Dominica

Geology

With the exception of a minor discontinuous formation of uplifted Pleistocene to Holocene conglomerates and corals along the west coast, Dominica is essentially made up of volcanic rocks. Based on 43 K-Ar and 50 radiocarbon dates the stratigraphy of the island can be subdivided into four units: 1) Miocene, 2) Pliocene, 3) 'Older Pleistocene' and 4) 'Younger Pleistocene' - Recent. The four units are separated by three unconformities which are not all island-wide, as volcanism continued at some centers while weathering and erosion took place at others which had become extinct.

The west coast of Dominica, along the entire outcrop length of the Pliocene volcanoes (discussed below), is remarkably linear. Along much of this coastline are Pleistocene outcrops of water-worked block and ash flow deposits now present as pebble and conglomerate beds which locally contain raised coral reef limestone (Martin-Kaye 1960; Sigurdsson and Carey 1991). This strongly suggests that this linear coastline marks a normal fault where the island is being uplifted.

Miocene rocks

The oldest rocks lie along the east or Atlantic coast and are deeply dissected and weathered low-K basaltic terranes yielding radiometric ages between 6.92 and 5.22 Ma (Monjaret 1985; Bellon 1988). These older rocks are cut by numerous younger andesitic dikes yielding Pliocene ages (3.35 to 2.76 Ma) (Bellon 1988). With the exception of a suspect 13 Ma date given by Monjaret (1985), there are as yet no dated rocks older than 7 Ma on Dominica that would correspond to the extinct Limestone Caribbee Arc present on Martinique immediately to the north (Andreieff et al. 1976; Bellon et al. 1974; Westercamp 1976; Westercamp and Andreieff 1989).

Pliocene rocks

A major unconformity above the Miocene rocks is suggested by a distinct gap in the radiometric ages between 5.2 and 3.7 Ma. Field evidence for this unconformity is, however, lacking, as the appropriate outcrops are located in the inaccessible, densely forested eastern side of the island. In contrast, from about 3.7 Ma volcanism appears to have been almost continuous, forming a number of now largely extinct centres that are so deeply dissected that only outlines of their characteristic morphology can be seen. The most widespread deposits of these Pliocene volcanoes appear to comprise remnants of large basaltic to andesitic stratovolcanoes. In the northern half of the island (north of latitude 15^{o} 25' N) a cream-coloured saprolite surface (up to 7 m thick) overlain by 3 m of laterite is widely developed on the Pliocene deposits. It is estimated that the age of this surface, which indicates a hiatus, is around 2 Ma. This surface does not appear to be present on top of Pliocene deposits of the Foundland center in the south, suggesting that this centre remained active through the Pliocene and into the Pleistocene; an idea supported by a date of 1.12 Ma for its younger deposits.

Pliocene volcanoes

The geology of the south central part of Dominica is dominated by the eroded remains of a large stratovolcano termed the Cochrane-Mahaut centre (Bellon 1988). This centre is composed of basaltic pillow lavas and submarine volcanic breccias in its older sections and thick subaerial andesitic lava flows interbedded with pyroclastic deposits in its younger sections. The youngest age of the submarine deposits appears to be around 2.83 Ma (Demange et al. 1985; Monjaret 1985; Bellon 1988) suggesting that after this time the volcano was above sea level. Morne Cabrits Marons, Morne Cola Anglais, Deux Saisons, Morne Boyer, Morne Couronne and Morne Negres Marrons all represent remnants of this stratovolcano.

In the central and northern parts of the island highly dissected remnants of other Pliocene volcanoes were recognized, mainly on the basis of morphology, by Martin-Kaye (1960), who named two of the centers Grand Bois and Concord. The identification of these highly dissected terranes as Pliocene was later confirmed by K-Ar dating (Monjaret 1985; Bellon 1988). These centres range from basaltic to dacitic in composition, with much of the former occurring as subaqueous deposits. The more siliceous deposits occur as subaerial pyroclastic deposits, lava flows and domes (e.g. Morne Espaniol, a well preserved Pelean dome on the northwest coast that is probably related to Pliocene activity at Morne Diablotin).

The Pliocene Foundland center in the south of the island is separated from the remnants of the Cochrane-Mahaut stratovolcano by a belt of Pleistocene to Recent volcanoes (discussed below). Foundland is a stratovolcano of dominantly basaltic composition. The oldest rocks are exposed at the base of the Wai Wai and Daroux sea cliffs where they form sequences of volcanic breccias interpreted as the deposits of subaerial lava flows that entered the sea (Wills 1974). Further inland, subaerial flows up to 30 m thick of basalt with some andesite are interbedded with scoriacous pyroclastic deposits (Wills 1974; Sigurdsson and Carey 1991; Smith unpub. data).

There is no seismicity or geothermal activity associated with any of the Pliocene centres and they are considered unlikely to erupt again.

