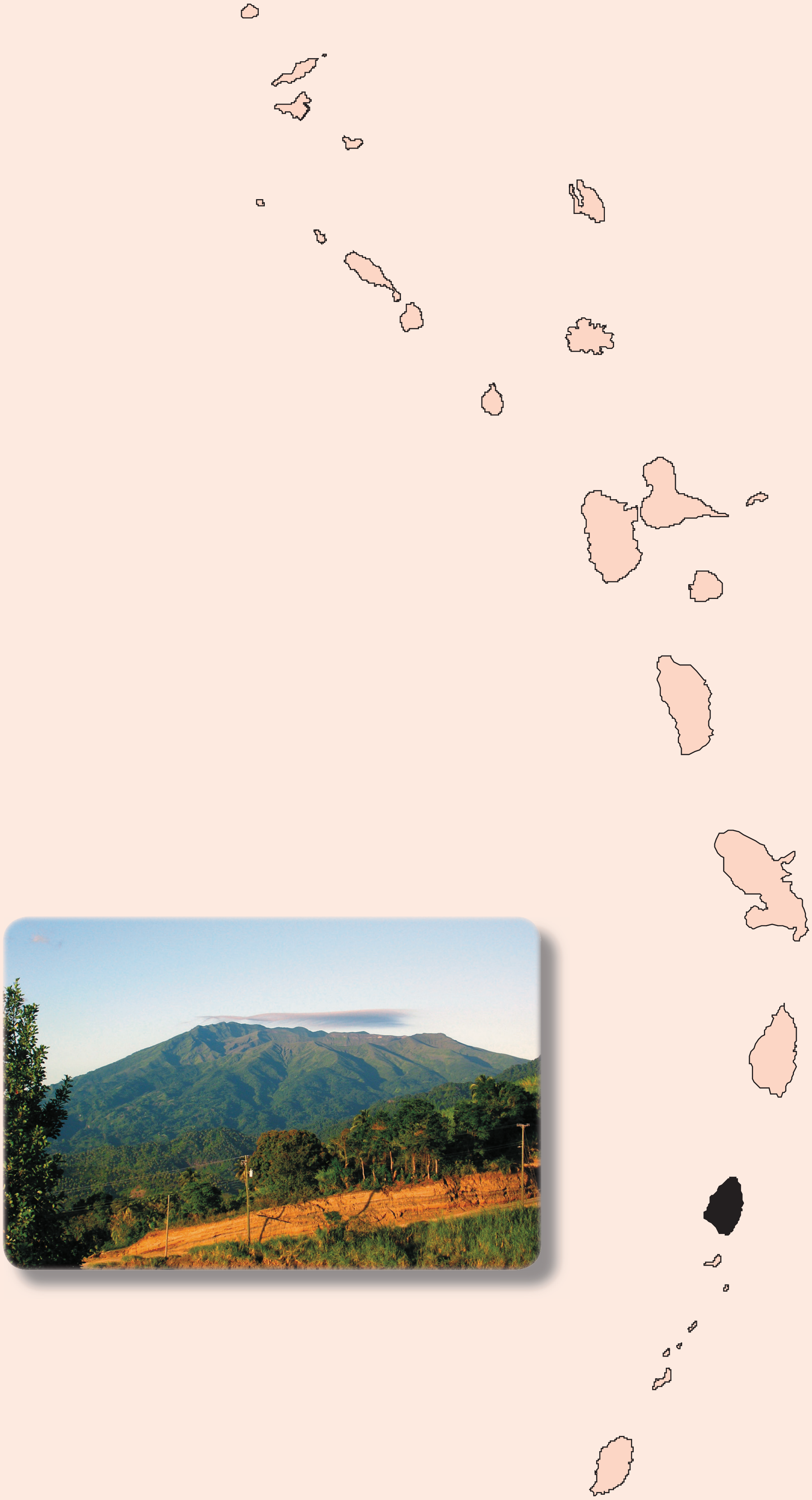
St. Vincent



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Abstract

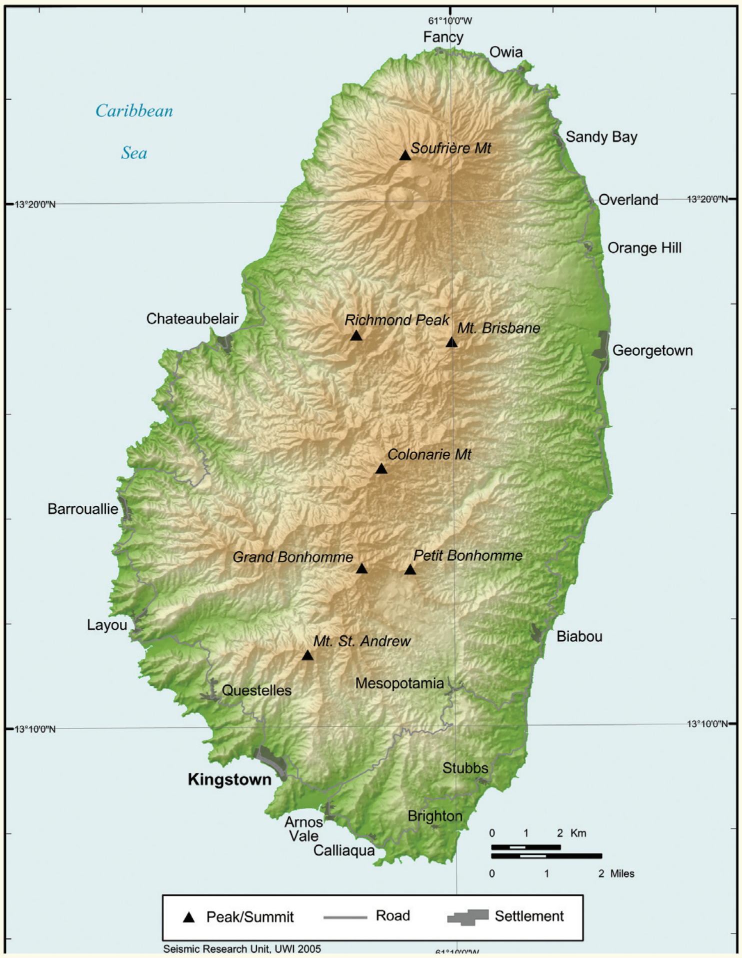
The Soufrière Volcano is the only live volcano on St. Vincent and is the most likely location for future eruptive activity on this island. Future eruptions are most likely to occur from the summit crater and may involve either quiet effusive or violent explosive activity. An effusive eruption is most likely to be confined to the summit crater and will involve the creation of a lava dome. There is a very slim possibility that this dome may overtop the crater rim in which case it may impact areas along the flanks of the volcano. Otherwise it is unlikely that such an eruption will impact surrounding areas. Explosive magmatic eruptions generating ash fall and possibly pyroclastic flows and surges will affect a wider area. 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. Vincent, the Soufrière Volcano has shown that it is capable of erupting and future eruptions are very likely. In the event of future eruptions, the northern parts of the island would need to be evacuated. The extent to which this area extends towards the south will depend on the magnitude of the eruption and whether it is effusive or explosive.

Introduction

Volcanic hazard assessment for St. Vincent presented in this entry was carried out using an empirical approach. This method is justified by the fact that current knowledge of the Soufrière Volcano is sufficiently detailed to enable a fairly comprehensive record of past events to be assembled.

Throughout its recorded history (post-1700) the Soufrière Volcano has exhibited two contrasting styles of activity, a quiet effusive versus an explosive style. Activity during the pre-historic period was similar, with the exception of one major period of cataclysmic Plinian type activity. Once provision is made for the possibility of occasional events such as large sector collapse, hazard assessment based on existing knowledge of the volcano provides a reasonably accurate foundation upon which to plan for future eruptions.

Relief Map of St. Vincent



Seismic Research Unit, UWI 2005

The 1902 eruption is used as the basis on which to model future activity in the short term while activity exhibited during the Pleistocene period is used as the model for long-term hazard assessment. The assessment presented summarises the work of Robertson (1992; 1995).

Geographical Setting

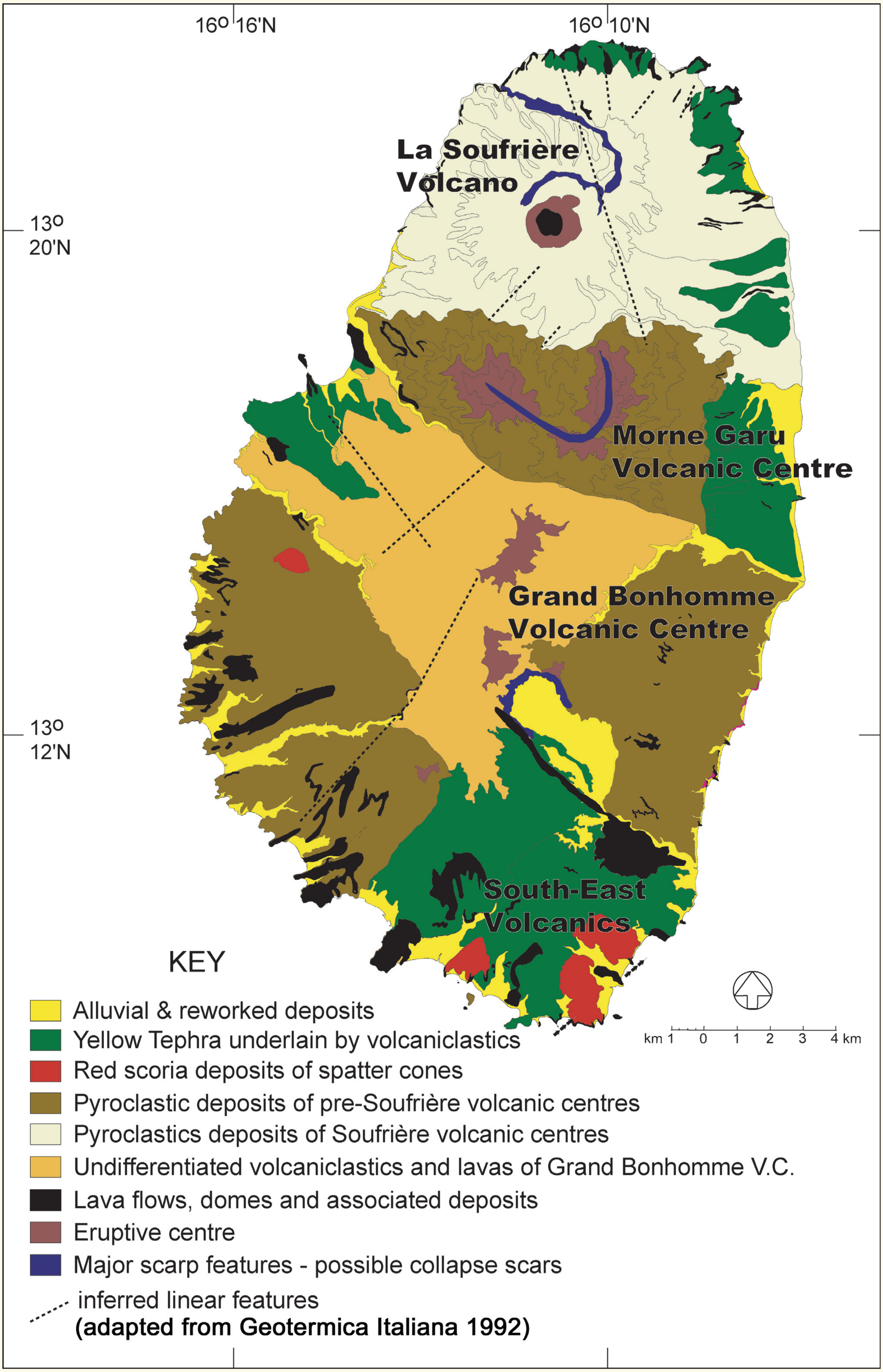
St. Vincent is located between latitude 13° and 13° 30' N and longitude 61° and 61° 30' S, about 100 miles west of Barbados, 68 miles north of Grenada and about 306 km north of Trinidad. The island is roughly oval and has an area of 344 km^2. It is approximately 29 km long and 17.5 km wide and is located within the southern part of the Lesser Antilles island arc. The island consists of a central axial range of mountains starting from La Soufrière (1,178 m) in the north to Mount St. Andrew (736 m) in the south. This range of volcanic mountains divides the island almost equally between a gently sloping eastern or windward side and a deeply dissected and rugged western or leeward side. The north-south trending stratovolcanic centres which make up the backbone of the island show a northward migration in age from 3 Ma, near the south of the island, to 0.6 Ma - Recent at the Soufrière Volcano (Rowley 1978a; Heath et al. 1978b). After the main centres of activity had migrated to the Morne Garu and Soufrière Mountains to the north, minor eruptions may have occurred at Belleisle Hill and Kings Hill to the south, producing red, olivine microphyric basalt scoria cones in small explosive eruptions (Rowley 1978a).

