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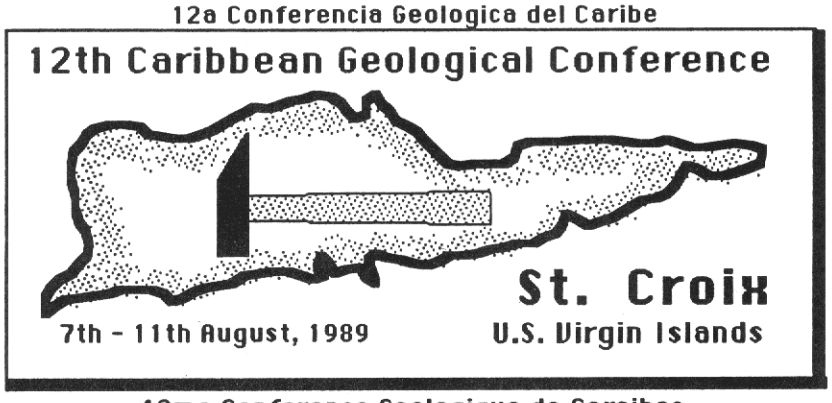

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CHARACTERISTICS OF VOLCANIC CENTERS FROM THE LESSER ANTILLES

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ABSTRACT

The active volcanoes of the Lesser Antilles are characterized both by effusive eruptions producing lava flows and domes, and by explosive eruptions producing various types of pyroclastic deposits. Five major styles of explosive eruptions have been distinguished, these styles and their products are:

Pelean - block and ash flows, dense andesite surges, ash and dust falls;
St. Vincent - scoria and ash flows, scoriaceous surges, lapilli-, and ash-falls;
Plinian - pumice and ash flows; ash hurricanes, pumiceous surges, lapilli-, and ash-falls;
Asama - semi-vesicular block and ash flows;
Phreatomagmatic/Phreatic - block flows, base surges, ash falls.

Based on their eruptive products the volcanoes of the Lesser Antilles can be grouped into five types:

a) Centers composed almost entirely of pyroclastic deposits - Mt. Pelée (Martinique), the Quill (St. Eustatius);
b) Centers composed of dome clusters and associated aprons of block and ash flow deposits (produced by Pelean eruptions) - Saba island, Soufriere Hills (Montserrat);
c) Centers with numerous dacitic pumice and ash flows - centers on Dominica, south-central St. Lucia;
d) Centers with significant lava flows associated with pyroclastic deposits of various types - the Peak (Nevis), Soufriere (St. Vincent);
e) Centers composed of basic and intermediate lava flows and associated fall deposits- South Soufriere Hills (Montserrat);

The pyroclastic deposits from all volcanic centers are often reworked soon after eruption by fluviatile processes so that stratigraphic sections commonly show intercalations of pyroclastic deposits with their epiclastic derivatives. Eruptions from Lesser Antillean volcanoes also produce submarine deposits such as subaqueous ash falls, subaqueous volcaniclastic flows and ash turbidites.

INTRODUCTION

The Lesser Antilles island arc extends from the Anegada Passage, east of the Virgin Islands, to just north of the South American continent. The active arc (Fig.1) includes, from north to south, the islands of Saba, St. Eustatius, St. Kitts, Nevis, Redonda, Montserrat, Basse Terre of Guadeloupe, Dominica, Martinique, St. Lucia, St. Vincent, the Grenadines and Grenada, as well as a number of submarine centers, including the active volcano of Kick'em Jenny (Robson and Tomblin, 1966; Bouysse et al, 1980; Roobol and Smith, 1989). Eruptions from the subaerial volcanoes are both effusive and explosive, with the latter representing the dominant eruptive style (Roobol and Smith, 1989).

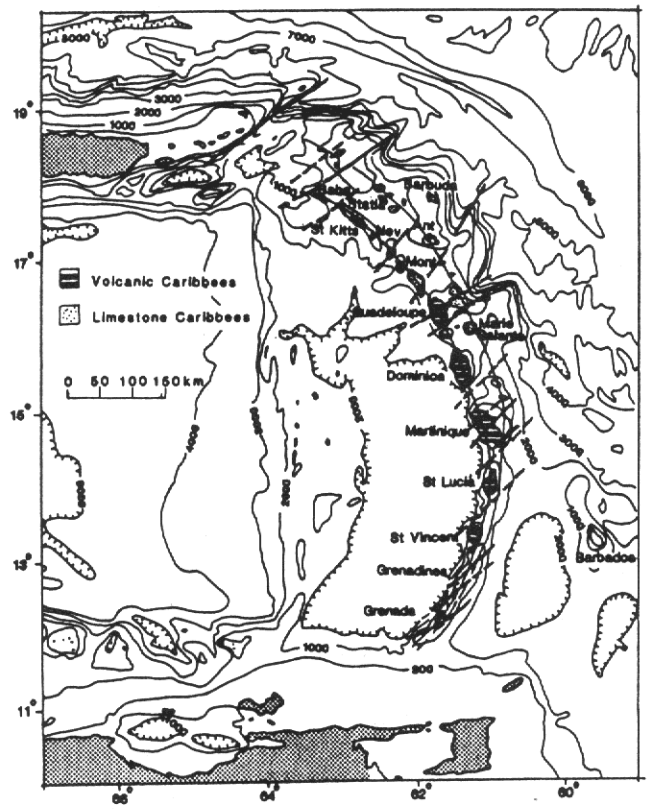

Figure 1. Map of the Eastern Caribbean and Lesser Antilles island arcs. Isobaths in meters; proposed transverse faults after Westercamp (1979). Mont - Montserrat; Ant - Antigua; Nev - Nevis (After Smith and Roobol, in press.)

