St. Kitts

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Abstract

Mt. Liamuiga is the only live volcano on St. Kitts and is the most likely location for future eruptive activity. Future eruptions are most likely to occur from the summit of the volcano but it is possible that effusive activity could occur from the flanks. Based on the eruptive history of Mt. Liamuiga, the most likely style of eruption is an explosive magmatic eruption that is likely to generate column-collapse scoria and ash flows and surges with accompanying scoriaceous fall deposits. Explosive activity may be accompanied by lava dome formation which would produce dome-collapse pyroclastic flows and surges and ash fall. Lahars will be a hazard in times of heavy rainfall during and after eruptions. Although there are no signs of increased activity at present on the island of St. Kitts, Mt. Liamuiga is considered potentially active and an increase in activity could occur at any time. In the event of a major volcanic eruption on St. Kitts, the entire northwest of the island would need to be evacuated.

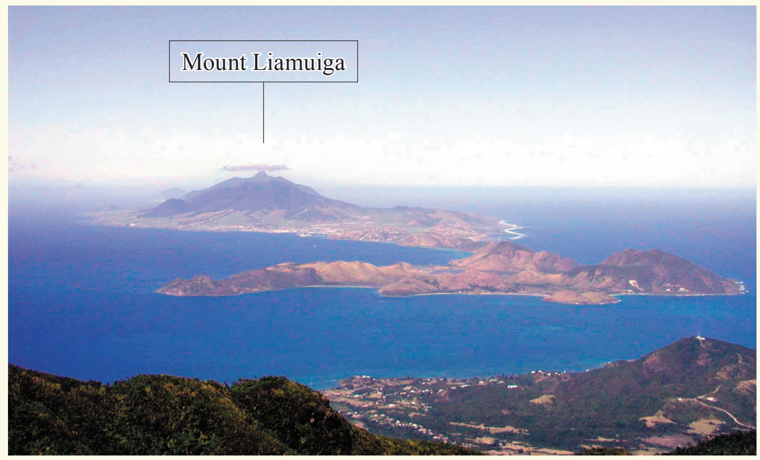
Introduction

The information in this contribution has been compiled from previous research on St. Kitts as well as from a recent hazard assessment done by the Seismic Research Unit in Trinidad (Simpson and Shepherd 2002).

Geographical setting

The island of St. Kitts is located in the northern region of the Lesser Antilles. It is 176 km^2 in size with a population of 36,000. The capital of St. Kitts is Basseterre, located 12 km southeast of the summit of Mt. Liamuiga. The main part of the island has a mountain range that runs northwest through the centre of the island. The higher mountain slopes are densely vegetated by rainforest. The foothills gently slope from the base of the mountain range to the coast and are largely covered by sugar cane. Mt. Liamuiga is the northwestern-most mountain and is the highest peak on the island at 1155 m (3792 ft). In contrast, the topography and vegetation of the Southern Peninsula is dramatically different. It consists of numerous low, rounded hills that reach a maximum height of 319 m (1047 ft), but are generally much lower and are separated by flat, low-lying areas and salt ponds. Vegetation is sparse with dry land grasses, low shrubs, cacti and yucca. The sharp contrast in both the topography and the vegetation from the north of the island is in part due to the older age of the rocks and the lower annual rainfall in the south.