Previous Work

Pre-twentieth century accounts of Vincentian geology are scanty, largely descriptive and mainly deal with the historically active Soufrière Volcano in the north of the island. Anderson (1784) gave the first detailed account of conditions at the summit of the Soufrière. In addition, several descriptions of the 1812 eruption were published in the Barbados Mercury and Bridgetown Gazette during the period May-July, 1812.

During the twentieth century, a number of scientific investigations were carried out on the Soufrière Volcano and its products. Flett (1902) gave an account of ash that fell in Barbados from the 1902-03 eruption. This eruption was documented in detail by Anderson and Flett (1903). Anderson (1903; 1908), Sapper (1903) and Treves (1908) all gave further details of various aspects of the 1902-03 eruption. These works were, however, largely descriptive and based on eyewitness accounts of the eruption. Since then investigators have concentrated on analysis of specific aspects of the Soufrière Volcano.

Geological map of St. Vincent



(adapted from Geotermica Italiana 1992)

Late Pleistocene tephra deposits (YT) overlying pink agglomerate beds (PA) along the west coast of St. Vincent

Work on the petrology of various cumulate blocks ejected by the volcano was published by Lacroix (1949), Sandrea (1949) and Lewis (1973a; 1973b). Rowley (1978a) and Graham and Thirlwall (1981) examined aspects of the petrology and geochemistry of the volcano. Sigurdsson (1977) and Shepherd and Sigurdsson (1978) investigated the chemistry and heat absorption properties of the pre-1979 Crater Lake.

Studies on the relatively thick sequence of late Pleistocene tephra which mantles the island were initiated by Hay (1959a) and continued by Rowley (1974; 1978b). Pyroclastic deposits of more recent eruptions have also been studied by a number of workers including Hay (1959b), Rowley (1978a), Carey and Sigurdsson (1978), Fiske and Sigurdsson (1982), and Sparks and Wilson (1982).

Due to closer monitoring of the volcano's activity since the 1902-03 eruption, several papers have been presented on all eruptions since that event. The 1971 eruption is dealt with by Aspinall et al. (1972), Tomblin et al. (1972), Baker (1972), Aspinall et al. (1973), Roobol (1973), Roobol and Smith (1975), Sigurdsson (1977), and Shepherd and Sigurdsson (1978). The 1979 eruption is covered thoroughly in Shepherd et al. (1979), Michel (1980), Graham and Thirlwall (1981), Fiske and Sigurdsson (1982), Shepherd and Sigurdsson (1982), Huppert et al. (1982), Sparks and Wilson (1982), Fiske (1984) and Fiske and Shepherd (1990).

Several workers have also addressed the very important questions of eruptive mechanism, possible eruptive pattern, premonitory signs, and detailing causative relationships with other phenomena. Mauk (1979) proposed a correlation between eruptions of the Soufrière Volcano and earth tides. Aspinall et al. (1973) suggested that the volcano exhibited a cyclical pattern of eruptive activity. Roobol (1973), Roobol and Smith (1975), Carey and Sigurdsson (1978), Graham and Thirlwall (1981) and Shepherd and Sigurdsson (1982) have all suggested different mechanisms to describe the present and past activity of the volcano. Finally, Shepherd and Aspinall (1982) and Shepherd (1989) have examined the issue of premonitory signs expected before an eruption.

Several workers including Flett (1908), Earle (1924; 1928), Khan (1965), Martin-Kaye (1969), Pushkar et al. (1973), Brown et al. (1977), Rowley (1978a) and Wadge (1986) have all worked on various aspects of the general geology of the island. Flett (1908) was the first to describe the headlands and prominent ridges along the west coast of St. Vincent and the thick yellow ash layers exposed along the east coast. Earle (1924) was the first to note the distinct alteration in deposits along the west coast and the presence of raised terraces on the windward coast.

Pushkar et al. (1973) and Brown et al. (1977) dealt with the geochemistry and isotopic ratios of volcanic rocks on the island. Pushkar et al. (1973) recognised that there were three major volcanic centres present on St. Vincent with the Soufrière Volcano, which occupied the northern-most third of the island, being the youngest. They suggested that St. Vincent consists exclusively of basalts and basaltic andesites, but were undoubtedly only referring to the Soufrière Volcano to the north. Briden et al. (1979) presented nine whole rock K-Ar age determinations for lavas from St. Vincent that illustrated a northward migration in age from 2.74±0.11 at Prospect in the south to 0.36±0.07 at the Soufrière Volcano in the north of the island.

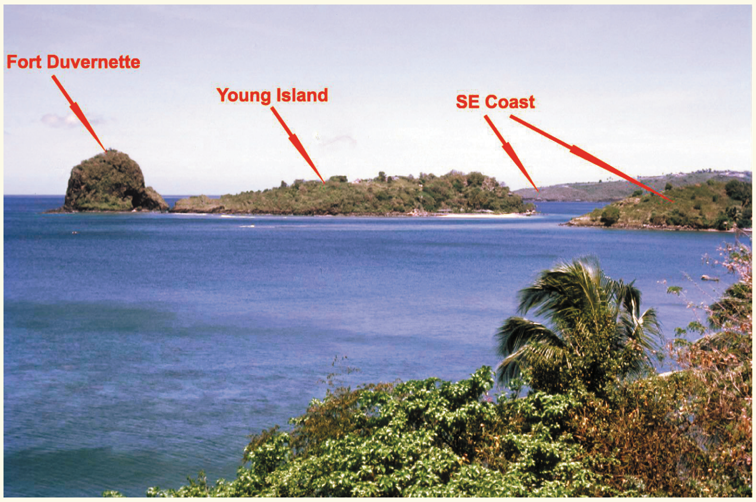
Lava flows at Brighton in southern St. Vincent forming part of the South East Volcanics

Wadge (1986) examined the dykes and structural setting of the volcanic front in the Lesser Antilles and mapped several dykes located in the south-eastern part of St. Vincent. Exploration for underground water supply (Underwood McLellan & Associates 1969; Lekkerkerker 1985) and geothermal resources (Geotermica Italiana 1992) yielded additional information on the island with new geological sketch maps and age determinations being completed. Heath et al. (1998a) and Robertson (2003) examined the petrogenesis and evolution of calc-alkaline magmas from the Soufrière Volcano and the pre-Soufrière volcanic centres of St. Vincent respectively. They provided new insights on the geochemistry and presented new dates for rock samples collected from Mt. Brisbane and the Soufrière Volcano. Hazard and risk assessments were presented in Robertson (1992; 1995).

Age determinations of volcanic rocks from St. Vincent

Sample Number	Description	Location	Age±error (Ma)	Volcanic Centre	Method	Ref.
683762	Calliaqua	13° 07’ 61° 11’	2.49 ± 0.07	South-East Volcanics	K-Ar	1
683761	Prospect corner	13° 08’ 61° 11’	2.74 ± 0.07	South-East Volcanics	K-Ar	1
683763	Cane Garden road	13° 09’ 61° 14’	1.65 ± 0.18	South-East Volcanics	K-Ar	1
683741	Lowmans Leeward	13° 10’ 61° 14’	1.16 ± 0.08	Grand Bonhomme V.C.	K-Ar	1
683749	Coulls Hill	13° 16’ 61° 16’	1.33 ± 0.09	Grand Bonhomme V.C.	K-Ar	1
683747	Richmond Vale	13° 18’ 61° 15’	1.18 ± 0.10	Morne Garu V.C.	K-Ar	1
683756	Rouges Hill, Owia	13° 22’ 61° 08’	0.69 ± 0.09	Soufrière Volcano	K-Ar	1
683755	Commantawana Bay	13° 22’ 61° 09’	0.36 ± 0.07	Soufrière Volcano	K-Ar	1
683740	Porter Point	13° 23’ 61° 10’	0.66 ± 0.10	Soufrière Volcano	K-Ar	1
SV-18	Arnos Vale	13° 09’ 61° 13’	1.54 ± 0.62	South-East Volcanics	K-Ar	2
SV-29	Villa Dyke	13° 08’ 61° 12’	2.50 ± 1.4	South-East Volcanics	K-Ar	2
STV 301	Black Point	13° 15’ 61° 07’	0.18 ± 0.02	Morne Garu V.C	Ar-Ar	3
STV 323	Sandy Bay	13° 21’ 61° 07’	0.291 ± 0.01	Soufrière Volcano	Ar-Ar	3
STV 345	Indian Estate	13° 17 61° 08’	0.011 ± 0.014	Morne Garu V.C	Ar-Ar	3
STV 358	Rabacca River	13° 18’ 61° 08’	0.324 ± 0.015	Soufrière Volcano	Ar-Ar	3

[1]Briden et al. (1979); [2]Geotermica Italiana (1992); [3]Heath (1997).



Fort Duvernette, Young Island and the SE coast of St. Vincent showing the typical topography of the South-East Volcanics

Pyroclastic sequence at Chalmars Hill on the western side of the Grand Bonhomme volcanic centre

Geology

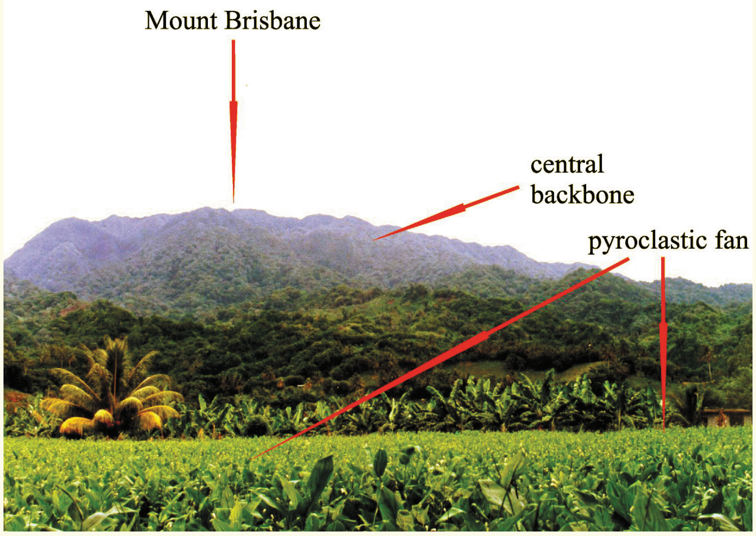
The Pre-Soufrière volcanic centres of St. Vincent

The pre-Soufrière volcanic centres of St. Vincent comprise the South-East Volcanics and the Grand Bonhomme and Morne Garu Volcanic Centres (Robertson 2003).

The South-East Volcanics is the most southerly geologic region on the island. It is a dissected landscape of rounded hills with low topography (<210 m) which extends from the Warrawarrow River in the west to the extensive Yambou lava flow in the east. The area is dominated by red scoriaceous basaltic spatter interbedded with, and often overlying massive to well-jointed basaltic lava flows, which are intruded by dykes. It contains the oldest rocks exposed on the island (2.74±0.11 Ma; Briden et al. 1979) and is mostly overlain by fine-grained yellow ash, which has been correlated with late Pleistocene Yellow Tephra erupted by the Soufrière Volcano (Hay 1959a; Rowley 1978b). The youngest deposits exposed in the area are alluvial silt, sand and gravels found in the river valleys.