ERUPTIVE STYLES

Effusive eruptions have produced both lava flows and domes and range in composition from basalt to rhyolite. Lava flows are usually basalt or andesite in composition and have been produced by both central and flank eruptions. Many flows exhibit a massive or columnar jointed core with a blocky or rubbly surface (when preserved) (Fig.2). Most have high-aspect ratios, having flowed usually only a few kilometers from their source. Aspect ratio is V/H where V is the average thickness of the flow or deposit in meters and H is the diameter of a circle covering the same areal extent as the flow or deposit in kilometers (Walker, 1973, 1983). Domes have been extruded from both central vents, for example, the 1902-05 dome of Mt. Pelée, Martinique (LaCroix, 1904), and from parasitic vents, for example,Great Hill, Saba, (Westermann and Kiel 1961), and are usually andesitic or dacitic in composition. All historic domes are covered by a carapace of blocks: these are often lacking on the older domes because of erosion. A section through The Great Hill dome on Saba is shown in Figure 3. This dome is cut by a number of fractures

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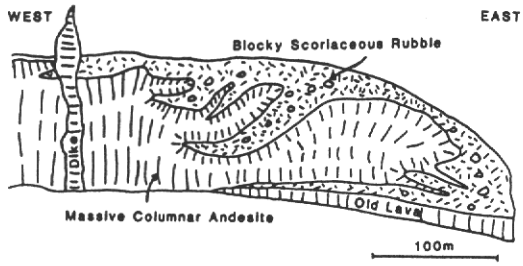

Figure 2. Section through a pre-historic lava flow exposed in the northern crater wall of Soufriere volcano, St. Vincent (After Sigurdsson, 1981).

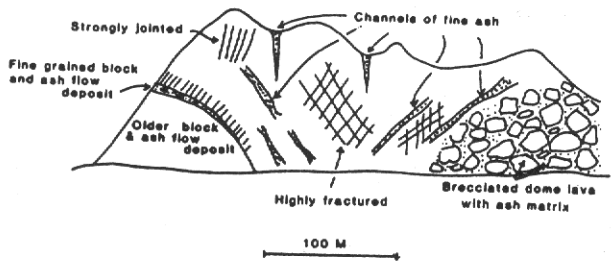

Figure 3. Sketch of a section through Great Hill dome, Saba.

which are filled with fine ash and has a breccia-like outer margin on one side in which blocks of dome lava are enclosed in an ash matrix.

Explosive eruptions have produced various types of pyroclastic deposits including flow, surge and fall. Most of the pyroclastic flow deposits from Lesser Antillean volcanoes are of high - aspect ratio type and form valley infills, although some low-aspect ratio deposits, eg ash hurricanes, do occur (Smith & Roobol, in press). Pyroclastic surges may occur either associated with pyroclastic flows (ground surges and ash-cloud surges), or as independently derived low density flows (base surges, groundsurges). Various mechanisms proposed for the production of pyroclastic flows and surges are shown in Figure 4. Fall deposits from eruptions of Lesser Antillean volcanoes range from coarse Plinian lapilli deposits to fine ash and dust deposits characteristic of Pelean and phreatic or phreatomagmatic eruptions. The distribution pattern of fall deposits depends on the interaction of the height of the eruption column and the velocity and direction of the wind at various heights in the atmosphere (Figure 5). For the Lesser Antilles, which are located in the belt of the Trade Winds, relatively low eruption columns generate deposits elongated towards the west (Fig. 6a). In contrast eruption columns that reach the upper troposphere produce deposits that have a distribution pattern to the east or southeast (Figure 6b).

Five major styles of explosive activity have been identified for the volcanoes of the Lesser Antilles. Each style has produced a variety of distinct deposits (Table 1). Pelean-style eruptions (LaCroix, 1904) are characterized by the growth of a dome throughout the eruption. Partial or complete destruction of this dome by explosions produces the large angular blocks which give the pyroclastic flow deposits generated by these eruptions their characteristic appearance - block and ash flow deposits (Fig.7). Most Pelean- style eruptions tend to affect only a limited sector of the volcano's flanks (Fig. 8) (Westercamp and Traineau, 1983; Roobol and Smith, 1975; Smith and Roobol, in press). St. Vincent- and