Relief Map of St. Kitts



The island of St. Kitts viewed from Nevis Peak

Previous work

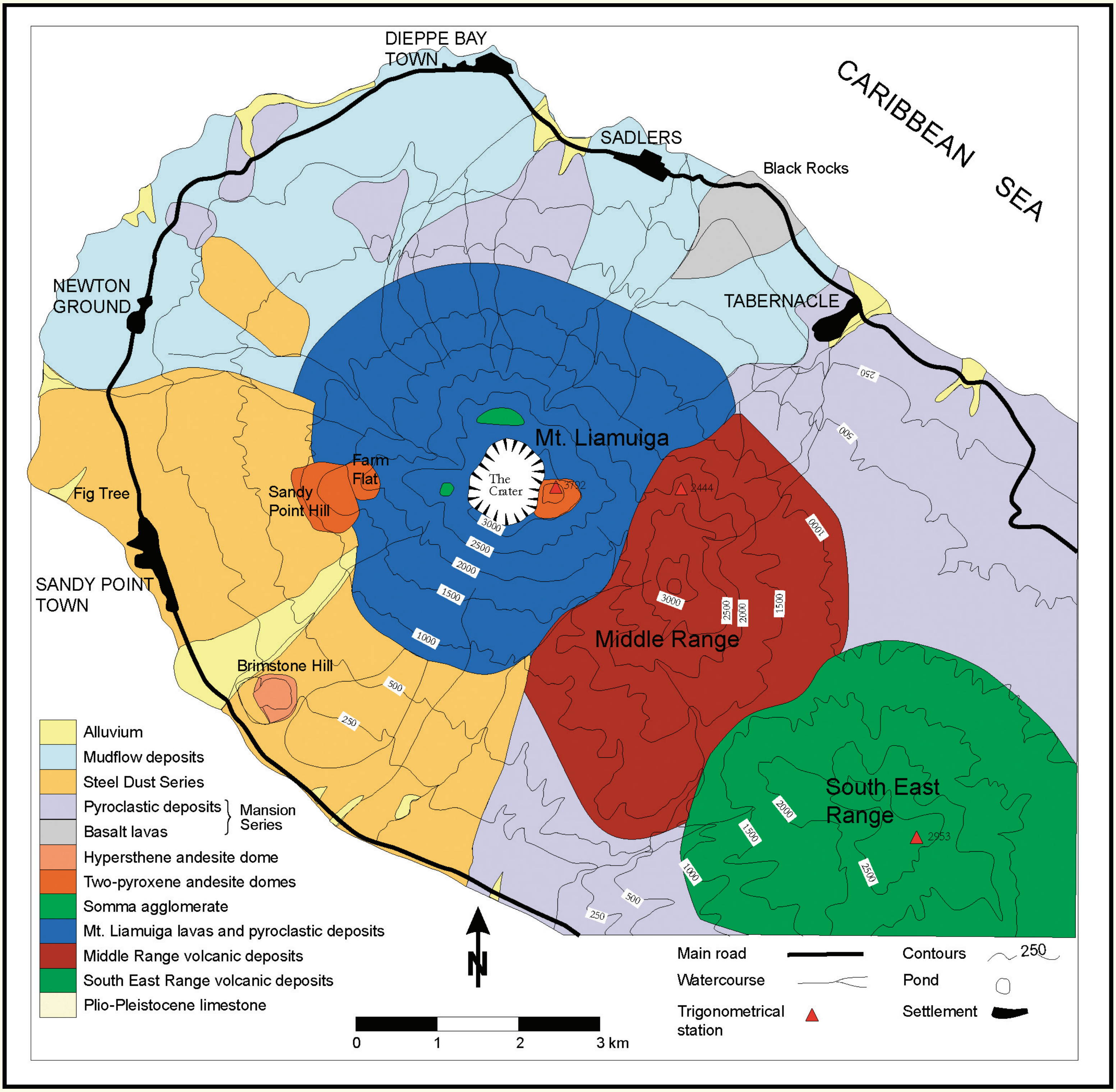
Most of the early geological work on St. Kitts was confined to the volcanic dome of Brimstone Hill and its associated limestone. Maclure (1817), Cleve (1871, 1882), Spencer (1901), and Westermann and Kiel (1961) examined the characteristics and age of the Brimstone Hill limestones. In addition, Spencer (1901), Sapper (1903), Earle (1925), Trechman (1932) and Westoll (1932) examined the general geology and formation of Brimstone Hill.

The general geology of St. Kitts has been examined by Hovey (1903, 1905), Sapper (1904), Davis (1924), Martin-Kaye (1959), and Westermann and Kiel (1961). Fels (1903), Lacroix (1904), and Earle (1925) provided some of the first chemical and mineralogical data on the island.

The geology of Mt. Liamuiga has been investigated by several workers. Hovey (1905) referred to Mt. Liamuiga in his more general comparison of West Indian volcanoes. Robson and Willmore (1955) did heat flow measurement at the active fumaroles located at the summit crater. The earthquake series of 1950-51 was examined by Willmore (1952), while Robson et al. (1962) looked at the 1961-62 series.

Martin-Kaye (1959) was the first to identify four volcanic centres on the island; namely (from south to north) the Salt Pond Peninsula, the South East Range, the Middle Range and Mt. Liamuiga. He concluded that the four volcanic centres became progressively younger towards the northwest, and produced the first geological map of St. Kitts. Baker (1963) undertook a PhD thesis focusing on the geology and geochemistry of St. Kitts, and numerous publications followed, including Baker (1965, 1968, 1969, 1980, 1984, 1985) and Baker and Holland (1973). Smith et al. (1985) and Roobol et al. (1981) were the first to identify pyroclastic

Geological sketch map of the northwestern part of St. Kitts (adapted from Baker 1969)



flow and surge deposits on St. Kitts, and since then a number of publications have focused on the detailed description of such deposits (e.g. Tate and Wilson 1988; Roobol et al. 1985, 1987).

Baker (1981, 1985), Roobol et al. (1985, 1987) and Smith and Roobol (1993) discussed various aspects of the volcanic hazards from Mt. Liamuiga and constructed maps showing the distribution of volcanic products from past eruptions. The most recent work on the island was a hazard assessment done as part of a post-doctoral study (Simpson and Shepherd 2002).

Geology

There are four volcanic centres on St. Kitts: the Salt Pond Peninsula, South East Range, the Middle Range, and Mt. Liamuiga (Martin-Kaye 1959).

The Salt Pond Peninsula

This is an area dominated by lava domes with minor volcaniclastic deposits that are interpreted to be pyroclastic flow (block and ash flow) deposits and/or lahar deposits. The area consists of a number of eroded volcanic hills (≤ 1,000 ft.) which are connected by low-lying sandy flats and salt ponds. Ages of 2.3±0.6 Ma, 2.3±0.5 Ma and 2.77±0.3 Ma (Baker 1969) were obtained for lava domes of this centre. These are the oldest known ages for volcanic deposits on the island of St. Kitts.