The Grand Bonhomme Volcanic Centre extends from Argyle to Colonarie in the east and Sion Hill Bay to Chateaubelair in the west. It is the largest geologic region on the island and is interpreted as a large stratovolcano with interbedded sequences of block and ash flow deposits, ash fall deposits, lava flows and subordinate domes. The landscape is heavily forested and the interior inaccessible and composed of deeply weathered lavas and volcaniclastic deposits. This volcanic centre is a composite of several eruptive centres that are now represented by the topographic highs of Grand Bonhomme (970 m), Petit Bonhomme (747 m), Mount St. Andrews (735 m) and an unnamed peak (1021 m). These peaks are central domes or plugs of volcanoes that coalesced to form a large composite volcanic centre. Previous dating of lavas from the western flank of the Grand Bonhomme Volcanic Centre by Briden et al. (1979) obtained ages of 1.33±0.09 and 1.16±0.08 Ma respectively for lava flows at Westwood and Chateaubelair.

The Morne Garu Volcanic Centre occurs immediately to the north of Grand Bonhomme and consists of Mount Brisbane (932 m) to the east and Richmond Peak (1074 m) to the west. These two peaks are the remnants of an eroded Morne Garu crater or caldera that is estimated to have been 3 km in diameter (Sigurdsson 1981). Morne Garu is largely inaccessible, and the underlying volcanics are extensively covered with fine-grained yellow ash fall deposits. Recent ages obtained by Heath et al. (1998b) from lavas at Indian Estate (11±14 ka) and Black Point (180±20 ka) on the western flank of Mount Brisbane indicate that volcanism may have been much younger at this centre and may have overlapped with the Soufrière Volcano to the north. The major formations exposed are lava flows, undifferentiated volcaniclastics, red scoria bombs and yellow ash fall deposits. Reworked alluvial deposits occur in the major river valleys.



Mt. Brisbane (932 m), part of the Morne Garu Volcanic Centre, viewed from the east coast near Georgetown

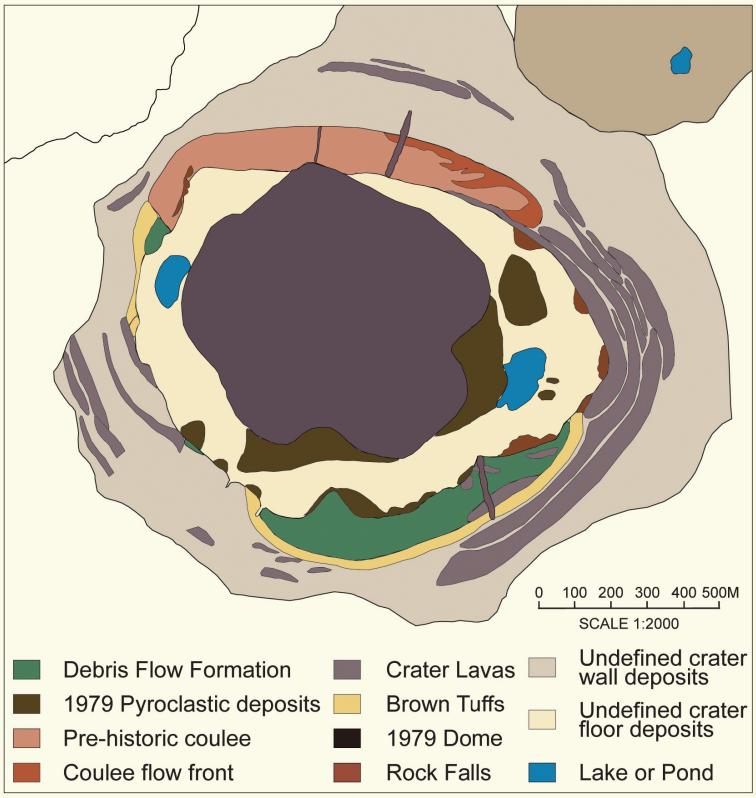
Monogenetic spatter cones

A number of rounded spatter cones composed of poorly consolidated sequences of clast-supported, pumice lapilli airfall, scoria bombs and ash resting on old lava flows occur mainly in the southeast of St Vincent, although some are found further north. Eruptive centres were identified at Kings Hill, Diamond (South) and Rose Cottage. Eruptions produced abundant scoria bombs, which fell close to these centres and formed thick and sometimes welded deposits. Ash and small projectiles deposited further from the vents produced discrete beds.

The best exposure of spatter cones in the northern part of the island occurs at Belleisle Hill where a thick sequence (>20 m) of interbedded grey lapilli-sized ash and red scoria is overlain by yellow ash. The red scoria clasts are composed of olivine microphyric basalts, but the scoria beds also contain angular basaltic-andesite.

The two rounded hills of the Brighton spatter cone as seen from Milikin Bay on the east coast of St. Vincent

Geological sketch map of the crater of the Soufrière Volcano (after Sigurdsson 1981)



The Soufrière Volcano

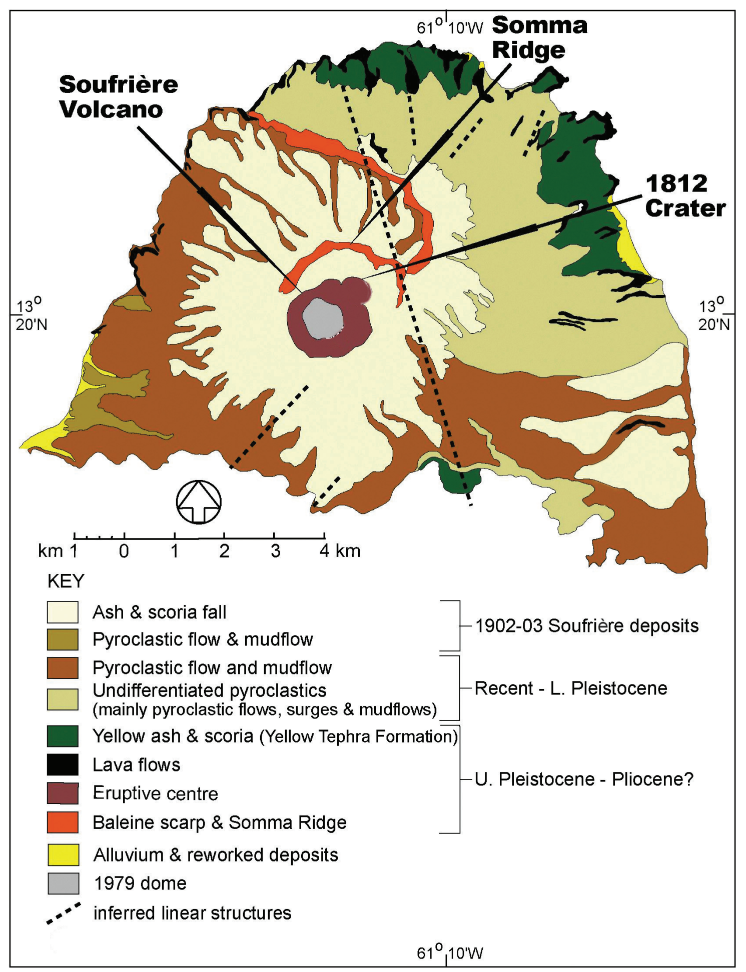
The youngest volcanic centre on St. Vincent is the Soufrière Volcano, which occupies the northernmost third of the island. This is considered to be the only volcano that is likely to erupt in the future and as such is the focus of the hazard assessment forming the bulk of this document. No detailed geological map of the volcano exists, although the principal formations have been identified (Robson and Tomblin 1966; Rowley 1978a; Sigurdsson 1981; Robertson 1992). The volcanic edifice consists of an older strato-cone or Somma (2.5 km diameter), which forms a steep arcuate ridge to the north, and a younger pyroclastic cone, which has been the source of historical (post 1700) eruptions, nestled within this crater. The older stratovolcano is thought to have been active during the late Pleistocene (~700 ka). The main crater of the Soufrière Volcano is about 1.6 km in diameter and is 300-600 m in depth. Located immediately to the northeast is the 1812 crater, an oval shaped depression (~450 m diameter and 60 m depth), from which the volcano erupted once (April 27 to June 6, 1812).

It has not yet been possible to correlate the flank stratigraphy, as exposed in the deep gullies that radiate from the summit, with that exposed in the crater walls. The lack of dated samples from the crater wall succession allows only a lithological correlation of crater wall formations with the radiocarbon and Ar-Ar dated deposits on the lower flanks (Sigurdsson 1981). The generalised stratigraphy suggested by Rowley (1978a) and Sigurdsson (1981), based largely on an investigation of deposits found within the crater and along the flanks of the volcano, provides the best interpretation of the Soufrière Volcano deposits. The description given below summarises these ideas.

Four principal rock formations have been identified in the crater (Sigurdsson and Carey 1981). The Debris Flow formation is the lowest exposed formation and is a massive matrix-supported

Panoramic view of the Soufrière Volcano (1178 m) showing the vulnerable town of Chateaubelair in the foreground

Geological map of the Soufrière Volcano (based on Robson 1966; Rowley 1978a; Robertson 1992)



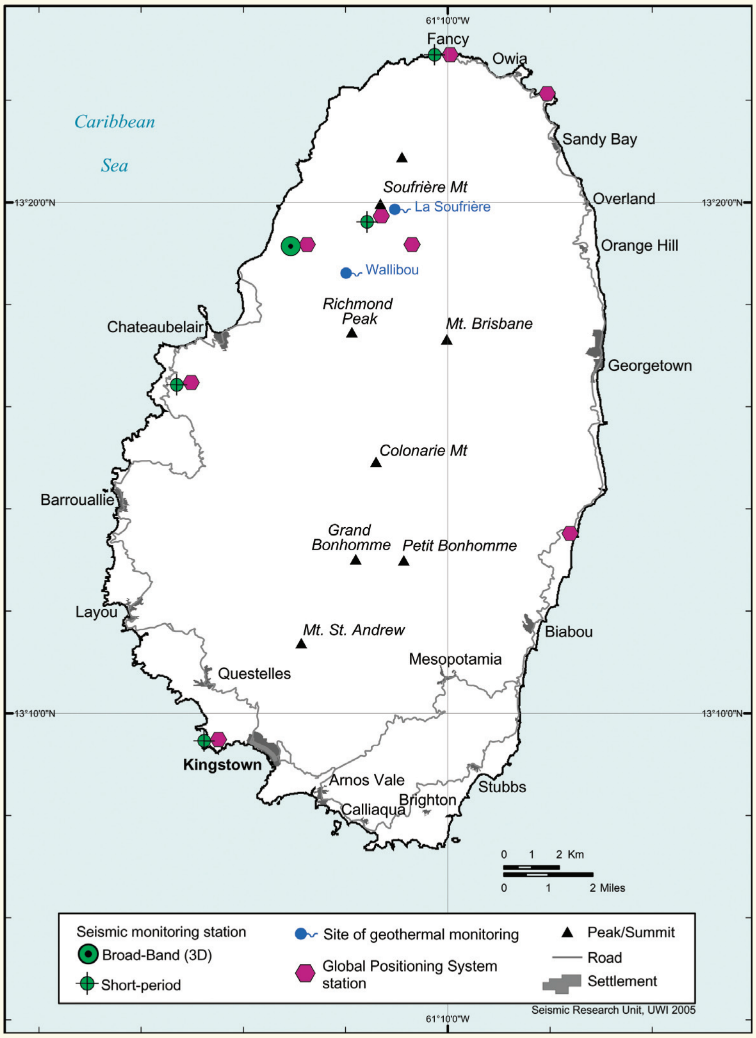
deposit consisting of angular basaltic blocks (maximum 3 m diameter), in a poorly sorted sandy matrix. Overlying this is the Brown Tuff, a 20 m thick, well-bedded succession of ash and scoria airfall deposits and minor surge layers, which contain angular basaltic lithic fragments. Thick basaltic andesite and andesite lava flows, which form the lower half of the vertical eastern and northern crater walls, are called the Crater Lavas formation. The topmost deposit exposed in the crater consists of a thick sequence of pyroclastic flow and airfall deposits called the Pyroclastic Formation.

