the event of an emergency, expected to be informed by the PSEA representatives. However, when the PSEA representatives were interviewed, they claimed that they were expecting to be informed by the sub-prefecture. The PSEA representatives were both civil engineers and had received no training in order to assume such a post within the local authority.

From the interviews with the dignitaries, we learned that:

- There is no emergency plan other than the National Xenokratis Emergency Plan and that this plan has not been adjusted to the needs of Santorini.
- There is no micro-zonation or risk map for the areas near the caldera rim around Fira.
- A geological survey is not a requirement for obtaining a building consent permit even when the proposed structure is to be built on the caldera's edge.
- The number of doctors on the island is insufficient for the size of the population, as is the equipment and the facilities of the health centre of Fira.
- The number of Firemen is insufficient.
- The municipality of Santorini has taken no initiative to educate the dignitaries or the local population on issues regarding the evolution of the volcano. Nor has it investigated possible eruption scenarios and developed emergency drills.
- The only hazard mitigation measures that do apply are those developed following the 1956 AD magnitude 7 earthquake. Specifically, all buildings must use anti-seismic construction materials. However, since a geological survey is not needed for the construction of buildings, this measure is not as efficient as it should be.
- The president of Oia Community has ordered a restriction of building construction within Oia. With the assistance of scientists, a micro-zonation map has been constructed for the town and construction within "dangerous" areas of Oia is not allowed. Moreover, Oia is cooperating with the departments of geology of the University of Athens and University of Thessaloniki to investigate the geology of the area and to evaluate ground stability.

5.3.2. Discussion of responses from local residents

Interviews with the residents confirmed a clear lack of understanding and information at the community level. We consider this result as significant because residents have been exposed to a vigorous programme of education during the 1990s (Fytikas et al., 1998). A population's understanding of volcanic hazards is not just determined by scientific information or by direct physical consequences, but also by the interaction of psychological, social, cultural and institutional processes (Burns et al., 1993). From our data, it is not clear which factors are "blocking" the retention of knowledge learned during previous educational initiatives. Further work is needed to elucidate this problem. Although almost all of the interviewees know that Nea Kameni is active, only one in three people know when the last eruption occurred. Two out of three people know that Mt. Columbo is active, but only 7% of them know that its last eruption was in 1650 AD. There is an obvious confusion regarding what residents believe the most dangerous volcanic hazards will be for Fira and Oia.

What is also clear from the results is that the majority of residents believe that a future eruption will have the greatest impact on buildings and tourism. It is interesting that 40% of residents fear that negative impacts on tourism will have the greatest effect on their community. Only 23% of residents believe that a loss of life will have the greatest impact. In our opinion, this reflects the fact that the majority of the resident population is involved with the tourist industry, and it is the main source of income. Therefore, if tourist related income was reduced due to an eruption, the island would face a serious economic crisis. It is a concern to us that few residents appreciate the fact that even a moderate sized eruption could result in the loss of relatives and friends, serious damage to properties and damage to the land that might affect agricultural activity.

Residents are aware that there is no evacuation plan and some of them have considered what their actions might be in the event of an emergency. Most

would attempt to abandon the island by plane or ferry (assuming such options are possible). One in three residents would move to remote areas away from the eruption point. Finally, all residents seemed concerned about the future activity of the volcanoes and stated that they would like to be informed about the history, functioning and evolution of the volcanoes and would like to know what to expect if an eruption were to take place.

5.3.3. Discussion of response by age class distribution

Our results suggest that people below the age of 18 have a knowledge of the volcanoes. This suggests that they are being educated to some extent in school and, as such, this education may be considered as a mitigation measure. However, residents in the <18 and 18–50 age classes indicated that they would attempt to abandon the island by public transport in the event of an eruption. This is in contrast to residents of the 51> age class who say they would move to areas away from the eruption. These results indicate that the elderly have retained their memories from previous eruptions of Nea Kameni and would act accordingly. However, the results indicate that experience of past eruptions has not been passed from older generations to younger members of the community. It has been shown elsewhere that personal experience of volcanic hazards significantly increases awareness and perception (Johnston et al., 1999). Inherited memory of an eruption is a very important element of community resilience. For example, in the case of the 1991 Rabaul eruption, local residents evacuated the town before the red state alert was given by the scientists. This was because the elderly could recall the behaviour of the volcano from the 1950s eruption and recognized signs that drove them away from the town. In this case, prior knowledge and experience proved to be very useful (Decker and Decker, 1997, p. 279).