'Older Pleistocene' rocks

The saprolite-laterite disconformity discussed above is overlain by the third stratigraphic unit, which is of 'Older Pleistocene' age. Centers belonging to this unit are all confined to the northern half of the island, and are characterised by the presence of Pelean domes and associated aprons of block and ash flow deposits.

'Older Pleistocene' volcanoes

A number of independent 'Older-Pleistocene' volcanic centers are present north of the Layou River, including Morne aux Diables (forming a peninsula at the north end of the island), and the largest volcano on the island, Morne Diablotins. The 'Older Pleistocene' portion of Morne Diablotins was built over an extensive base of Pliocene volcanic rocks, and, like Morne aux Diables, is composed of andesitic lava flows, domes, and block and ash flow deposits. Both of these volcanoes are also associated with young unconsolidated pyroclastic deposits suggesting that the volcanism at these centres continued into the Holocene. This, together with occasional shallow seismicity in the area, indicates that there is a possibility they may erupt again in the future. These volcanoes are described in more detail below under the section on potentially active volcanoes.

Three smaller peaks on the southern flanks of Morne Diablotins (Mosquito Mountain, Morne McFarlin and Morne Pierre Louis) are interpreted as single Pelean domes surrounded by their pyroclastic aprons. These centers are thought to be of 'Older Pleistocene' age and are regarded as being extinct.

In March 2002, a SeaBeam bathymetric survey was conducted from the NOAA ship Ronald H. Brown directly off the coast of Domincia. This survey revealed the presence of two large submarine domes, informally referred to as 'Twin Peaks', approx. 5 km off the northern coast. The summit of the highest dome (15.671^o N; 61.476^o W) was 153 m below sea level, and both domes rise >1,000 m from the ocean floor. Another smaller submarine dome was observed approx. 6 km west of Lamothe Bay on the northwest coast (summit = 15.62^o N; 61.53^o W). This dome is >700 m high, and has a summit depth of approx. 550 m. These northern submarine domes may be similar in age to the older portions of Morne Diablotins and Morne aux Diables, although a detailed oceanographic investigation is needed to determine whether or not these centres are potentially active.

'Younger Pleistocene' - Recent rocks

About 1 Ma ago a major change occurred in the focus of volcanism, with activity switching from the northern to the southern half of the island. In the north, volcanism continued in a reduced manner at Morne Diablotins and Morne aux Diables.

'Younger Pleistocene' - Recent volcanoes

Six major andesitic/dacitic volcanoes with summit lava domes were active in south Dominica during the 'Younger Pleistocene' to Recent: Morne Trois Pitons, Wotten Waven/Micotrin, Watt Mountain, Grand Soufrière Hills, Morne Anglais and the Plat Pays volcanic complex. In addition, the Valley of Desolation, a major geothermal area, has been active during this time, sourcing Dominica's two historic phreatic eruptions.

Available age dates for the more recent magmatic activity at these centres range from ~50,000 to 450 years B.P. and most have had eruptions within the last ten thousand years. These volcanoes are associated with geothermal and/or shallow seismic activity and are considered likely to erupt again. These centres, together with Morne Diablotins and Morne aux Diables, are all discussed in more detail below under 'potentially active centres'.

Geothermal activity

Valley of Desolation

Along the length of Dominica are a number of crater-like features, usually in the rain forest and not easily studied, that may be phreatic/phreatomagmatic explosion craters. The best known concentration of these craters is the Valley of Desolation/Boiling Lake area, referred to in the past as the "Grand Soufrière" (e.g. Sapper 1903; Robson and Wilmore 1955), where several small explosion craters are associated with vigorous hydrothermal activity. Since the name "Grand Soufrière" is no longer commonly used in Dominica, we refer to this area (extending from the actual Valley of Desolation to the Boiling Lake) as the "Valley of Desolation".

This region is characterised by numerous hot springs, bubbling pools and fumaroles over an area of approximately 0.5 km^2. Over the last 100 years, temperatures of fumaroles have generally ranged between 91 and 99^o C, and those of hot springs and bubbling mud pools between 40 and 96^o C (Sapper 1903; Robson and Willmore 1955; Brown 2002).

The Boiling Lake itself has an area of approximately 85 x 75 m and its usual depth has been estimated at about 10-15 m. Over the last 100 years, temperatures taken at the edge of the Boiling Lake have generally ranged between 80 and 90° C (Sapper 1903; Robson and Willmore 1955; Brown 2002). However, the water level and temperature of the lake have both been known to drop considerably in the past, for example in 1876, 1900, 1901, 1971, 1972 and in 1988 (Ober 1880; James 1988). A small explosion in 1901 from an "empty" lake released harmful gases (probably mainly CO_2) into the atmosphere and killed two people who were at the water's edge at the time (Elliot 1938; Bell 1946). In 1972, locals reportedly bathed in the Boiling Lake, whose levels and temperatures had dropped. In 1988 the normal water level had dropped by about 30 ft, and the temperature at the waters edge was <30° C (James 1988).