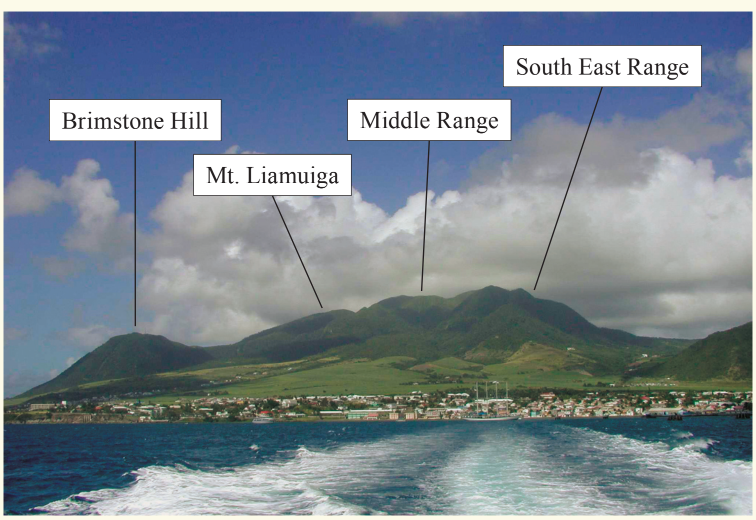
The South East Range

This is a youthful-looking volcano (≤ 2,953 ft.) that has a partly preserved crater at its summit (Baker 1969). Ottley's Level and Monkey Hill are lava domes that formed on the flanks of the

^{14}C age dates of rocks from Mt. Liamuiga, St. Kitts

Description	Locality	Age (years BP)	Ref.
‘Steel Dust’ Series	Bourkes Estate Mansion	1,620 ± 50	2, 4
Pyroclastic flow deposit	Upper Lamberts (Belmont)	1,710 ± 80	2, 4
Andesite pumice surge deposit	Mansion	1,750 ± 90	3, 4
Pyroclastic flow deposit	Godwin Estate	2,030 ± 40	2
Pyroclastic flow deposit	Brothersons Estate	2,038 ± 21	4
Pyroclastic flow deposit	Dieppe Bay - Hacket Point	2,060 ± 40	2
Fine ash and carbon deposit	Church Gut, Lamberts Estate	2,070 ± 50	2, 4
Dense andesite pyroclastic flow deposit	Crantouns Gut	2,280 ± 135	3
Basaltic andesite pyroclastic flow deposit	Headland SE of Sandy Bay	2,340 ± 80	3
Dense andesite pyroclastic flow deposit	Newton Ground	1,817 ± 38	4
Mixed magma surge deposit	East side of Sandy Bay	1,840 ± 55	4
Mixed magma pyroclastic flow deposit	Coast below Brothersons	1,852 ± 27	4
Dense andesite pyroclastic flow deposit	Masshouse Bay	3,060 ± 200	
Ash and carbon deposit	Christchurch	3,658 ± 94	1, 4
Pyroclastic flow deposit	Charles Fort	4,270 ± 140	2, 4
Cinder Unit	North of Mt. Pleasant Estate	>41,730	3, 4
Cinder Unit		>41,140	3
Lower Green Lapilli Unit	Mansion	>41,420	3, 4
Pre-Mansion ‘Series’ pyroclastic deposit	Sea cliffs between Mansion and Tabernacle	>43,000	4

Source of data: 1 Baker (1969); 2 Baker (1985); 3 Roobol et al. (1981); 4 Harkness et al. (1994)
BP Before Present



Brimstone Hill, Mount Liamuiga, Middle Range and South East Range from the south east coast near Basseterre

volcano. The South East Range mainly consists of lava flows and volcaniclastic deposits (Baker 1969), although it is poorly exposed and little is known about its past eruptive history. An approximate age of 1 Ma was obtained from a lava flow on the southern slopes of the South East Range (Baker 1985).

The age, lack of seismicity and lack of geothermal activity suggest that both the Salt Pond Peninsula and the South East Range are unlikely to be the sites of future volcanic activity