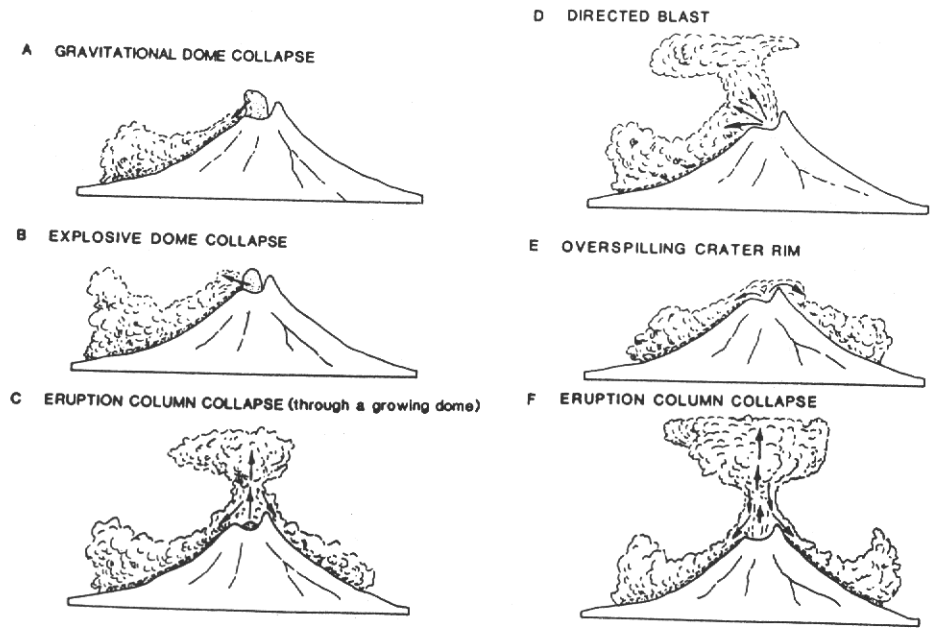

Figure 4. Diagram showing the different mechanisms proposed for the generation of pyroclastic flows (After Smith and Roobol, in press).

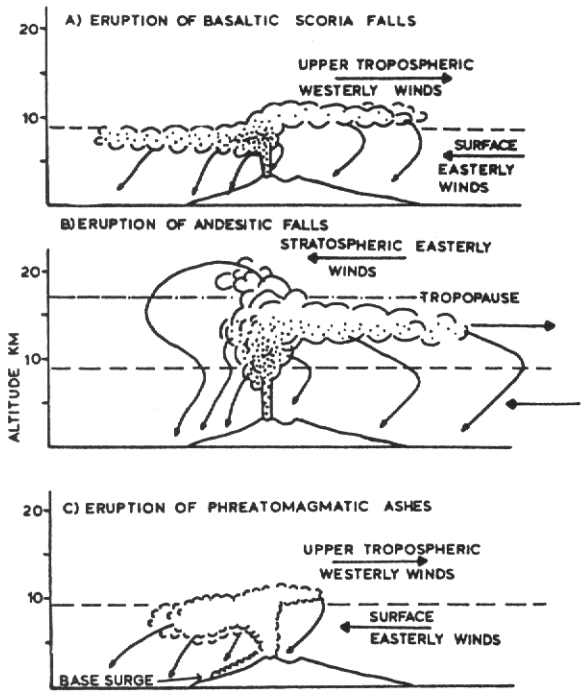

Figure 5. Schematic diagrams showing the effects of a layered atmospheric system and eruptive column heights on the dispersal of airfall ejecta from the Lesser Antilles. The heights given, correspond to data from today's wind system in the vicinity of St. Kitts where the lower Trospospheric easterlies are confined to altitudes of 5-9 km depending on the season. The tropopause is shown at about 17 km. Trajectories are schematic transport paths of airfall ejecta (After Roobol et al., 1985).

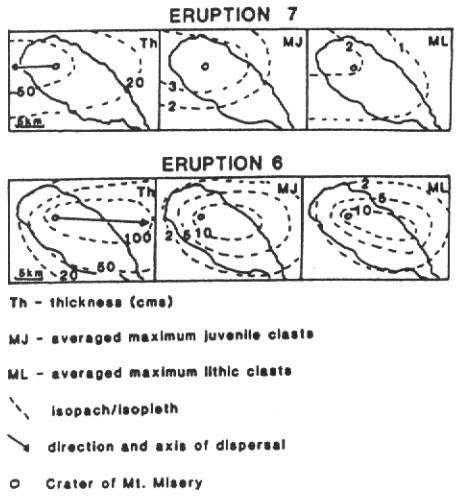

Figure 6. Dispersal maps for fall deposits for the Mansion Series, St. Kitts, A) Basaltic scoria fall deposit of eruption 7 (Unit B, Black Cinders) B) Andesite fall deposits of eruption 6 (Unit C, Upper Green Lapilli) (After Roobol et al., 1985)

Table I . Deposits produced by the Eruptive Styles Characteristic of Lesser Antillean Volcanoes

Eruptive Style	Deposits
PELEAN	Block and ash flow (high aspect ratio): Block and ash flow (low aspect ratio): Dense andesite surge; ash and dust falls
ST. VINCENT	Scoria and ash flow (high aspect ratio): scoriceous surge; lapilli-and ash-falls
PLINIAN	Pumice and ash flow (high aspect ratio): ash hurricanes (low aspect ratio): lapilli- and ash-fall
ASAMA	Semi-vesicular block and ash flow (high aspect ratio)
PHREATIC/PHREATOMAGMATIC	Block flow; base surge; lapilli-ash and dust falls

Plinian- style eruptions both occur from open craters and their pyroclastic flows are generated by eruption column collapse (Fig. 4). Pyroclastic flows from both eruptive styles can affect all flanks of a volcano, with coarse high - aspect ratio flow deposits occupying the valleys, and, in the case of Plinian eruptions, low- aspect ratio ash hurricane deposits extending out to tens of kilometers from the central vent (Roobol and Smith, 1980; Smith and Roobol, in press). Fall deposits are usually associated with both of these eruptive styles (Fig. 8). Asama-style activity describes eruptions which produce very low eruptive columns so that the pyroclastic flows essentially only overtop the crater rim and flow down the flanks of the volcano under gravity. Fall and surge deposits associated with this eruptive style have not been identified in the Lesser Antilles. Phreatic and phreatomagmatic deposits are very common on the "wet" volcanoes of the Lesser Antilles. Most of the historic activity has been of this style (Roobol and Smith, 1989) and many of the deposits from supposedly magmatic eruptions show evidence of water/magma interaction (Roobol et al, 1985, Smith and Roobol, in press). Phreatic/ phreatomagmatic eruptions are mostly of limited lateral extent.