Plat Pays volcanic complex

Three main areas of geothermal activity are associated with the Plat Pays volcanic complex. The largest area is located on the margin of the Soufrière depression in the Sulphur Springs National Park region, and was termed the Terre Elm fumaroles by Wadge (1985) but is now more commonly known as Sulphur Springs. Another smaller area of geothermal activity is located in a cliff adjacent to Galion, a village between the Patates and Crabier domes. The Sulphur Springs and Galion fields are characterised by areas of steaming, altered ground with numerous sulphur-coated fumaroles and minor hot springs. The few temperature measurements taken over the last 100 years reveal fumarole temperatures of between 90 and 100° C (Sapper 1903; van Soest et al. 1998; Brown 2002). The fumaroles of Galion and Sulphur Springs have high concentrations of H_2O, CO_2 and H_2S and generally low concentrations of SO_2, HCl and CO (Brown 2002). These concentrations, together with the low temperatures of the fumaroles, are consistent with a meteoric-fluid dominated hydrothermal system. The third area of fumarolic activity is found at Champagne, a zone of gas emission 200 m north of Pte. Guignard on the beach and extending to at least 20 m offshore. The underwater fumaroles here are manifested by bubble trains rising towards the surface, and appear to be aligned along roughly east-west trending fractures in lava which can be correlated with similarly-trending fractures in adjacent lava onshore. Minor thermal activity is also present at the foreshore near Soufrière village, where diffuse gas discharge occurs in shallow water. Some minor fumaroles in the crater of Morne Patates were described by Wills (1974), but are no longer present (Lindsay et al. 2003). In recent years the geothermal activity in the Soufrière valley region has been monitored at roughly yearly intervals. Other than minor changes in gas flux and sulphate content, no significant changes have been observed in their character, temperature or chemistry (J-C. Komorowski, pers. comm. 2000; Brown et al. 2002; P. Joseph pers. comm. 2004).

Wotten Waven

Several fumaroles and hot springs are located within the Wotten Waven caldera. The largest area of activity is located near the village of Wotten Waven, in and adjacent to the River Blanc, a tributary of the Roseau river. Within the river valley itself there are numerous bubbling pools and fumaroles with temperatures of up to 99° C. A 2 m wide cave approximately 6 m above the river bed on the northern side of the river is the site of a milky-white pool of water (80-93° C) whose level rises and falls every 10 seconds. Loud bubbling sounds issue from within the depths of the cave. About 40 m north of the cave, above the River Blanc, several other vigorously bubbling pools are present. The largest of these, Yellow

Pool, is ca. 2 m x 1.5 m in size, and is milky white or clear, depending on whether it is the dry or wet season, respectively. Its temperature also varies according to season: 71-74^o C in the wet season; and 87-93^o C in the dry season (Joseph and Lindsay 2002). Several other smaller pools in and adjacent to a small stream that passes through the area range in temperature from 50 to 99^o C. A fumarole in a nearby field had a temperature of 100^o C in May 2000. An old report by Drumm (1849) on the Wotten Waven geothermal area suggests it was just as active, if not more active, 150 years ago.

Minor warm spring activity is also present at the Trafalgar Falls, in Papillote and a temperature of 39.2^o C was recorded by van Soest et al. (1998). A landslide in September 1995 buried the pools and hot spring at the base of the 'father falls' (James 1997) impeding access to this once-popular tourist destination.

Micotrin

Although there are no major areas of geothermal activity associated with Micotrin, some of the streams adjacent to the southern dome have banks with patches of orange-stained rocks indicating that there may be some as yet unidentified warm springs higher up the dome.

Morne aux Diables

Numerous hot springs and patches of hot ground are present in the vicinity of Glanvillia south of Portsmouth. They form an area of thermal activity 2.5 km by 1.5 km in size, roughly half of which is immersed in the shallow waters of Prince Rupert Bay at depths of 20 to 70 ft. Onshore temperatures of up to 102^o C were recently (February 2004) recorded from an area of hot ground near the mouth of the Picard River in Glanvillia. The submarine springs occur as both large isolated springs and as areas of more diffuse degassing via many smaller springs. The largest and deepest solitary spring is located in 70 ft of water to the south of the thermal area. Vigorous venting of hot discolored water from this feature has led to the formation of a depression in the sea bed 110 ft in diameter. Bubbles from this spring reach the water surface despite the 70 ft water depth (compared to a maximum depth of origin of only 15 ft at Champagne Pool in the south). Divers visiting the area in February 2004 reported the sea bed too hot to push their hands into the sand and the boat anchor, when raised, was still warm to the touch.

Morne Diablotins

Minor fumarolic activity has also been reported on the northwestern slopes of Morne Diablotins (Robson and Tomblin 1966), to the west of Morne aux Diables on the coast at Toucari village (in a roadside excavation now infilled) and on Morne Turner (A. James pers. comm. 2003). An area of cold spring activity, known as the 'Penville Cold Soufrière', is located in the northwestern, younger crater of Morne aux Diables (Robson and Tomblin 1966), in the upper part of the Lamothe River. The springs are located to the north of the main summit area, and cover an area of about 25 m^2. The activity is manifested as milky to clear vigorously bubbling pools and cold "frying pan" features with temperatures of 23-29^o C and an acidic pH (1-2) (Joseph and Lindsay 2002; Joseph and Robertson 2003). A strong H_2S odour is present and vegetation is dead or absent in the immediate area. Several bubbling springs also occur in a nearby stream, and are surrounded by large patches of white filamentous algae.

