MSc Geophysical Hazards

Ben Austin Carrett

Geophysical Hazards and Hazard Awareness on Nisyros Volcano, Greece

A dissertation submitted in partial fulfilment of the requirements for the award of MSc in Geophysical Hazards at University College London

2006

Abstract:

The Kos-Yali-Nisyros volcanic field, as well as the island volcano of Nisyros lie in an area of intense tectonic activity.

In the past 160 thousand years the island has witnessed many volcanic eruptions of different types and magnitudes presenting varying degrees of hazard.

Several types of hazard are possible on Nisyros: seismic activity from regional tectonics, seismic activity associated with magmatic and hydrothermal unrest, hydrothermal eruptions, volcanic eruptions, landslides, and tsunami.

In 1995, the volcano gave signs of renewing activity in the form of intense seismicity, ground deformation and significant variations in the chemical and temperature parameters of fumaroles, however volcanic activity did not result.

The data attained on Nisyros show that the local population have little hazard awareness regarding the range of hazards that potentially affect the island. Sixty-six percent of locals interviewed were unsure regarding the most recent volcanic activity on the island, which manifested as hydrothermal eruptions in the late half on the nineteenth century.

Fifteen percent of locals are aware that no civil protection plans currently exist for the island, along with a further 48% who are unsure.

The Mayor of the island confirmed that no plans are in place regarding any magnitude of volcanic eruption, and commented that the current, general disaster management plan – Xenokratis, has not been revised to consider the hazards affecting Nisyros.

Both residents and tourists are at a high risk from the hazards affecting the island and from a future eruption of the Nisyros volcano.

Acknowledgements:

Local residents and the Mayor of Nisyros are thanked for their time and assistance.

Dr. Carmen Solana is thanked for her advice regarding interview questions.

Dr. Gerassimos Papadopoulos from the National Observatory of Athens is thanked for his time and help prior to data collection on Nisyros.

Professor Evangelos Lagios is thanked for providing a copy of his most recent research paper on ground deformation.

Finally, Elaine Kindinis and Spyros Athaniasidis are thanked for their time and help regarding the Greek questionnaires.

Contents list:

Introduction:

Geophysical events have at some time affected all four corners of the Earth. Whether they occur unexpectedly or are preceded by years of precursory activity, their impact can be both local and global.

Greece has been inhabited for thousands of years; some archaeological finds dating back to the time of Palaeolithic Man. Throughout the country's long existence, major natural disasters have occurred creating history and spawning legends of fire raining from the sky and islands disappearing into the sea – like that of Atlantis, or the city of Helike, which on a cold winter's night in 373BC, sank out of site into the earth taking with it all inhabitants.

Today, Greece is a country renowned worldwide for hot summers, beautiful beaches, a laid-back way of life and a rich history, drawing in some 16.5 million tourists in 2004 (Greek National Tourist Organisation). However, just as in ancient times, Greece is still geologically active and periodically rocked by disaster.

The 1990's were the International Decade for Natural Disaster Reduction (IDNDR) whose primary aim was, as in the name, to reduce the destruction and disruption caused by natural disasters. During recent decades many hazard-related emergencies have seen intervention of civil authorities to both reduce the hazard impact and aid recovery (Chester et al., 2002). It has been shown that successful responses have a strong correlation with the degree to which hazard/disaster policies are already in place prior to the event occurring (Chester et al., 2002).

In today's world, foreign travel is an option for anyone owning a passport. However, how many of those travelling to the sun-kissed beaches of the Mediterranean for example, are actually aware of the potential dangers they face from natural hazards?

The aims for this project are:

- To determine the range of geophysical hazards which affect the region.
- To use a short interview to determine the level of local and tourist awareness on geophysical hazards affecting the island of Nisyros.
- To look at the current civil protection plan for the island and deem its usefulness.
- To make recommendations to improve both local and tourist hazard awareness levels.

Regional geological setting: The Southern Hellenic Volcanic Arc

Nisyros can be found at the eastern most edge of the Southern Hellenic Volcanic Arc (known as SHVA from here on), which runs from Methana in mainland Greece, through Poros, Milos, Santorini, Kos, Yali and Nisyros to the coast of Turkey (figure 1.1). The volcanic arc marks the magmatic expression due to the subduction of the African lithospheric plate beneath the Aegean-Anatolian lithospheric plate at a rate of up to 5cm per year (Friedrich., 2001). The geometry of the arc varies with an average depth of the Benioff zone of around 100km, being shallower in the west and deeper in the east (Keller., 1982; Papazachos & Panagiotopoulos., 1993) The SHVA consists of mainly andesitic, dacitic and rhyolitic volcanoes of a typical calc-alkaline composition (Papadopoulos., 1984).

The volcanic centres along the SHVA, along with both shallow and intermediate strong earthquakes (120-180km) form five seismovolcanic linear centres; due to five shallow normal faults with the same strike N60^{o}E (figure 2.1. Papazachos., 1997).

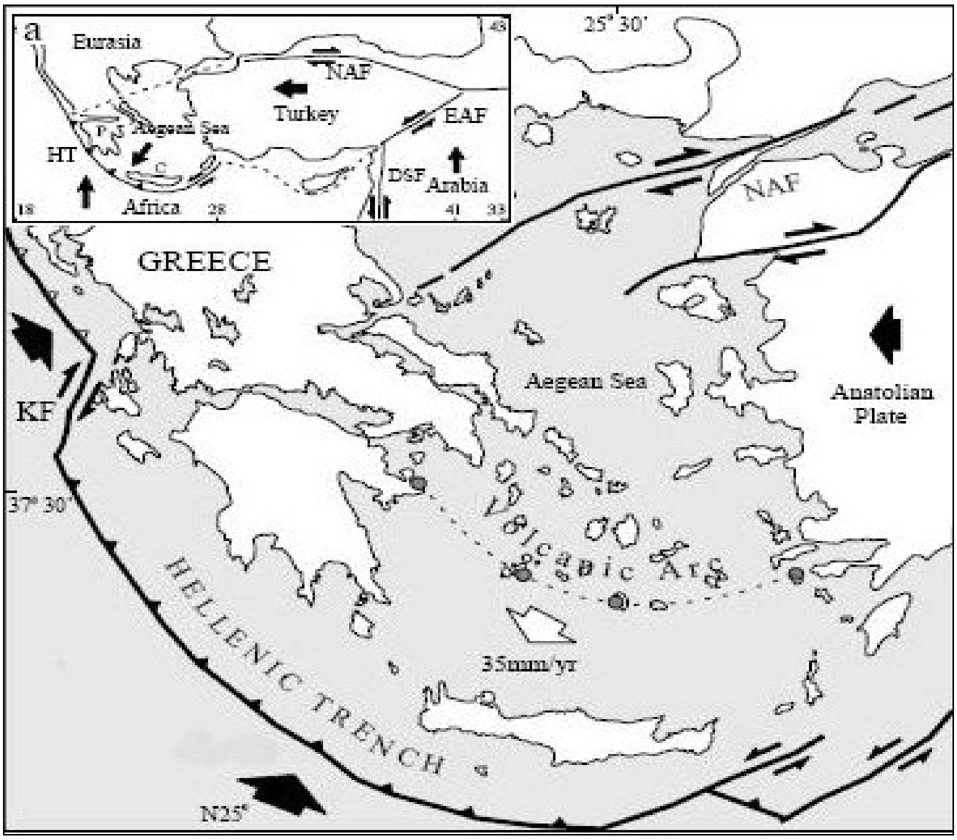

Figure 1.1 The tectonic setting of Greece with the main structural features. KF, Kefallonia Fault. NAF, North Anatolian Fault. EAF, East Anatolian Fault. DSF, Dead Sea Fault. HT, Hellenic Trench. P, Peloponnese,. C, Crete (Doutsos & Kokkolas., 2000)

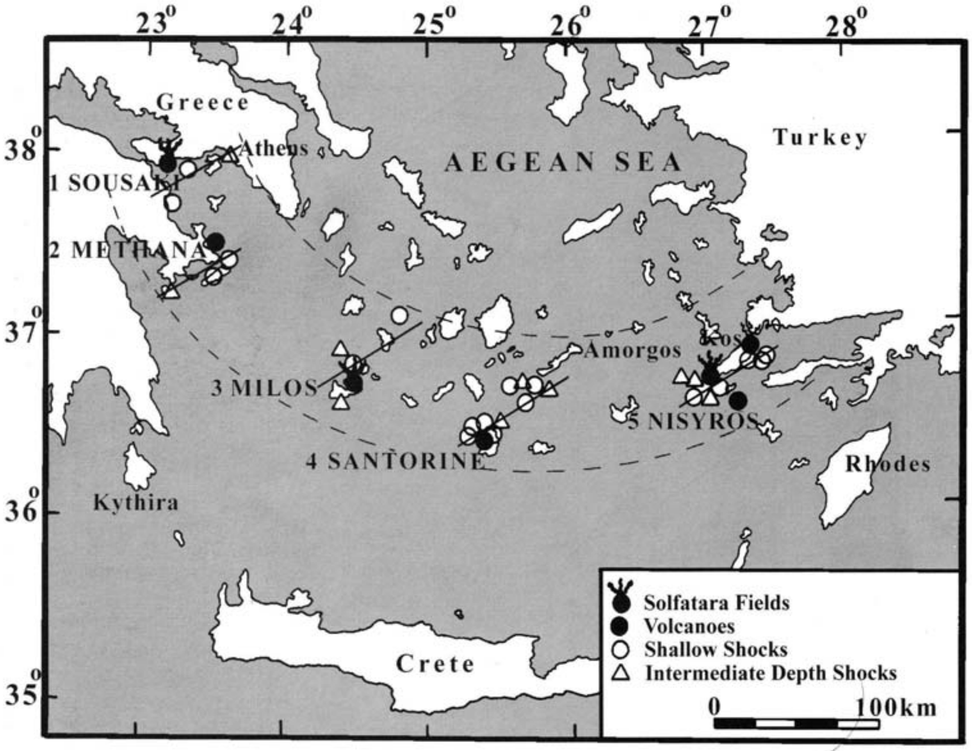

Figure 2.1 The five volcanoseismic lineaments along the SHVA (Papazachos., 1997)

Regional geological setting: Kos-Yali-Nisyros area:

The island of Nisyros can be found approximately 10 miles south of the island of Kos, and, along with the islet of Yali, make up the Kos-Yali-Nisyros volcanic complex at the eastern margin of the SHVA. The islands of the Dodecanese together with the Bodrum peninsula have been volcanically active for the previous 12 million years (Fytikas et al., 1976 & 1984; Pe-Piper & Piper., 2002), however, it was in the Pliocene around 2.6-2.8 million years ago that high levels of geodynamic activity began in the region (Lagios et al., 2004). This period of high geodynamic unrest culminated in the phreatomagmatic ignimbrite eruption of the Kos Plateau Tuff. Dated at 161ka (Smith et al., 1996) the Kos Plateau Tuff eruption produced more than $100km^3$ of pyroclastic material, devastating an area of approximately $3000km^2$ over the adjacent islands and the Anatolian coast. The exact location of the eruptive vent is not known, but the Kos Plateau Tuff was erupted from a stratocone volcano, remnants of which are present beneath Yali, Nisyros and Pachia (Pe-Piper et al., 2005). It is thought by Lagios et al (2005) that the vent was probably to the north or northeast of the islet of Yali, creating a submarine caldera with a diameter of 15-20 km.

The Kos-Yali-Nisyros volcanic field is also comprised of numerous submarine volcanic vents discovered using swath multibeam mapping and seismic tomographic profiling (Nomikou & Papanikolaou., 2000) most of which emerge as small volcanic vents proximal to Nisyros; as well as the volcanic islands of Pachia, Pyrgousa and Strongili (Vougioukalakis., 1998)

The area is still highly active with five major fault systems having been identified in the Kos-Yali-Nisyros volcanic field from geological and structural investigations (Papanikolaou et al., 1991; Vougioukalakis., 1993; Papanikolaou and Nomikou., 2001) as follows: (figure.3.1)

F1 – (NE-SW trend) Part of the general horst-graben system between the islands of Kandelousa, Kos and the Datca Peninsula.

F2 – (NW-SE trend) Found approximately perpendicular to the F1 faults with steep inclinations. These faults are characterised by extensional features and down-faulting of up to 70m.

F3 – (E-W trend) These localised faults are thought to be the result from deep reaching conjugate F1 & F2 faults.

F4 – (N-S trend) Again, thought to be relating to deep reaching conjugate F1 & F2 faulting. These faults are identified locally on Nisyros Island, and equivalent faults can also be seen on the Kephalos Peninsula, Kos.

F5 – (ESE-WNW trend) Found in both the oldest and youngest volcanic rocks on Nisyros, and thought to be due to regional tectonic regimes.

Stiros (2000) notes that the faults found outside of the caldera are arranged in a radial pattern, and along with geological evidence of uplift during the 3-4 thousand years, interpreted this as being due to magma-inflation episodes.

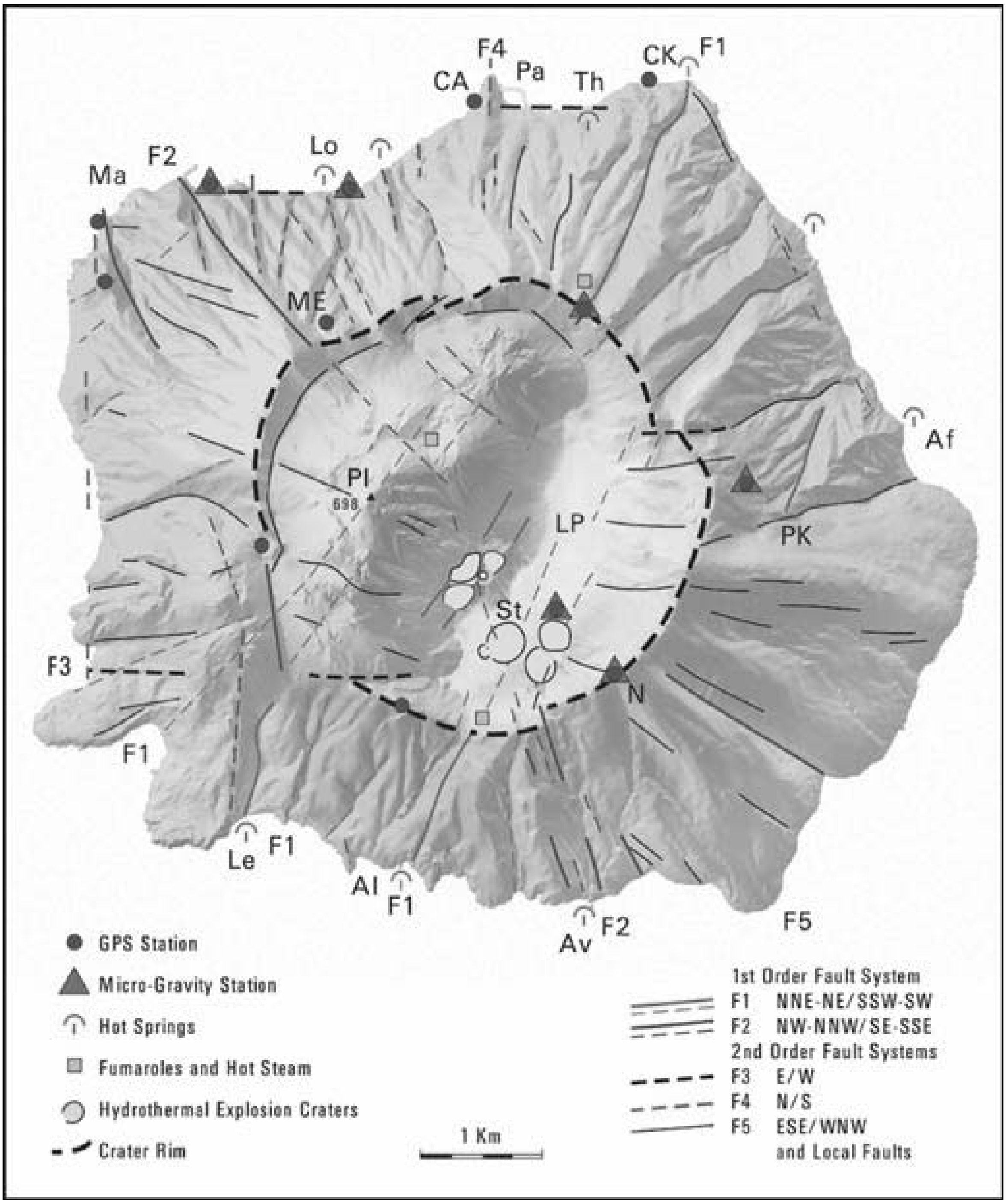

Figure 3.1 Map of Nisyros showing the tectonic fault systems, location of hydrothermal eruption craters, location of hot springs, and location of GPS/Gravity monitoring stations (Lagios et al., 2005)

The Kos-Yali-Nisyros volcanic complex has been described by some (Caliro et al., 2005; Tibaldi., 2005) as a resurgent caldera, having the same characteristics as Long Valley (California), Campi Flegrei (Italy) and Rabaul (Papua New Guinea). During the 1980's these three Calderas experienced heightened activity with regards to seismic, ground uplift and gas emission. Activity within the Long Valley Caldera (California) continues periodically until present. The unrest at Campi Flegrei (Italy) ceased in 1985 without any eruption (Caliro et al., 2005). The Rabaul Caldera (Papua New Guinea) experienced uplift and tilting throughout 1983-1984 along with intense seismic activity. Post November 1984, the activity reduced and it was not until September 1994 that two shallow earthquakes occurred before a Plinian eruption from one of two erupting vents (Francis and Oppenheimer., 2004)

Nisyros Island:

Nisyros can be found in the centre of the Dodecanese Island group (36.35N 27.10E). The island covers an area of 42km^2 and reaches a maximum height of 698 metres above sea level. The island has a pentagonal shape with an average diameter of 8km. The main feature of the island is the central caldera with a diameter of 4km. The rim of the caldera varies in height from 250m to around 600m above sea level. The caldera can be split into two halves. The eastern section, known as the Lakki plain, can be found at an average altitude of 100m above sea level. The western section consists of a range of lava domes which formed after the last magmatic eruption of the island some 15 thousand years ago (Vougioukalakis., 1998). Pre-volcanic basement rock is not exposed on the island; however boreholes drilled into the Lakki plain indicate Mesozoic limestone forms the most shallow part of the underlying crust at a depth of 691m (Marini et al., 1993).