VOLCANIC CENTERS

A summary of the activity recorded from the different islands/volcanoes of the active arc of the Lesser Antilles is given in Table 2. Based on the relative abundance of the different types of eruptive products, the volcanoes of the Lesser Antilles can be subdivided into five types of centers.

I - Centers composed almost entirely of pyroclastic deposits eg. Mt. Pelée, Martinique and the Quill, St. Eustatius. Both of these volcanoes, with the exception of a few dome and lava flow remnants in the summit region, are composed entirely of pyroclastic deposits (Fig.9) and their epiclastic derivatives.

II - Centers composed of Pelean-dome clusters and associated aprons of block and ash flow deposits: The dominant mode of activity on the island of Saba has been the extrusion of summit and flank domes, some of which

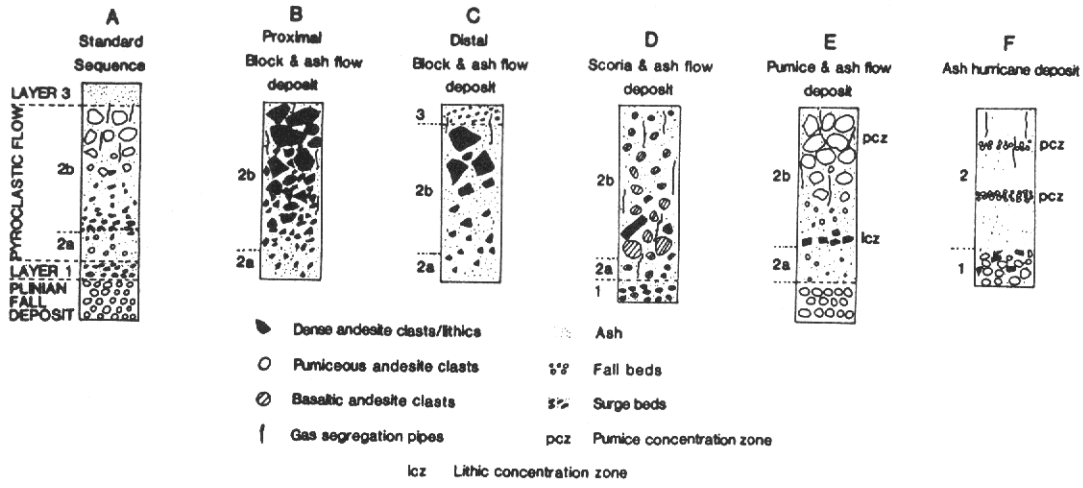

Figure 7. Diagrammatic sections through pyroclastic flow deposits. Layer 1 can be either a ground layer or a ground surge deposit; Layer 2a is the fine-grained basal layer of the pyroclastic flow; Layer 2b is the overlying "body" of the pyroclastic flow; Layer 3 is a co-pyroclastic flow airfall or an ash-cloud surge. Thickness of all the types of deposits, except the ash hurricanes, can range from 1 meter upto 50 meters; the ash hurricanes do not exceed 3 meters.

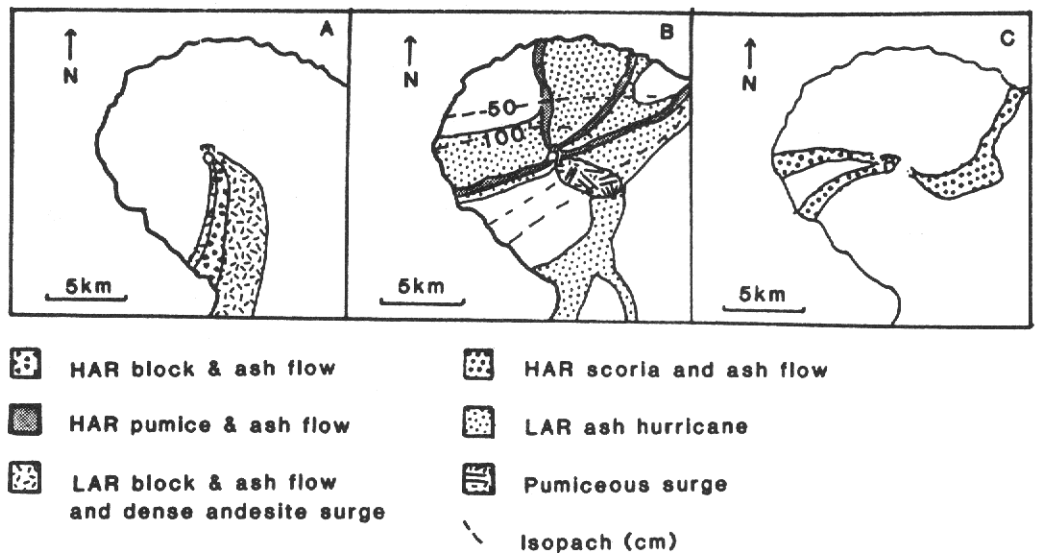

Figure 8. Maps showing distribution of deposits from prehistoric eruptions of Mt. Pelée. A - Pelean-style eruptions of stratigraphic subunit 14 (5,000-5,300 years BP); B - Plinian-style eruption - stratigraphic subunit d (1,800-2,200 years BP); C - St. Vincent- style eruption - flow A (~25,500-28,000 years BP) (After Smith and Roobol, in press).

have produced small short lava flows, and the associated eruption of block and ash flows. Although other types of volcanic activity have occurred on the island, their deposits only form a small percentage of the eruptive products (Fig.10).