Volcanism

There are nine potentially active centres in Dominica and are each discussed below.

Valley of Desolation

Past eruptive activity

Demange et al. (1985) provide three dates related to prehistoric phreatic activity of the Valley of Desolation. One of these dates (4,050 years B.P.) is of a lahar deposit exposed in the River Blanc near Casso, thought to have originated from the Valley of Desolation. The other two (3,750 and 2,900 years B.P.) are from lithic ash deposits within two small explosion craters in the Valley itself. These dates suggest that explosive activity has occurred from vents within the Valley of Desolation for at least 4,000 years.

Historical eruptions

The Valley of Desolation has been the source of two historic phreatic eruptions, on January 4th, 1880 and on July 9th, 1997. Neither explosion was directly witnessed.

Future eruptions

The most likely type of volcanic activity to occur from the Valley of Desolation is a phreatic eruption from the Boiling Lake or one of the other explosion craters in the area. Phreatic eruptions are steam-driven eruptions that eject fragments of old rock and ash into the air and are very common in geothermal areas. They are not true volcanic eruptions in that they do not erupt fresh magma, although they can emit dangerous gases. Individual phreatic explosions may last up to an hour or more, and a series of blasts may continue intermittently for several months or even years. They may be accompanied by volcanic earthquakes. In some instances, particularly if they occur in a sequence, phreatic eruptions may represent precursory activity to an actual magmatic eruption.

In the event of a phreatic eruption from the Valley of Desolation the direct effects will probably only be felt over a small area of up to a few 100s of metres from the vent, although ballistic projectiles may be throw up to 1-2 km and ashfall may affect areas a considerable distance downwind of the vent. The ash cloud generated during the 1880 phreatic eruption from the Valley of Desolation was carried westward by the wind, and ash fell over an elongated area downwind of the source about 3 km wide. The sky darkened over Roseau, and up to 6 mm of ash and accretionary lapilli fell over the town. In general, however, such an eruption will only be dangerous to humans if they are near the vent at the time; and major effects are likely to be constrained within a two km radius of the vent. However, the water, ash and steam ejected during a phreatic eruption are likely to be acidic, and would contaminate nearby streams. Phreatic eruptions may also eject enough water to generate small floods or lahars in nearby streams, and lahars were generated in the Roseau and Pointe Mulatre rivers in this way during the 1880 phreatic eruption. Despite these possible effects, the area affected by a phreatic eruption will be very small compared with that affected by a magmatic eruption.

Plat Pays Volcanic Complex

Morne Plat Pays is a stratovolcano with a central complex of eroded summit domes that rises to an elevation of 960 m. The volcano is truncated on its southwestern side exposing a ~ 900 m high collapse scarp beneath Morne Plat Pays which forms the northeastern margin of the adjacent Soufrière depression. At least 16 small lava domes occur in this complex, some within and some outside the depression.

Past eruptive activity

No dates are available for the early activity directly associated with the Plat Pays stratovolcano. Exposures near the summit are dominantly of thick andesitic lava, indicating effusive activity. Minor exposures of block and ash flow and other volcaniclastic deposits are present in heavily vegetated areas below the summit area, indicating periods of dome growth and collapse. A poorly-exposed, surficial pyroclastic deposit containing semi-vesicular andesitic clasts crops out on the eastern edge of the Soufrière depression and to the north and east of Morne Plat Pays. This deposit, which probably formed by Asama-style activity, has been dated at 6.6 to 6.8 ka and may represent the most recent activity from this volcano (Lindsay et al. 2003).

Historical eruptions

There have been no reports of volcanic eruptions from the Plat Pays volcanic complex in historic time. However, radiocarbon ages of pyroclastic flow deposits from Morne Patates indicate that this dome may have been active as recently as 450 years ago, which roughly coincides with the period of earliest European arrival in the area. In 1994 spontaneous combustion and subsequent melting of native sulphur in the lower Sulphur Springs area led to a "sulphur fire" over an area of approximately 1 km^2. This slow-flowing, molten sulphur resulted in false rumours of an eruption of lava.

Future eruptions

1. Effusive dome-forming eruption from Morne Canot or Morne Patates

The last 25,000 years of volcanic activity at the Plat Pays volcanic complex have been dominated by effusive dome-forming activity, and this is considered the most likely style of activity for the next magmatic eruption from this volcano. Based on the location and pattern of seismicity in recent decades, in particular the 1998-2000 swarm, a future dome-forming eruption is more likely than not to occur within the next 100 years, and is likely to occur in the vicinity of Morne Canot. Such an eruption could, however, occur from anywhere within the complex, and until precursory signs (such as an escalation of the earthquake swarm and/or onset of phreatic activity) appear which will provide a more accurate estimate of vent location, it is difficult to say with certainty where activity will occur. Morne Patates is, in fact, the site of the most recent magmatic eruptions in Dominica. The scenario of a dome-forming eruption from Morne Canot is considered the most likely for a future magmatic eruption in Dominica.