5.3.4. Discussion of comparison of responses between residents and dignitaries

Comparison of responses between residents and dignitaries suggests that, in general, the local dignitaries seem to be better informed about the volcanoes than the residents. However, residents are more concerned about negative impacts on tourism, whereas dignitaries are more concerned about potential loss of life. This reflects different priorities and perspectives of these groups. Many residents are involved in the tourist industry and their annual income is directly related to the number of tourists. On the other hand, the local dignitaries will be, in considerable part, responsible for the management of an emergency that could result in significant loss of life. Therefore, their concerns are motivated by a sense of public accountability of office.

6. Recommendations

Based upon the discussion, we make a number of recommendations. These are categorised as provision of education programmes and development and implementation of risk management strategies. We feel there is justification for recommending a programme of public education even though such initiatives have previously been undertaken (Fytikas et al., 1998) because our data show that residents of Santorini have already forgotten what they learned during the 1990s.

6.1. Educational programmes

We acknowledge two approaches to the development of educational programmes. One is termed "top-down" and relates to education of the highest ranking officials and their representatives involved in the process of managing a volcanic crisis. The second is termed "bottom-up" and relates to community-based educational initiatives that involve all community members as stakeholders (Newport and Jawahar, 2003; Paton and Johnston, 2001). It is not our intention to discuss here the relative advantages and limitations of each of these approaches. We believe that in the case of Santorini, *both* approaches are required for successful vulnerability reduction of the community to occur. We therefore recommend both education of the dignitaries, officials of the various offices likely involved in managing an eruption and the public.

6.1.1. Education of local dignitaries

The elected officials of the municipality *have* to take responsibility for the education of all appointed

officials of the various offices and charged with the responsibility of managing an eruption. Of particular importance, in our view, is the fact that the health centre operates with many seasonal doctors and that the fire department operates with 5 seasonal firemen and 10 volunteers. Our results suggest that there is a significant probability that many of these individuals will not have a sufficient knowledge of the effects and consequences of an eruption and therefore are unlikely to be prepared to respond to such an emergency. Therefore, we recommend a series of compulsory volcano disaster training workshops in which officials receive appropriate training. It would be particularly important that these training workshops were repeated regularly for the benefit of new staff appointees and for seasonal and volunteer staff.

6.1.2. Education of the public

Local authorities have a responsibility to educate the public about the hazards and risks within their municipal area. Such programmes should include seminars that are focused at different segments of the community (e.g., school children, high school students, adults). Such seminars ought to be organized in cooperation with volcanologists and members of the Civil Protection Office. Through these seminars, the behaviour of Nea Kameni and Mt. Columbo could be explained, and the volcanic products that might be expected to accompany an eruption and the threats that these products would pose could be explored.

Additional seminars and workshops could be organized in collaboration with the health centre and the fire department to offer the public advice on volcano-related first aid and techniques for protecting homes and businesses.

We believe such public education initiatives would serve the dual purpose of reducing the magnitude of negative primary effects of an eruption by informing the public of appropriate strategies to follow and, significantly, help to overcome misconceptions and misinformation about the volcano and the risks it poses. This latter benefit, we believe, is important since Fytikas et al. (1998) report that on an annual basis, uncorroborated theories appear in the local press that indicate that the volcano is going to erupt in the near future and that such an eruption will have a negative impact on the economy. Then again, during the period of our research, one newspaper article appeared that suggested the next eruption of Nea Kameni would be nothing more than a very pleasant spectacle for the residents of Fira and Oia to admire (Eleftherotypia, 2001).

6.2. Development of risk management structures

Just as important as educational programmes is the need to identify, develop and implement risk management structures. Once implemented, these structures should be regularly tested and based on the lessons learned, revised, updated or modified as appropriate.