The oldest formations exposed on the flanks of the volcano are basaltic lavas, which form the remnants of the pre-historic Somma crater. These are overlain by beds of pumiceous yellow tephra (the Yellow Tephra Formation), which have been correlated with yellow pyroclastic fall deposits that mantle the island (Hay 1959a; Rowley 1974; Rowley 1978b). The yellow tephra units are often reversely graded and contain airfall beds made up of black scoria and yellow lapilli-sized pumiceous tuff that ranges in composition from basalt to andesite. In the river valleys, the Yellow Tephra is overlain unconformably by alluvial deposits, basaltic andesite pyroclastic flow deposits and mudflow deposits. The mudflow deposits are massive, thick (up to 25 m) and contain angular blocks of basalt and basaltic andesite. On the lower flanks of the volcano, the mudflow deposits are overlain by and interbedded with basaltic andesite pyroclastic flow deposits, thin tephra fall deposits and minor alluvial deposits. The pyroclastic units are discontinuous, channel-fill deposits that show little variation in lithology. There is little distinction between deposits erupted during historical eruptions, apart from deposits from the 1979 eruption which are distinctively rich in basaltic andesite.

Volcano monitoring

Monitoring of the Soufrière Volcano is carried out by the Seismic Research Unit based in Trinidad and a small local unit (the Soufrière Monitoring Unit) based at the Ministry of Agriculture in Kingstown, St. Vincent. The volcano monitoring network consists of five seismic stations, eight GPS stations and several dry tilt sites. Seismic data are transmitted from field sites to Belmont, where a custom-built observatory building is maintained by the Soufrière Monitoring Unit. The data are then accessed from Trinidad via the Internet. Regular visits are made to the summit of the volcano by members of the local unit. During these visits measurements of lake and fumarole temperature are made and any observed changes in the state of the volcano noted. Occupation of GPS and dry tilt sites is conducted bi-annually or as often as activity levels at the volcano dictate.

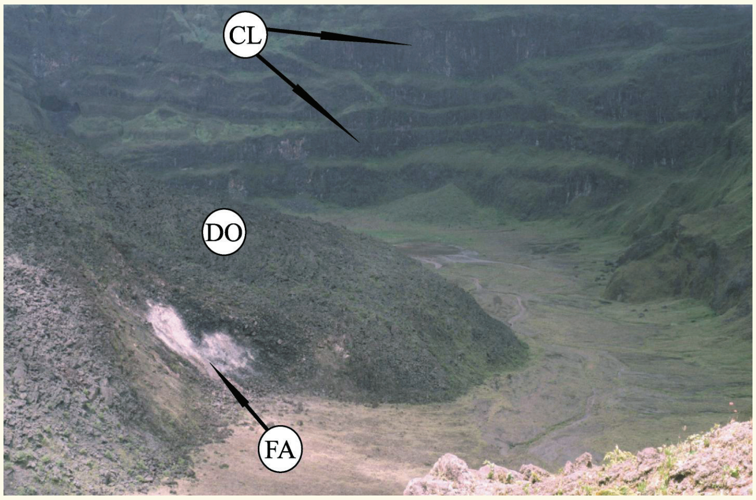
Volcano monitoring network in St. Vincent



Potentially Active Volcanic Centres

The Soufrière Volcano

The Soufrière Volcano is considered to be the only live volcano on the island so the discussion that follows examines activity at this centre only. Activity at the Morne Garu Volcanic Centre may have overlapped with the early stages in the evolution of the Soufrière Volcano, and as such the volcanoes of this volcanic centre are relatively young. However, apart from their well-preserved morphology there is no other indication (e.g. seismicity and/or geothermal activity) that the volcanoes that comprise the Morne Garu Volcanic Centre are capable of future activity.



The crater of the Soufrière Volcano (1.4km diameter), showing the 1979 dome (DO; 870x130 m), crater lavas (CL) and fumaroles (FA)

Past eruptive activity

A detailed picture of the Soufrière Volcano's evolution is still incomplete. Robson (1965), Rowley (1978a) and Sigurdsson (1981) have proposed several distinct stages in the volcano's history, based respectively on the stratigraphy and geochemistry of the entire volcano and on the stratigraphy of the summit crater. The evolutionary stages identified are of a generalised nature only and are not accurately established. During the past 4000 years the volcano has had an average of one explosive eruption every 100 years. More recently (during the past 250 years) the Soufrière Volcano has displayed two distinct types of eruptions (Aspinall et al. 1973):

Type 1:Explosive eruptions: These are the typical "St. Vincent style" eruptions. They are highly explosive eruptions usually preceded by frequent, strong earthquakes. Rapid rates of magma production result in the ejection of large volumes of new material. This type of activity is exemplified by the 1902-03 and 1979 eruptions.

Type 2:Non-explosive or effusive eruptions: This type of eruption is effusive and may be unaccompanied by earthquakes. It involves the extrusion of a viscous lava dome and results in the production of smaller volumes of new material than type 1 eruptions. This type of eruption is exemplified by the 1971-72 eruption.

A cyclical pattern of eruptive activity during the past 250 years with alternating eruptions of Type 1 and Type 2 has been observed at the volcano (Aspinall et al. 1972).

Rowley (1974; 1978a) examined the distribution, grain-size, petrology and origin of the late Pleistocene pyroclastic deposits found on the island (the Yellow Tephra Formation). He concluded that the Soufrière Volcano experienced a relatively short period of activity during the Pleistocene that was more violently explosive than that exemplified by Type 1 eruptions. This may have been unique in the volcano's history and involved different styles of activity - Strombolian, Vulcanian and Sub-Plinian - with the summit crater possibly occupied intermittently by lava domes similar to the 1971-72 dome (Rowley 1974; Rowley 1978a).

Seismicity

Earthquakes have been associated with most of the explosive eruptions in the historical past. The only documented effusive

Summary of historical eruptions (post 1700s) at the Soufrière Volcano based on historical records. The table is adapted from Robertson (1992) where more details on these eruptions can be found

Date	Summary of activity
1718	Explosive volcanic eruption preceded by one month of earthquake activity; possibly started on May 26 and continued until May 29. Ash fell on Martinique, St. Kitts, Barbados and Hispaniola and noise of the eruption was heard as far as Trinidad and Antigua. This eruption was estimated to have been the most violent of the historical period (Anderson and Flett 1903).
1780	Increased fumarolic activity, possibly accompanied by lava emissions.
1811	Strong earthquakes.
1812	Explosive volcanic eruption preceded by >200 earthquakes during the previous year. The eruption started on April 27 and continued up to June 9. Pyroclastic flows, mudflows and ash falls affected the areas of Wallibou to Baleine and Grand Sable to Tourama. Fifty-six people died; a new crater was formed. The eruption is estimated to have been of a lower magnitude than the 1902 eruption.
1814	Small eruption of January 9; rocks thrown 0.5 km from the crater.
1880	The lake temperature increased accompanied by a major rise in the water level. Increased fumarolic activity with possible development of lava dome.
1901	Strong earthquakes.
1902-1903	Explosive volcanic eruption preceded by approximately 12 months of earthquake activity. The eruption began on May 6, 1902 and continued up to March 30, 1903. Pyroclastic flows, mudflows, and ash falls affected areas to the northeast, east and west of the volcano. Over 1500 people died and extensive damage was caused to agriculture in the areas around the volcano.
1948-1954	The 1946 mean temperature of the Crater Lake was 4 ^oC above ambient air temperature (~23 ^oC). The annual mean temperature of the Crater Lake increased to ~28 ^oC during the period 1948-1949 but returned to the 1946 value by 1954. This was attributed to fumarolic activity on the lake bottom (Tomblin 1970).
1971-1972	An aseismic effusive eruption occurred resulting in the discharge of 80 x $10^6 m^3$ of lava into the crater and an increase of 30 m in the level of the crater lake. The eruption started between September 28 and October 10 and lava extrusion continued up to 1972. A dark grey basaltic andesite with 54% SiO_2 was emitted. The vegetation was destroyed in a 30 m zone above the lake level. A spontaneous evacuation of people from the area started in November but the official evacuation of population from areas north of the Rabacca River only began on December 7.
1978	Local earthquake swarm.
1979	An explosive eruption occurred accompanied by effusive activity. The eruption was preceded by increased numbers of earthquakes, an increase in the temperature of the crater lake and a slight inflation of the volcano flanks. The eruption started on April 3 with dome building continuing up to 1983. There were no fatalities, but there was loss of crops and livestock. The final cost of eruption to the economy was estimated at EC$13,784,797. Over 14,000 people were evacuated from areas located north of Union Village (east) and Belleisle Hill (west); explosions continued for two weeks followed by six months of non-explosive emission of lava.
1983-2005	Weak and infrequent earthquakes.

eruption of the historical past (the 1971-72 eruption) began without any seismic activity detected at the closest seismic station located 10 km from the volcano (Aspinall et al. 1973). However, the eruption was not entirely aseismic, and emergent, low-frequncy events were subsequently detected within a few kilometers of the vent (Sheperd and Aspinall 1982). Premonitory earthquake activity preceding an explosive eruption has varied from a few days to months and even years (Anderson and Flett 1903; Shepherd et al. 1979). The value of such activity as an alarm is limited since earthquakes can occur with no ensuing eruptions.

Geothermal Activity

Geothermal activity associated with the Soufrière Volcano is confined to the crater and the base of the southern flank of the volcano. Two groups of high temperature fumaroles are present near the base of the southern part of the andesitic dome that occupies the north-western portion of the summit crater. The fumaroles emit steam and gases and have reduced in vigour since their first manifestation immediately following dome emplacement at the final stages of the 1979 eruption. Along the northern streambed of the Wallibou River at an elevation of 280 m (approximately 1 km from the Trinity waterfalls) a group of lukewarm springs (37^o C) is present.

Hazardous Phenomena

The review of past activity at the Soufrière Volcano presented earlier enables definition of the likely hazardous events expected from future eruptions. The following paragraphs examine in some detail the effects of these events during past eruptions of the volcano. Pyroclastic flows and surges, mudflows, ash fall and projectiles are the most hazardous events expected and are therefore outlined in greater detail than lava flows, atmospheric phenomena, earthquakes and phreatic explosions. Secondary effects such as landslides and events of more remote possibility such as directed blasts and structural collapse are only given brief mention. Future eruptions are likely to be explosive or effusive - similar to those experienced in the historical past. Details of two possible scenarios are contained in a later section.

Ballistic projectiles and ash fall

Ballistic projectiles and tephra falls have been a common feature of all explosive eruptions of the volcano in the past and it is likely that any future explosive eruption will generate ash falls and projectiles. In the past these phenomena have caused extensive damage to agricultural crops, minor damage to buildings and livestock, reduction in visibility, disruption of traffic and minor damage to vehicles and respiratory illness in the human population.