2. Explosive eruption from Morne Plat Pays

The 6.8 ka old andesitic pyroclastic flow deposit (Asama style activity) exposed on the flanks of Morne Plat Pays indicates that explosive magmatic eruptions have occurred from this center in the recent past, and may occur here again in the future. A similar eruption in the future may produce a low eruption column, collapsing a few hundreds of meters above the vent. Collapse of such a low column may generate pyroclastic flows and surges radially around the volcano, but would not produce significant ash fall. Ballistic projectiles would be a hazard within ~5 km of the vent, and lahars and volcanic earthquakes could also occur. Such an eruption would affect an area radially around Morne Plat Pays and could potentially impact a greater area than a dome-forming eruption.

Morne Anglais/John

Morne Anglais is a prominent peak located just to the east of Roseau. It is a stratovolcano with a prominent summit dome. Morne John, a single Pelean dome with its own apron of block and ash flows, lies on its northeastern flank.

Past eruptive activity

Demange et al. (1985) describe three stages of past activity at Morne Anglais. Stage 1 involved a period of dome growth and collapse, resulting in a series of block and ash flow deposits. A period of St. Vincent style activity occurred during Stage 2, producing a sequence of basaltic-andesite scoria and ash flow, scoriaceous surge and scoriaceous fall deposits, some of which contain evidence of magma co-mingling. These deposits are exposed intermittently along the west coast and in roadcuts to the west and southwest of the volcano. A sequence of scoriaceous deposits exposed within the Soufrière depression and dated at 28,450 (Wadge 1985) and 26,400 (Demange et al. 1985) years B.P. may possibly be correlated with these deposits. The most recent major phase of activity, stage 3, was again characterised by dome growth and collapse, and resulted in the present morphology of a central Pelean dome complex surrounded by aprons of block and ash flow deposits. A block from one of the Anglais block and ash flow deposits gave a K-Ar age of 0.43 Ma, which, based on morphological criteria and the possible presence of excess argon, is thought to be too old (Demange et al. 1985). The western and southern flanks of Morne Anglais contain outcrops of an undated andesitic pumice and ash-rich pyroclastic flow deposit <2 m thick that represent a period of explosive activity and are thought to be the youngest deposits from Anglais (Lindsay et al. 2003). Very little is known about the age and nature of Morne John.

Historical eruptions

There have been no reports of historical eruptions from Morne Anglais or Morne John.

Future eruptions

The proximity of Morne Anglais to the recent volcanic earthquake swarm, and in particular the cluster of earthquakes directly beneath its summit, indicate that eruptions are likely to occur from here in the future. The most recent activity at Morne Anglais has been explosive in nature (Lindsay et al. 2003) and St. Vincent style explosive activity occurred extensively during Stage 2. The most likely future activity at this centre is therefore considered to be an explosive andesitic or basaltic magmatic eruption, possibly preceded by a period of phreatic activity. The vent would probably be located at or near the summit, as in past eruptions.

Such an eruption would generate a buoyant eruption cloud of ash and larger rock fragments, which may subsequently collapse to generate pumiceous pyroclastic flows and surges in all directions around the vent, particularly down all major nearby valleys including the Roseau and Geneva rivers and their tributories (brown area on the hazard map). Less frequent but more energetic pyroclastic flows and surges would be less restricted by topography and would have the potential to cover greater areas and may even reach as far south as Soufrière and as far north as Massacre to the west and Boetica to the east (yellow area on the hazard map). In the absence of ash fall data specific to Morne Anglais, the pattern of ash fall thickness and distribution exhibited during the 1902 eruption of the Soufrière in St. Vincent (Robertson 1992) has been used to define a possible ash fall pattern. Ballistic projectiles would be common, and would mainly affect an area within 5 km of the vent. Lighter fragments (such as pumice or scoria) may be kept buoyant in the eruption plume for much greater distances before falling back to Earth. The explosive phase of the eruption may be followed by rapid extrusion of a lava dome. Lahars and volcanic earthquakes would also occur, and may continue long after the eruption itself has ended. Such an explosive eruption may last for years but could also be short-lived (weeks to months). Whatever the duration, areas affected by the eruption will remain uninhabitable for many years.

There have been several periods of dome growth and collapse at Morne Anglais in the past, and this type of activity may also occur in the future. A scenario involving a dome-forming eruption from Anglais would not significantly alter the hazard map, although the area affected by pyroclastic flows and surges would be smaller and more concentrated on the west of the volcano, due to the presence of channeling river valleys to the west and topographic highs to the east.