III - Centers that have produced extensive andesite/dacite pumice and ash flow deposits: The youngest major eruptive activity on the islands of St. Lucia and Dominica (Figs. 11 and 12) have been of this type. On these islands numerous pumice and ash flows have flowed down most of the large valleys radiating away from the vent regions. On Dominica, many of these vents were subsequently blocked by the extrusion of Pelean domes, which are associated with the eruption of relatively small- volume block and ash flow deposits (Fig. 12).

IV - Centers with significant lava flows associated with pyroclastic deposits of various types: Mt. Misery, St. Kitts is an example of this type of center. During the last 40,000 years the volcano has erupted basic and intermediate composition lava flows, basaltic/basaltic andesite scoria falls, andesitic sub-plinian falls, lithic-rich scoria and ash flows and phreatic/pheatomagmatic falls and surges (Baker, 1969; Baker 1985, Roobol et al 1981, Roobol et al, 1985, 1987) (Fig.13).

V - Centers composed of basic and intermediate lava flows and associated fall deposits: The South Soufriere Hills on Montserrat with a thick sequence of basaltic and andesitic block, scoriaceous lapilli and ash fall deposits (White River Succession), and associated lava flows and domes, is an example of this type of center (Fig. 14).

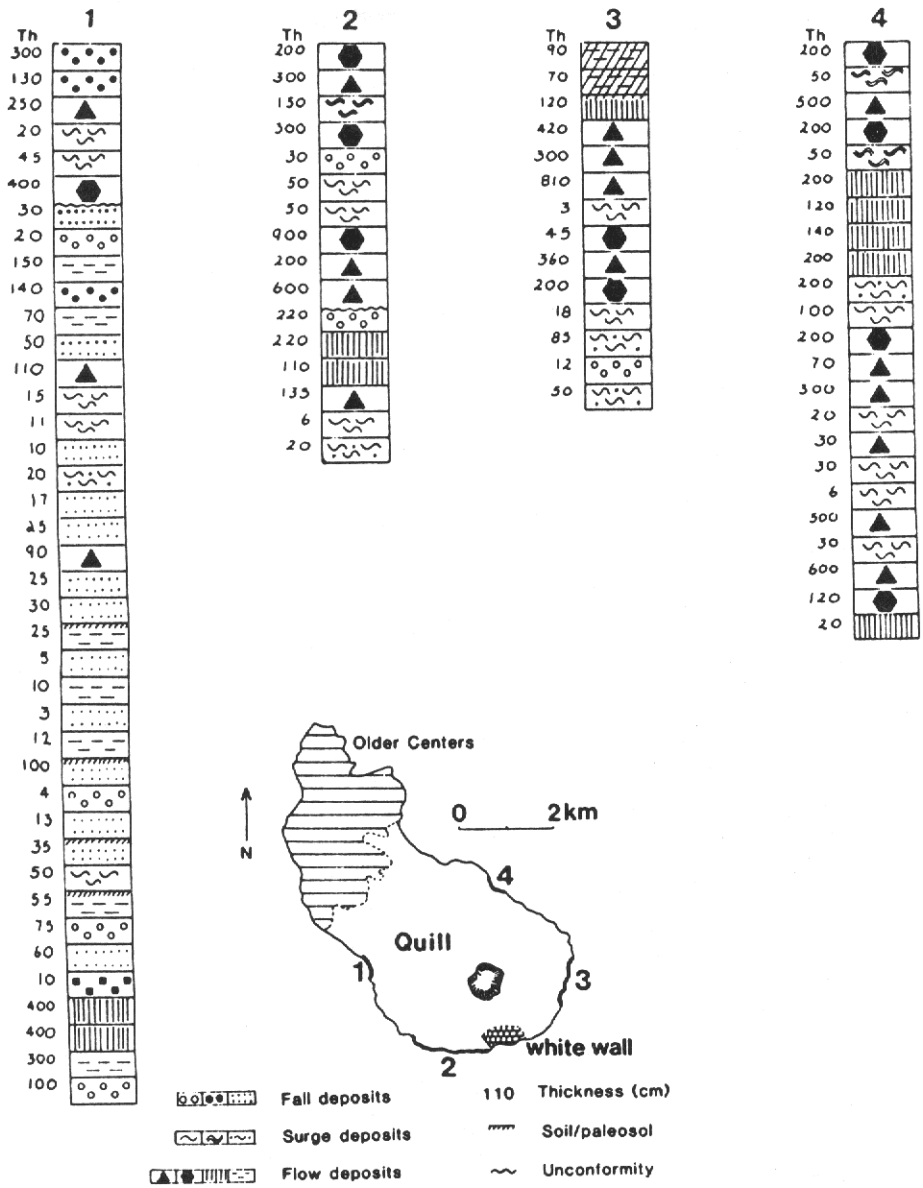

Figure 9. Stratigraphic sections through deposits from the Quill, St. Eustatius. Also shown is the uplifted limestone block of the White Wall and the older Northern Centers.

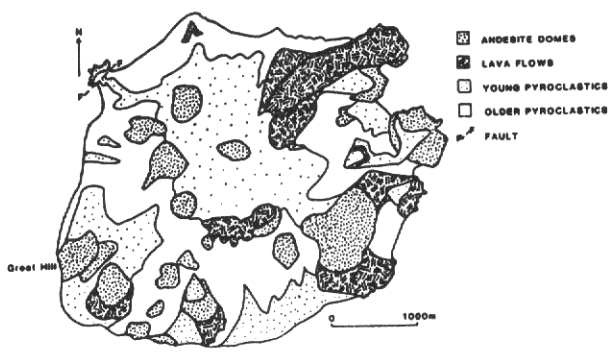

Figure 10. Geologic Map of Saba showing distribution of domes, lava flows and older and younger pyroclastic deposits (dominantly andesitic block and ash flows).