^{14}C ages of rocks from the Soufrière Volcano

Sample No	Location	Age ± error (yBP)	Latitude	Longitude	Reference
SVE-104	Rabacca River;	20 ± 45	13º 18’ 30”	61º 08’ 40”	Heath (1997)
SRR-3972	Dry Wallibou River	20 ± 4			Robertson (1992)
SVE-102	Rabacca River	30 ± 45	13º 18’ 30”	61º 08’ 30”	Heath (1997)
STV-123	Dry Wallibou River	40 ±45	13º 19’ 20	61º 13’ 20	Heath (1997)
SRR-3973	Dry Wallibou River	45 ± 40			Robertson (1992)
SVE-094	Wallibou River	55 ± 50	13º 19’ 30”	61º 13’ 00”	Heath (1997)
SVE-111	Camariabou River	70 ± 45	13º 19’ 15”	61º 07’ 10”	Heath (1997)
SVE-105	Rabacca River	75 ± 45	13º 18’ 40”	61º 08’ 50”	Heath (1997)
SVE-090	Dry Wallibou River	75 ± 40	13º 18’ 40”	61º 13’ 20”	Heath (1997)
STV-112	Sandy Bay Village	75 ± 45	13º 21’ 20”	61º 08’ 00”	Heath (1997)
SRR-3974	Dry Wallibou River	80 ± 40			Robertson (1992)
SVE-101	Rabacca River	90 ± 45	13º 18’ 20”	61º 08’ 20”	Heath (1997)
SVE-103	Rabacca River	100 ± 45	13º 18’ 30”	61º 08’ 30”	Heath (1997)
SVE-106	Rabacca River	105 ± 45	13º 18’ 30”	61º 08’ 50”	Heath (1997)
SVE-086	Wallibou River	120 ± 40	13º 18’ 40”	61º 13’ 40”	Heath (1997)
SVE-097	Dry Wallibou River	125 ± 45	13º 19’ 30”	61º 13’ 30”	Heath (1997)
SVE-085	Wallibou River	130 ± 45	13º 18’ 40”	61º 13’ 40”	Heath (1997)
SRR-3967(a)	Morne Ronde River	135 ± 40			Robertson (1992)
SRR-3967(b)	Morne Ronde River	145 ± 40			Robertson (1992)
SVE-089	Dry Wallibou River	150 ± 40	13º 18’ 41”	61º 13’ 30”	Heath (1997)
SVE-099	Owia	155 ± 45	13º 22’ 30”	61º 08’ 30”	Heath (1997)
SVE-084	Wallibou River	160 ± 40	13º 18’ 30”	61º 13’ 50”	Heath (1997)
STV-106	Dry Rabacca River	165 ± 45	13º 17’ 50”	61º 08’ 00”	Heath (1997)
37302	Rabacca Valley	173 ± 50			Rowley (1978a)
842	Chibarabu Pt	200			Rowley (1978a)
838	Wallibou sea-cliff	200			Rowley (1978a)
STV-366	Dry Wallibou	215 ± 45	13º 19’ 20”	61º 13’ 30”	Heath (1997)
SRR-3960	Wallibou sea-cliff	220 ± 40			Robertson (1992)
SRR-3968	Morne Ronde River	220 ± 40			Robertson (1992)
SRR-3971	Wallibou sea-cliff	225 ± 40			Robertson (1992)
79-56	Morne Ronde Valley	270 ± 45	13º 19’ 40”	61º 13’ 20	Heath (1997)
STV-131	Dry Wallibou River	290 ± 45	13º 19’ 30”	61º 13’ 00”	Heath (1997)
902	N. Wallibou Dry River	300 ± 60			Rowley (1978a)
SRR-3961	Wallibou sea-cliff	315 ± 40			Robertson (1992)
901	N. Wallibou Dry River	320 ± 60			Rowley (1978a)
SVE-095	Dry Wallibou River	320 ± 45	13º 19’ 30”	61º 13’ 10”	Heath (1997)
STV-329	Windward Trail	320 ± 45	13º 19’ 37”	61º 09’ 50”	Heath (1997)
STV-117	Dry Wallibou River	330 ± 45	13º 19’ 20”	61º 13’ 20”	Heath (1997)
SVE-088	Dry Wallibou River	325 ± 45	13º 19’ 10”	61º 13’ 30”	Heath (1997)
SRR-3965	Larikai sea-cliff	340 ± 40			Robertson (1992)
SRR-3964	Larikai sea-cliff	390 ± 40			Robertson (1992)
870	Larikai sea-cliff	400 ± 60			Rowley (1978a)
SRR-3959	Wallibou sea-cliff	405 ± 40			Robertson (1992)
SRR-3962	Larikai sea-cliff	425 ± 40			Robertson (1992)
STV-066	Windward Trail	440 ± 45	13º 19’ 10”	61º 09’ 30”	Heath (1997)
SVE-087	Wallibou River	465 ± 45	13º 18’ 41”	61º 13’ 30”	Heath (1997)
37273	Larikai River	467 ± 150			Rowley (1978a)
903	Larikai sea-cliff	470 ± 60			Rowley (1978a)
STV-072	Windward trail	475 ± 70	13º 19’ 20”	61º 10’ 00”	Heath (1997)
SRR-3963	Larikai sea-cliff	485 ± 40			Robertson (1992)
STV-370	Larikai beach	490 ± 45	13º 20’ 20”	61º 13’ 00”	Heath (1997)
SRR-3970	Roseau River	535 ± 45			Robertson (1992)
841	Wallibou sea-cliff	555 ± 70			Rowley (1978a)
843	Soufrière path (E. 650m)	615 ± 60			Rowley (1978a)
840	Wallibou Dry River	635 ± 65			Rowley (1978a)
SRR-3969	Roseau River	915 ± 45			Robertson (1992)
844	Soufrière path (E. 650m)	1045 ± 70			Rowley (1978a)
SVE-080	Mouth of Waribishy River	1985 ± 40	13º 18’ 50”	61º 07’ 30”	Heath (1997)
STV-348	Waribishy River	2135 ± 40	13º 18’ 40”	61º 07’ 58”	Heath (1997)
STV-104	New Sandy Bay	2360 ± 50	13º 20’ 30”	61º 07’ 20”	Heath (1997)
781	Overland Village	2480 ± 70			Rowley (1978a)

Sample No	Location	Age ± error (yBP)	Latitude	Longitude	Reference
778	Waribishy River	2700 ± 90			Rowley (1978a)
37209	Rabacca Valley	3510 ± 65			Rowley (1978a)
27737	Rabacca Valley	3520 ± 70			Rowley (1978a)
STV-360	Dry Rabacca bed	3550 ± 45	13º 18’ 10”	61º 08’ 50”	Heath (1997)
900	Lower Rabacca	3590 ± 70			Rowley (1978a)
STV-084	Dry Rabacca River	3705 ± 70	13º 18’ 00”	61º 08’ 20”	Heath (1997)
59-1	Lower Rabacca	3890 ± 300			Rowley (1978a)
STV-305a	Rabacca River	3925 ± 45	13º 18’ 01”	61º 07’ 24”	Heath (1997)
845	Rabacca	3960 ± 80			Rowley (1978a)
766	Rabacca Gorge	3980 ± 80			Rowley (1978a)
SRR-3966	Waterloo sea-cliff	4040 ± 45			Robertson (1992)
760	Rabacca	4080 ± 60			Rowley (1978a)
59-2	Rabacca River	4090 ± 50			Rowley (1978a)
STV-305b	Rabacca River	4120 ± 45	13º 18’ 01”	61º 07’ 24”	Heath (1997)
777	Sea-cliff, North Rabacca	4130 ± 160			Rowley (1978a)
846	Rabacca valley	4165 ± 70			Rowley (1978a)
765	Rabacca gorge	4260 ± 120			Rowley (1978a)
764	Rabacca gorge	4325 ± 95			Rowley (1978a)
761	Rabacca valley	4335 ± 95			Rowley (1978a)
SVE 098	Owia	5140 ±55	13º 22’ 30”	61º 08’ 30”	Heath (1997)

Pyroclastic flow deposits in the Wallibou river located on the west flank of the Soufrière Volcano

Pyroclastic flows and surges

Pyroclastic flows and surges have been a common feature of every explosive eruption of the Soufrière Volcano during the Historical Period and future explosive eruptions are likely to generate pyroclastic flows and surges. Pyroclastic flows have tended to follow the river valleys that radiate from the volcanic centre. The mechanism of flow generation has in all cases been due to either one of the following: (a) partial or complete gravitational collapse of an overloaded vertical eruption column (e.g. 1902 eruption) or (b) fluidised overspill of highly gas-charged magma from an open vent (e.g. 1979 eruption). Extension of the flow to the lower flanks of the volcano has been largely a function of the violence of the propelling explosion, the height at which collapse occurred and the morphology of the volcanic cone and the surrounding river valleys. Flows follow paths of least resistance down the volcano’s flanks. In most cases these have been the principal river valleys, especially where their headwaters have cut back to the crater. The impact of flows in the past has been extremely severe, bringing death and destruction to all areas located within their paths.

Mudflows

Mudflows (lahars) have been generated in most explosive eruptions during the Historical Period. As would be expected given the nature of the terrain and the pattern of explosive activity, mudflows have generally followed the same valleys as the pyroclastic flows. The paths of pyroclastic flows can be taken to illustrate the paths of mudflows since they are almost identical. The nature of mudflows has depended largely on the magnitude of the eruption. Given the steep gradient of the volcano and the abundant rainfall expected from the tropical climate, future explosive eruptions are expected to produce mudflows.

Lava flows and domes

Soufrière lava flows comprise highly viscous ‘aa’ and blocky type lavas that have not surmounted the crater walls during the historical past. Stratigraphic evidence shows that prior to this period extensive lava flows had reached the lower flanks of the volcano. These flows were most likely formed during the Pre-Caldera/Pre-Somma phase of the volcano’s evolution when the crater may have been breached in some sectors.

Assuming no marked changes in the dimensions of the present crater, it is very unlikely that effusion of magma from the vent would produce lava flows *senso strictu* or domes that surmount

Lavas from prehistoric eruptions (Crater Lavas formation) exposed on the southeast crater rim of the Soufrière Volcano the crater rim. Such effusive activity is more likely to produce basaltic domes that would be confined to the crater floor. Such domes constitute a hazard since they may create conditions that favour explosive eruptions. They act as plugs that facilitate the build-up of pressures in a subsurface conduit. This pressure build-up may eventually cause explosive destruction of the dome.

Should the crater walls be breached in any manner (e.g. by a vertical blast causing collapse of a section of the crater wall), the potential for lava flows to extend down the volcano sides becomes very high. In addition, flank eruptions may occur providing a direct outlet to the surface and thus bypassing the crater walls. Despite the generally high gradient of the volcano flanks, lava flows would not be expected to pose any significant threat to surrounding areas since their high viscosity and yield strength should prevent them flowing very far.

Volcanic gases

There have been no recorded incidences of volcanic gases causing death or destruction during historical eruptions of the Soufrière. However, the impact of gases in the past has been so closely associated with other hazardous phenomena that no distinction could be made with any certainty.

Earthquakes

Future eruptions may be expected to have associated earthquakes, the effect of which is likely to be small to moderate, both in terms of hazardous impact and emergency planning.

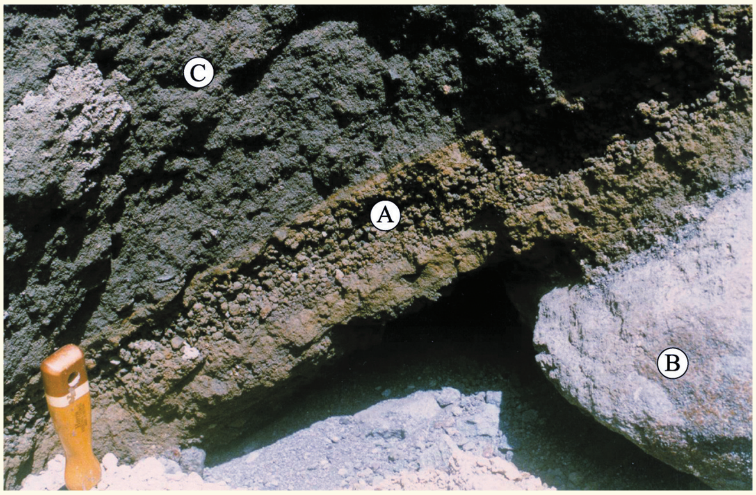
Atmospheric phenomena

Electrical discharges were associated with the 1902 and 1979 eruptions. In both cases the discharges were restricted to areas in the immediate vicinity of the volcano and caused problems to monitoring equipment. In 1902, lightning strikes are believed to have been responsible for some deaths in the villages of Owia and Fancy.