On a geological timescale Nisyros is a young volcanic island. The oldest volcanic material which forms the island belongs to the basal volcanic complex. This complex consists of basaltic and andesitic pillow lavas (figure 4.1), which gradually transform into sub-aerial lava flows in the upper sections, erupted 160–100 thousand years ago along the NE-SW trending horst between Kondelousa and the Turkish coast (Gogu et al., 2005).

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Figure 4.1 Section of a N-S (F4) fault found to the west of Mandraki. The lithology here is composed of pillow lavas from the basal volcanic complex.

The stratigraphies overlying the basal volcanic complex were formed in a sub-aerial environment. They consist of basaltic, andesitic, dacitic and rhyolitic lava flows, pyroclastics and tuffs ranging from 100-30 thousand years old (Gogu et al., 2005).

The stratocone volcano which formed is estimated by Vougioukalakis (1998) to have been approximately the same dimensions as the current island volcano, approximately 600m in height with a diameter of 7km.

Between 30-15 thousand years before present, the island experienced two phases of caldera formation. The first phase is estimated to be between 30-20 thousand years before present. By this stage in the island's development, a large magma volume had accumulated at shallow depths resulting in the generation of the hydrothermal system (Gogu et al., 2005).

The first Plinian eruption produced more than 20 billion cubic metres of pumice and ash, which covered the island in a tephra layer known as the 'lower pumice' up to 15m in thickness (Vougioukalakis., 1998). Post Plinian eruption, rhyolitic lavas were erupted forming lava domes and flows on the eastern side of the caldera, known as the Nikia Rhyolites (Gogu et al., 2005).

The second Plinian eruption occurred between 20-15 thousand years before present forming the ‘Upper Pumice’ deposits. These deposits consist of both wet and dry surge and flow sequences. The estimated volume of magma erupted in this event is similar to that of the ‘Lower Pumice’. Again, post Plinian eruption, dacite-rhyodacite lavas were erupted, this time forming lava domes in the western side of the caldera along a NE-SW trend (figure 5.1) (Gogu et al., 2005).

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Figure 5.1 Looking SW towards the NE-SW trending lava domes on the western side of the Nisyros caldera.

According to the 1991 census, the island was home to 929 inhabitants. The majority (677) lived in the island’s capital, Mandraki, found on the NW coast of the island. Pali, the next largest town, found on the northern coast was home to 150 inhabitants, whilst in the two small villages of Emborio and Nikia, over-looking the caldera, 41 and 61 people resided.

The 2001 census records the population at 938, so within a decade, the population has changed very little with time.

However, the population is not static through the summer period. Although Nisyros is not a direct tourist destination, its close proximity to the islands of Kos and Rhodes in Greece, and also to the Turkish resorts of Bodrum and Marmaris, make the island an ideal place for day trippers; the hydrothermal craters receiving hundreds of tourists per day (Gogu et al., 2005). The island's population also increases during the summer months due to the influx of island-related tourists i.e. Greeks now living away from the island returning to spend time with family and friends.

Although tourism is not as well established as other islands, tourist facilities do exit. The Nisyros Guidebook (Arfaras., 2002) states that the daily visitors to the island from the surrounding ports can be as many as 8000. There are numerous hotels, rooms for rent, tavernas, bars and craft shops; the majority of which are found in Mandraki.

Due to the size and geomorphology of the island, all tourists as well as supplies arrive by sea as an airport is not viable. However, a helipad does exist on the island in case of an emergency.

Nisyros, along with most of the other islands belonging to the Dodecanese, suffers from a lack of drinking water. In 2000, over 80 thousand cubic metres of potable water were transported to the island (REDDES Project., 2001). In order to combat the lack of water, Nisyros, along with other islands were fitted with Reverse Osmosis desalination units. The Nisyros desalination unit, located at Mandraki, came into operation in 2001 and produces 300 cubic metres of water daily (Tzen., 2003).

Nisyros obtains its power via a submarine cable from the neighbouring island of Kos, even though the island is very capable of producing its own electricity through geothermal means. The Greek Power Corporation proposed the construction of a geothermal power plant, which would provide the residents with cheaper electricity. However, local reaction to the power plant was negative (Popovski., 2003). The reasoning behind the refusal of the power plant was primarily that the locals believed it dangerous to interfere with the volcano, but also that they did not want their island's beauty disturbed (Popovski., 2003). These reasons were also given by Mr Panagiotis Katsimatidis, the Mayor of Nisyros, during the interview carried out on 29.06.2006, and also by a local shopkeeper, interviewed for this project, from Mandraki.

Identification of the potential geophysical hazards affecting the region:

As previously mentioned the Kos-Yali-Nisyros volcanic field is situated in an area of high geodynamic unrest. Although the previous magmatic eruption from the Nisyros volcano occurred 15 thousand years ago (Gogu et al., 2005), and 10 thousand years ago on the islet of Yali (Vougioukalakis., 1998), the area is still considered volcanically active as well as seismically active, and presents major geophysical hazards for the area. During the period of 1995-1998 the region gave signs of potential renewed volcanic activity in the form of intense seismicity, ground deformation and significant variations in the geochemical parameters of fumaroles (Caliro et al., 2004).
Each type of hazard will now be examined in detail.

Seismic Hazard due to Regional Tectonics:

Due to the location of the Kos-Yali-Nisyros volcanic complex, strong seismic activity is not uncommon. The seismicity in the region is intense and extends from the upper crust to a depth of around 180km (Telesca et al., 2006). The Southern Aegean regional morphology results from the large-scale normal faulting initiated during the Late Neogene and Quaternary; the neotectionic evolution of this area is thus dominated by extensional tectonics (Telesca et al., 2006). Examples of large historical events affecting the region are the earthquakes of 1856 (Ms 8.2) in northeast Crete and 1926 (Ms 8.0) from Rhodes (Papazachos., 1997). Examples of large faults can be seen in figure 1.2.

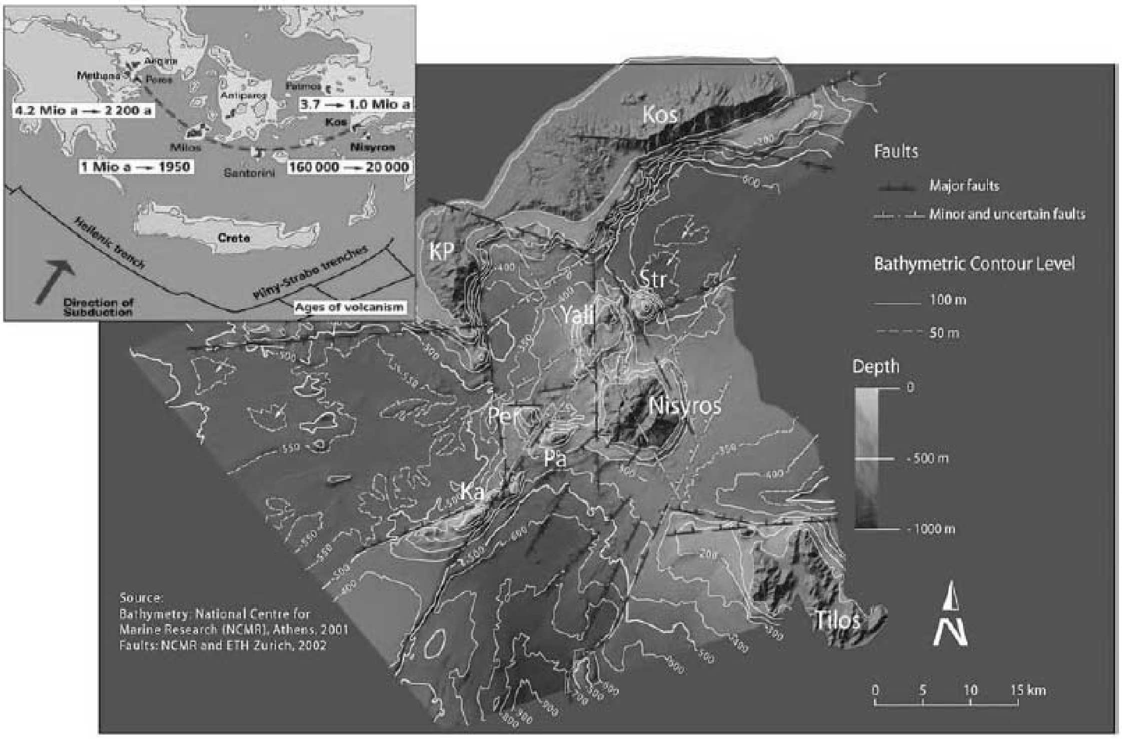

Figure 1.2 shows the Kos-Yali-Nisyros volcanic complex with major faults marked in red and minor/uncertain faults marked in yellow. Abbreviations were used marking some place names: KP – Kephalos Peninsula, Str – Strongili, Per – Pyrgousa, Pa – Pachia, Ka – Kandelousa (Lagios et al., 2005)

The most prominent set of faults are those trending in an E-W direction. These define the horst-graben systems of the western coast of Turkey (Pe-Piper et al., 2005). These large faults are in general extension and are listric in morphology (Seyitoglu et al., 1992).

The area to the east of the Kos-Yali-Nisyros volcanic complex, the coast of south-western Turkey, is comprised of the major rift and graben systems of Gediz, Buyuk Menderes, Kucuk Menderes and Gokova (Ulug et al., 2005). The Gulf of Gokova which lies immediately west of Kos has a length of about 90km from east to west, and a width about 25km from north to south. It is bordered to the north by the Bodrum Peninsula and to the south by the Datca Peninsula.

The bathymetry, along with the geology and geomorphology of western Turkey have been used in determining that the area is under a N-S regional tectonic system (Ulug et al., 2005) and that this system is related to the western movement of the Anatolian plate relating to the collision of the African and European plate (Dewey and Sengor., 1979). It has also been suggested by Le Pichon and Angelier (1981) that the N-S extension has been caused by back-arc spreading of the relatively thickened Aegean crust.

Investigations in the area by Ulug et al (2005) have shown that the gulf is bound by three main directions of faults. The first prevailing direction is WSW-ENE, which correspond to steep scarps following the south coast of the Bodrum Peninsula. These faults could be related to the F1 (NE-SW) fault system found on Nisyros during research conducted by Papanikolaou et al (1991); Vougioukalakis (1993); Papanikolaou and Nomikou (2001).

The second group is marked by major E-W trending scarps along the southern edge of the Gulf of Gokova. These scarps mark active normal faults characterised by large displacements of up to 500M, one of which is the Datca Fault which bounds the northern side of the Dacta Peninsula (Figure 2.2).

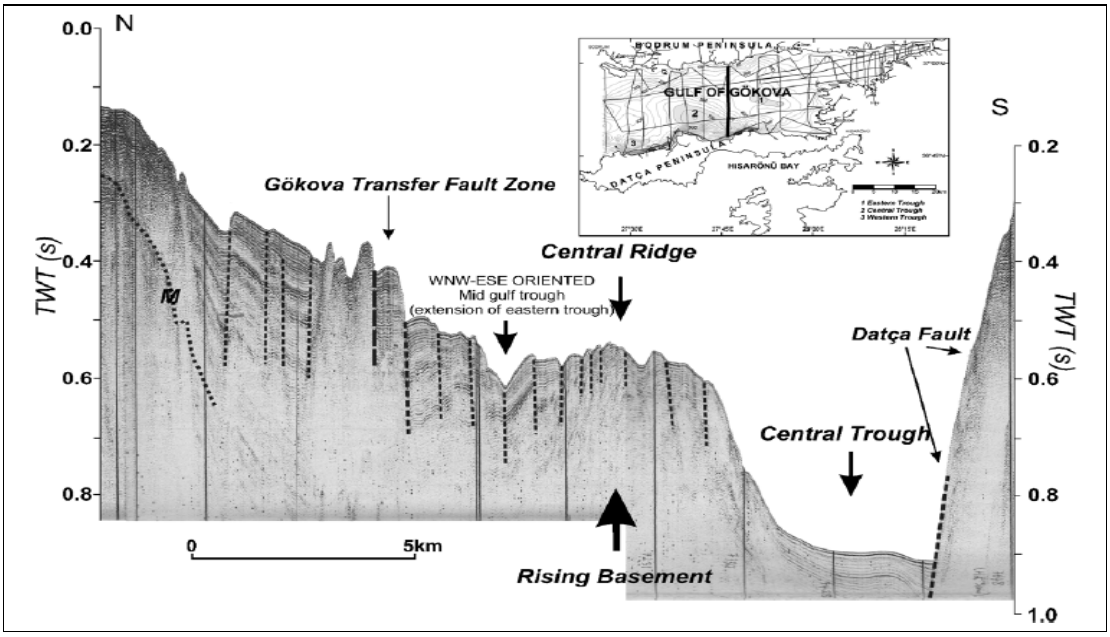

Figure 2.2 Airgun profile from a N-S section of the Gulf of Gokova, sub-vertical dashed lines mark faults (Ulug et al., 2005)

The final fault group consists of a WNW-ESE horst-graben system at the eastern end of the Gokova Gulf (Ulug et al., 2005).

The region around Kos has active faults and high rates of seismicity (Makropoulos and Burton., 1984). The southeast coast of Kos, along with the northern edge of the East Kos basin is defined by an active ENE-SWS trending fault (Hatzfeld., 1999).

Throughout history, large seismic events have shaken the area. A catalogue of earthquakes compiled by Papazachos (1997) records the effects from major earthquakes affecting Greece and the surrounding areas since ancient times (550BC until present).

This catalogue shows two earthquakes with magnitudes measuring 8 and over. The first earthquake, given a magnitude 8.2, occurred on the 12.10.1856, had its epicentre in the Aegean Sea to the northeast of Crete. From the catalogue the effects are not recorded for Nisyros, probably due to the islands small size and low population. However, it is noted that for the island of Rhodes (a distance of approximately 65km SE) the shaking lasted from 40 seconds up to 90 seconds in parts of the island and caused damage to 2000 homes in 8 villages.

The second largest earthquake affecting the area occurred on the 26.06.1926. This earthquake, with a magnitude of 8.0, occurred at a depth of 100km with its epicentre approximately 35km from the island of Nisyros. Again, the damage is not recorded for Nisyros, but the earthquake caused major damages to both Rhodes and Kos.

On 23.04.1933 an earthquake measuring M6.6 occurred off the SE coast of Kos in the East Kos Basin. This event caused major damage on Nisyros as well as Kos where it completely destroyed Kos town.

The next large event to affect the region occurred on 05.12.1968. The earthquake's epicentre was located 20km west of Mandraki, Nisyros. The town suffered damages with intensities of V+ seen.

These examples, however, are not the only events to have affected the island.

Papadopoulos (1984) used an earthquake catalogue (Comminakis and Papazachos., 1982) from 1901-1980 of the area. The area was divided into two parts; the internal (Nisyros and proximal islands) and external regions (The remaining area outside the internal) (Papadopoulos., 1984). By plotting the earthquakes onto a map of the area it can clearly be seen that there are many events focussed around the island of Nisyros (Figure 3.2).