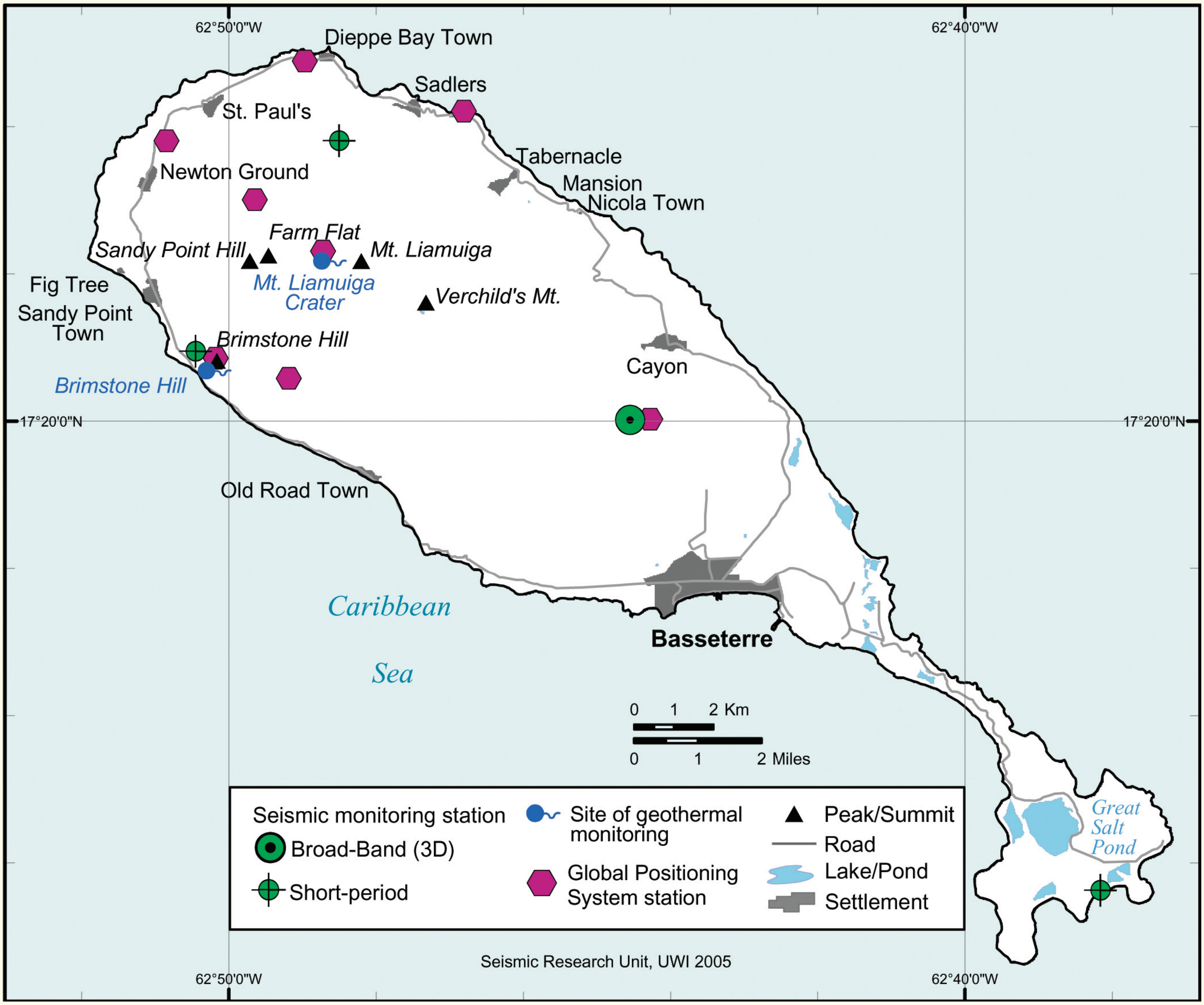
The Middle Range

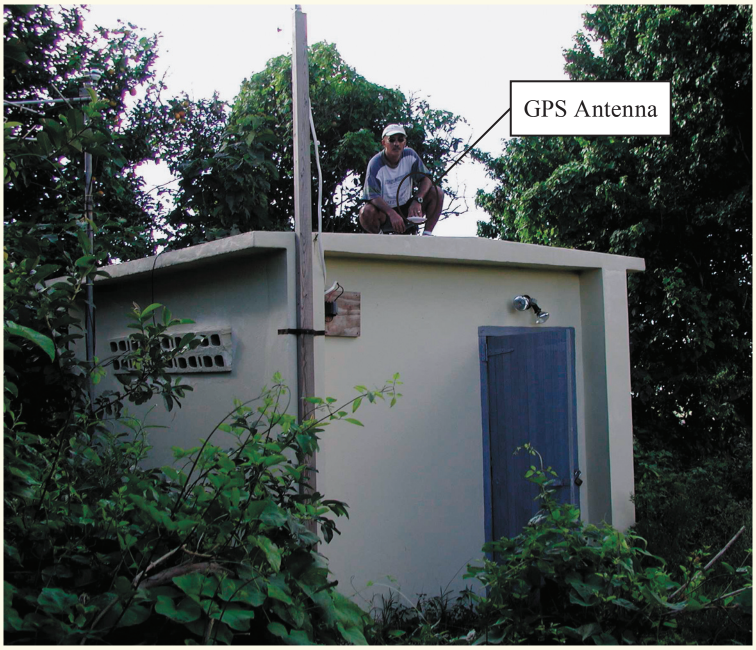
The Middle Range is a poorly exposed area of St. Kitts with few descriptions of its geology, although Baker (1963) described it as consisting of similar deposits to the South East Range. The Middle Range has a youthful appearance with a small summit lake that has filled a former crater. There are no age dates available for the Middle Range. Previous workers have considered the Middle Range to be extinct; however, its youthful appearance, and the lack of age dates makes the current state of the volcano difficult to interpret. New information (i.e. age dates) is necessary to clarify its eruptive history. There is no geothermal activity and no seismicity associated with the Middle Range at present.

Mt. Liamuiga

This is the youngest of the volcanic centres and probably last erupted about 1620 years BP (Baker 1985). The age, geothermal activity and seismicity associated with Mt. Liamuiga suggest that it is a potentially active volcano and likely to erupt again in the future.

Volcano monitoring network in St. Kitts





Base station (Bayfords Farm) for the ground deformation network

Volcano monitoring

The Seismic Research Unit of The University of the West Indies, St. Augustine, Trinidad is responsible for monitoring volcanic and seismic activity on the island of St. Kitts. Between 1957 and 2002, Mt. Liamuiga was monitored continuously by a single short-period seismograph station at Bayfords Farm, 8 km southeast of the crater. In 2002 three additional stations were installed on St. Kitts, one to the north of the crater, one on the Salt Pond peninsula at Turtle Beach and one at Brimstone Hill. Geothermal activity in the summit crater of Mt. Liamuiga is also monitored for changes in location, chemistry, temperature and vigour. Ground deformation is monitored using a network of 8 stations, 5 at the periphery, two on the flanks and one on the summit of Mt. Liamuiga.

Mount Liamuiga volcano

Potentially active volcanic centres

Mt. Liamuiga is a potentially active volcano and is the most likely location for future eruptions on the island of St. Kitts.