Ash plume from the April 13, 1979 eruption of the Soufrière Volcano

Laterally directed blasts and structural collapses

There is no evidence of directed blasts during historical eruptions of the Soufrière Volcano. Blasts may have occurred in the pre-historic period, particularly during the Transitional to Later Explosive phase of the volcano's evolution. Structural collapse may have occurred at least once during the pre-historic period at the volcano. Collapse is believed to have involved movement of the southern portion of the volcano towards the southeast, with displacement occurring along the Baleine scarp (Sigurdsson 1981). Such collapses could produced debris avalanches that may be triggered by intrusion of new magma, phreatic explosions or earthquakes. Catastrophic edifice failure could, therefore, occur again at the volcano but is considered to be a low frequency event.



Accretionary lapilli beds of the Soufrière Volcano (A) lying at the contact between fluvial (B) and pyroclastic flow (C) deposits

Phreatic explosions

Periods of phreatic activity have been associated with explosive eruptions of the Soufrière Volcano in the past, whenever there was a pre-existing crater lake. The early phases of the 1812, 1902 and 1979 eruptions involved violent steam emissions from the volcanic centre. The impact of these was restricted to the vicinity of the crater with plant and animal life on the crater floor, walls and rim being destroyed.

Landslides

Landslides are a common feature in both young and old tephra deposits on St Vincent. Movement has occurred most often in the thick Pleistocene tephra deposits that border the major roads along the east coast and has been largely one of four types: rockslides and rockfalls, debris slides and debris flows (DeGraff 1988), with the latter type being the most common. Any future volcanic activity generating large amounts of ash would be expected to have associated landslides.

Future Activity

Future volcanic activity at the Soufrière Volcano is likely to be similar to activity exhibited in the past. Two scenarios have been defined and are described below. The boundaries of hazard zones have been determined by consideration of the following factors:

1. Past incidences of hazardous volcanic events;

2. The areas of maximum projected extent of the most damaging events such as pyroclastic flows, mudflows, ballistic projectiles and heavy ash falls;

Emergence of a lava dome during the 1971-72 effusive eruption of the Soufrière Volcano (January 1971)

3. Maximum extent of hazardous events based on past experience at similar volcanoes;

4. Maximum extent of hazardous volcanic events based on theoretical considerations of mass discharge rate of magma, wind direction, and morphology of the volcano;

5. The likelihood of specific hazardous events affecting areas during eruptions expected in the future.

Scenario 1: Short-term or most-likely scenario

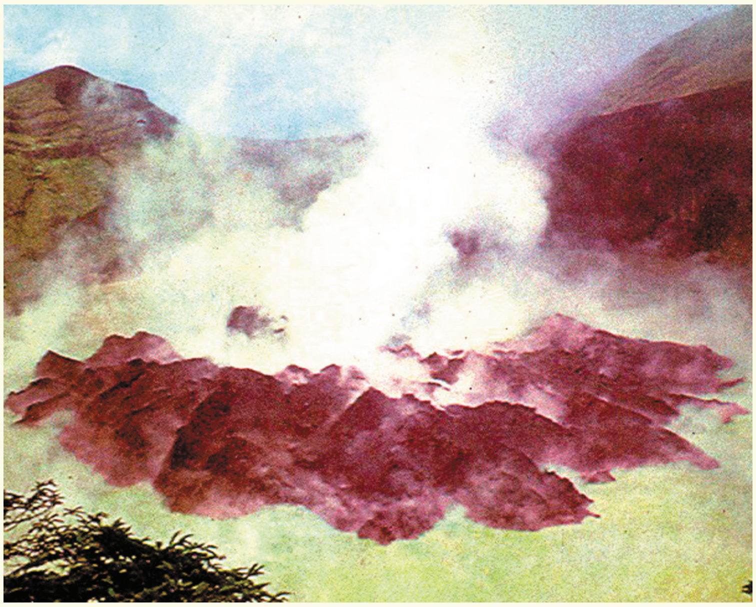
In the short-term (i.e. <100 years), the volcanic hazard at the volcano is expected to be quite similar to that experienced in the historical past (i.e. the past 250 years). The volcano would become hazardous during periods of eruptive activity, remaining a threat for the intervening periods that must be catered for in national development plans. Activity in the short term could be either explosive or effusive or both. Both events may be separated in time but can be regarded as part of a two-phase pattern of eruption. The scale of the explosive phase is expected to range from that of a 1979-type event to that of a 1902-type event. The effusive phase is expected to be quite similar to the 1971-72 eruption. The specific characteristics of these phases, as well as the hazards they are expected to pose, are outlined below.

Scenario 1a: Effusive or dome forming eruption

Eruption Mechanism, Magnitude and Intensity

This phase involves the relatively quiet emission of viscous basaltic andesite magma from the central vent. The event may be aseismic with premonitory activity limited to changes in water temperature (if a lake is present), increased fumarolic activity or changes in ground deformation. Based on activity experienced during the historical past, the extrusion rate may vary between 10^5m^3 and 10^6m^3 per day. The eruption duration may last from a few hours to several months. Given the present configuration of the crater and the viscosity of the magma, effusive eruptions would result in the formation of a lava dome on the crater floor.

This type of activity is exemplified by the 1971-72 eruption as well as the latter phase of the 1979 event. Furthermore, the presence of lava flow deposits on the volcano points to periods of effusive activity in the early evolution of the volcano which produced lava flows rather than domes.



Lava dome formed during the 1971-72 effusive dome-building eruption of the Soufrière Volcano (February 1972)

Hazardous events

The hazard associated with the effusive phase will be largely confined to the crater and its immediate surroundings. Destruction of plant and animal life is expected in the crater area. The extent of destruction increases with the presence of a crater lake, but the impact on the human population will be more psychological than physical. The potential exists that sightseers may put themselves at risk as well as obstruct volcano-monitoring activities. Agitation of the local population in the communities located on the volcano may cause premature evacuation resulting in economic damage.

Effusive emissions may develop into lava flows in the event of breaching of the crater walls due to sector collapse or a directed blast. The length and direction of such flows will depend to a large extent on the location of the breach as well as the effusion rate of the magma (Walker 1973). It is unlikely that this event would occur during the short term. Even with development of lava flows the hazard posed will be still limited to the natural environment since there would be sufficient time for evacuation of people and property from potential danger areas.

The summit crater of the Soufrière Volcano showing the crater lake and dome extruded during the 1971-72 eruption (June 1973)

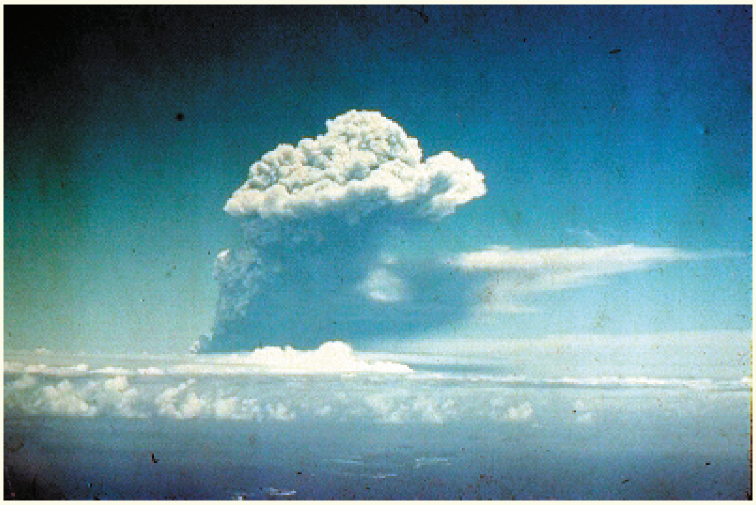
Scenario 1b: Explosive eruption

Eruption Mechanism, Magnitude and Intensity

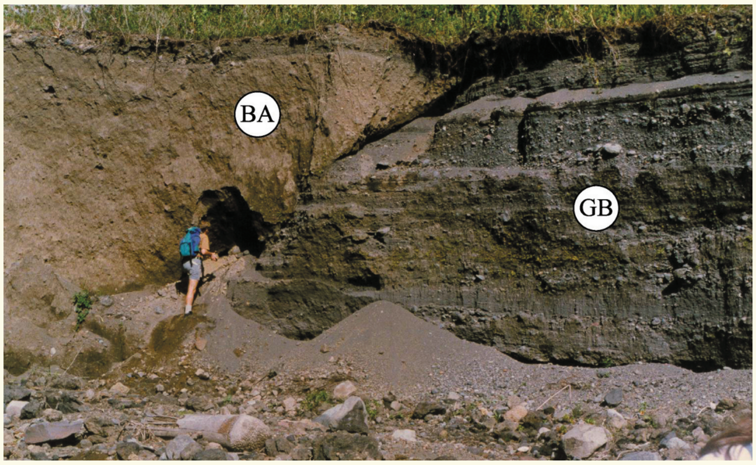
This type of activity is exemplified by the 1902 eruption of the volcano as well as by all of the historical explosive eruptions of the Soufrière. Activity is expected to involve discrete Vulcanian to phreatomagmatic discharges from the volcanic centre. Explosive activity will usually follow an effusive dome building phase when the vent becomes plugged, allowing the build-up of pressure in a shallow magma chamber. Fragmentation and explosive eruption of material onto the surface may result from the combined effects of volatile exsolution and the interaction of hot rising magma with groundwater and/or lake water.

The magmatic composition is likely to be similar to material erupted in the past (i.e. 50-57% SiO_2) with similar mass discharge rates (i.e. 4-6 x 10^7kg/s). The eruption may last from a few days to several months with explosive discharges lasting for several minutes during the first few days of the eruption. Initially explosions may last two to three hours, generating plumes up to 18 km and higher.

Several types of premonitory signs are to be expected and will vary depending on the conditions in the crater at the time of eruption. Changes in the incidence of earthquake activity are expected with an increase in the number of shallow earthquakes beneath the crater. Increased fumarolic activity, inflation of the volcano and a change in the water level contained in any lakes present are also likely (water level rises initially due to extrusion of lava then falls due to increased evaporation (Shepherd et al. 1979).



Ash plume from the 1979 eruption of the Soufrière Volcano



Scoria and ash flow deposits (BA) from the Soufrière Volcano overlying gravel beds (GB) in the Rabacca River

Grey pyroclastic flow deposit from the 1979 explosive eruption resting on fluvial deposits in the Larikai river valley