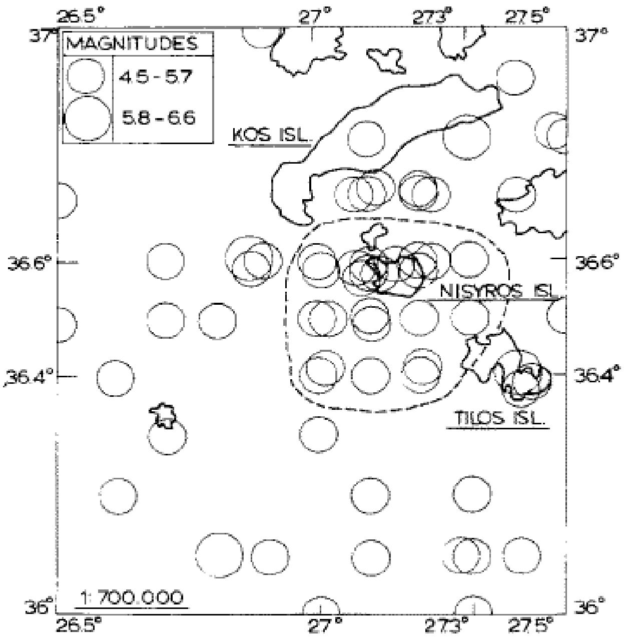

Figure 3.2 Earthquake epicentres taken from the Comminakis – Papazachos earthquake catalogue (1982) showing the Internal and External regions subdivided by Papadopoulos (1984).

Papadopoulos (1984) calculated a seismic b-value for both the Internal and External regions (Figure 4.2).

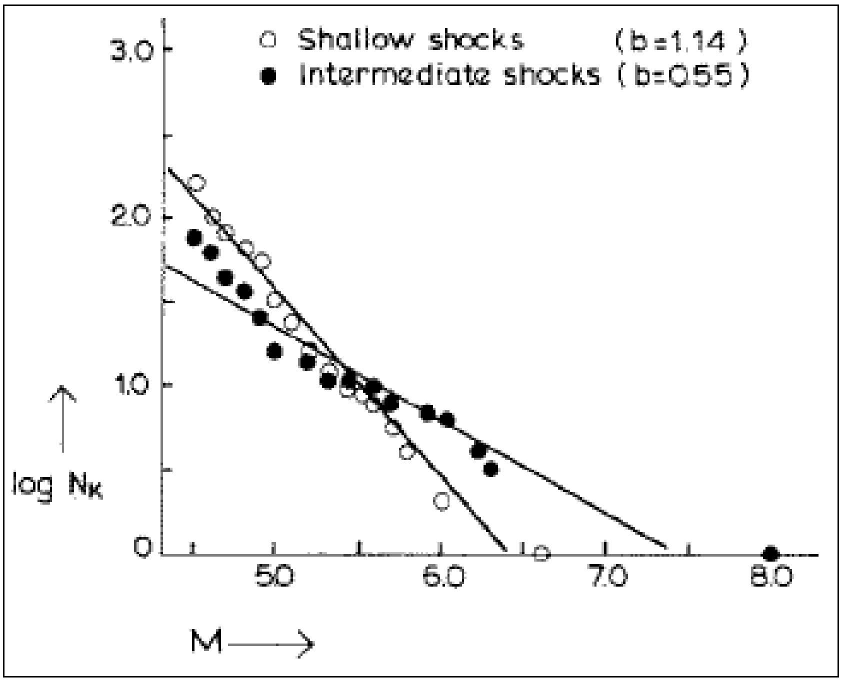

Figure 4.2 Cumulative plots showing the Log Exceedence against Magnitude, for the shallow and intermediate seismic events in the Nisyros-Kos area (Papadopoulos., 1984)

It was found that in this Internal region, the maximum earthquake magnitude observed during the 1901-1980 period is 5.7, however, in the External region four seismic events occurred over the same time period with magnitudes between 5.8-6.6 (Papadopoulos., 1984).

In a general study, Papadopoulos (1984) found that the Internal region around Nisyros has a high concentration of earthquake epicentres although there is an absence of large magnitude earthquakes, along with a high b-value. However, the External region has a normal concentration of earthquake epicentres and large magnitude seismic events do occur.

November 1995 saw the onset of shallow seismic activity in the Nisyros area culminating in two very shallow (5km) events with magnitudes of Ms 5.3 and Ms 5.2 on the 27.08.97 (Papadopoulos et al., 1998).

In March and July 1997, two field surveys were held. In this study, Sachpazi et al (2002) recorded between 30-50 seismic events daily with very low magnitudes between 0.7-2.1. A focal migration was found from a region situated off of the NW coast of Nisyros towards the central caldera. This was interpreted as the brittle response of the volcanic edifice to an inflation of a magma chamber located to the NW of the island. (Sachpazi et al., 2002).

Volcanotectonic Seismic Activity:

Seismic events triggered by tectonic processes are not the only type of earthquake that poses a hazard to the region. Volcano-Tectonic earthquakes are caused when magma is on the move. In order for magma to reach a different part of the crust, it must create a pathway, physically fracturing the surrounding rock to propagate, resulting in VT earthquakes.

A seismic survey was conducted on Nisyros using instruments specifically intended for detecting broadband, emergent signals associated with magmatic-hydrothermal activity, installed within the Nisyros caldera by Caliro et al (2004) in June 2001. During this experiment, two long-period (LP) events were recorded, which are commonly seen in active volcanic environments (Chouet., 1996). These events were interpreted as the interaction between hydrothermal or magmatic fluids and their host rock, or are related to an over-pressurisation of the system due to ascension of hot fluids from depth, or even the rapid de-pressurisation due to failure of a crack's tip (Caliro et al., 2004).

Volcanic Eruption:

The islands of Nisyros, Yali, Pachia, Pyrgousa and Strongili, owe their existence to volcanism (Vougioukalakis., 1998). Over the thousands of years it has taken for them to evolve into the islands we know today, many types and styles of volcanism have taken place, which today would pose varying degrees of hazard. The type and style of eruptions are due to the volcano's location - submarine or sub-aerial, magma chemistry, magnitude of eruption etc. The differences in eruption styles will briefly be described, using geological/stratigraphical examples from Nisyros and the surrounding region.

During the submarine eruptions of the Basal Volcanic Complex (~160-100 thousand years BP) basaltic and andesitic eruptions produced pillow lavas and hyaloclastites (Gogu et al., 2005). Pillow lavas are formed when lava, usually of basaltic chemistry, is erupted in a submarine environment. The pillows of lava which are commonly about 1m in diameter, can accumulate into deposits hundreds of metres in thickness (Francis and Oppenheimer., 2004).

Hyaloclastites are extensively fragmented glassy deposits, formed when lava extruded into a sub-aqueous environment causes minor explosions and implosions abruptly cooling the lava (Francis and Oppenheimer., 2004)

These eruptions occurred along the NE-SW trending "horst-graben" system previously mentioned between Kondelousa and the coast of Turkey. Through successive eruptions the base of Nisyros began to form and rise towards the surface.

The early stratovolcano (100-30 thousand years BP) comprises deposits and units with varying magma chemistry - from basalt through to rhyodacite (Gogu et al., 2005).

The Argos-Stavros Complex consists of red andesitic spatter cones found at the southern rim of the caldera, along with a well-exposed scoria cone. The Argos lavas are found in the form of rhyolitic lava flows (Figure 5.2), lava domes and block and ash flows formed from lava dome collapse (Gogu et al., 2005).

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Figure 5.2 Cliff section at Lefkos Cove, south coast of Nisyros with exposed Argos lava flows and scoria deposit.

Scoria cones are a type of monogenetic volcano, which means they are the product of a single eruption of Strombolian style. They are rarely more than 200-300m high and have an asymmetrical geometry (Francis and Oppenheimer., 2004). Scoria is a pyroclast containing vesicles typically on the scale of several millimetres, which from the time of eruption have sufficiently cooled and solidified before reaching the ground.

Strombolian style eruptions take their name from Stromboli volcano, Italy, and are characterised by intermittent explosions that produce showers of ejecta (ballistics) with a range of a kilometre or less.

A lava dome is the build-up of viscous (silica rich) lava either endogenously (builds internally) or exogenously (builds externally) over a vent. Lava domes can range in size from several metres to over a kilometre in diameter (Sigurdsson., 2000). Lava domes are known to be incredibly unstable. When they fail they produce a range of pyroclastic density currents. Lava domes can precede volcanic eruptions, for example, Mt. Pinatubo, 1991; occur after an eruption, for example Mt. St. Helen's, 1980, or be the sole product of an eruption, for example, Mt. Unzen, 1991.

Vulcanian eruptions, named after Vulcano, Italy, occur in magmas of andesitic chemical composition. By some mechanism the upper conduit of a volcano plugs itself, forming a barrier between the magma and the surface. Vulcanian eruptions consist of typically brief, low magnitude explosions, which can vary in duration. Vulcanian activity produces much larger eruption columns than Strombolian activity, sometimes reaching 10-20km dispersing tephra (Francis and Oppenheimer., 2004).

The Lakki and Avlaki Complexes consist of several metres of pumice fall deposit, which show the first sub-Plinian deposit. This deposit is followed by pyroclastic flow and surge deposits and terminates in a fallout deposit. (Gogu et al., 2005).

Sub-Plinian activity refers to an explosive, high-sustained eruption column which produces extensive sheets of tephra fallout deposit from new magmatic material, rather than shattered old material (Francis and Oppenheimer., 2004). Sub-Plinian eruptions eject between 0.5-0.05km^3 of material during phases of low intensity (Mass Discharge Rate of about 10^6kg/sec) (Sigurdsson., 2000)

Pyroclastic flows are high concentration, topographically confined, flows of hot (100-1100 degrees Celsius) tephra and gas (Sigurdsson., 2000). They are formed in several ways, for example, through the collapse of a lava dome, or the collapse of an eruption column/fountain collapse. The can travel at velocities of 10-100m/sec, but at such speeds there is an element of blast, not just gravity driving the flow.

Pyroclastic surges are low concentration, topographically unconfined, flows of material, which can form the head of a pyroclastic flow, or be generated from the base of an eruption column.

Volcanic eruptions in which magma and water interact can produce base surges. The abundance of condensed steam from the magma-water interaction ensues that hydrovolcanically derived pyroclastic density currents are often wet and sticky, and have a much lower temperature than pyroclastic flows (Francis and Oppenheimer., 2004).

Between 30-20 thousand years ago, the first of two caldera-forming Plinian eruption occurred on Nisyros (Vougioukalakis., 1998; Gogu et al., 2005). Large volumes of magma were erupted covering the island in pyroclastic flows and a large air-fall deposit known as the 'Lower Pumice' (Gogu et al., 2005). The 'Lower Pumice' can be found up to 15m thick in parts of Nisyros (Vougioukalakis., 1998).

The second caldera-forming Plinian eruption occurred some 20-15 thousand years ago, and produced the tephra deposit known as the 'Upper Pumice', which in parts of the island exceeds 100m in thickness (Gogu et al., 2005). In the basal sequences, which have a thickness up to 8m, deposits of wet and dry surges can be seen (Gogu et al., 2005).

It was estimated by the GEOWARN Project team, that the erupted volume of magma for both the Upper and Lower Pumice eruptions was between 2-3km^3.

As a comparison it can be noted that the magma volume erupted at Mt. St. Helen's, Washington State, 1980, was in the area of 1km^3.

Plinian style eruptions are named after Pliny the Younger, who described the eruption of Mt. Vesuvius (Mt. Somma) in AD 79. Plinian eruptions are generally magnitude 4 and higher, and globally occur on average 5 times per decade (Francis and Oppenheimer., 2004).During Plinian eruptions, a mixture of gas and particles is discharged from a vent at speeds of 100-400m/sec, with the volume of ejected material ranging from 0.1-10km^3 (Sigurdsson., 2000).

Hydrovolcanic eruptions occur due to the interaction between hot volcanic material and water. This can occur if a vent opens up under water; when a vent on dry land comes into contact with water stored in an aquifer; or simply when pyroclastic flows or lava flows move over water-saturated sediments (Francis and Oppenheimer., 2004).

Pe-Piper et al (2005) proposed that propagating ENE trending strike-slip faults from Santorini to Kos, would have produced extension along the older NE trending fault system in the Yali-Nisyros region, and might have lead to water gaining access to the volcanic conduits, producing the explosive Kos Plateau Tuff eruption.

Phreatomagmatic eruptions occur when a greater amount of water and magma interact, and can be much more explosive leading to phreatoplinian eruptions (Francis and Oppenheimer., 2004).

Chiodini et al (2002) hypothesised that the historical hydrothermal activity, the geochemical change in fumarolic composition, along with the seismic activity of Nisyros could be the long-term pre-cursor for renewing volcanic activity, which could possibly culminate in a magmatic eruption.

Chiodini et al (1996) and Hammouya et al (1997) note that similar precursory activity preceded the magmatic eruption of Montserrat, and Guagua Pichincha in Ecuador (Marini et al., 1991).

Hydrothermal Eruptions:

Hydrothermal, or Phreatic eruptions as they are also known, are triggered by an instability in a hydrostatic liquid column very close to boiling temperature (Encyclopedia of Volcanoes., 2000). The related deposits of these eruptions consist of pre-existing fragments usually having undergone hydrothermal alteration prior to the eruption (Marini et al., 1993).

In geothermal fields susceptible to hydrothermal explosions, liquid water lies below the surface at boiling point conditions. The water is then suddenly exposed to a much lower level of pressure due to an initiation event (Smith., unknown date). The resultant decrease in pressure allows boiling and the expansion of the fluid. If an escape path is created during the initiation event, the fluid will move towards regions of lower pressure; usually towards the surface (Smith., unknown date). The ascending fluid velocity provides the lift to rock particles above, and providing the net lift out-weighs the cohesive stresses of the rock, a rock and fluid mixture will be ejected upwards (Figure 1.4, Smith)

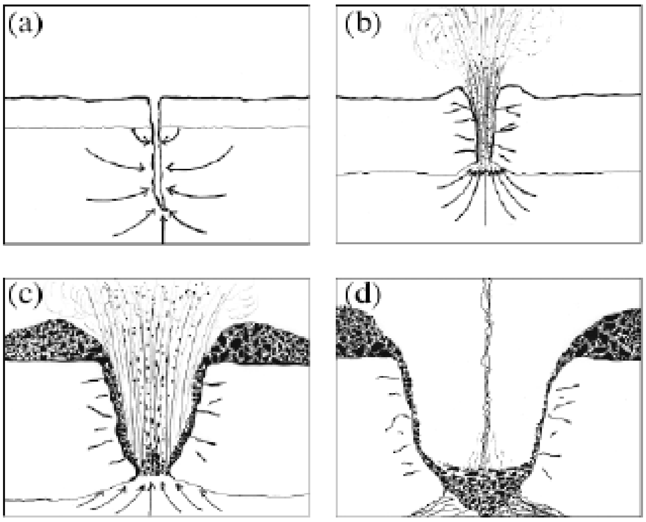


Figure 1.4 A sketch showing the eruptive processes producing a hydrothermal eruption, (a) initiation of pathway, (b) onset of eruption, (c) eruption, (d) Cessation of eruption (Smith., unknown date)

As the depressurisation propagation progresses downwards, it prompts the boiling front to also continue downwards, causing more fluid to be erupted (Smith., unknown date).

There are several ways in which a hydrothermal eruption can be triggered. One such way proposed by Muffler et al (1971) and Dench (1988) involves the removal of the overburden above the superheated water. This removal reduces the confining pressure in the underlying system. Should there be water present near boiling temperature, the pressure reduction will cause boiling to occur and an eruption could follow.

Initiation due to hydraulic fracturing proposed by, among others, Nelson and Giles (1985) show that hydraulic fractures which link a body of high temperature fluid to the atmosphere will initiate boiling and cause an eruption.

The initiation of hydrothermal eruptions by seismicity is a widely accepted hypothesis, among others; Marini et al (1993) believe the hydrothermal eruptions of Nisyros in the 1870's were initiated seismically. This will be discussed in more detail further on.

The final method for hydrothermal eruption initiation is due to a sealing of the thermal area preventing fluid flow. This might occur from landslide events, the collapse of post-eruptive crater walls, or by the sealing of an area due to mineral precipitation (Smith., unknown date).

The Hydrothermal Eruptions of Nisyros:

As previously mentioned, the caldera of Nisyros (Figure 2.4, Lagios et al., 2005) may be divided into two sections. The western half comprises the post-eruptive lava domes following the NE-SW trend, from Boriatiko in the northern-most part, through Nifios, Diavatis, Profitis Ilias, Trapezina, and Karaviotis in the southwest.

The eastern section of the caldera, known as the Lakki plain, is bound by the previously mentioned lava domes to the west and north, and by the caldera rim to the east and south.

The Lakki plain can itself be divided into two parts. The northern section where there is very little hydrothermal activity and the southern section that consists of active fumarole fields and hydrothermal eruption craters (Figure 3.1).