EPICLASTIC DEPOSITS

The pyroclastic deposits from all eruptive styles are commonly reworked by rainwash and fluviatile processes soon after eruption, so that stratigraphic sections commonly show intercalations of pyroclastic deposits with their epiclastic derivatives. For relatively small eruptions the primary pyroclastic deposits may be almost completely reworked and eroded so that hardly any evidence of the eruption remains in the stratigraphic record (Smith and Roobol, in press). In the lower part of Stratigraphic Division A of Mt. Pelée, Martinique epiclastic deposits make up approximately 75% of the stratigraphy (Fig. 15). These deposits are dominantly fluviatile conglomerates composed of boulders of dense andesite which alternate with fluviatile sandstones rich in andesitic pumice (Smith and Roobol in press). The former are thought to represent reworked Pelean block and ash flow deposits and the latter reworked Plinian fall and flow deposits.

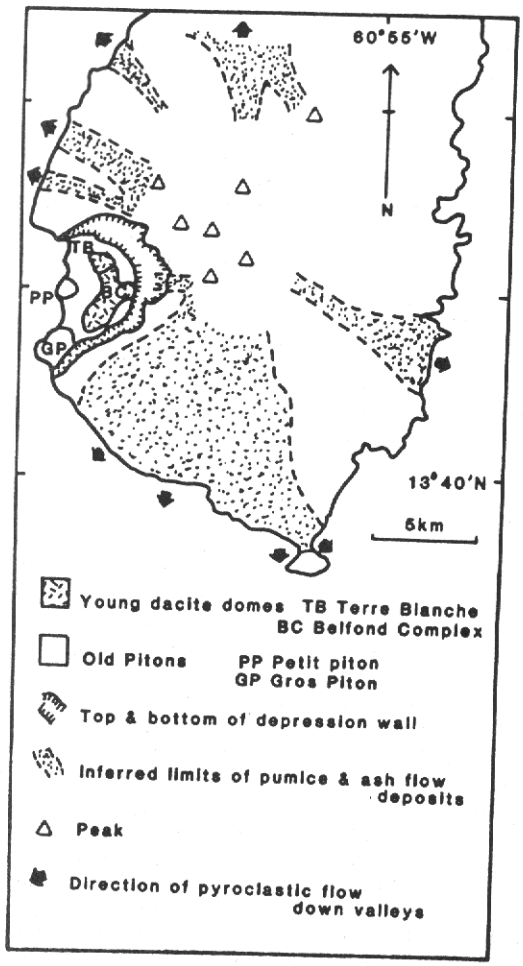

Figure 11. Map of southern and central St. Lucia showing radial distribution of pumice and ash flow deposits from a possible source in the central rainforest. (After Roobol et al, 1983; Wright et al., 1984).

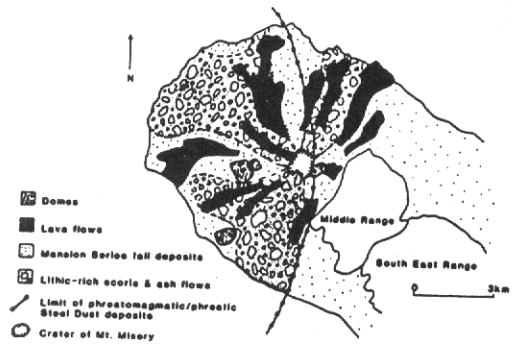

Figure 13. Map showing distribution of young (<45,000 years BP) volcanic deposits from Mt. Misery St. Kitts. Steel Dust Series deposits occur to the west of the line designating their limit (After Baker,1969; Roobol et al., 1987).

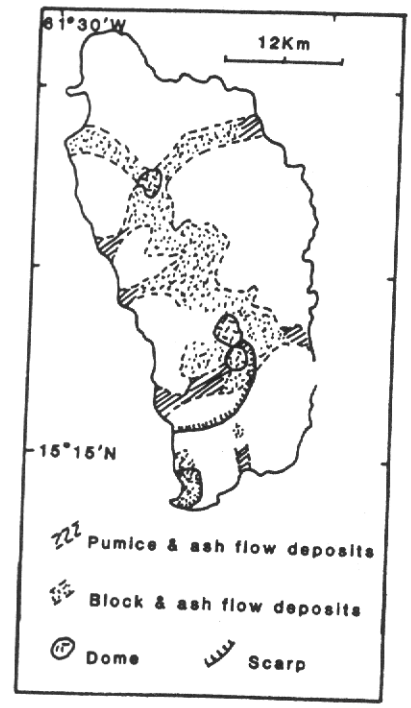

Figure 12. Distribution of youngest pyroclastic flow deposits in Dominica (After Carey and Sigurdsson, 1980; Roobol et al., 1983).

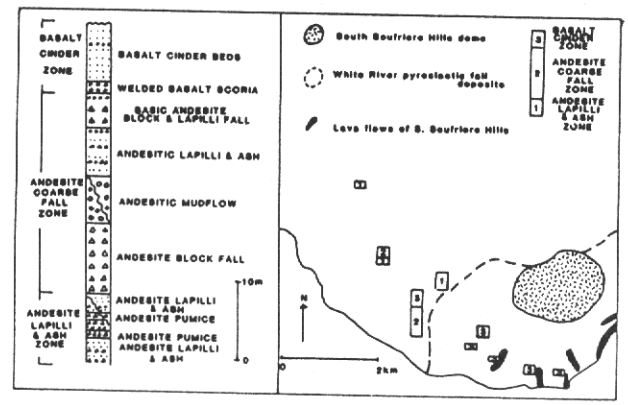

Figure 14 Map of southeastern Montserrat showing distribution of White River pyroclastic deposits and location of associated lava flows and the South Soufriere Hills dome (After Rea, 1974).