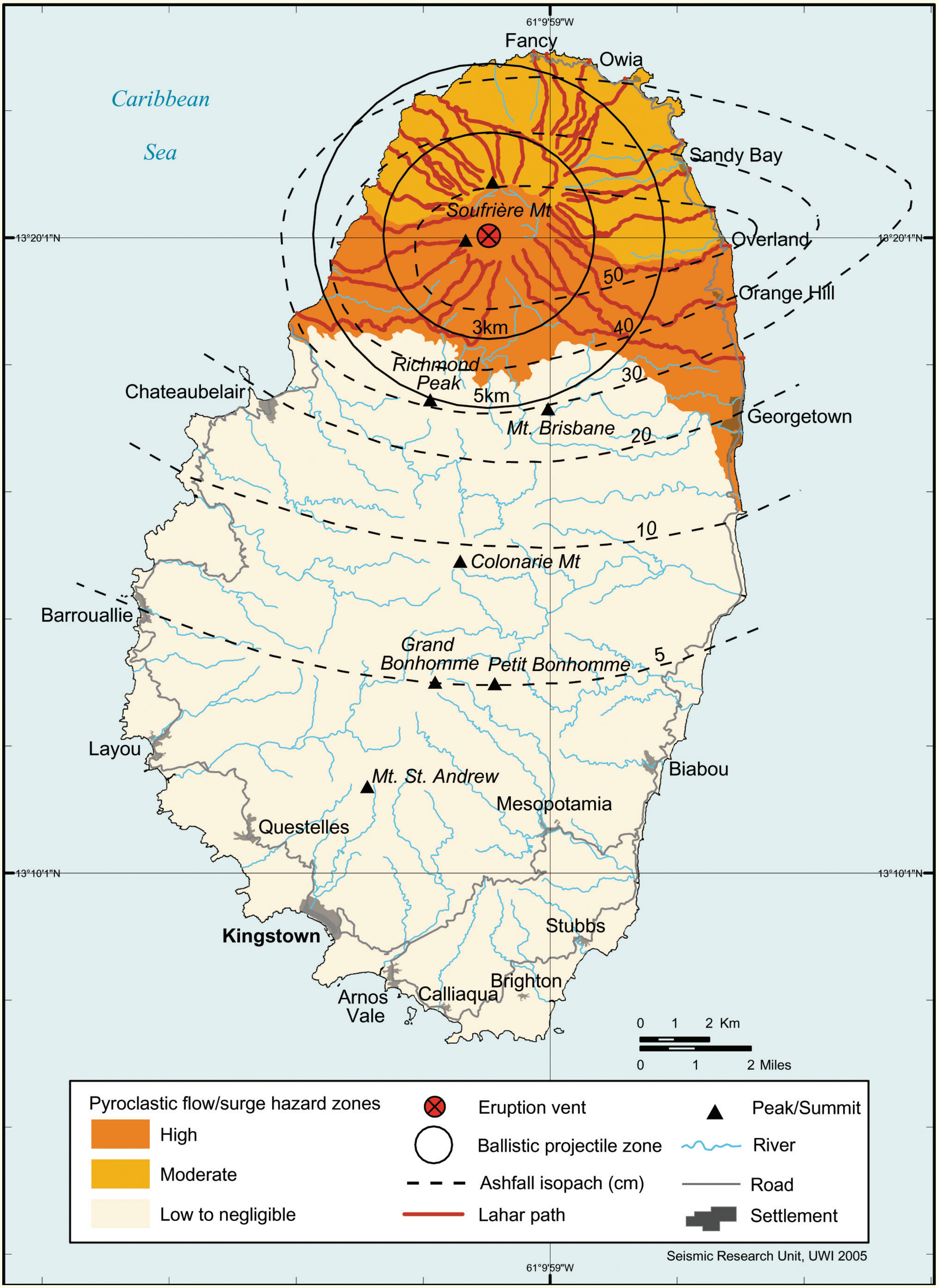
Hazardous events

The explosive phase is expected to be much more disruptive than the effusive phase. Pyroclastic flows and surges, mudflows, ash falls and ballistic projectiles will cause near total destruction of plant and animal life and infrastructure in areas north of the Richmond-Mount Brisbane mountain barrier (see hazard map). Some damage may occur due to volcanic tremors, lightning flashes, volcanic gases and secondary landslides.

Pyroclastic flows in future eruptions will be generated either by partial or complete collapse of eruption columns or by the boiling over of dense gas-charged ejecta from the crater rim. Although dome growth has been associated with explosive eruptions in the past, it has always occurred at the end of an explosive phase. Experience from past eruptions of the volcano suggests it is unlikely that pyroclastic flows will develop whilst a dome is actively growing in the crater. However, based on the evidence of past eruptions at similar volcanoes (e.g. Mt Pelée, 1902), the possibility still exists that flows could develop from the collapse of domes that rise above the crater rim.

Fluidised overspill of hot, fragmented ejecta from the crater rim may be the dominant method of pyroclastic flow formation during the early stages of an explosive sequence when large eruption plumes have not yet developed. Such flows occurred during the 1979 eruption (Shepherd et al. 1979) and will most likely follow paths of least resistance down river valleys that extend from minor depressions in the otherwise continuous crater rim. Flows will initially go down the Rabacca river valley to the east, and the Wallibou and Larikai river valleys to the west of the volcano. Eruptions of the magnitude of 1902 are likely to generate additional flows down river valleys leading to Baleine Bay and Morne Ronde on the western side of the volcano. These flows, due largely to partial collapse of an eruption column, may also advance down the Tourama and Waribishy river valleys on the east. With increasing magnitude, collapse of large dense columns (>>20 km) may lead to flows that surmount the Somma Ridge and follow the Fancy, Owia, Agrabay, Karo and Cayo rivers to the north and northeast coast.

Volcanic hazard map or Scenario 1: Eruption from the Soufrière Volcano involving both effusive dome-forming and explosive activity



Pyroclastic surges will tend to affect areas in all azimuths from the crater since they are less constrained by topography. Those which flow towards the northeast are likely to be particularly destructive due to the relative proximity of settlements on the lower flanks of the steep northern slopes. Eruptions of 1979 magnitude may generate surge deposits ≥0.5 m thick within 2 km of the crater rim in all directions (Brazier et al. 1982). With larger eruptions, the area affected may increase to a possible maximum of 5 km (Anderson and Flett 1903). Obstacles may cause bending of the flow resulting in flow directions opposed to the main path. Villages and communities located behind topographic barriers are therefore not necessarily protected.

Mudflow deposit in the Wallibou river, possibly from the 1902 eruption of the Soufrière Volcano

Mudflows (lahars) can be generated at any point on the volcano's flanks since the radial drainage pattern provides ample depressions to guide mobilised tephra. The likelihood of flows developing early in an eruption sequence is greatly increased if there is a crater lake to be discharged. Abundant tropical rainfall provides adequate moisture for the development of mudflows later in the eruption.

Discharge of mudflows along the Rabacca and Wallibou river valleys is of particular importance in the evaluation of hazards. The accumulation of debris in these valleys and destruction of the coastal road will effectively cut off villages to the north and sever links with the rest of the island.

Mudflows may continue to present a hazard for some time after an eruption has ceased. Secondary mudflows are expected to occur as rainfall washes tephra from the upper slopes of the volcano. Mudflows may reach further downslope than pyroclastic flows, adversely affecting a larger area. During the 1902 eruption, secondary mudflows overturned several small houses at Georgetown, approximately 7 km from the volcano summit (Anderson and Flett 1903).

The impact of ash fall on crops in northern St. Vincent - the explosive phase of the 1979 volcanic eruption

The impact of ash fall, volcanic gases and lightning strikes will depend largely on atmospheric conditions in the area at the time of the eruption. The explosivity of the eruption and the force with which material is ejected will also contribute to the scale of these phenomena. The Easterly Trades are the dominant surface winds and will affect plumes located below 5 km. Above 5 to 8 km height, the Easterly Trade winds are replaced by the westerlies which are in turn replaced by the easterlies at the tropopause which can vary between 16 and 18 km (Sigurdsson and Carey 1981). At low altitudes the Easterly Trades will cause dispersal of pyroclasts towards the west of the island. The effect of the higher-level westerlies (>10 km) will be more marked since most eruption columns are likely to attain this altitude. Fine ash may be transported eastwards across the Atlantic to Africa in 3 to 5 days (Barr and Heffter 1982; McCormick et al. 1982), and ash plumes from the 1902 eruption were carried over 1200 km east into the Atlantic (Sigurdsson and Carey 1981). If the ash plume gets above the tropopause and into the stratosphere the wind direction is again east to west and ash will be deposited to the west of the volcano. Regionally the effect will be most marked in an area extending from 350 km east-west, and 150 km north-south of the volcano.

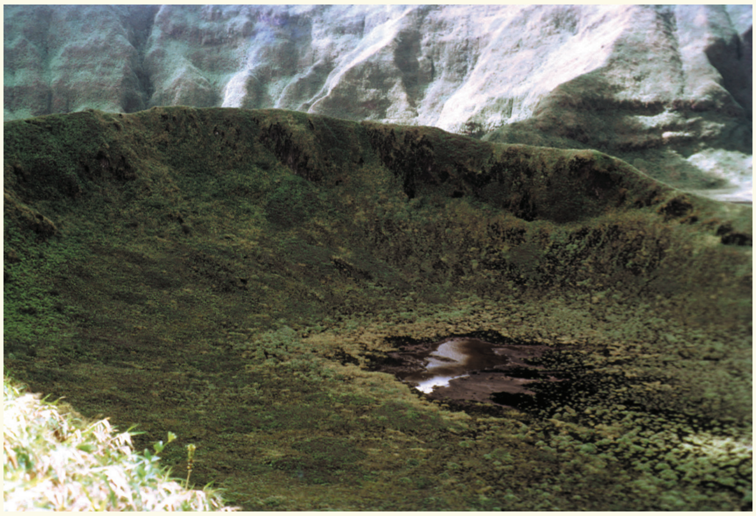
Locally a continuous ash blanket may extend up to 9 km in all directions. Within 2.5 km of the vent, in eruptions of the scale of 1979, up to 45 cm may accumulate (Brazier et al. 1982). This may decrease to 45 mm up to 4 km from the crater rim. Eruptions with greater magnitude will cause the ash deposited from an entire eruption to reach up to 6 mm in Kingstown (Anderson and Flett 1903), 21 km from the volcanic centre. The effects of ash falls during an eruption will vary with distance from the crater and with local variation in the wind speed and direction. Changes in wind direction may cause areas previously unaffected to experience heavy ash falls for brief periods. The pattern of ash fall produced during the 1979 eruption has been scaled upwards to a 1902-magnitude eruption to obtain isopachs for this eruption scenario.

The range and effect of projectiles will be limited by the velocity of their emission from the crater. Although 21 kg bombs reached up to 6 km from the summit during the 1902 eruption (Blong 1984), the area of maximum impact is not expected to extend beyond 5 km from the volcano. Damage will be minimal in areas far away from the summit since most of the energy of the bombs will be expended in movement through the atmosphere.

The size of the area affected by volcanic gases will be determined by the horizontal velocity of eruption clouds such that the greater the velocity the greater the area affected. These velocities may vary from 36 to 60 km/hr (Brazier et al. 1982), depending on the level of atmospheric injection. Rapid rain flushing within proximal areas is liable to limit the impact of gases to areas close to the volcanic centre. The maximum effect will probably be on animals abandoned by the evacuating population.

Lightning strikes will be similarly restricted to high areas close to the volcano, possibly within 7 km (Anderson and Flett 1903). The destructive influence will be minimal since communications and power transmission lines are often sited on lower ground.

During the 1902 eruption, volcanic earthquakes caused minor damage to buildings in Georgetown (Anderson and Flett 1903). Local earthquakes and volcanic tremors are therefore expected to have maximum effect within 7 km radius of the crater rim. Damage is likely to be minimal and will be confined in the worst cases to cracks in masonry and breakage of glass panes. The effect of volcanic earthquakes on the local population will be psychological rather than physical, with anxiety and emotional tension increasing in villages surrounding the volcano.



Explosion crater (~300x600m) created by the 1812 explosive eruption of the Soufrière Volcano

PROBABILITY OF ERUPTION

During the historical period, the volcano has erupted at least twice per century in the two-phase manner described above. Although this is an insufficient time span for an accurate estimate of eruption probability, it still gives some basis upon which to assess the likelihood of future activity. The available record suggests that in the short-term the volcano may be expected to erupt in the manner described above at least once every 100 years. On such occasions, the population will be exposed to some or all of the hazards described above. Activity before the historical period seems to have been of a generally similar nature although its frequency is not accurately known.