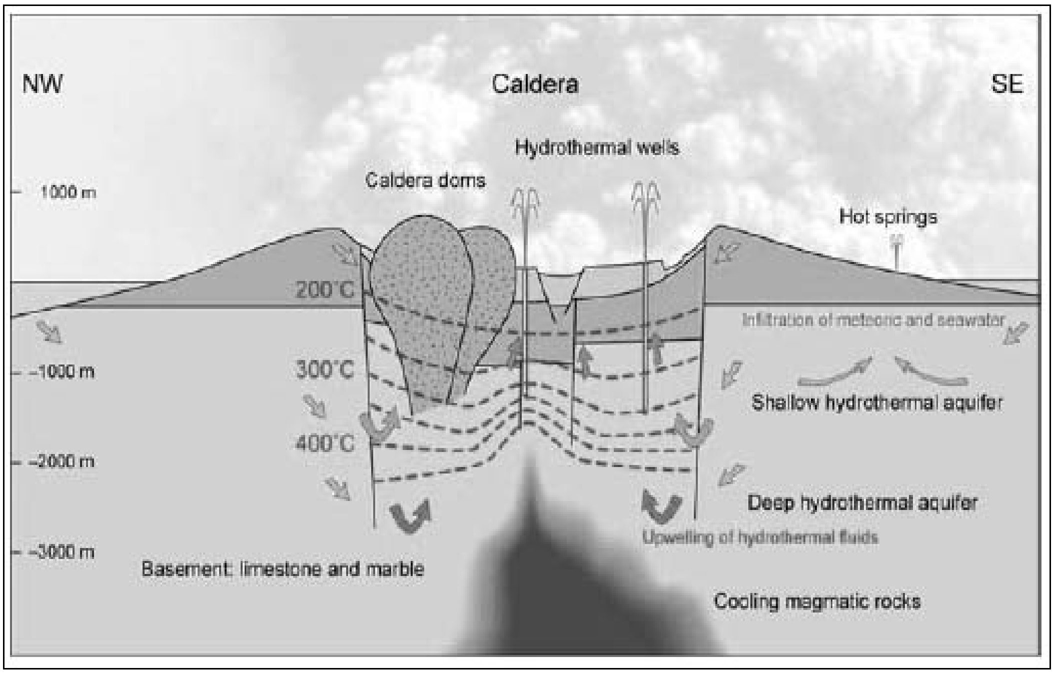


Figure 2.4 A cross-sectional diagram of Nisyros showing the caldera and the hydrothermal systems (Lagios et al., 2005)

The hydrothermal system of Nisyros has been recognised since ancient times; Hippocrates having chosen springs on the island as natural healing spas (Vougioukalakis., 1998).

Dawes and Lagios (1991) proposed two distinct hydrothermal aquifers may be present beneath the caldera based on temperature distribution, fluid chemistry, physical-chemical characteristics of fumarole gas and thermal waters at the surface, and also waters in deep geothermal wells.

Two geothermal wells were drilled down into the Lakki plain in the early 1980's (Figure 3.4).

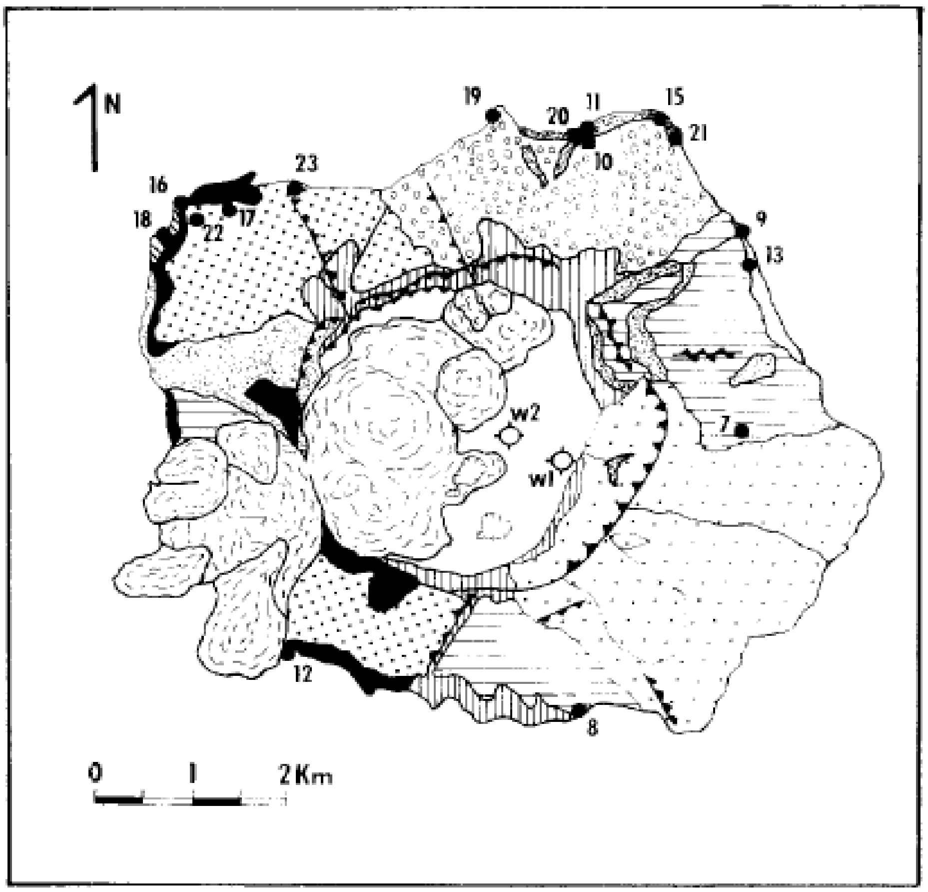


Figure 3.4 A map of Nisyros indicating the locations of two geothermal wells on the Lakki plain (w1 & w2) (Marini et al., 1993)

The results from the drilling showed that Well 1 crossed the carbonate basement beneath the volcanic sequences, however, this was not to be the case for Well 2, indicating that the central region of the caldera experienced a larger collapse than the marginal parts (Marini et al., 1993).

Both Wells terminated in a complex of sub-intrusive rock, interpreted as feeding conduits or batches of magma which did not reach the surface, and thermo-metamorphic rock. Both lithologies had undergone heavy alteration by hydrothermal activity (Marini et al., 1993).

Marini et al (1993) found that chlorite was the most abundant mineral in Well 1, probably due to a rock-seawater interaction, indicating that part of the Well is affected by seawater inflow.

Well 1 reaches a depth of 1816m where temperature values are higher than 350^{o}C. Well 2 reaches a depth of 1547m and has temperature values of over 290^{o}C (Marini et al., 1993).

Within the southern Lakki plain remnants can be found of over 20 hydrothermal eruption craters, 10 of which are well preserved (Figure 4.4)(Vougioukalakis., 1998). They are found in two distinct locals; near to the Lofos dome, and by the SE caldera rim (Figure 5.4).

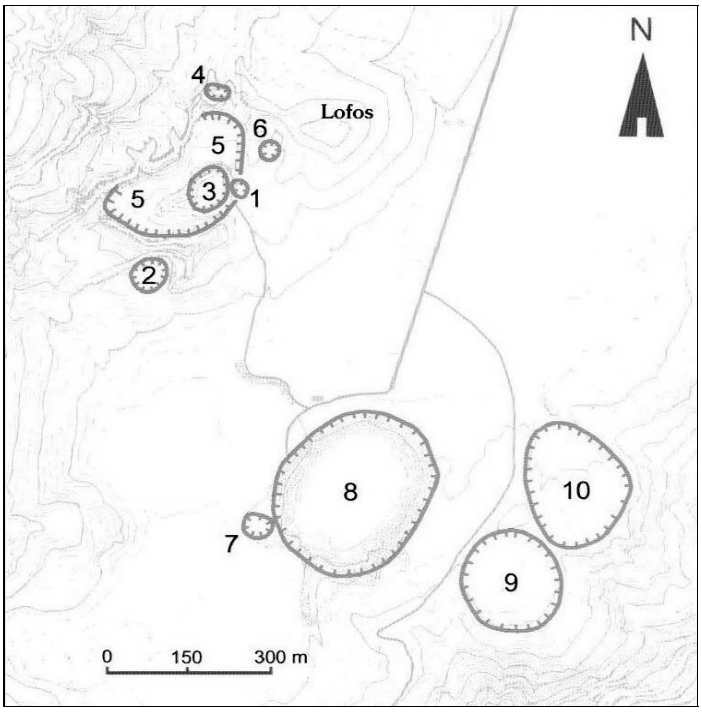


Figure 4.4 Sketch map indicating the locations of the Lakki plain hydrothermal eruption craters: 1. Mikros Polyvotis (1887), 2. Alexandros/Flegethro (1873), 3. Polyvotis (1873), 4. Archilleas, 5. Megalos Polyvotis, 6. Logothetis, 7. Mikros Stefanos, 8. Stefanos, 9-10. Kaminakia (Vougioukalakis., 1998).

The oldest hydrothermal craters on Nisyros are the Kaminakia and three other craters north of the Lofos dome.

The two craters at Kaminakia, with an average diameter of 150m each, are linked to a NE trending fault against the caldera wall beneath the town of Nikia, their position having favoured erosion of their morphological forms (Marini et al., 1993; Vougioukalakis., 1998).

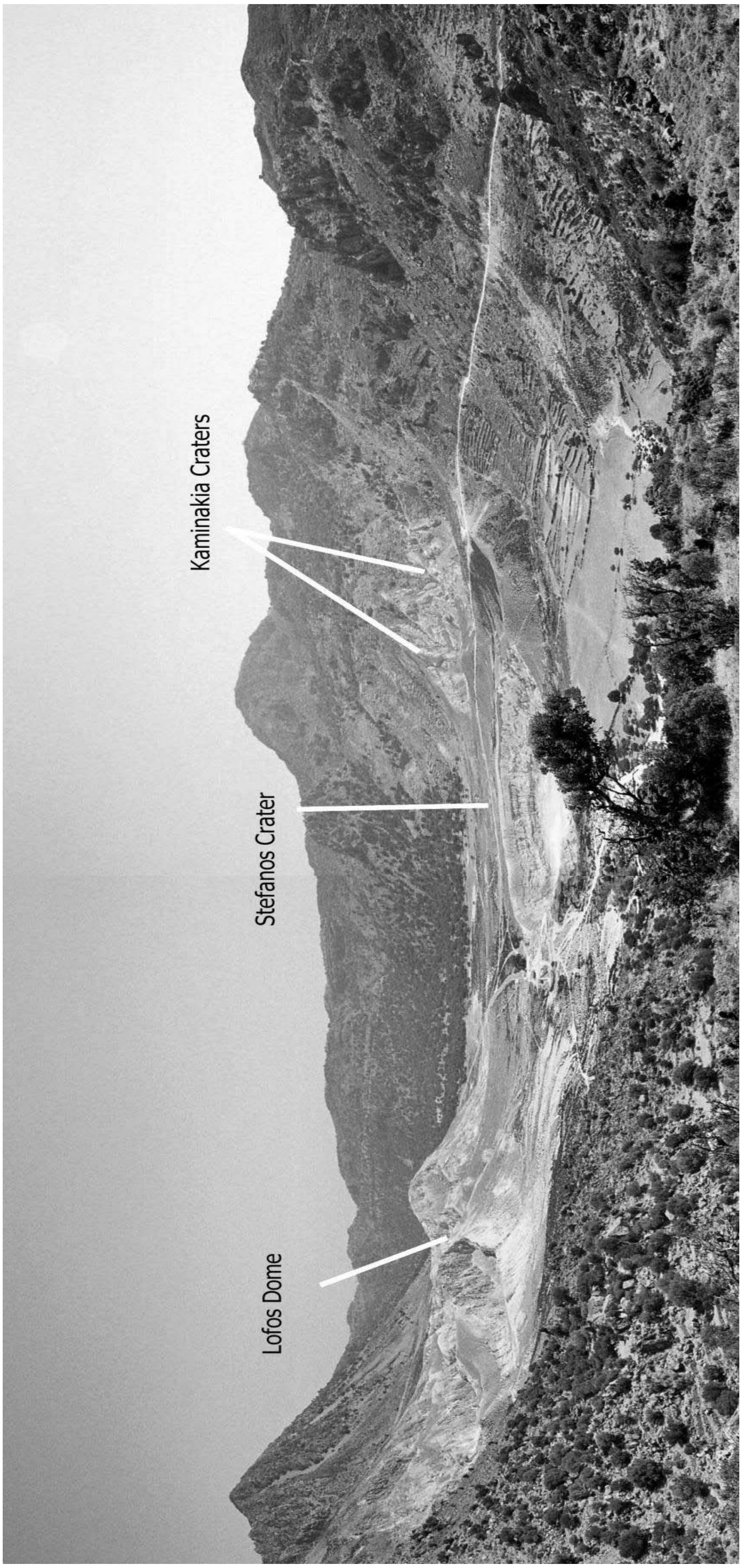


Figure 5.4 View of Nisyros caldera towards the NE. Labelled are the Lofos Dome, the Stefanos Crater and the craters of Kaminakia

The largest hydrothermal crater in the Nisyros caldera is that of Stefanos, measuring 330m long, 260m wide and 27m deep. It is considered to be one of the best preserved hydrothermal craters in the world, and is thought to be at most 3-4 thousand years old as it is situated in soft, hydrothermally altered rock which is easily washed away by wind and rain (Vougioukalakis., 1998). The NE-SW fault which controls fumarole activity within Stefanos is not visible at the surface instead was located using a detailed diffuse $C0_2$-flux survey carried out under the GEOWARN Project (Gogu et al., 2005).

According to Vougioukalakis (1998), Stefanos monopolises the interests of tourists as it is pointed out to them as *the volcano*.

The area around the Lofos dome is very complex and consists of several hydrothermal eruption craters and their products within a morphologically uneven zone (Marini et al., 1993). The western-most NE-SW fault systems of the caldera act as pathways from the hydrothermal aquifers below feeding the fumarole systems in the Lofos dome area (Chiodini et al., 2001).

The oldest hydrothermal crater in the area around the Lofos dome is Logothetis, which can be found on the SW flank.

The largest hydrothermal crater around Lofos dome is Megalos Polyvotis measuring 350m in length and 180m in width. This eruption was the most important in the area of Lofos dome, and marks the site of subsequent events (Marini et al., 1993). Vougioukalakis (1998) states this eruption crater to be younger than Stefanos (3-4 thousand years old).

The deposits left by this eruption consist of hydrothermally altered lavas of the dacitic-rhyodacitic domes supported in a clay matrix (Marini et al., 1993).

The craters of Polyvotis and Alexandros/Flegethro were formed during the period of 1871-1873. The large Alexandros/Flegethro eruption crater is located to the south of Megalos Polyvotis, whilst Polyvotis is found within the crater of Megalos Polyvotis. The small eruption crater of Mikros Polyvotis formed in 1887.

All hydrothermal deposits found on the Lakki plain show similar characteristics and it is thought that they all originate from the same mechanisms of emplacement (Marini et al., 1993). The deposits are poorly sorted, matrix-supported pieces of pre-existing rock varying in shape from angular to sub-rounded, and have a maximum size of up to a few metres (Marini et al., 1993).
The characteristics of the hydrothermal deposits e.g. absence of impact sags, poor sorting, low block/matrix ratio, suggest that they were emplaced as debris flows (Marini et al., 1993).

The Historical Hydrothermal Eruptions of Nisyros 1871-1887:

Towards the end of the 19th Century the islanders of Nisyros began to notice changes in fumarolic activity within the caldera. Throughout 1871 the activity inside the Stefanos crater decreased, whilst in the crater of Megalos Polyvotis an increase was observed (Marini et al., 1993; Vougioukalakis., 1998).
During October or November 1871, a violent earthquake occurred, followed by a series of explosions, whereby fragments of rock were propelled over the highest peaks of the island into the sea, forming two small craters; Polyvotis and Alexandros/Flegethro (Marini et al., 1993; Vougioukalakis., 1998).

The deposits of these explosions can no longer be found in the field and it is thought that either they were entrained in the debris flows of 1873, or were eroded by atmospheric agents (Marini et al., 1993).

During 1872, seismicity and probable hydrothermal activity continued within the caldera. A French geologist, H. Gorseix, was sent to Nisyros from the Academy of Science in Paris and recorded the following eruptions (Vougioukalakis., 1998).

June 1873 saw strong local earthquake events causing the Alexandros/Flegethro crater to widen and unite with Polyvotis via a NE trending fissure. For three hours hot brine discharged along with ejected rock fragments. Dark fluid mud was discharge intermittently from both Polyvotis and Alexandros/Flegethro craters and moved southward down slope, accumulating in the lowest part of the Lakki plain. The dimension of the flow was approximately 500m long, 150m wide and had a mean thickness of 3m. These eruptions caused some slight injuries, but the location where these injuries occurred is not recorded.

Throughout the summer of 1873, small seismic shocks were felt. Steam was still emitted from the newly formed vents, however, without solid or liquid material.

Violent seismic activity preceded the opening of a submarine fracture sited a few metres from the Mandraki coast on September 11th; jetting H_2S steam into the air and turning the sea a milky colour. This also occurred 5km north of Nisyros on the island of Yali. Minor damages due to the seismic activity were reported in Mandraki.

September 23rd saw new emissions of hot brine from the Polyvotis and Alexandros/Flegethro craters which enlarged both craters. Steam continued to be discharged for a few months after the eruption, along with geyser-like eruptions of water to a height of 30m.

The final eruption occurred in September 1887 and formed the small crater of Mikros Polyvotis. This eruption is far less described than the 1871-1873 eruptions as it was far less impressive (Marini et al., 1993).