Mt. Liamuiga

Past eruptive activity

Mt. Liamuiga has a summit crater ~900 m wide and 244 m deep. The summit of Mt. Liamuiga exposes remnant lava flows and/or domes, but the most common deposits identified on the lower flanks of Mt. Liamuiga are pyroclastic deposits. Cliff exposures along the coastline reveal 5-30 m thick successions of pyroclastic deposits (fall, flow and surge deposits), debris avalanche deposits and lahar deposits. Lava domes are prominent on the flanks of the volcano at Brimstone Hill, Sandy Point Hill and Farm Flat. There are also apparently two small craters located on Bourke's Estate (Baker 1965).

The earliest eruptions of Mt. Liamuiga volcano probably involved the emission of andesitic and basaltic lavas and pyroclastics which formed the basic substructure of the volcano (Baker 1969). The formation of a massive summit dome and its subsequent destruction formed the steep-walled, deep crater that is present at the summit of Mt. Liamuiga. The most recent deposits at Mt. Liamuiga consists of voluminous pyroclastic flow deposits (Baker 1969, Roobol et al. 1981). The final phase of activity involved explosive collapse of NW section of the summit area producing lithic-rich scoria and ash flows (Baker 1985, Roobol et al. 1985, Smith and Roobol 1993).

Age determinations

Age dates on charcoal found in pyroclastic flow and surge deposits indicate an age range of 1620 to >41,000 years BP (Baker 1969, 1985; Baker et al. 1987; Harkness et al. 1994; Roobol et al. 1981). These are the youngest known deposits on the island. The lava domes on the flanks of the volcano have not yet been dated, and it is not known what the relative ages of these features are with respect to the dated pyroclastic deposits from Mt. Liamuiga.

Historical eruptions

There are two unsubstantiated reports of historical eruptions of Mt. Liamuiga in 1692 and 1843. The first report was by a Franciscan friar (Sloane 1694) who describes the island as being troubled by earthquakes and mentions an eruption "of a Great Mountain of Combustable Matter". The second report comes from Capadose (1845) who describes a white spiral cloud of smoke and bubbling sulphurous springs from the crater of Mt. Liamuiga. There are no other historical reports to support the occurrence of either eruption, and both of these alleged eruptions occurred immediately after major earthquakes. It is possible that the effects of the earthquakes were confused with genuine eruptions or that the earthquakes could have triggered minor eruptions.

Baker (1985) references S. Skerrit (pers. comm.) as describing a Carib legend about Brimstone Hill implying that the hill grew out of the lower slopes of Mt. Liamuiga. This suggests that the pre-Columbian Indians possibly witnessed the growth of Brimstone Hill.

Hydrothermally altered ground in the steep-walled summit crater of Mt. Liamuiga volcano

Geothermal activity

Active low temperature (up to 100° C) fumaroles are present in the crater of Mt. Liamuiga. Cracks within the limestone at the base of Brimstone Hill emit a strong smell of sulphur, but no steaming was observed by Simpson and Shepherd (2002). The temperatures within these cracks were only slightly elevated above ambient air temperature, and sulphur crystals line the cracks locally. A strong smell of sulphur is also present along the coastline below Brimstone Hill. No obvious source for the smell was observed; however, discoloration of rocks near the shore may indicate that the vents are located just offshore and that diffuse venting occurs through the ground along the coastline.

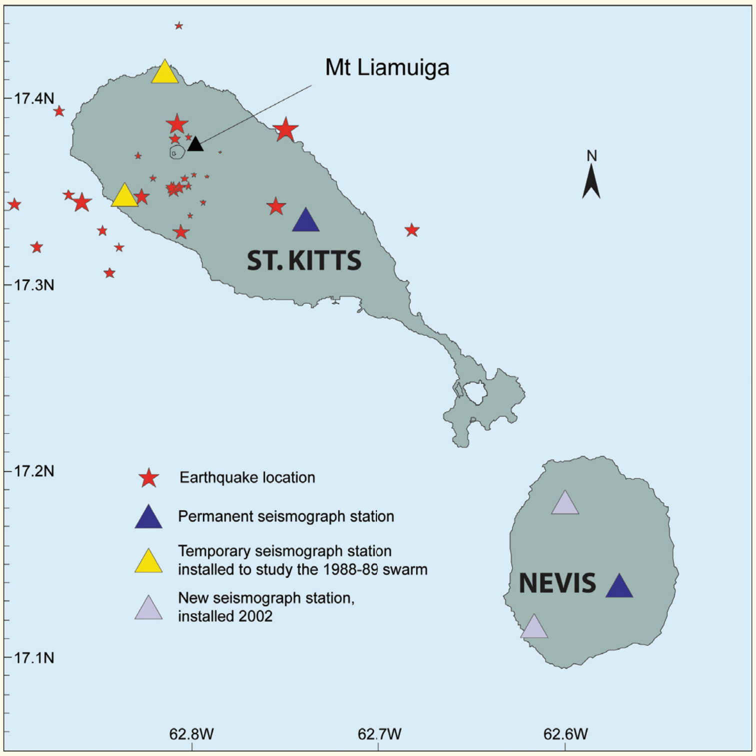
Seismicity

Since 1957 the background rate of occurrence for small earthquakes has been about one per month. Since this time, there have been two major earthquake swarms associated with Mt. Liamuiga (1974 and 1988) and a number of minor ones. The first swarm occurred during August 8-11, 1974 when 21 small earthquakes occurred beneath the volcano. At the time, there was only one seismograph in operation, and the swarm died away before the monitoring system could be reinforced.