Wotten Waven/Micotrin

This centre comprises the Wotten Waven caldera (the southernmost caldera within the Central Graben) together with the twin Pelean domes and associated craters of Micotrin. The caldera is elongated SW-NE, parallel to the chain of Pelean volcanoes that bound the southern margin of the Central Graben. It is approximately 7 km long and 4.5 km wide, and parts of the margin are fault controlled. Subsidence volume has been estimated at 5-7.7 km^3 (Demange et al. 1985). The two coalesced domes of Micotrin, located in the caldera near its northeastern margin, lie within a number of craters, the largest of which has a diameter of 3.5 km. Between the crater rim and the domes is a “moat” which is now filled in places by lakes (e.g. the Boeri and Freshwater lakes).

Past eruptive activity

This centre has exhibited a variety of past eruptive activity. Activity between 40 and 20 ka was characterised by large explosive Plinian eruptions generating ignimbrites; more recent activity has taken the form of Pelean dome-forming eruptions producing block and ash flows and smaller pumiceous pyroclastic flows.

The Roseau Tuff

The Roseau Tuff is a thick sequence of ignimbrites (partly welded), pumiceous surges and pumice lapilli fall deposits (Sigurdsson 1972) that crops out in the area between the Micotrin dome and the west coast at Roseau. The source for the Roseau Tuff is not well known. Sigurdsson (1972) proposed vents under the Micotrin/Trois Pitons domes, whereas Demange et al. (1985) proposed that much of the ignimbrite originated from within the Wotten Waven caldera. The Plinian eruptions that produced the Roseau Tuff are thought to have occurred over a >20,000 year period (from >46,000 to ~25,000 years B.P.)

Other large ignimbrite-producing eruptions

Within southern Dominica there are other ignimbrite sequences with similar ages to the Roseau Tuff, suggesting that they may also be associated with these Plinian eruptions. These include thick ignimbrite sequences on the east coast at Grand Fond and Rosalie, and on the south coast at Grand Bay. If these ignimbrites indeed had a similar source area to the Roseau Tuff, then the former may have overtopped ridges north of Watt Mountain (now covered by the domes of Trois Pitons and Micotrin), whereas the latter, termed the Grand Bay Ignimbrite by Lindsay et al. (2003) and thought by them to have originated from the Plat Pays volcanic centre, may have flowed over a low divide between Watt Mountain and Morne John and down the Perdu Temps river valley to reach the present coast at Grand Bay. A submarine fan extending at least 7 km offshore is thought to represent an offshore extension of the Grand Bay ignimbrite (Lindsay et al. 2003). Lateral equivalents of the Grand Bay ignimbrite have been recognised along the south coast from west of Morne Fous to Petit Savane in the east (Lindsay et al. 2003). Another Plinian sequence composed of ignimbrites, pumiceous surges and one fall layer of similar age to the Roseau ignimbrites (38,610 to 30,270 years B.P.), has been described from the Wall House quarry on the western flanks of Morne Anglais. Whether these deposits represent distal facies of the 'Wotten Waven' ignimbrites or the products of a contemporaneous eruption from Morne Anglais is not known. If the Wotten Waven/Micotrin centre is the source area for all major ignimbrites in southern Dominica, then the 17 available radiocarbon dates from the Roseau, Grand Fond-Rosalie and Grand Bay tongues, together with field relations, suggest that this major Plinian eruptive sequence can, in fact, be subdivided into 6 possible phases of activity: ~25,000; ~29,000; ~35,000; ~38,000; ~46,000 and >46,000 years B.P.

After the emplacement of the Roseau Tuff and associated ignimbrites, activity continued from the Wotten Waven/Micotrin area as indicated by an ignimbrite at En Bas Petit Fond (Ma Robert) on the east coast dated at 19,500 years B.P, and the occurrence south of Micotrin of deposits from small Plinian and Pelean eruptions that occurred approximately 1,000 years ago. The latter represents the most recent activity associated with the Wotten Waven caldera, and may have originated from the Micotrin domes or other unrecognised vents associated with the caldera margin.

Historical eruptions

There have been no reports of historical eruptions from the Wotten Waven/Micotrin centre.

Future eruptions

1. Dome-forming eruption from Morne Micotrin

The recognition of relatively recent (~1 ka) Pelean and Plinian activity associated with Micotrin, together with the proximity to historic seismicity, indicates that the Wotten Waven/Micotrin centre could be the site of future eruptions. The most recent activity from this centre has occurred from the Micotrin dome complex, and this is considered the most likely vent area for future eruptions. Recent past behaviour at this volcano indicates that future activity is most likely to be dome forming. The type and duration of hazardous phenomena associated with such an eruption would be similar to that described for a dome-forming eruption from the Plat Pays volcanic complex. The phase of effusive dome-forming activity is likely to be preceded by a series of phreatic eruptions, and possibly even by a period of 'vent-clearing' explosive magmatic activity. Dome collapse pyroclastic flows and surges could occur down major valleys on both sides of the volcano, and reach the sea at Roseau and Canefield to the west and Rosalie on the east (brown area on the hazard map). The town of Roseau is, in fact, built on top of a pyroclastic flow fan which was produced during past eruptions at the Wotten Waven/Micotrin centre. More energetic pyroclastic flows and surges would not be so constrained by topography and may reach as far as Mahaut, Loubiere and La Plaine (yellow area on hazard map). Ballistic projectiles would be a hazard within ~5 km of the vent, and lahars and volcanic earthquakes could also occur. The pattern of accumulated ash fall thickness and distribution exhibited between 1995 and 2001 by the ongoing eruption of the Soufrière Hills volcano in Montserrat (Norton et al. 2001) has been used to define the probable ash fall pattern on the hazard map for this scenario. Ash would fall in copious amounts downwind from the volcano.