Chiodini et al (2002) along with Lagios et al (2005) consider the hydrothermal eruption hazard much higher today than in the 1990's, with Lagios et al (2005) expressing concern over the Mandraki fault. This fault running through the town of Mandraki having a clear submarine continuation has been active since the 19th Century with vertical extension continuing down deep into the crust. It is thought possible future hydrothermal, volcanic and tectonic activity could occur along this zone (Lagios et al., 2005).

Research carried out by Marini et al (1993) states that the area of the southern Lakki plain is at most risk from hydrothermal eruptions. However, it should be considered that this work was completed prior to the volcanoseismic crisis of 1996-1997, thus does not take into consideration re-activation of the Mandraki fault and crustal deformation within that area.

Hydrothermal activity can also occur prior to magmatic eruptions. Prior to the eruption of Mt St Helens on 18th May 1980, hydrothermal eruptions began on 27th March 1980 (Newhall and Punongbayan., 1996). The same was seen before the eruption of Mt Pinatubo in 1991. Hydrothermal eruptions commenced on 02nd April and the final eruption occurred on 12th June (Newhall and Punongbayan., 1996).

Landslide:

Landslides (slope failure) and tsunami are generally placed in the category of secondary hazards resulting from seismic and volcanic activity.

There are many factors, which can influence a slope failure event, both natural and anthropogenic. Slope failure events, also known as landslides and mass movements are all driven by gravity. Friction acts as the opposing force, and when gravity exceeds the frictional force a failure is observed. The resulting slope failure can occur in two ways; either it will be a sudden event, as in a landslide/rockslide or avalanche, or it will happen over days/months and perhaps even years, and result in 'creep'.

Various types of ground failure can be associated with both moderate and large seismic events. Papadopoulos and Plessa (2000) analysed 47 earthquakes affecting Greece as a whole from 1650 until 1995. Their results show that landslide events are common on Mainland Greece as well as on the islands of the Ionian and Aegean.

Using a worldwide database of landslide events, Keefer (1984), estimated that the smallest earthquake of local magnitude (M_L) likely to trigger a landslide is M_L4, up to a magnitude of ~M_L6.5.

The study by Papadopoulos and Plessa (2000) shows that within Greece, earthquake magnitudes which trigger landslide events range in magnitude from M_S 5.3 to M_S 7.9, with peaks at M_S 6.4 and M_S 6.7. It should however be noted that Keefer (1984) used the local magnitude (M_L) where as Papadopoulos and Plessa (2000) have used surface wave magnitude (M_S).

In the duration on Nisyros for data collection, two landslide events were noted: the first (Figure 1.5) was located within the town of Mandraki on the northwest coast of Nisyros.

(Image removed to reduce file size)

Figure 1.5 Landslide that occurred in 2003 along the Mandraki fault, Mandraki town.

The landslide caused damage to several buildings and covered the sea path leading to the local beach situated west of Mandraki town. The opposite side of the headland can be seen in figure 4.1. The landslide occurred in 2003 as a single event.

The second, much larger, event occurred along the main road between Mandraki and the Loutra Spa (Figure 2.5). This event consisted of a large rock fall, which took many days to fully clear.

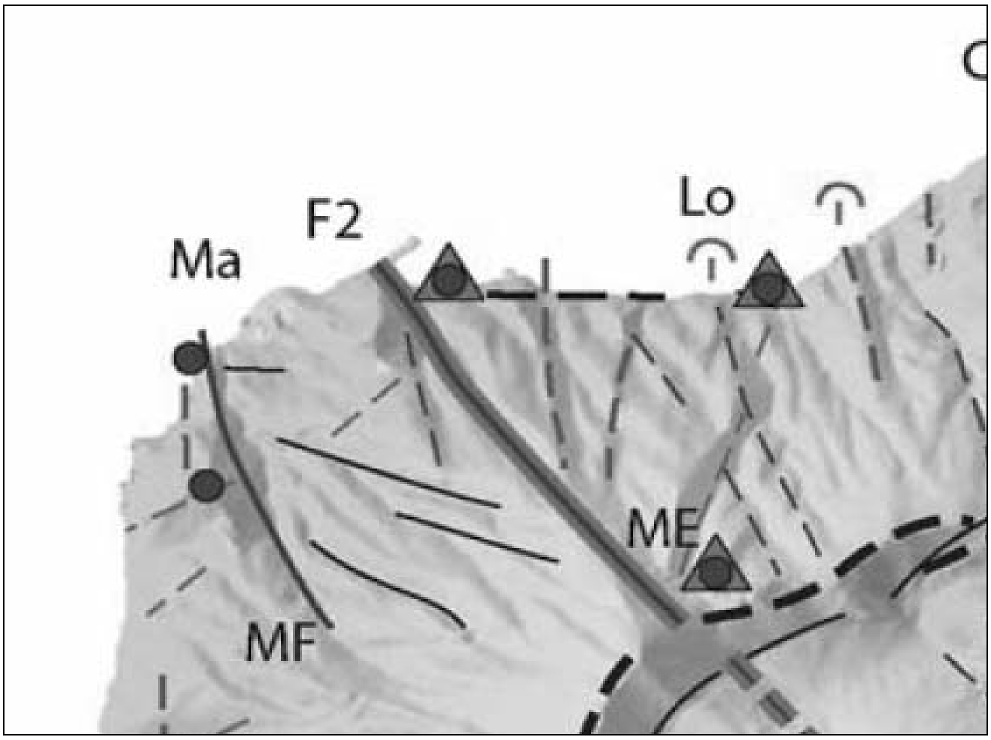


Figure 2.5 The NW coastline of Nisyros showing the location of Mandraki town (Ma), the Loutra Spa (Lo), and an E-W F3 fault that bounds the coastline, and the Mandraki fault (MF) (adapted from Lagios et al. 2005)

It can also be noted that the rock fall event occurred along a section of coastline bounded by an E-W (F3) fault. No seismic event was associated with the collapse. However the collapse itself could be associated with brecciated material along the fault.

It should be noted however, that the study by Papadopoulos and Plessa (2000) does not show earthquake-induced landslides in the immediate area around Nisyros. The most proximal event to Nisyros occurred in 1843 on the island of Chalki, a distance of some 50km southeast of Nisyros, from a magnitude 6.5 earthquake. Given the high levels of seismic activity which affect the region, coupled with steep slopes, it is likely that earthquake-induced landslides are a relatively common occurrence.

On several of the roads above Mandraki, parallel cracks were seen in the road's surface (Figure 3.5). These tension cracks have formed perpendicular to the direction of slow movement of material down slope, known as creep.

(Image removed to reduce file size)

Figure 3.5 A road above the town of Mandraki, deformed due to gradual ground movement.

Landslides do not necessarily need to be of a large volume to generate tsunamis. The Sciara del Fuoco landslide, (Stromboli 2002) had a volume of just $0.02km^3$, however it generated a tsunami of 11m which hit the village of Stromboli and affected the other islands of the Aeolian Arc (Tibaldi., 2005).

Tsunami:

Tsunami are a further secondary hazard affecting the region.

Tsunami are generated when a water column is vertically displaced. This can be caused in a number of ways:

- Offshore seismic event associated with some vertical displacement of the seabed.
- Offshore seismic events, which also trigger submarine landslides.
- Submarine landslides.
- Subaerial landslides moving rapidly into a water body.
- Submarine volcanic activity
- Asteroid impacts

Greece and the surround area have the highest tsunami potential in the European-Atlantic Ocean area (Perissoratis and Papadopoulos., 1999). However, the occurrence of large tsunami in Europe is less frequent than the Pacific region (Dawson et al., 2003).

The three most tsunamogenic regions within Greece are (Papazachos and Dimitriou., 1991):

1. The convex side of the Hellenic trench and its continuation to western Greece and Albania.
2. The Cretan Trough and the Southern Aegean Volcanic Arc
3. The northern Aegean Sea and the Sea of Marmara.

The largest tsunami in Greece have occurred in the Cretan Trough; the most recent, a 20m high tsunami generated by the 1956 M_S 7.5 Amorgos earthquake (Galanopoulos., 1957; Ambraseys., 1960; Papazachos., 1997; Perissoratis and Papadopoulos., 1999; Dominey-Howes., 2002).

The most detailed and up-to-date tsunami catalogue for Greece is that by Papadopoulos (1998), which was undertaken as part of the European Union project; Genesis and Impacts of Tsunami on the European Coasts (GITEC), and Genesis and Impacts of Tsunami on the European Coasts – Tsunami Warning and Observation (GITEC – TWO) (Papadopoulos., 1997).

A total of 159 tsunami events are included by Papadopoulos (1998) dating from 1628 BC to 1996 AD, 5 of which have been associated with volcanic eruptions or other volcanic activity.

One such volcanogenic tsunami occurred on the 30th September 1650. For the previous year leading up to the eruption, the residents of Santorini felt frequent seismic events. The volcanic eruption of Mt Columbo (Figure 1.6) began on the 26th September reaching a maximum on the 30th (Dominey-Howes et al., 2000).

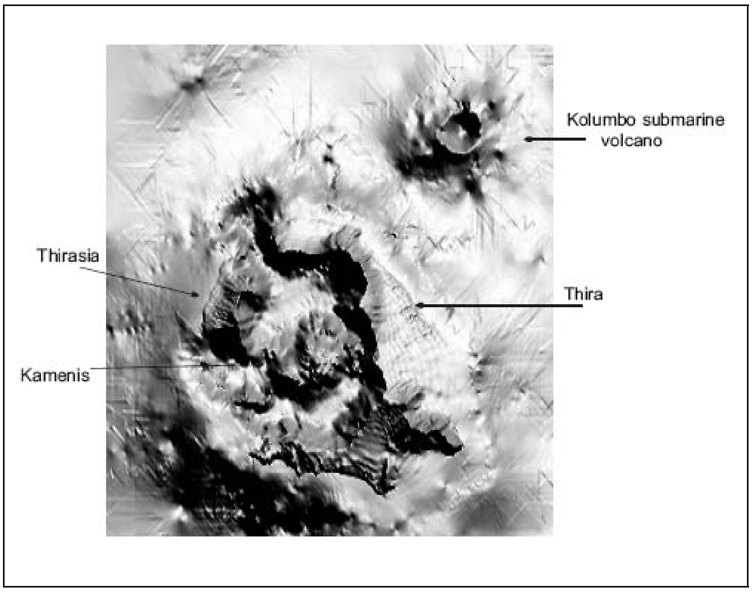


Figure 1.6 A pseudo-photo of Santorini and the Columbo Bank volcano located to the NE of the islands (ISMOSAV)

The tsunami triggered on the 30th September 1650, is thought to have occurred by submarine sediment slides or the collapse of the volcanic cone (Fytikas et al., 1990; Dominey-Howes., 1996).

As previously introduced, the largest tsunami of the 20th Century occurred on 9th July 1956. A large, shallow M_S 7.5 earthquake occurred to the southwest of Amorgos, in the Cycladic Island group. The strongest aftershock occurred 13 minutes later and had a magnitude of M_S 7.2 (Papazachos., 1997).

The earthquake was associated with a large tsunami of 20m in height (the tsunami event triggered by the Boxing Day 2004 earthquake had a height in excess of 30m along parts of the coastline of Sumatra). The tsunami wave affected all of the central and southern Aegean Islands, along with the northern coast of Crete, where wave heights reached between 1-2m (Galanopoulos., 1957). The tsunami is not thought to have been triggered by the earthquake alone but also by extensive submarine landslides (Galanopoulos., 1957; Ambraseys., 1960).

It should be noted that tsunami are commonly generated by submarine or coastal landslides within the Greek borders (Galanopoulos et al., 1964; Perissoratis et al., 1984; Papadopoulos., 1993)

Recent work by Tibaldi and Vezzoli (2004) demonstrates that resurgent calderas can produce voluminous lateral collapses, which, prior to this work, had not been regarded as potential tsunami generation mechanisms. The initial 2004 research was conducted on the volcanic island of Ischia (Italy). In 2005, Tibaldi conducted research on both Ischia and Nisyros, and found that they both share evidence for potential tsunami generation; both are sites of historical eruptions – collapses are more likely on active volcanoes due to volcanic pressures, and both have been affected by shallow seismic events with high peak ground acceleration. Tibaldi (2005) also adds that neither island is currently studied for any form of lateral instability. Should volcanism reactivate, the risk from collapse-generated tsunami increases due to seen increases in magmatic and hydrothermal pressures causing deformation of the island and surrounding area.

7. Summary of Potential Geophysical Hazards:

- Seismic hazard due to regional tectonics
- Seismic hazard due to volcanotectonics
- Volcanic eruptions and eruptive products:
    - Ash Fall
    - Ballistics
    - Gas Emissions
    - Ground Deformation
    - Lahar
    - Lava Flows
    - PCDs
    - Tephra Fall
- Hydrothermal eruptions
    - Gas Emissions
    - Ballistics
    - Lahar
- Landslide
    - Seismically Induced
    - Volcanically Induced
- Tsunami
    - Seismically Induced
    - Volcanically Induced
    - Landslide Induced

8. The Current State of Nisyros:

The current state of activity on Nisyros manifests as gas emissions from soil degassing, fumaroles and hot springs along the coast. Recently however, activity has not always been this benign.

In 1995, the volcano gave signs of renewing activity in the form of intense seismicity, ground deformation and significant variations in the chemical parameters of fumaroles (Caliro et al., 2004). Intense shallow seismic activity began in November 1995 in the Nisyros area and culminated in two very shallow (h ~ 5km) strong earthquakes (Papadopoulos et al., 1998) The intense seismicity continued and was still recorded by the end of October 1997 (Papadopoulos et al., 1998).

Sachpazi et al (2002) carried out two field surveys in March and July 1997, whereby the approximate daily rate of seismic events ranged from 35-50, with low magnitudes between 0.7-2.1. The results of the surveys showed a migration in earthquake hypocentres from an offshore region NW of Nisyros, towards the island's central caldera.

Combining this information with SAR interferometry, Sachpazi et al (2002) interpreted the 140mm of uplift as the brittle response of the volcano to the inflation of a magma chamber located NW of Nisyros.

Geochemical changes seen over the same period included an increase in the ratio of H_2S/CO_2 and a decrease in CH_4/CO_2 ratios throughout the island's fumaroles and an increase in fumarolic temperature around the area of Lofos dome (Chiodini et al., 2002). Chiodini et al (2002) interpreted these changes as an increasing contribution of sulphur-rich, oxidising magmatic fluids into the hydrothermal system, and local temperature and pressure increases within the hydrothermal system.

The GEOWARN Project, started in 2000, ran for three and a half years. Its focus is that of long-term monitoring and forecast for short-term eruption prediction. The project, conducted in the Kos-Yali-Nisyros volcanic field, along with Campi Flegrei, Italy, regards potentially active volcanoes located in regions with high geodynamic activity. The aim of GEOWARN was to establish a multimedia-based geo-spatial warning system comprising both graphical and geo-spatial data with real-time monitoring of surface movement, seismic activity and geochemical changes in fumarolic and hydrothermal fluids (Gogu et al., 2005).

For Greece, and Nisyros specifically, there are no civil protection plans for any magnitude of volcanic activity. Volcanism is regarded as second place to seismicity even though active volcanoes exist in Greece; the most recent volcanic eruption occurring on the islands of Santorini in 1950.

It can therefore be mentioned that should any form of volcanic activity from the Nisyros area arise, officials would need to implement an evacuation under an as yet, non-existent plan.

9. Method for Data Collection:

As the past has shown, successful disaster management is usually combined with pre-event public awareness and knowledge (Chester et al., 2002).
Since natural hazards are relatively rare events; the last period of volcanic activity on Nisyros occurring in 1887, residents have time to forget the impacts.

A set of questions was constructed in the form of a short interview regarding the hazards and their potential effects to the island of Nisyros. The majority of questions used were constructed so that concise yes/no/unsure answers could be given. Reasoning for answers and any important information was also noted.

Two groups were targeted for interviews: the first group being the island's permanent residents, and the second group being the tourists visiting Nisyros.

The first group, being that of the permanent residents, were presented with a list of geophysical hazards that potentially affect the region, and asked to acknowledge those hazards they thought posed a threat. They were then questioned on what they thought would be the main impacts upon the island; if they knew the current state of the volcanic; when the last episode of activity was; if the volcano was monitored; whether an emergency plan exists for the island, and lastly, if they had ever been informed regarding the potential hazards affecting the area.

The second group, the tourists, were presented with the same list of hazards and asked to identify those they thought affect the region. They were then asked whether they had ever experienced any form of geophysical hazard themselves; if they knew the current state of the volcano; when the last episode of activity was; whether the volcano was monitored; if they considered the need for an evacuation plan regardless of the activity or inactivity of the volcano, and lastly if they knew of the existence of such a plan.

In order to gain further knowledge into hazard awareness, tourists were also asked if they booked their holiday independently or through a travel agent. A comparison between the data could therefore be made.

For both groups of interviewees, a wide range of ages was questioned where possible. For the island's permanent residents, interviews were carried out in the main town of Mandraki, as well as the villages of Pali, Emborio and Nikia to obtain more varied and conclusive data.