The 1988 earthquake swarm

On October 24, 1988 an earthquake swarm began and rapidly built to a climax on October 26 when 186 earthquakes were recorded. The two biggest events, which occurred on the morning of October 26, were of magnitude 4.3 and 4.5. These are larger in magnitude than any of the earthquakes that preceded the eruptions in St. Vincent in 1979 and Montserrat in 1995. On this occasion, the single seismograph station was reinforced by additional stations on St. Kitts and on the neighbouring island of Statia. The earthquakes were also sufficiently large to be recorded by other seismograph stations throughout the Leeward Islands.

Location of earthquakes in St. Kitts during 1988-89



Although this particular earthquake swarm did not culminate in a volcanic eruption, it clearly indicated that the volcano is still potentially active.

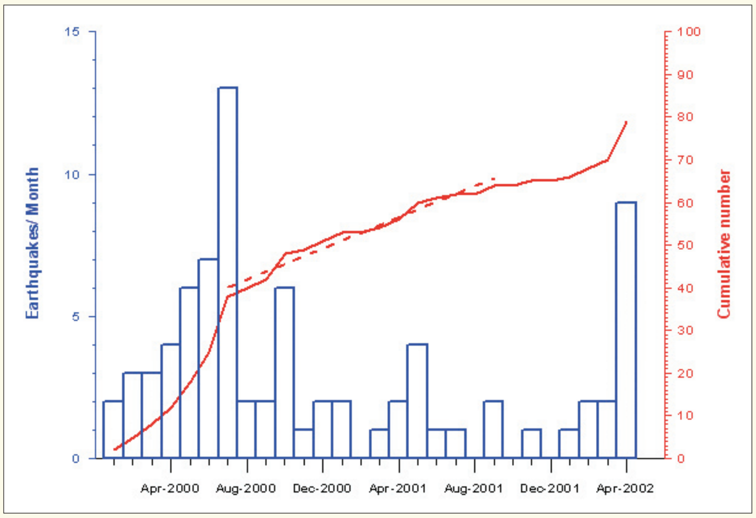
Elevated activity 2000-2001

Between 2000 and 2001 the rate of earthquake activity in St. Kitts was elevated above the background historical level but did not reach the level that could be described as a swarm.

In the first half of 2000, the number of earthquakes escalated to an average of more than 5 per month with a peak of 13 events in July 2000. Subsequently, and throughout 2001, numbers dropped back to about 2 per month, which was still almost twice the previous rate.

Currently (2005) seismicity is at its pre-2000 level with an average of about one earthquake per month.

Monthly earthquake numbers; December 1999 – April 2002



Future eruptions from Mt. Liamuiga

Present and past studies indicate that the northern part of St. Kitts at or near to Mt. Liamuiga is the most likely location for future eruptions. The stratigraphy described by Baker (1969) and subsequently revised by Roobol et al. (1981) along with recent work done by Simpson and Shepherd (2002) indicate that the evolution of Mt. Liamuiga has involved both explosive and effusive types of activity. Both types of eruptions are capable of producing hazardous volcanic events such as pyroclastic flows and surges, associated ash fall and lahars. Two scenarios have been defined and are described below. Both scenarios are likely to be preceded by an increase in the frequency of volcanic earthquakes associated with Mt. Liamuiga. It is also possible that changes in temperature and volcanic gas emission may be observed at summit fumaroles and that the initial phase of eruptive activity will involve phreatic emissions from the eruptive centre (steam venting or phreatic explosions).

Scenario 1: Explosive eruption

Explosive magmatic eruptions, which could generate a sustained eruption column and widespread ash fall, have been the most common type of activity within the recent past at Mt. Liamuiga. Future volcanic activity is likely to follow the St. Vincent-style activity exemplified by the 1902 eruption of Soufrière, St. Vincent, and described by Roobol and Smith (1975), and Smith and Roobol (1993). Such eruptions involve discrete explosions from an open crater producing scoriaceous fall deposits and column-collapse scoria and ash flows that move radially down valleys around the volcano. All flanks of the volcano could be affected by these flows and their associated surges (Smith and Roobol 1993).

The distribution of ash fall described by Baker (1969, 1980, 1985), Roobol et al. (1985, 1987) and Smith and Roobol (1993), based on their mapping of pyroclastic fall deposits, has been used to define a generalised isopach map for this type of eruption at Mt. Liamuiga. This map indicates that Basseterre, the capital of St. Kitts, could experience ash deposits of >20 cm (Baker 1985, Roobol et al. 1985) and as much as 50 cm (Roobol et al. 1985).

The overall distribution of the pyroclastic flow hazard will be similar to that described for dome-forming eruptions but the lateral extent is likely to be more extensive. The northwestern part of the island from Old Road Town to Dieppe Bay Town is likely to be most adversely affected by pyroclastic flows. Baker (1985), estimated that one major pyroclastic flow can be expected to affect this area every few thousand years.

Due to the larger amounts of ash expected during this type of eruption, the generation of lahars is even more likely to occur. Ballistic projectiles would typically be a hazard within ~5 km of the vent.

Scenario 2: Effusive or dome-forming eruption

The presence of domes at Sandy Point, Farm Flat, Brimstone Hill and the summit of Mt. Liamuiga provides evidence that effusive dome growth has occurred in the past at Mt. Liamuiga.