Scenario 2: Long-term or worse case scenario

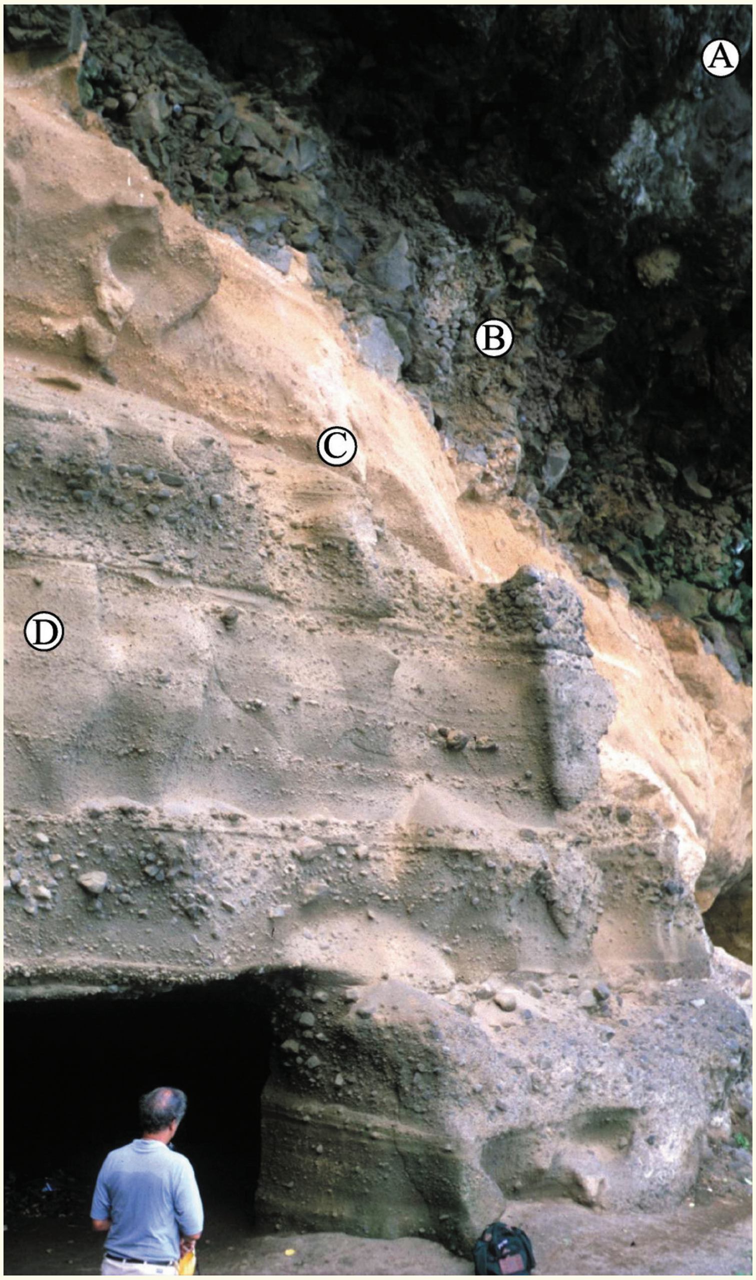
In the longer term, allowances must be made for the possibility of large scale explosive eruption generating sustained ash plumes and thick airfall deposits. Although there are no historical records of such activity, the presence of thick late Pleistocene ash fall deposits throughout St. Vincent as well as thick scoriaceous ash fall on the lower flanks of the volcano demonstrates that the Soufrière has the capacity for events of this kind.

ERUPTION MECHANISM, MAGNITUDE AND INTENSITY

The eruption would be characterised by very high mass discharge rates and sustained explosions from the crater generating columns extending well into the troposphere (>10 km) with the possibility of stratospheric injection (>20 km). Eruptions could begin with explosive vulcanian discharges resulting in the emptying of the vent and continuing until the upper magma chamber has been emptied. Involvement of more deep-seated magma might eventually lead to a period of sustained ash venting alternating with strombolian discharges.

HAZARDOUS EVENTS

Hazardous events resulting from such an eruption would be similar to those anticipated for the explosive phase of the most likely scenario (i.e. scenario 1b). However, the scale and extent of impact will be several orders of magnitude higher. Pyroclastic flows will be expected to affect areas north and northeast of the volcano with much greater regularity. The area of total devastation is expected to extend from Colonarie in the east in a semicircle to Petit Bordel in the west. If the eruption lasts for sufficient time the entire island may become covered in ash falls several centimetres thick.



Basaltic lava (A), autobreccia (B), alluvial (C) and yellow tephra (D) deposits at Black Point on the east coast of St. Vincent

Technician from the Soufrière Monitoring Unit assisting with GPS measurements at the summit of the Soufrière Volcano

PROBABILITY OF ERUPTION

Current records of the volcano's history suggest that catastrophic events such as the one described above may be expected to occur once every 4000 years.

Integrated Volcanic Hazard Zones

A summation of the information outlined in the foregoing sections allows the demarcation of a number of volcanic hazard zones. These provide a simple map that can be used in designing an emergency plan for effective management of the Soufrière Volcano. The zones are based on the projected effect of explosive activity from scenario 1b, although some consideration is also given to activity in the long term outlined in scenario 2. Since the effects of effusive eruptions (described in scenario 1a) are quite limited, these have had little impact on the determination of hazard zones.

Hazard Zone 1 (Red Zone):

This includes all areas expected to experience maximum damage in the short term, and is the zone where all hazardous events have their greatest influence. It is defined by the zone of expected total destruction from pyroclastic flows, surges and mudflows and by the zone of maximum expected damage from all projectiles. Whatever the scale of the eruption, all areas in this zone are likely to be covered by >30 cm of ash. During the course of an eruption this zone would be unsuitable for human habitation. Eruptions of the type expected in the long term as outlined in scenario 2 will cause total devastation in the area.

Hazard Zone 2 (Orange Zone):

These areas will be affected in a similar manner as Zone 1 during larger scale versions of scenario 1-type eruptions. The division between Zone 1 and Zone 2 is based on the thickness of ash expected in Zone 2 (10-30 cm) and the experience of past eruptions which indicate that the latter areas are somewhat sheltered by topographic highs from the direct impact of pyroclastic flows, mudflows and ballistic projectiles. A distinction is therefore made between areas that are certain to be destroyed by mudflows, pyroclastic flows, surges and ballistic projectiles (Zone 1), and those that will only be destroyed during large scale eruptions (Zone 2). The potential for damage may be similar, but the greater distance of villages from the volcanic centre would reduce the likely impact. Eruptions of the type expected in the long term as outlined in Scenario 2 will cause total devastation in the area of Zone 2.

Hazard Zone 3 (Yellow Zone):

This zone will be free from the effects of flows and surges but will be affected by thick ash falls, minor earthquakes and lightning strikes. The 10 cm ash isopach for the 1902 eruption is taken as the cut-off point between this zone and integrated hazard Zone 2. The area of Zone 3 will experience less physical damage than Zones 1 and 2. Damage to flora will probably be restricted to the foliage with root systems left intact. Despite relatively minor impact on the physical infrastructure, hazardous events, nevertheless, may still cause major problems for the human population. The area will be included within the zone of total devastation during eruptions expected in the long term (scenario 2).

Hazard Zone 4 (Green Zone):

This embraces an area expected to experience relatively minor impact from eruptions. The 5 cm ash isopach is taken as the inner boundary for this zone. Crop damage and disruption of water supply due to ash fall will be the main effect but other physical damage will be minimal. However, in areas close to the boundary with zone 3 the physical signs of volcanic activity may cause some anxiety to the local population.

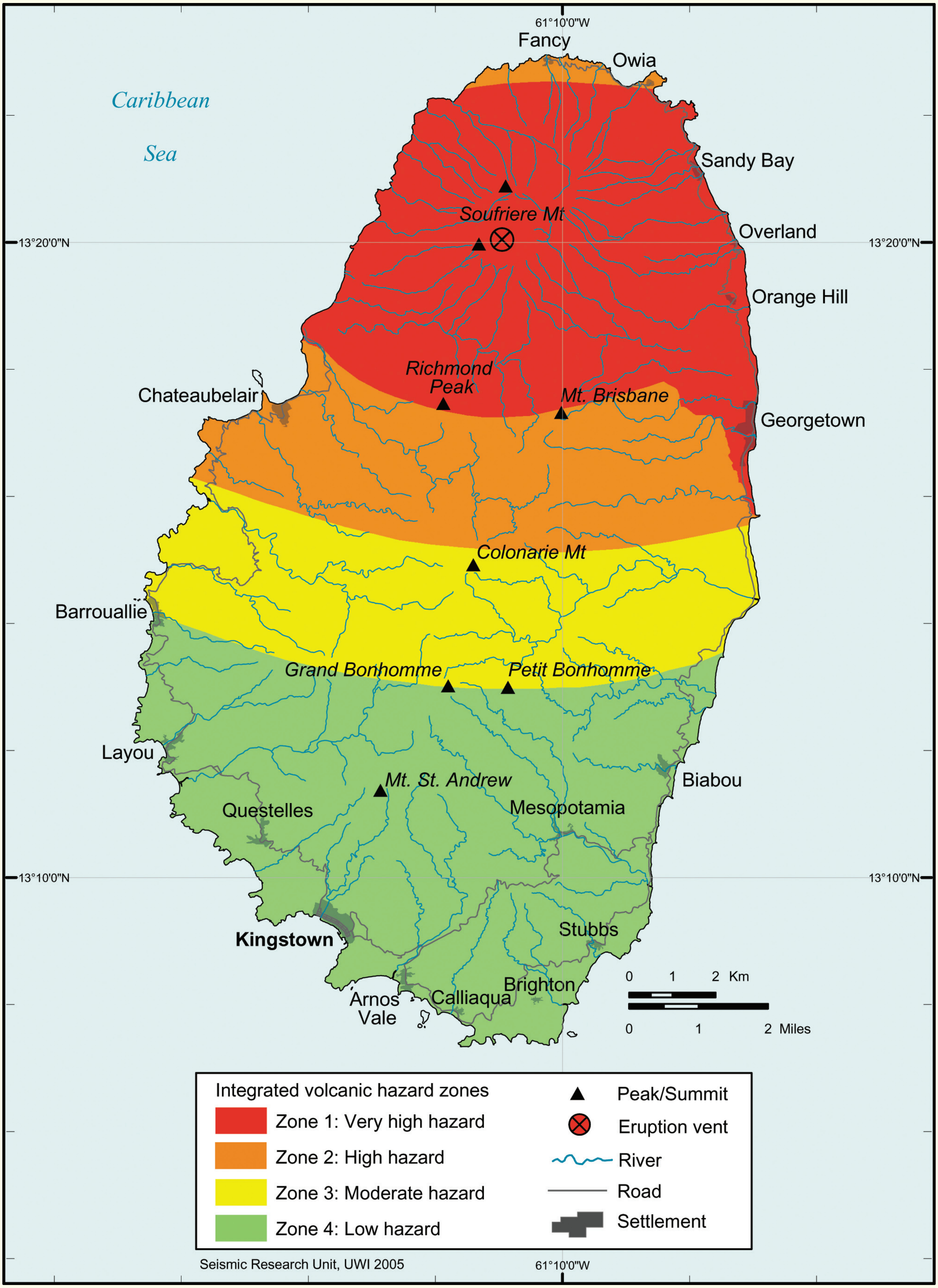
Zone 4 will be relatively safe from hazardous events. In areas located in the south of this zone infrequent heavy ash fall may occur due to exceptionally strong local winds. In these areas the impact of the eruption will be felt only in terms of the additional burden placed on resources by people evacuated from higher risk zones further north. In the long term (scenario 2), these areas will be more strongly affected by ash fall. They may remain largely unaffected during the first few months of activity but will become increasingly impacted with time, due to the accumulation of ash fall.

Secondary school students learning about volcanoes at a national exhibition in St. Vincent

Conclusion

The Soufrière Volcano is the only live volcano on the island of St. Vincent. It has the potential to undergo volcanic activity in the future. Given the present configuration of the summit deposits, the most likely type of eruptive activity would be explosive possibly followed by a period of quiet, effusive dome growth. Such activity is likely to be preceded by increased local seismicity and ground deformation which may last for a few weeks to months and even years. Activity at the volcano is therefore likely to follow the pattern established by historical eruptions such as the 1902 and 1979 eruptions.

Integrated volcanic hazard zones for Scenario 1: Eruption from the Soufrière Volcano involving both effusive dome-forming and explosive activity



There is sufficient information available in this chapter and in previous publications (Robertson 1992; 1995) to enable the relevant authorities to prepare effective plans to cater for the impact of future eruptions. Continued monitoring is essential as is ongoing public education. The people of St. Vincent and the Grenadines must cope with the present and future impacts of the volcano on their lives. These impacts can be significantly reduced with proper planning. It is therefore sensible that the time between now and the next period of heightened activity be used wisely to put contingency measures in place and to educate the public.

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