Prior to visiting Nisyros for data collection, I was informed that formal permission would be required from the Greek government in order to carry out research. Dr. Gerassimos Papadopoulos at the National Observatory of Athens was contacted for advice on this matter. He advised that government permission was not needed considering that data collection was simply in the form of a structured interview, but did advise contacting the Mayor of Nisyros beforehand to inform him about the project and method of data collection.

The Mayor of Nisyros was informed by letter regarding the project, the method of data collection and the dates to which the data collection would be carried out. No appointment was made to see the Mayor or the island police for questioning, as they were available when approached.

In order to analyse the differences in awareness between tourists who booked their holiday independently and those who booked via a travel agent, it was necessary to obtain an idea of the level of information available to tourists regarding geophysical hazards.

Holiday brochures on Greece were obtained from several High Street travel agents. A letter was also sent to the headquarters of each travel agent briefly explaining the outlines for the project and the purpose of the data.

The level of information given from the Greek Tourism Organisation was also regarded as useful, so they were also contacted along with the Greek Minister for Tourism for further information.

The final organisation contacted was the British Foreign and Commonwealth Office in London, who give travel advice and information to tourists when travelling overseas. However, their natural hazards information for Greece consists solely of *"Greece and the Greek islands are seismically active zones and, as a result, earth tremors are a common occurrence".*

A letter was sent briefly informing them about the research, and enquiring the reason that other hazards known to affect Greece have not been mentioned; the most recent Santorini eruption in 1950, and the 1956 Amorgos tsunami given as two recent examples. Also, a brief summary of the tourist results obtained in Nisyros was also given, indicating that there is severe lack of hazard awareness, certainly among British tourists.

Data collection for both groups was carried out on Nisyros from 29th June until 04th July 2006.

10. Results:

In total, 64 people were interviewed on Nisyros of whom 27 were permanent residents and 37 were tourists. The Mayor and a member of the Nisyros police force were the only dignitaries interviewed for this research.

The results are presented both written and graphically. For conciseness the results for both groups are given as percentages, however some questions add up to over one hundred percent as multiple answers were allowed.

Response from the Permanent Residents:

Seventy-eight percent of permanent residents interviewed were from Mandraki, eighteen percent from Nikia and four percent from Pali.

With regards to the geophysical hazards affecting the region:

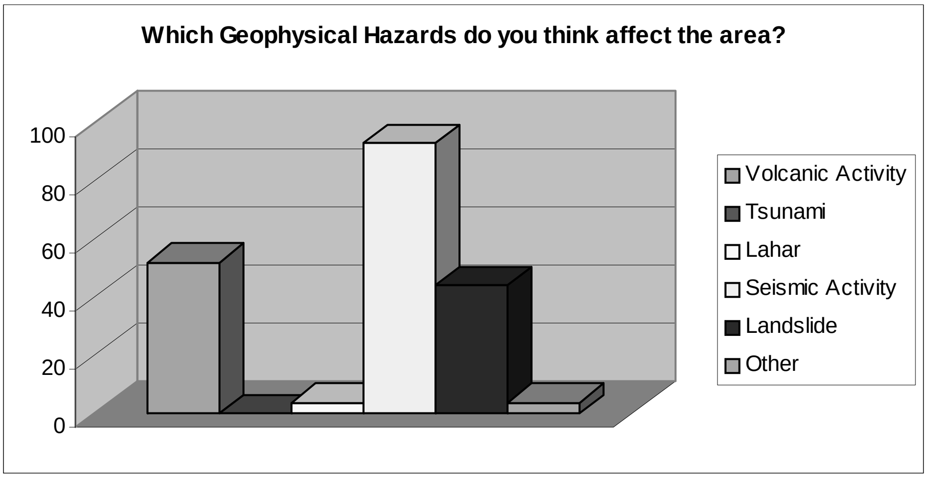


Figure 1.10 Percentage of geophysical hazards thought to affect the region

Fifty-two percent of respondents gave volcanic activity as a hazard, ninety-three percent gave seismic activity, not one single person mentioned tsunami as a hazard, forty-four percent gave landslides, four percent gave lahar as a hazard, and four percent gave ground displacement due to faulting as a hazard in option 'other'.

With regards to the greatest impact affecting the island:

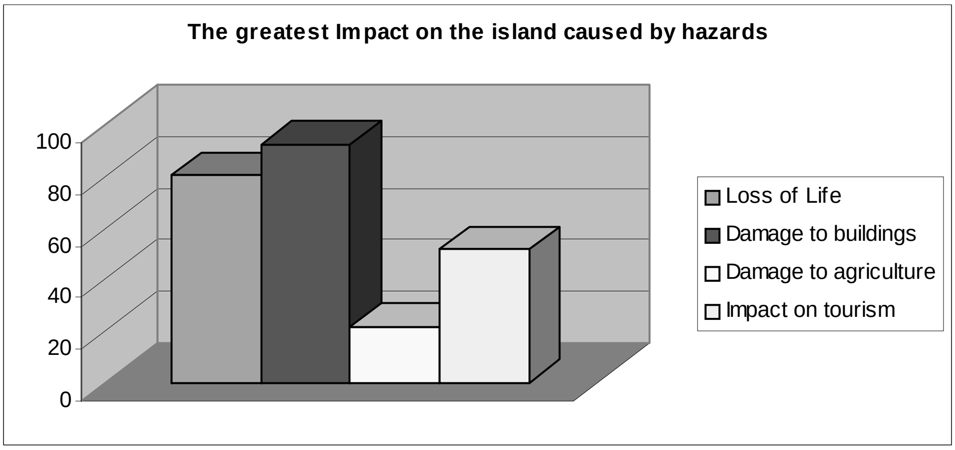


Figure 2.10 Percentages of the main impacts considered affecting the island.

Eighty-one percent gave loss of life as the greatest impact affecting the island, ninety-three percent gave damage to buildings, twenty-two percent gave damage to agriculture, and fifty-two percent gave an impact on tourism.

With regards to the current state of the volcano:

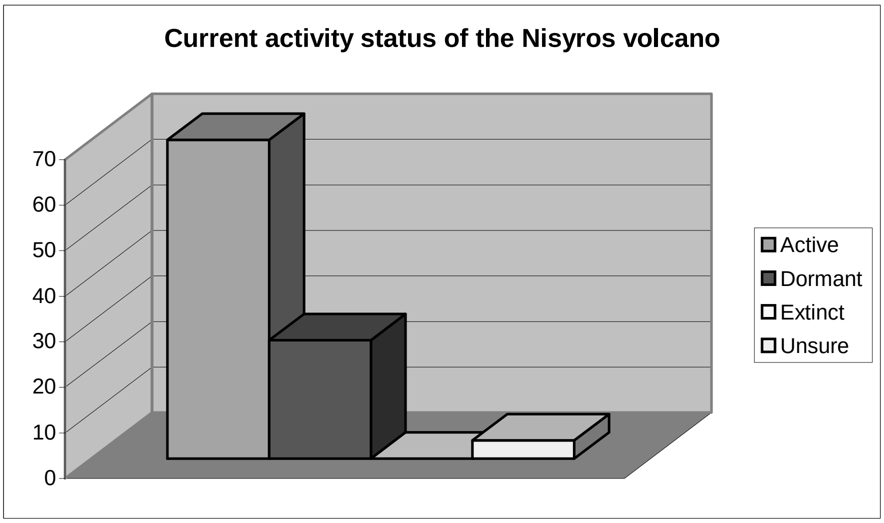


Figure 3.10 The results for the current activity status of the volcano.

Seventy percent believe the volcano to be active, twenty-six percent said it is dormant, nobody believed the volcano to be extinct, and four percent were unsure of the current state of activity.

With regards to the most recent activity from the volcano:

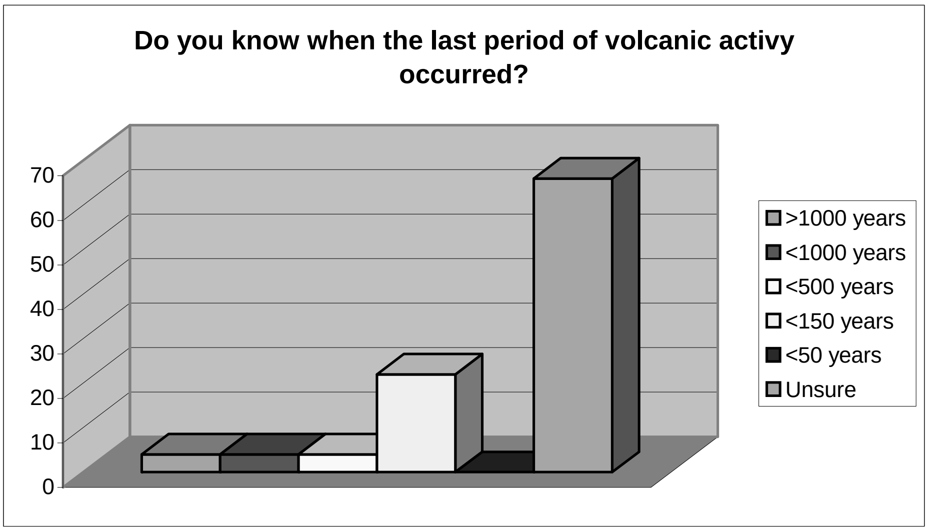


Figure 4.10 The results showing the knowledge of the most recent volcanic activity.

Four percent believed over a thousand years had past since the last episode volcanic activity, four percent gave less than a thousand years had past, four percent gave less than five hundred years, twenty-two percent gave less than one hundred and fifty years, nobody gave less than fifty years, and sixty-six percent of those interviewed were unsure.

With regards to monitoring of the volcano:

One hundred percent knew the volcano is currently monitored.

With regards to the existence of an emergency plan for the island:

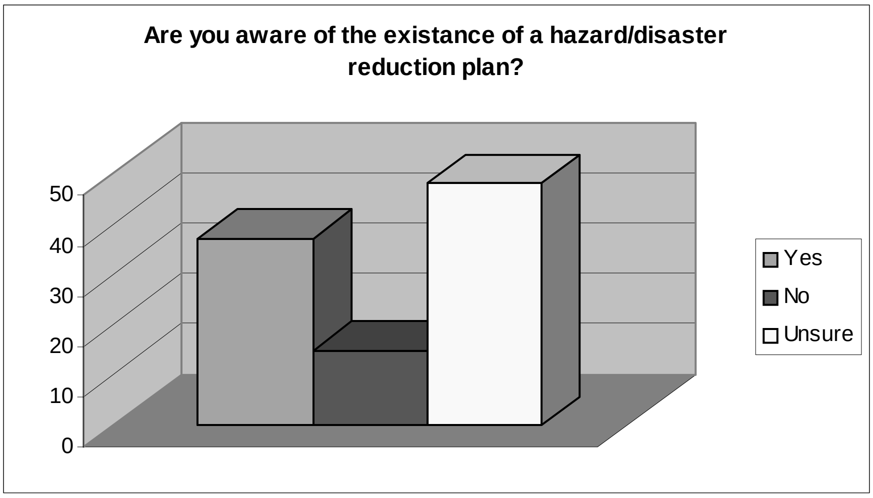


Figure 5.10 The results showing the awareness of the existence of a hazard reduction plan.

Thirty-seven percent said that a plan exists; fifteen percent said a plan did not exist, and forty-eight percent were unsure if a plan exists.

With regards to having been informed on the hazards affecting the area:

Eighty-five percent said they had been informed regarding the hazards affecting the area, and fifteen percent said they had not been informed.

With regards to the population wanting more information on the hazards:

Fifteen percent said that were interested in more information regarding hazards, eighty-one percent were not interested in more information and four percent said perhaps they would want more information.

11. Response from the Tourists (Combined):

With regards to the hazards affecting the region:

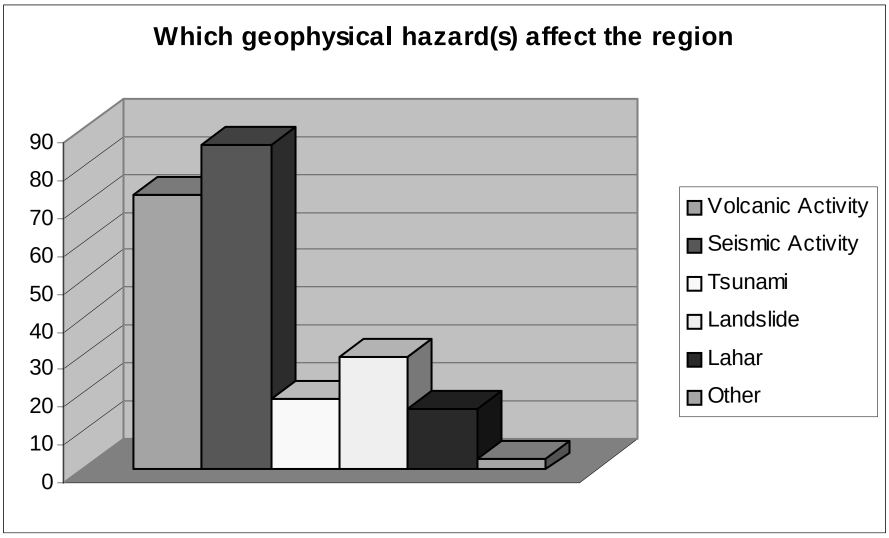


Figure 1.11 The results of the geophysical hazards thought to affect the region.

Seventy-three percent of those questioned were aware of volcanic activity affecting the region, eighty-six percent were aware of seismic activity, nineteen percent gave tsunami as a hazard, thirty percent gave landslide, sixteen percent said lahar, three percent gave volcanic gas emission under the 'other' category, and a further three percent were unsure.

With regards to the hazards experienced by the interviewees:

Thirty-five percent of those interviewed had experienced some type of geophysical hazard, while sixty-five percent had not experienced some type of geophysical hazard.

With regards to the current state of volcanic activity on Nisyros:

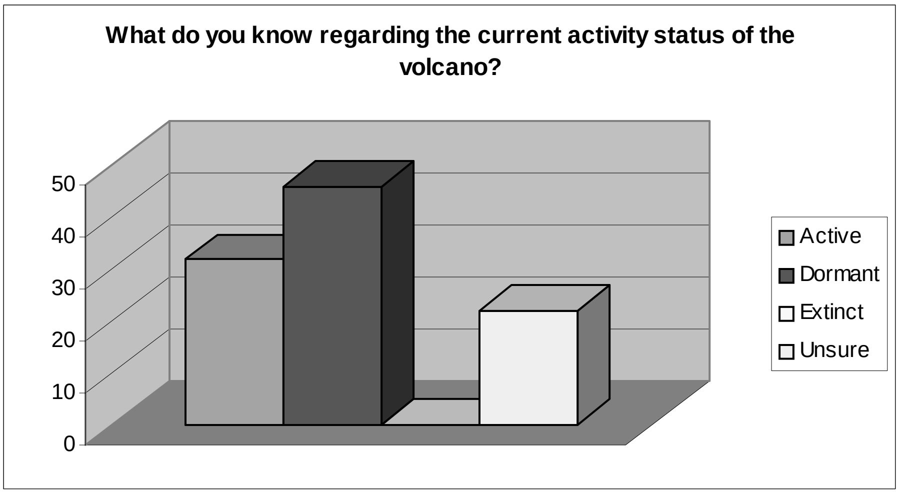


Figure 2.11 The obtained answers regarding the current volcanic activity status.

Thirty-two percent of those interviewed knew the volcano to be active, forty-six percent believed the volcano to be dormant, nobody believed the volcano to be extinct, while twenty-two percent of those asked were unsure of the volcano's current status.

With regards to the last episode of volcanic activity:

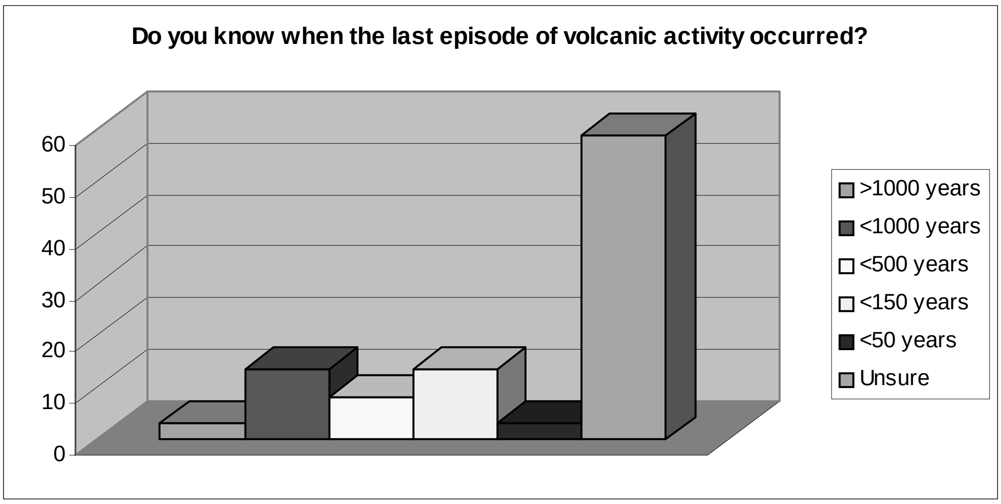


Figure 3.11 Results showing the awareness of the last episode of volcanic activity.