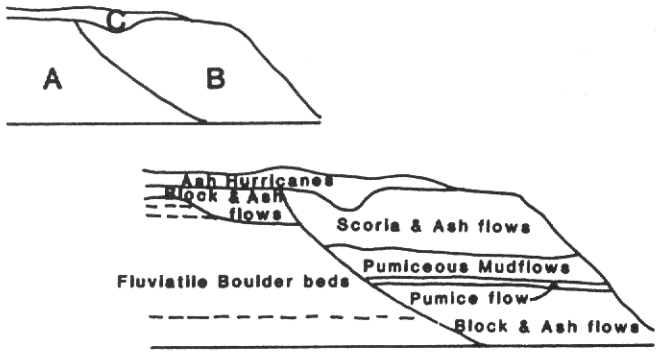

Figure 15. Sketch of the geology in the sea cliffs to the east of the town of Grande Riviere, Martinique.Dashed lines in fluviatile boulder beds represent crude stratification; the small inset shows the stratigraphic divisions. (After Smith and Roobol, in press).

Thus the alternation in eruptive style between Pelean and Plinian, so characteristic of the younger deposits of Mt. Pelée, can also be seen in the fluviatile reworked core of the volcano (Roobol and Smith, 1976, Smith and Roobol in press).

Mudflows also occur within the stratigraphic sequences. Some of these may represent lahars produced directly by volcanic activity, for example, the lahar of May 7th, 1902 that destroyed the Le Guerin sugar factory on Martinigue (LaCroix, 1904), others are purely secondary in origin. Mudflow deposits can often be confused with block and ash flow deposits as both have similar lithologies. For the Lesser Antilles two criteria have proved useful to distinguish between them. These are the presence, of gas escape structures and carbonized wood in the pyroclastic deposits. The former are not found in mudflows, and, although mudflows can contain wood, it is not usually carbonized (Smith and Roobol, in press).

SUBMARINE DEPOSITS

The Lesser Antilles represent a chain of relatively small volcanic islands so that much of the material erupted from the subaerial volcanoes is deposited on the surrounding sea floor. It has been estimated that for large explosive eruptions only about 5% of the magma erupted is deposited on land (Cary and Sigurdson 1980). Thus, in order to described the volcanic products from Lesser Antillean volcanoes, one must take into account the submarine deposits . The main types of subaqueous deposits described from subaerial eruptions from the Lesser Antillean volcanoes are: fall deposits, subaqueous volcaniclastic flow deposits and ash turbidities (Sigurdsson et al, 1980). These authors showed that most of the fall deposits occur to the east of the islands as a consequence of the effects of the upperTropospheric winds. In contrast, volcaniclastic flow deposits and ash turbidites are most abundant in the Grenada basin to the west. Stratigraphic evidence suggests that volcanic activity in the Lesser Antilles has, for the last 100,000 years, been predominantly subaerial in nature, and subaqueous volcaniclastic flow deposits have been produced by two main mechanisms. First, the entry of subaerial pyroclastic flows into the sea, for example, Mt.Pelée, 1902 (LaCroix,1904), and second the slumping of littoral or submarine accumulations of pyroclastic deposits into deeper water, for example, St. Vincent, 1902 (Anderson and Flett, 1902). Dilution of these subaqueous volcaniclastic flows by mixing with sea water eventually generate ash turbidities. The abundant ash turbidities described from the Grenada Basin (Sigurdsson et al, 1980) indicate that this is a common occurrence. A third mechanism for the generation of subaqueous volcaniclastic flow deposits is the sector collapse of the flanks of volcanic edifices. Such collapse would give rise to subaqueous debris fans and associated slump and debris flow deposits. Such a process has been well described for Piton de la Fournaise volcano on Reunion island (Duffield et al., 1982; Rousset et al., 1987) and has been proposed as the mechanism to explain the arcuate depressions on the western flanks of Soufriere volcano, St. Vincent, the Soufriere area of St. Lucia and areas in southern Dominica (Roobol et al, 1983).

VOLCANICLASTIC FACIES

Based on the above discussion it is evident that different volcaniclastic facies can be described for the volcanoes of the Lesser Antilles. The major facies division is between the subaerial deposits and the more voluminous submarine deposits. The subaerial facies, within approximately 10km of the crater, would be composed of high level intrusions/extrusions, lava flows, high-aspect ratio pyroclastic flows showing an irregular distribution (i.e confined to valleys) between which would be finer grained deposits derived from surges, low-aspect ratio pyroclastic flows and coarse- to medium- grained fall deposits. Beyond this limit would be found fine- grained fall deposits and deposits from the more extensive low-aspect ratio pyroclastic flows. The subaerial deposits would pass, at the shore line, into subaqueous debris flow and volcaniclastic flow deposits. Such deposits would be concentrated off the mouths of the valleys down which the subaerial pyroclastic flows travelled. For the Lesser Antilles, with their relatively steep western margin, extensive deep water subaqueous volcaniclastic flows are concentrated on the west. On the eastern side of the islands with their broad insular shelves, most subaqueous volcaniclastic flow deposits accumulate relatively close to shore, so that the dominant volcanic component offshore are fall deposits.