Brimstone Hill, an andesite lava dome surrounded by uplifted limestone strata, located on the lower flank of Mt. Liamuiga volcano

Stratigraphic work by Baker (1969, 1985) and Roobol et al. (1981) indicate that effusive eruptions may have been more common during the early evolution of the volcano. A future effusive eruption may occur either on the flanks of Mt. Liamuiga (e.g. as at Brimstone Hill) or within the crater itself and is likely to involve the growth and subsequent collapse of a lava dome.

Volcanic hazards associated with this eruption will include dome-collapse pyroclastic flows and surges, ash fall and lahars. Pyroclastic flows and surges would travel down the flanks of the volcano, initially being confined to valleys and then spread out onto the gentle slopes towards the sea. If the pyroclastic flows and surges are large enough they may enter the sea. Particularly vigorous flows and surges may be energetic enough to cross topographic barriers, and will have a more widespread effect (see tan area on hazard map). Such flows and surges may result from collapse of the upper flanks of the volcano as occurred at the Soufrière Hills Volcano in Montserrat on December 26, 1997 (the "Boxing Day" event). If such a lateral blast should occur in St Kitts, then a large area in the direction of the blast may be devastated, largely irrespective of topography.

The eruption is likely to be centred on the present crater and the dome collapse events may be initially directed to the northwest where the crater wall is the lowest. As the lava dome becomes larger, collapses would likely affect all flanks of the volcano.

Significant amounts of ash would be dispersed widely around the volcano but particularly in the direction of the dominant wind flow. Depending on the height to which the ash is carried it may be dispersed by the low-level winds (easterly winds) or else the antitrade winds (westerly winds). Ash fall may also significantly affect neighbouring islands and disrupt air traffic. The type of activity exhibited by the ongoing eruption of the Soufrière Hills volcano in Montserrat is a good model for what may occur in the event of this type of activity on St. Kitts. The distribution of ash fall and pattern of accumulated ash fall thickness experienced between 1995 and 2001 at this volcano by the ongoing eruption (Norton et al. 2001) has been used to define a probable ash fall pattern for this type of eruption at Mt. Liamuiga.

If a volcanic eruption of Mt. Liamuiga occurred during a time of heavy rainfall, lahars may be generated along with pyroclastic flows, surges and ash fall. Post-eruptive lahars could also occur. Lahars would be confined to valleys and thus their flow paths would be the main drainage systems and their fans.

Earthquakes may also be a significant hazard before, during and after an eruption.

Integrated Volcanic Hazard Zones

The areas affected by the individual hazardous events presented in the hazard maps have been combined to produce maps of integrated volcanic hazard zones for each scenario that give an indication of overall hazard in different parts of the island in the event of an eruption from Mt. Liamuiga. The zone boundaries are defined in a similar manner for both scenarios. Zone 1 (shown in red) includes all the areas of high pyroclastic flow and surge hazard, areas within 30 cm ash isopach and the area within the 3 km ballistic projectile zone. Zone 2 (shown in orange) includes the areas of moderate pyroclastic flow and surge hazard, 10-30 cm ash thickness and the area within the 5 km ballistic projectile zone. It also includes all lahar paths that are not otherwise included in Zone 1. Zone 3 (shown in yellow) includes all areas expected to experience 5-10 cm of ash. Zone 4 (shown in green) comprises the rest of the island and is not expected to be affected by any other hazard besides <5 cm of ash.

In the event of a dome-forming eruption from Mt. Liamuiga pyroclastic flows, surges, ash fall and lahars will likely cause total destruction of buildings and property in Zone 1 (area of very high hazard). This zone will need to be evacuated before this type of eruption begins. In the case of the explosive scenario, where the pyroclastic flow and surge hazard does not extend throughout the zone, it is likely that the southeastern parts of Zone 1 will only be affected by thick ash fall and could remain habitable during the early stages of the eruption. Evacuation of these areas will become necessary if the eruption continues and ash accumulates. For dome-forming eruptions buildings and property in Zone 2 (area of high hazard) may be affected by significant ash fall (causing the collapse of some roofs) as well as particularly energetic pyroclastic surges and ballistic projectiles. In the case of the explosive eruption scenario, Zone 2 should not be affected by pyroclastic flows and surges at all, as these should be confined within Zone 1. In this scenario, the main hazard in Zone 2 will be from moderate to thick ash fall which may cause roof collapse and breathing difficulties. Zone 3 (the area of moderate hazard), may be affected by ash fall during both explosive and dome-forming eruptions, but should be free from the effects of pyroclastic flows, surges and ballistics. In Zone 4 (the area of low hazard), little to no direct effect of the volcano will be felt with the exception of some minor ash fall.