Three percent believed the last volcanic activity to have taken place over tone thousand years ago, thirteen and a half percent believe less than one thousand years ago, eight percent believe less than five hundred years ago, thirteen and a half believe less than one hundred and fifty years ago, three percent believe less than fifty years ago, while the majority at fifty-nine percent are unsure when the last volcanic activity took place.

With regards to monitoring of the Nisyros volcano:

Forty and a half percent of those interviewed believed that the volcano is monitored, thirteen and a half percent believe it is not monitored, while the majority at forty-six percent are unsure if the volcano is monitored or not.

With regards to the existence of a hazard/disaster reduction (or evacuation) plan regardless of the activity of inactivity of the volcano:

A vast majority, eighty-nine percent, of those interviewed believed that there should be a plan in place, five and a half percent believe there is no need for a plan, and the remaining five and a half percent were unsure whether a plan needed to exist.

With regards to the interviewee's awareness of such a plan:

One hundred percent of those questioned were not aware of a hazard/disaster reduction (or evacuation) plan for the island.

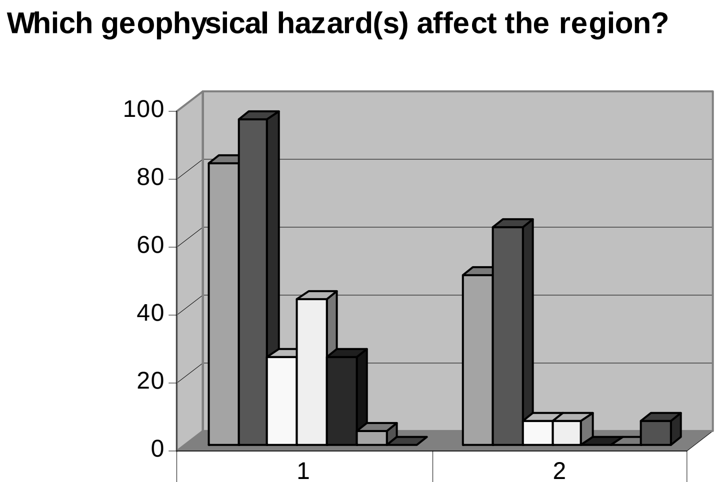
12. Comparison Between The Tourists Who Booked Independently and Those Who Booked Through Travel Agents:

In order to obtain a better understanding of the tourist's hazard awareness, they were asked whether they booked their holiday independently (group 1) or through a travel agent (group 2) at the start of the interview.

In total 37 tourists were interviewed, 23 of whom booked independently, and 14 who booked through an agent.

In order to make the data easier to compare, the data is presented for some questions both graphically and also in tabular form.

With regards to the geophysical hazards affecting the area:



	1	2
Volcanic Activity	83	50
Seismic Activity	96	64
Tsunami	26	7
Landslide	43	7
Lahar	26	0
Other	4	0
Unsure	0	7

Figure 1.12 Results for the awareness of geophysical hazards affecting the region for both group 1 (independent tourists) and group 2 (booked through an agent) in percentages.

With regards to having experience of any type of geophysical hazard:

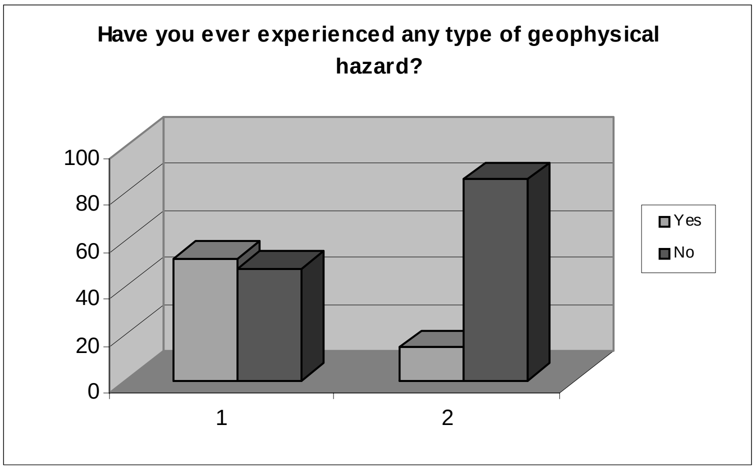


Figure 2.12 Results between group 1 and 2, past hazard experience.

Fifty-two percent of group 1 tourists had experienced some type of geophysical hazard compared with only fourteen percent of group 2.

With regards to the current volcanic activity status of Nisyros:

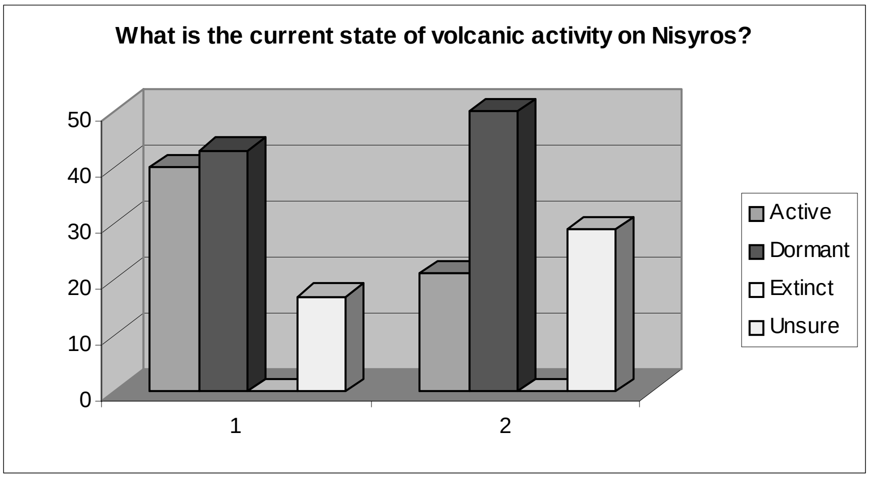
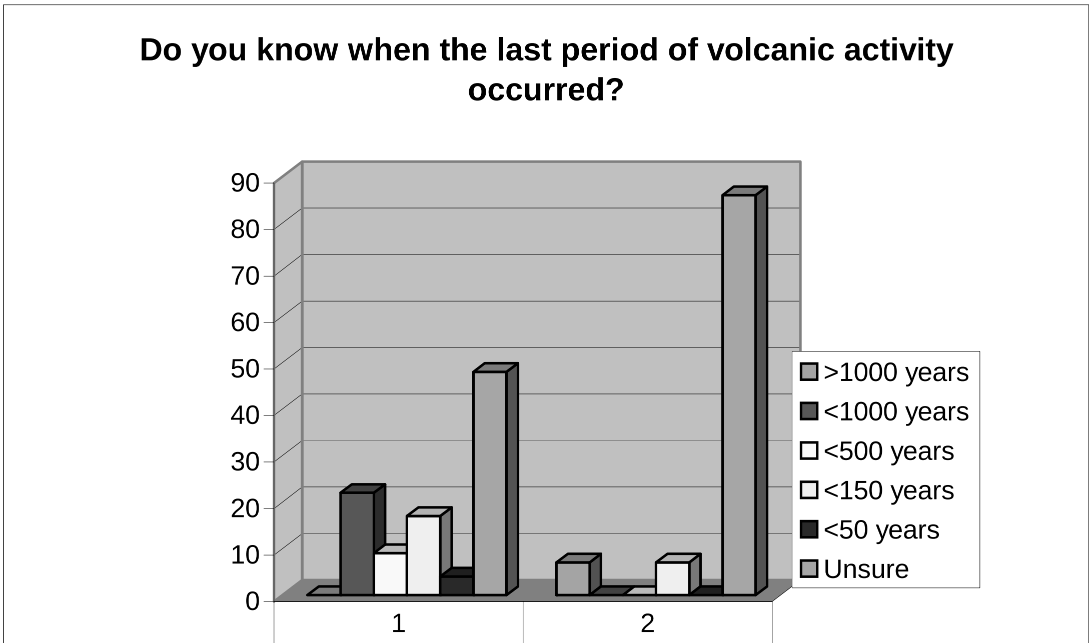


Figure 3.12 Results between groups 1 and 2 showing their understanding of the current state of volcanic activity.

Forty percent of those interviewed from group 1 are aware that the Nisyros volcano is active compared to only twenty-one percent from group 2. A further seven percent from group 2 believe the volcano to be dormant compared to group 1. As previously mentioned no tourists believed the volcano to be extinct, while a greater percentage of group 2, twenty-nine compared to seventeen, are unsure the current activity status of the volcano.

With regards to the last period of volcanic activity:



	1	2
>1000 years	0	7
<1000 years	22	0
<500 years	9	0
<150 years	17	7
<50 years	4	0
Unsure	48	86

Figure 4.12 Results for the knowledge for most recent volcanic activity on Nisyros.

With regards to monitoring of the volcano:

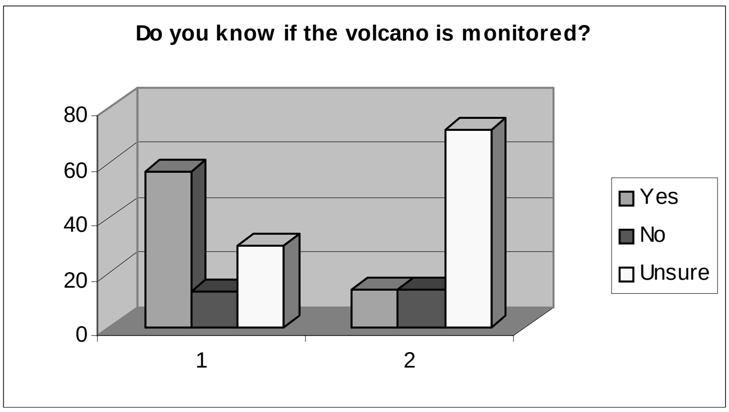


Figure 5.12 Results showing the awareness of volcano monitoring.

Fifty-seven percent of those questioned from group 1 were aware of monitoring on Nisyros, compared to fourteen percent of group 2. Thirteen percent of those questioned from group 1 believed that the volcano was not monitored, along with fourteen percent from group 2. Thirty percent were unsure if Nisyros volcano is monitored from group 1 compared to seventy-two percent from group 2.

With regards to the need to a hazard/disaster (or evacuation) plan for the island:

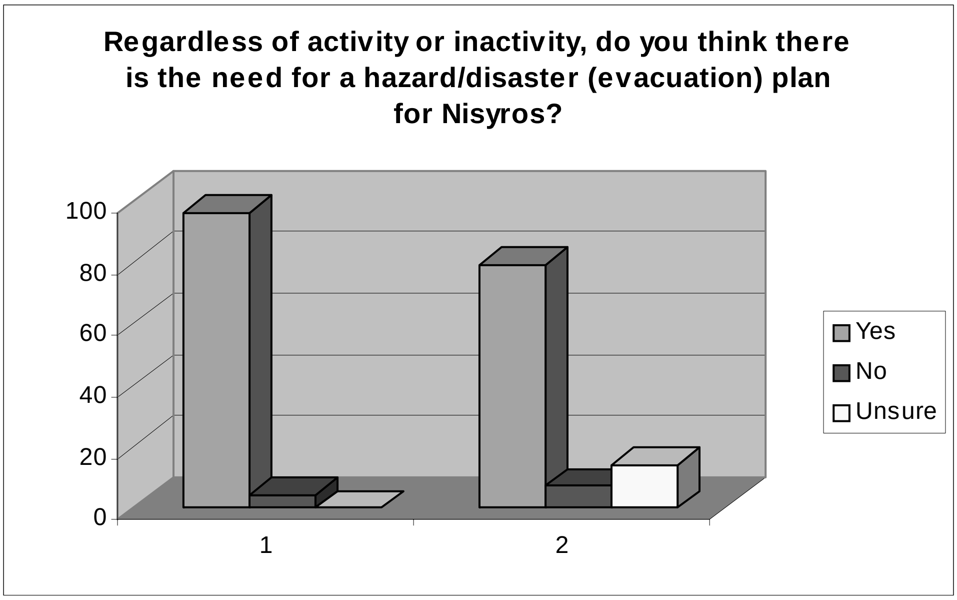


Figure 5.13 Results showing if interviewees thought the need for a hazard/disaster plan for Nisyros.

Ninety-six percent of group 1 thought Nisyros should have a disaster/hazard (evacuation) reduction plan in place regardless of inactivity or not from the volcano. The same can also be said for the respondents from group 2, seventy-nine percent. Four percent from group 1 believed that there is no need for such a plan, along with seven percent from group 2. Fourteen percent from group 2 were unsure whether the island would require such a plan.

With regards to the awareness of such a hazard plan:

Unanimously, both groups were unaware of a hazard/disaster reduction plan.

Interview with the Mayor:

The Mayor of Nisyros was interviewed on 29.06.2006. Initially, the same questions were asked of him as those asked of the local residents, and then further questioning was conducted.

The Mayor believed the only hazards affecting the area were from seismic activity and ground displacement due to faulting and landslides, given in that order of importance. He believed that should any of these hazards occur the major impacts on the island would be from loss of life and damage to buildings.

The Mayor believed the current state of the volcano to be active, but strangely did not think volcanic activity might present a hazard.

The Mayor believed that over a thousand years had past since the last form of volcanic activity, and was aware that the volcano is currently monitored.

When asked if there is a hazard/disaster reduction (evacuation) plan the Mayor answered that no, such a plan did not exist for the island, only that of the general Xenokratis Plan.

The Mayor acknowledged he had been informed regarding the hazards affecting the area by I.G.M.E. (Institute for Geology and Mineral Exploration), the University of Athens, and the National Geodynamics Institute in Athens.

When asked if he would be interested in further information regarding potential hazards, the Mayor declined saying he received adequate information from the many scientists from around the world conducting research on the island.

The Mayor was very honest in the respect that the island had no emergency plan, and even the one it does have, the Xenokratis Plan, really cannot be replied upon. He said from previous seismic events, rock falls had lead to roads being impassable, but also ground displacement from faulting had made roads impossible to use with heavy machinery; something which the Xenokratis Plan fails to take into consideration.

When asked what the Mayor would do if he was suddenly informed of an impending volcanic eruption, his reply was “Then hope to God that we won’t be affected”.

The Mayor informed me of plans to convert the disused school in Emborios into the monitoring centre for the island. From here the seismographs and gravity meters monitoring both Nisyros and Yali would be connected to computers relaying information to the Geophysics Department of Thessaloniki University.

There are also plans to construct a volcano museum in the village of Nikia, which would provide information regarding the volcano’s current activity, past eruptions, likely future eruptions, monitoring techniques etc.

Interview with the Police:

No appointment was made for the interview, as the policeman on duty was willing to answer questions when approached.

When asked, seismic activity was the only hazard believed to affect the region, and he also added that in the past few years even the seismic activity was at a low.

The policeman believed that the impacts to the island would be mostly from loss of life, damage to buildings, but also tourism would be affected. He believed the volcano to be currently active but was unsure when the last volcanic activity occurred.

When asked if the island had a hazard/disaster reduction plan the policeman was unsure.

He said he had however been informed of the hazards affecting the area by the media and the local council, and was not interested in further information.

13. Discussion:

Nisyros and the surrounding volcanic field are currently in a phase of quiescence, which will give way to a period of renewed activity. The Kos-Yali-Nisyros volcanic field has seen intense geodynamic unrest for the previous 2.6-2.8 million years, with a large phreatomagmatic ignimbrite eruption 161 thousand years ago (Lagios et al., 2005; Smith et al., 1996). The caldera created by the massive eruption runs from Nisyros in the south, up to the shores of Kos in the north, a distance of some 15-20km (Lagios et al., 2005).

Due to intense tectonic activity, the region is affected by large magnitude seismic activity, magmatic volcanism (whose products include ash fall, ballistic ejecta, gas emissions, ground deformation, lahars, lava flows, pyroclastic density currents, and tephra fall), hydrothermal eruptions, landslides, and tsunami.

The island is relatively unknown to mass tourism, receiving mostly those tourists who make excursions for the day to see the volcanic craters and landscape. Should this change however, and Nisyros become a greater tourist destination, the level of risk posed by the hazards would greatly increase.

Discussion of the survey:

Due to the sensitive subject area of this research care had to be taken, especially regarding the island's residents, so as not to alarm or offend the interviewees. After a brief introduction regarding the research and the purpose of the data, the interviewee was asked whether or not they would mind answering several simple questions.

The interviews for the local residents were mainly conducted on the street and in shops. The majority of tourists were interviewed in and around the crater of Stefanos within the island's caldera.

Resident Population:

The results obtained for the local residents show a disappointing level of hazard awareness. Just over half of those interviewed (52%) were aware that potential volcanic activity would pose a hazard to their environment. The residents of Nisyros were much more aware of seismic activity (93%), probably as low-magnitude earthquakes are much more frequent events and felt on a regular basis.