2. Explosive Plinian eruption from the Wotten Waven caldera

Although the last Plinian eruptions from the Wotten Waven caldera probably occurred >19 ka ago, the vigorous geothermal activity at Wotten Waven, together with shallow seismicity beneath the caldera and the possibility that the Plinian eruptions around 1 ka were from vents on the caldera boundary faults, indicates that the possibility of a future Plinian eruption from this centre must be considered. The Wotten Waven caldera is a volcano-tectonic depression that in all likelihood has boundary faults extending to depth. Such a depression may hydrostatically attract any rising head of magma, with the boundary faults providing easy access to the surface. A reactivation of the Wotten Waven caldera could produce a major explosive eruption which would affect most of Dominica. Plinian activity is the most explosive type and results from gas-rich felsic magma that has differentiated in a high-level magma chamber. Such an eruption must be considered the worst-case scenario for a future eruption in Dominica.

Plinian eruption columns can reach altitudes of 50 km, although most are lower, generally in the 10-20 km range, so that the material is dispersed by both upper and lower tropospheric winds (Trades and Anti-Trades) as well as by the stratispheric easterlies. The pattern of ash fall thickness and distribution exhibited during the 1902 eruption of the Soufrière in St. Vincent (Robertson 1992) has been used to define a possible ash fall pattern. The collapse of a high Plinian eruption column rich in ash would result not only in ash fall over a wide area, but also extensive valley-fill ignimbrites and associated ash-rich surges (brown area on the hazard map), the latter representing the greatest hazard. Such surges would travel extensively; the pumiceous surges (or 'ash hurricanes') produced by prehistoric eruptions of Mt. Pelée extended at least 12 km south of the crater to the very outskirts of the island capital of Fort de France (Smith and Roobol 1990). All major surrounding valleys would be affected, including the Roseau river and its tributaries. Whereas Morne Trois Pitons and Micotrin would provide some morphological barrier to the east of the Wotten Waven caldera, there is no barrier to the west, and ash surges are likely to travel in that direction unimpeded. Energetic surges could also expand to the northeast and devastate the entire central part of the island (yellow area on the hazard map). Morne Diablotins and a ridge of older volcanic rocks to its southeast (see relief map) are likely to form a barrier to the far north; to the south, however, the surges are likely to jump over lower volcanoes and to pass through gaps between them so that most of the island would be devastated. Such an eruption would also produce extensive ballistic projectiles, lahars, volcanic earthquakes and lightning strikes. In such a scenario most of the island south of a line connecting the towns of Salisbury and Marigot would fall in the very high and high integrated hazard zones.

Morne Diablotins and Morne aux Diables

Both Morne Diablotins and Morne aux Diables comprise eroded Pelean domes and deeply gullied pyroclastic aprons. Morne Diablotins is the largest and highest volcanic center on Dominica, and is the second highest mountain in the Eastern Caribbean (La Soufrière in Guadeloupe is the highest). Measuring 22 km x 18 km at its base and rising to a height of 1,421 m, it dominates the northern part of the island. Morne aux Diables, forming a peninsula at the extreme north of the island, comprises a central complex of eroded Pelean domes and craters surrounded by flanks of dominantly lithified block and ash flow deposits.

Past eruptive activity

Diablotins

Morne Diablotins is a composite structure comprising several superimposed stratigraphic units. The 'Older Pleistocene' volcano, believed to have been very similar to Morne Trois Pitons and Micotrin in form, underwent extensive Pelean activity producing block and ash flows and andesite lava flows (Martin-Kaye 1960; Wadge 1989). A single age of 1.77 Ma (Bellon 1988) from an andesite lava flow has been obtained from these extensive deposits. Pelean-style eruptions also characterise the 'Younger Pleistocene' to Recent activity of Morne Diablotins, with block and ash flows reaching the southwest, northwest and northeast coasts. Available ages for these deposits range from 0.72 Ma (Monjaret 1985) to >46,620 years B.P. (Smith and Roobol unpublished data). This Pelean activity was followed by explosive Plinian activity that produced pumiceous fall deposits and ignimbrites dated from >22,200 to >40,000 years B.P. (Sparks et al. 1980a,b; Wadge 1989). The ignimbrite deposits form five radial tongues around the volcano, and have been referred to as the Grand Savanne ignimbrite (Sparks et al. 1980a). The ignimbrites on the wetter Atlantic coast are weathered yellow and lithified while those on the drier Caribbean coast remain white and unlithified, although at Grand Savanne they show welding (Sparks et al. 1980a). These pumiceous deposits are overlain by unconsolidated block and ash flow deposits, which are well exposed in two valley infills on the west coast near Pointe Crabier and Coulibistri.