6.2.1. Establishment of a permanent risk management team and development of a Santorini Xenocratis Emergency Plan

We strongly recommend that a permanent risk management team should be established on Santorini. Such a team should have members from the Civil Protection Office, the local government departments, the health service, the fire service, the harbour port and airport organizations, the chamber of commerce, scientists, the local media and other appropriate stakeholders. This team could take primary responsibility for coordinating the collation of basic research data on the volcano and its activity, identifying hazard and risk zones and the specific parameters that contribute to community vulnerability. The permanent risk manage team should also take primary responsibility for developing a “Santorini Xenocratis Emergency Plan” that specifically caters for local natural hazards (including earthquake, volcanic eruption, fire, heat wave, etc.). This team would also have the responsibility of identifying, developing and implementing appropriate risk reduction measures and preparedness strategies such as the establishment of muster stations and the notification of evacuation routes. All of the above actions would obviously need to take appropriate account of the fact that if any significantly hazardous event were to occur (not just an eruption) during the summer period, the Santorini Xenocratis Emergency Plan would need to cater for the needs of tens of thousands of tourists, all speaking many languages.

We recognize that for such a team to exist and to function successfully, its formation should be a matter of legal requirement, it should be afforded legal powers protected by a legislative framework and it should be provided with an adequate budget to meet its obligations.

6.2.2. Establishment of a permanent Santorini Volcano Observatory

It is our view that a permanent Santorini Volcano Observatory should be established, equipped, staffed and funded. Such an observatory would provide reliable information to the permanent risk management team and the population and could coordinate the identification, development and implementation of volcanic-hazard management strategies.

A justified criticism of our suggestion is the potential cost involved in the construction and maintenance of a permanent volcano observatory. We suggest that the Santorini Volcano Observatory could become a major tourist attraction in its own right. The observatory could charge an admission fee and part, or all of this charge, could be used to meet the costs of the management and maintenance of the observatory. Significant numbers of tourists pay fees in order to view the beautiful archaeological site of Akrotiri and/or visit Nea Kameni. We believe that many if not all of these tourists would similarly pay a fee to visit the Santorini Volcano Observatory—especially given the relationship between Akrotiri and the volcanoes. However, we anticipate that the observatory would need to provide meaningful well-illustrated displays on the history and geology of the volcano, together with information on the hazards the volcano poses and what management strategies have been developed and implemented. We believe that such a resource on the island would generate significant income, help to raise public and visitor awareness and act as a tourist attraction. We do not believe that visitors would be alarmed by the presence of such an observatory. We recommend that the resident population should be consulted about such a proposal. We also recommend that a cost-benefit analysis should be undertaken to determine the economic viability of this proposal. Such an analysis may also include interviewing tourists to determine whether they would be interested in making a visit to such an observatory, and if so, what fee they would be prepared to pay.

7. Conclusions

Santorini, Greece is a major explosive volcano. The Santorini volcanic complex is composed of two active volcanoes—Nea Kameni and Mt. Columbo. Holocene eruptions have generated a variety of processes and deposits and eruption mechanisms pose significant hazards of various types. It has recently been recognized that for major European volcanoes, relatively few studies have focused on the social aspects of volcanic activity. In particular, little work has been conducted on public perceptions of hazard, risk and vulnerability. Such assessments are an important element of establishing public education programmes and developing volcano disaster management plans. We investigate public perception of hazards on Santorini. We find that most residents know Nea Kameni is active but only 60% know Mt. Columbo is active. Forty percent of residents fear that negative impacts on tourism will have the greatest effect on their community. In the event of an eruption, 43% of residents would try to evacuate the island by plane/ferry. Residents aged >50 have retained a memory of the effects of the last eruption; younger residents have no such knowledge. We find that dignitaries (those responsible for planning and managing disaster response) are informed about the history, hazards and effects of the volcanoes but to varying degrees. However, there is no "emergency plan" for the island and there is confusion between different departments (civil defense, fire, police, etc.) about the emergency decision-making process. Greece is a member of the European Union and is a developed western nation. However, our research suggests that despite the incredible level of knowledge and understanding regarding the geological evolution, eruptive history and potential hazards, the general public and, more alarmingly, those with positions of authority and responsibility do not have a good idea of hazard and risk and even less of an idea regarding emergency planning, mitigation and management. Therefore, the assertion that as a developed western nation, Greece and its citizens are intrinsically less vulnerable to the impacts of an

eruption do not hold true. The resident population of Santorini is at high risk from the hazards associated with a future eruption. We recommend the development of appropriate educational programmes and development and implementation of risk management strategies.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jvolgeores.2004.06.002.

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