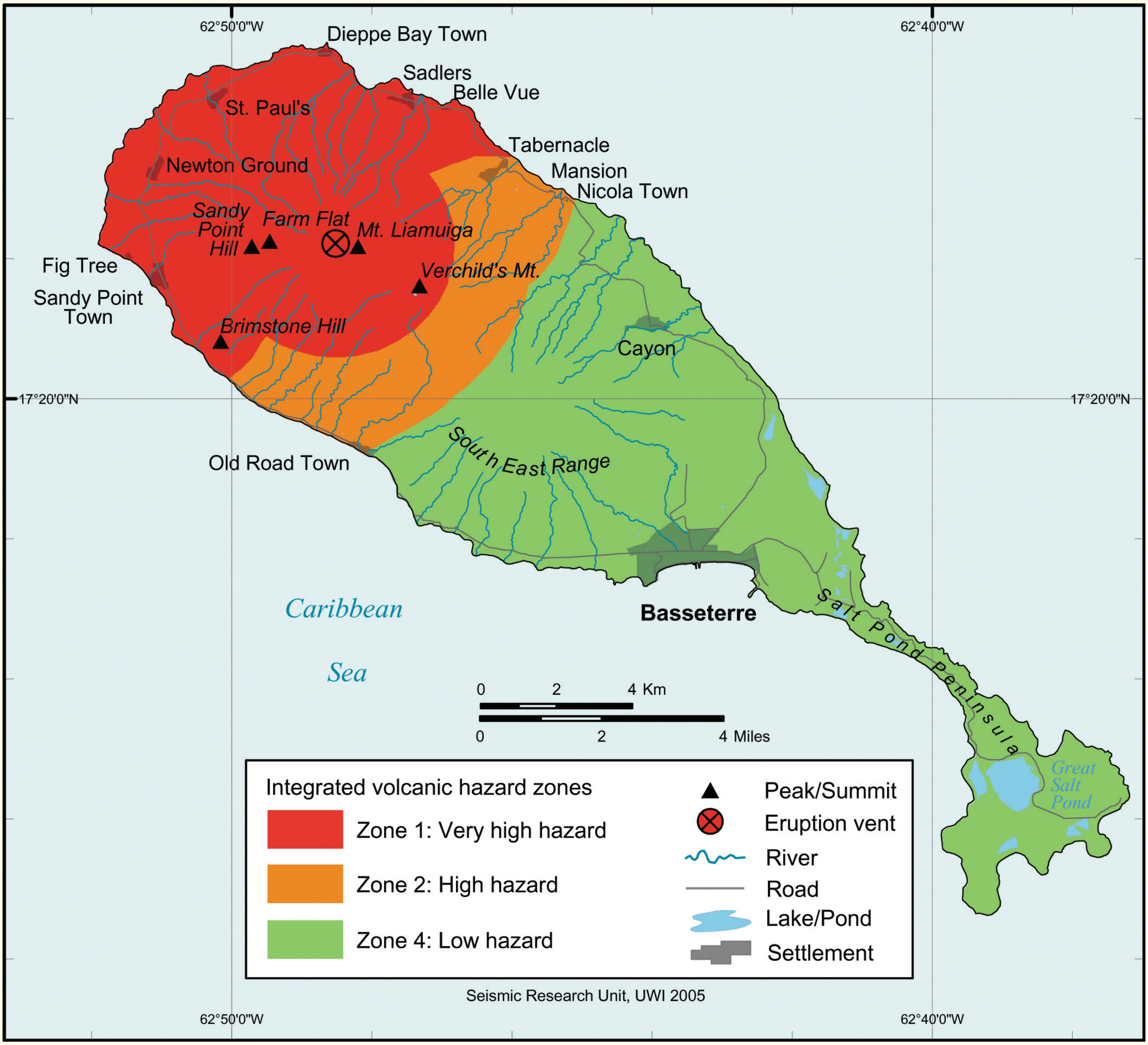
Pyroclastic flows and surges can travel over water and thus are a potential hazard to ocean vessels. Flows and surges generated by explosive eruptions are likely to be particularly mobile. Ash fall is also expected to be a significant hazard at sea particularly on the western side of the island. A maritime exclusion zone around the NW of the island would need to be enforced prior to the onset of a volcanic eruption as well as during the eruption.

Volcanic hazard map for an effusive dome-forming eruption from Mt. Liamuiga, St. Kitts

Volcanic hazard map for an explosive eruption from Mt. Liamuiga, St. Kitts

Integrated volcanic hazard zones for an effusive dome-forming eruption from Mt. Liamuiga, St. Kitts

Integrated volcanic hazard zones for an explosive eruption from Mt. Liamuiga, St. Kitts



Conclusion

At present, there are no signs of increased activity at Mt. Liamuiga, but it is a potentially active volcano that is likely to erupt again in the future. The most likely location for a future eruption is either from the crater of Mt. Liamuiga or on its flanks. Based on the study of past eruptive deposits the most likely style of eruption is an explosive magmatic eruption which may be accompanied by the formation of a lava dome. The most devastating effects of this eruption will be confined to the northern parts of the island but thick ash fall deposits can extend as far as the southern parts of the island and will pose a serious hazard. During such eruptions it is possible that ash emission could pose serious problems to aircraft and could result in the closure of the main airport. The hazards associated with a future eruption from Mt. Liamuiga include earthquakes, pyroclastic flows and surges, ash fall, ballistic projectiles, lahars and earthquakes. An effusive dome-forming eruption is also possible, and a scenario for this style of activity is also presented. Other eruption scenarios are possible, but only the most likely types of activity have been described in this chapter.

It should be noted that the hazard maps presented here are based on present understanding of the volcano and would need to be updated regularly. In addition, once eruptive activity begins it will be necessary to constantly revise the maps based on how the eruption actually develops. Continued monitoring of Mt. Liamuiga is essential to predict and mitigate a future volcanic eruption. An updated emergency plan should also be implemented based on the information presented in the chapter and contingency plans made prior to the onset of a volcanic eruption.

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