Further from shore the subaqueous volcaniclastic flow deposits would became finer grained and less common, only being represented by the deposits from the larger eruptions. These flow deposits would, through eventual intermixing with water pass into ash turbites. Interbedded with all these subaqueous volcaniclastic deposits would be marine pelagic and hemipelagic sediments and turbidites produced by non-volcanic mechanisms. (Figs. 16A and 16B).

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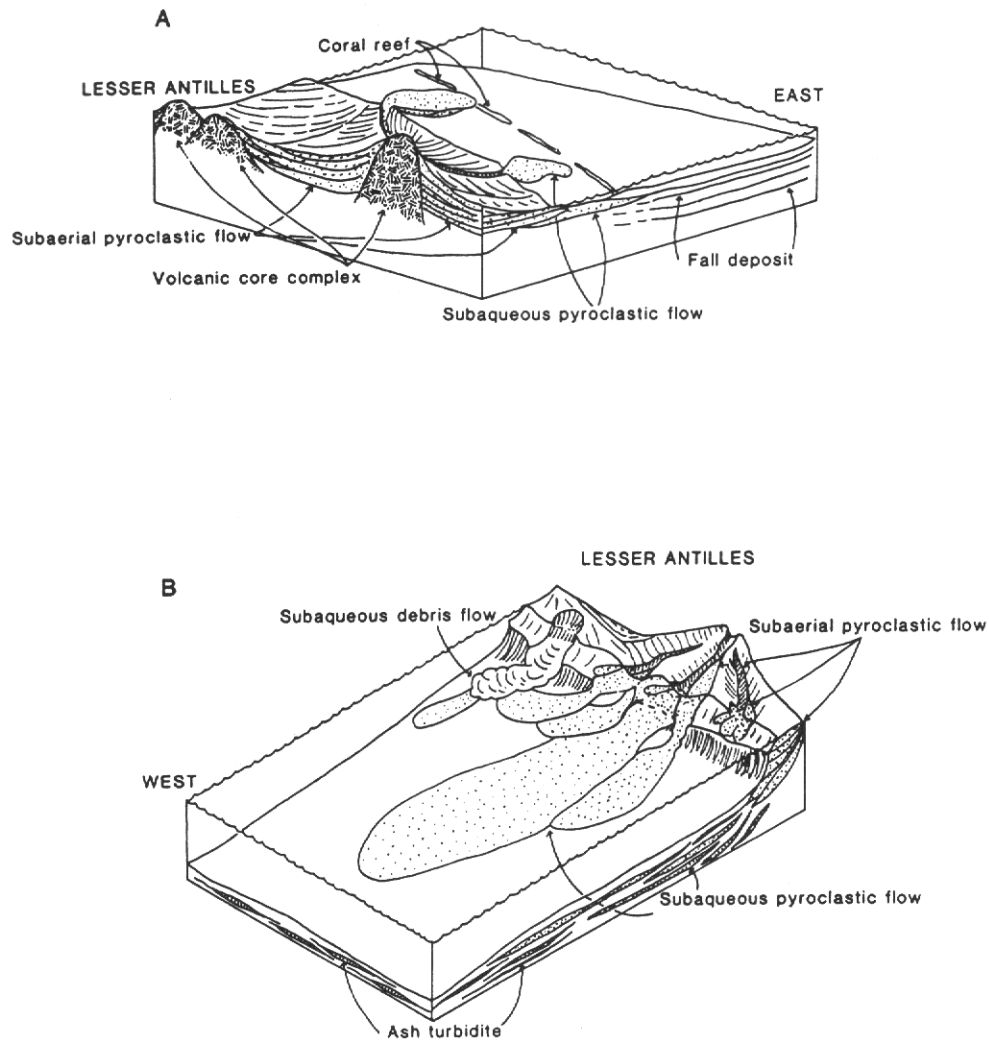

Figure 16. Schematic block diagrams showing potential distribution of volcaniclastic deposits (subaerial and submarine) in the Lesser Antilles. A - looking towards the east; B - looking towards the west.

TABLE 2. SUMMARY OF ERUPTIVE ACTIVITY FOR THE ACTIVE CENTERS OF THE LESSER ANTILLES

	EXPLOSIVE						EXTRUSIVE		
	Pyroclastic flows			Falls					
Island/ Volcano	Block & Ash	Scoria & Ash	Pumice & Ash	Pumice & Ash	Scoria & Ash	Dense/ Andesite	Domes	Lava-flows	Types of Center
Saba	A	S	S	S	S	S	A	M	II
Quill (St. Eustatius)	A	A	M	M	S	M	S		I
Mt. Misery (St. Kitts)		A	S	A	M	M	M	M	IV
Nevis Peak (Nevis)	A					S	A	A	II/IV
Soufriere Hills (Montserrate)	A			S	S		A		II
S. Soufriere Hills (Montserrate)				A	A		M	A	V
Soufriere (Guadeloupe)	M	M	M			A	A	M	IV
Monts Caraibes (Guadeloupe)					A			A	V
Dominica (latest volcanics)	M		A	A			M		III
Mt. Pelée (Martinique)	A	M	A	A	M	S	A	S	I
St. Lucia (lastest volcanics)	A		A	A			A		III
Soufriere (St. Vincent)	M	A			A		S	A	IV

A - abundant

M - moderate

S - scarce

FALLS

Deposits	Type
Pumice & Ash	Plinian/subplinian
Scoria & Ash	St. Vincent
Dense andesite & ash	Pelean/Phreatic

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