Disturbingly, not a single person was aware of the potential for tsunami generation in the area; several of those (7%) commenting that tsunami are not a hazard known to affect Greece. Before visiting Nisyros, it was thought that this research would have been extremely interesting had data been collected on geophysical hazard awareness prior to the 2004 Indian Ocean tsunami, so that a comparison could be made.

The Boxing Day 2004 event was of such a magnitude that it affected the entire planet, receiving weeks of media coverage, and informing the general public how tsunami are generated.

However, after obtaining the data, it is clear that the Boxing Day 2004 tsunami event has made no impact on geophysical awareness of the local residents of Nisyros.

Landslides were seen by 44% of those interviewed as a hazard.

Lahars were believed to be a hazard by only 4% of those questioned. However, the most recent lahars on the island were known to be those, which accompanied the hydrothermal eruptions of the Polyvotis and Alexandros/Flegethro craters in 1873, and were contained within the caldera.

The only person to suggest a further hazard that would cause implications on Nisyros was the Mayor. He added that ground displacement due to faulting has previously occurred on Nisyros causing damage to the island's small road network.

With regards to what impacts the hazards would have on Nisyros, 81% of those questioned believed loss of life would seriously impact the island. A greater majority at 93% believed the hazards would cause damage to buildings. Twenty-two percent believed agriculture on the island would be affected, and 52% believed the hazards would affect tourism. One respondent added that he believed any activity would encourage scientific curiosity and a greater influx of tourists to the island. There is very little doubt; renewed activity would cause scientific curiosity. This has already been witnessed in the mid 1990's during the so-called 'volcanoseismic crisis', when the island was inundated by scientists and researchers. However, it is unlikely that the same would occur with general holidaymakers.

Seventy percent of those questioned regarded the current status of the volcano as active. This is an interesting finding considering only 52% of the local residents believed volcanic activity to pose a threat.

Twenty-six percent of respondents believed the volcano to be dormant, while 4% were unsure of the volcanic activity status.

With regards to the most recent period of volcanic activity, the majority of respondents (66%) were unsure when it last occurred. Twenty-two percent were aware activity occurred less than 150 years ago, and the remaining 12% were unsure.

Undoubtedly, all respondents were aware the volcano is monitored.

When asked if the island had a hazard/disaster reduction (evacuation) plan, alarmingly 48% of the respondents were unsure. Fifteen percent of those asked believed that no such plan existed, whilst the remaining 37% believe that a plan was in place, that of the Xenokratis.

When asked if they had ever been informed regarding the hazards that potentially affect the area, 85% of the respondents replied they had.

Finally, when asked if they would be interested in further information, 81% declined saying that the local council, scientists, and research institutes from Athens had already informed them.

Only 15% said that they would be interested in further information, one of whom, a shopkeeper from Mandraki, said that any extra knowledge would always be appreciated so long as it was scientific and correct.

The remaining 4% were unsure whether they wanted further information.

In general a disappointing lack of awareness was seen in the results. According to the interviews, 85% of those questioned said that they had been informed about the potential hazards affecting the area by various scientists and researchers from different institutions; however not one person interviewed was aware that tsunami could occur and 66% were unsure about the most recent period of volcanic activity.

Further work is therefore needed to re-educate the inhabitants of Nisyros regarding potential hazards, in the main, a possible reactivation of volcanic activity and the subsequent consequences that would mean for the island.

Incredibly, 15% of those asked are aware that the island has no plans for disaster reduction or evacuation, but even more alarming is the 48% who are unsure whether a plan exists.

This indicates that the inhabitants of Nisyros are simply apathetic at the possibility of renewed volcanism.

After the final interview conducted on Nisyros, the respondent asked how the research had gone and what data had been obtained. It came as no surprise at all to the interviewee that the vast majority were unaware of the hazards and unconcerned at the lack of civil protection on the island. The respondent (an island resident all her life) put this down to simply the refusal to think about and accept the potential hazards, this denial mechanism allowing them to live without fear, and without that fear affecting their daily lives.

Tourist Population:

From the results obtained, it is evident that tourists who organised their holiday independently were far more aware of the geophysical hazards affecting Nisyros and the surround region.

Eighty-three percent of independent travellers were aware of volcanic activity as a hazard, in comparison to 50% of the group 2 (holiday arranged through a travel agent) tourists, and only 53% of the island's residents.

Seismic activity was recognised as a hazard by 96% of group 1 travellers compared with 64% from group 2.

Twenty-seven percent of group 1 tourists believed tsunami to pose a hazard to the region, compared to only 7% from group 2, and 0% of the local residents.

The landslide hazard was seen by 43% of group 1 tourists compared with only 7% from group 2.

Twenty-six percent of group 1 tourists believed lahar to be a hazard, and 4% of group 1 said that volcanic gas emission would pose a threat when asked if there are any other potential hazards thought to affect the island.

Gas emissions do currently pose a threat, but this is confined within the hydrothermal eruption craters on Lofos dome. There are several warning signs in place advising tourists not to descend into the craters on days with little wind due to the build-up of carbon dioxide.

When the respondents were asked if they had ever experienced a form of geophysical hazard, 52% of independent travellers had, compared with only 14% of group 2 travellers.

The majority of those having experienced a hazard had mostly felt low magnitude seismic activity, two people had seen small eruptions while visiting the Italian island of Stromboli, and several people had experienced small landslides.

Regarding the current volcanic activity status, 40% and 43% from group 1, believed the volcano to be active and dormant respectively.

Twenty-one percent of group 2 believed that volcano to be active, while a majority of 50% believed it to be dormant.

No respondents from either group deemed the volcano extinct, however 17% and 29% from group 1 and 2 were unsure the current activity status of Nisyros volcano.

With regards to the last period of volcanic activity, the data show that the majority of both groups 1 (48%) and 2 (86%) were unsure.

Group 1 however, were aware of volcanic activity occurring less than 1000 years ago (22%) and less than 500 years ago (9%). This needs to be taken into consideration considering its truth; the last activity was 119 years ago. Therefore the last period of activity was recognised by 48% of group 1 respondents.

Seven percent of group 2 thought that the last period of activity occurred over 1000 years ago. A further 7% confirmed activity occurred less than 150 years ago, but the vast majority (86%) were unsure.

Fifty-seven percent of respondents from group 1 were aware that Nisyros volcano is currently monitored compared with only 14% of group 2 respondents. Thirteen percent from group 1 believed the volcano is not monitored along with 14% from group 2.

Seventy-two percent of group 2 respondents were unsure if monitoring took place.

Combining both tourist groups, 89% of all respondents believed that some form of hazard/disaster reduction (evacuation) plan should be prepared for Nisyros regardless of the volcano's current state of activity or inactivity.
However, two of the respondents believed that no such plan was needed, considering the size of the island and only a small number of inhabitants.

In general, both parties were very receptive to the interviews, showing interest and giving, what can only be perceived as, honest answers.

The existing Xenokratis Plan for disasters:

No evacuation or specific emergency plan exists in Greece for any form of volcanic activity. Therefore, in the event of renewed activity from the Nisyros volcano, or within the surrounding Kos-Yali-Nisyros volcanic complex, the general 'Xenokratis Plan' would need to be utilised. The plan has the character of a guidebook and was designed as a general disaster management plan.
Civil protection authorities are named in terms of government authorities and local authorities and the plan describes the effective action that each one should take.
The plan sets out the responsibilities and duties from a national to local level and describes how they should co-operate.
It is required to be fully adjusted to a local level, taking into account the range of hazards and risk relevant to the area.

Even if a plan does exist, it is not always used. In the crisis after the Aigeon earthquake of 1995, the ‘Xenokratis-Earthquake Plan’, which had been modified to suit the area, could not be found! (Theofili and Arellano, 2001).
The plan is stored in the town hall of Nisyros; however, the Mayor confirmed that the plan, even in its general state, cannot be relied upon.

The civil protection department for Greece have created a website containing information on natural hazards (www.civilprotection.gr) including: intense snowfall, forest fires, storms, heat wave, flooding, and earthquakes. Volcanic eruptions do feature on the page; however, very little information is given. What information there is includes a brief summary of basic volcanic products and what one should do prior/during/post an eruption. However, specific examples of products resulting from eruptions of Greek volcanoes are not given.

The website also contains short videos and games for hazard awareness, primarily for seismic hazard. Both of these are very informative and easy to understand.
However, the site is solely in Greek, therefore would not be benefit foreign travellers at present.

Greece currently has disaster-orientated teams who are deployed in the event of seismic disasters. However, retraining and extra safety measures would need to be implemented in order to dispatch these teams into a multi-hazard environment.

Level of information available to tourists regarding geophysical hazards:

The island of Nisyros was mentioned in 2 out of 4 Greek holiday brochures. Nisyros is seen as an ideal family day-trip from Kos. However, only one brochure said that the island is volcanic, the other simply advertising Nisyros as having a traditional island way of life, where sulphur crystals can be seen growing along side pools of bubbling mud.

Out of the four travel agents contacted during the research for this project, only one response was obtained, stating the company regarded the safety of customers as its utmost priority and ensured that the information which is available to customers is up-to-date and obtained from the Foreign and Commonwealth Office.

As previously mentioned, the Greek Minister for Tourism and the Greek Tourism Organisation were contacted during the research for this project. Unfortunately a reply was not obtained.

A response was obtained from the British Foreign and Commonwealth Office (FCO) explaining that they have the responsibility to assist British holidaymakers formulate informed decisions when travelling abroad. Their job is to provide the traveller with factual information in order for the traveller to make his/her own judgement.

The FCO stated they provide travellers with the knowledge that "*Greece and the Greek islands are seismically active zones and, as a result, earth tremors are a common occurrence*".

With regards to the most recent volcanic activity (Santorini, 1950) and major tsunami (Southern Aegean, 1956) used as examples in the letter to the FCO, their response was "*Where there have been significant recent events, such as the examples you gave in your letter about tsunamis and eruptions, then it would be included if we considered that it helped the British traveller make an informed decision".*

Lastly, with regards to the brief summary of tourist results obtained on Nisyros, the FCO commented, *"We agree with you that it is important that people are aware of the hazards and risks that they face when travelling overseas. We therefore advise that they obtain all necessary information beforehand; this includes consulting our travel advice".*

The conclusion made from this section is therefore, should all travels agents obtain information regarding natural hazards from the Foreign and Commonwealth office (this cannot be assumed for certain since only one response from a well-known travel agent was received), they are only being informed on the potential seismic hazard affecting the country.

For those tourists who booked independently, a greater level of hazard awareness was found. It can therefore be deduced that more research was conducted by the independent travellers regarding the region and what hazards can affect it.

It is therefore no surprise that those tourists interviewed on Nisyros who had booked through travel agents had less hazard awareness than those who booked independently.

The question should therefore be asked, why aren't tourists given all the factual information by the Foreign and Commonwealth Office regarding the potential geophysical hazards affecting Greece?

Understandably, this is a very sensitive subject, especially when tourists are involved along side possible socio-economic implications, and such complications must be dealt with accordingly. However, it is also imperative people are provided with factual information regarding natural hazards, the same as they are provided with information regarding diseases and inoculations when travelling abroad, especially from a country like the UK where these hazards are rare or even negligible.

14. Recommendations:

A number of recommendations can be made based upon the results obtained and discussion: -

Educational Programs:

Educational programs should be implemented for both the local residents and dignitaries since there is a severe lack of hazard awareness on the island.

Residential Education Program would need to cover:

- Focussed at the various ages of the community.
- Past eruptions and products of the Nisyros volcano with possible future impacts.
- Information on the Kos-Yali-Nisyros caldera and its current activity.
- The potential hazards affecting the island and the risk they pose.

- The current Emergency Plan and the reasons why it will not work, allowing further development of the plan with input from the residents.
- Explain why the science of volcano forecasting is difficult, emphasising the uncertainties involved to try to eliminate the potential mistrust of scientists by the population should the volcano take a different course to what the scientists have forecast.
- Explain exactly what happened during the 1996-1997 volcanoseismic crisis (and those which have happened before), the recent increase in fumarole temperatures and what implications these might have for a future eruption.
- Where the residents would be evacuated to (if an evacuation was required), how the evacuation would take place, and depending on the hazard and magnitude – how long the residents might have to remain away from their island.
- The education program needs to address the subject of a 'denial mechanism' regarding the hazards, and reiterate to the residents that they are at risk.

Official Educational Program:

- The municipality needs to take responsibility for the education of officials.
- Officials need to be trained in how to deal with an emergency situation.
- How to communicate to the public during a crisis.
- To know how exactly an evacuation will take place, considering the island has no airport; the only option being by sea. However, depending on the magnitude and location of an eruption, this might not be an available option.

- The understanding that officials will not only be in charge of locals, but also tourists which will be on the island. Therefore plans also need to be available in languages other than Greek.

Other aspects that should be taken into consideration are:

- Apart from the general Xenokratis Plan, a specific hazard/disaster reduction and evacuation plan MUST be created for Nisyros.
- The plan would need to consider the likely magnitude of a potential hazard, in order to establish a plan for disaster reduction.
- The development of a permanent volcano observatory monitoring the region in real-time.
- International awareness of the geophysical hazards affecting the region. The hazards are not bound by political boarders. Any such hazard would likely affect the Aegean coastline of south-west Turkey.
- The Aegean Sea is a major shipping route; therefore it is a necessity that the volcanic centres of the Aegean are well-recognised on both nautical and aeronautical charts.
- Constructions built prior to the most recent building codes should be surveyed and retrofitted and reinforcements made where needed.

In order to improve geophysical awareness amongst tourists:

- Travel agents should provide information on the potential hazards affecting a region in the safety or ‘need to know’ section at the back of a brochure.
- The Foreign and Commonwealth Office MUST provide factual information regarding geophysical hazards for every country, for the benefit of both independent travellers and travel agents.

15. Conclusion:

The Kos-Yali-Nisyros volcanic field, as well as the island volcano of Nisyros lie in an area of intense tectonic activity.

In the past 160 thousand years the island has witnessed many volcanic eruptions of different types and magnitudes presenting varying degrees of hazard.

Several types of hazard are possible on Nisyros: seismic activity from regional tectonics, seismic activity associated with magmatic and hydrothermal unrest, hydrothermal eruptions, volcanic eruptions, landslides, and tsunami.

Today the island is home to around 1000 inhabitants, with hundreds of tourists per day visiting the island to see the famous hydrothermal eruption craters within the caldera.

The data attained on Nisyros show that the local population have little hazard awareness regarding the range of hazards that potentially affect the island. Sixty-six percent of locals interviewed were unsure regarding the most recent volcanic activity on the island. Fifteen percent of locals are aware that no civil protection plans currently exist for the island, along with 48% who are unsure. The Mayor of the island confirmed that no plans are in place regarding any magnitude of volcanic eruption, and commented that the current, general disaster management plan – Xenokratis, has not been revised to consider the hazards affecting Nisyros. Alarmingly, 85% of local residents consider themselves well informed regarding natural hazards, 81% of which stated that they were not interested in further information.

Education regarding hazards is of utmost importance considering the island inhabitants have never experienced any form of volcanic activity, the last activity in the form of hydrothermal eruptions from the volcano occurred in the late nineteenth century.

From tourists interviewed, a good range of hazard awareness was found. However, when comparing data from independent travellers and tourists who booked through a travel agent, the results clearly show that those who booked through an agent are far less aware of the potential hazards affecting the region.

As previously mentioned it is knowledge and planning before disasters that help in successful mitigation measures. Therefore is it very important that tourists are fully aware of the potential dangers they face when travelling abroad, especially those tourists coming from countries like the UK where geological hazards are rare to negligible.

It is advised that educational programs be considered, both for the local dignitaries of the island and the local population, which must take into consideration the culture, way of life, the pride of the population for their island, and also the psychological reasoning that the islanders dismiss the potential for these hazards to occur.

The installation of a permanent observatory on the island is regarded with utmost importance, which would serve to monitor the geodynamic activity in the area, but also could play a role in the education of both local populations and tourists.

Further Improvements:

- In order to improve/continue this research a much higher number of both local residents and tourists need interviewing for a better understanding of their level of geophysical hazard awareness.

- A much larger number of local authority members and dignitaries should be questioned, not only on Nisyros, but also on the islands of Kos and Rhodes, it is after all these members who will be leading and implementing hazard/disaster reduction plans and evacuations.
- It would also be of importance to interview other influential members of the community on hazard awareness and civil defence plans, for example the clergy. As trusted members of the community, they might also be of use in dissipating information to the public, instead of possible intimidation by scientists.
- The time of year for data collection should also be taken into consideration.

  For this research, data collection occurred 29th June – 04th July 2006. At this time the full tourist season had not yet started, and several days is not adequate for data collection.
- The interview questions need to be made more exact to remove uncertainties so that direct answers can be recorded, for example, giving actual dates to choose from instead of a timescale for previous volcanic activity.
- A broader range of questions might be introduced regarding specific volcanic products and evacuation plans, and what the island's inhabitants would do in the event of renewed activity.
- Language barriers also need consideration as data collection could only be gathered from Greek and English speakers. Many tourists were approached but could not be interviewed due to language problems.

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