Morne aux Diables

Morne aux Diables is a stratovolcano measuring 7 km by 7 km and rising to a height of 856 m. Its northern boundary is a steep, 3.8 km-long linear cliff oriented E-W suggesting a fault scarp. This volcano is composed of a central complex of eroded faceted Pelean domes from which dominantly lithified block and ash flow deposits radiate out in all directions to form the flanks. There are five parasitic domes that form an east-west belt across the southern flanks. One of these at West Cabrit is now linked to the island by beach deposits and a swamp. Although the stratigraphy exposed in the sea cliffs is dominated by block and ash flow deposits, a section measured near Douglas Point shows lithified ignimbrites, pumiceous surge deposits and lapilli fall beds that are overlain by lithified semi-vesicular block and ash flow and surge deposits. These indicate that, in addition to the dominant Pelean activity, this center has also undergone Plinian- and Asama-style activity.

Three K-Ar ages of 1.68, 1.72 and 2.01 Ma (Monjaret 1985; Bellon 1988) show Morne aux Diables to be essentially of 'Older Pleistocene' age. Despite this, there is considerable evidence for rejuvenation during the Late Pleistocene to Holocene. Three tongues of unconsolidated block and ash flow deposits extend to the northwest coast and two to the northeast coast; such unconsolidated pyroclastic deposits in the Lesser Antilles are believed to be younger than about 70,000 years (Smith and Roobol 1990). One of these tongues exposed in a new road section on the east coast near the hamlet of Enbas (north of Vieille Case) contains pieces of non-charred wood up to 30 cm long, which have yielded a radiocarbon age of >46,740 years B.P. Unconsolidated block and ash flow deposits associated with the East Cabrit dome on the west coast also indicate a young age. The presence of these unconsolidated pyroclastic deposits suggests that the Morne aux Diables volcano has been rejuvenated during the Late Pleistocene to Holocene, resulting in the formation of young Pelean domes near the current summit and on the western flank.

Historical eruptions

There have been no reports of historical eruptions from either Morne Diablotins or Morne aux Diables.

Future eruptions

Effusive dome-forming eruption form Morne aux Diables

Although lithified deposits around Douglas Point indicate that Plinian and Asama style explosive activity has occurred during the 'Older Pleistocene' stage of Morne aux Diables, the resurgent Holocene activity at this center has been restricted to Pelean-type eruptions and a dome-forming eruption is therefore considered the most likely scenario for future activity at this center. Past activity at Morne aux Diables indicates that a future dome could develop from either central or flank parasitic vents; for the purpose of this scenario a central vent is assumed.

The type and duration of hazardous phenomena associated with such an eruption would be similar to that described for dome-forming eruptions from the Plat Pays volcanic complex and Micotrin. The phase of effusive dome-forming activity is likely to be preceded by a series of phreatic eruptions, and possibly even by a period of 'vent-clearing' explosive magmatic activity. Dome collapse pyroclastic flows and surges could occur down major valleys on all sides of the volcano, and reach the sea at Portsmouth, Savane Paille and Clifton to the west, and Penville, Vieille Case and Hiroula Bay to the east (brown area on the hazard map). More energetic pyroclastic flows and surges would not be so constrained by topography and may reach Glanvillia in the southwest and affect areas in and around Thibaud to the east and Dos D'ane and La Source to the southeast (yellow area on hazard map). If the vent occurs on the western flank of the volcano, for example near The Cabrits or Portsmouth, towns to the east of the volcano such as Vieille Casse and Pennville are unlikely to be affected by pyroclastic flow and surge activity. Ballistic projectiles would be a hazard within ~5 km of the vent, and lahars and volcanic earthquakes could also occur. Ash would fall in copious amounts downwind from the volcano.

Watt Mountain

Past eruptive activity

Demange et al. (1985) describe the western foundations of the volcano as comprising massive andesite lavas now exposed in the River Claire on Curbin Estate and in a little ravine west of Robinson Estate. An age of 0.46 Ma was obtained on a block from a breccia exposed on the northeastern flanks of the volcano. The smooth outer eastern flanks of Watt Mountain, in association with the description of ignimbrites in the upper Jack River which have been dated at 10,290 years B.P. (Seismic Research Unit 2000), suggest that this center may also have undergone a period of Plinian eruptions. The most recent activity from this center is thought to have occurred around 1,300 years ago when an andesite cryptodome was intruded into the lower western flanks of the volcano in the vicinity of Du Mas Estate. Collapse of the uplifted flanks generated debris flows which were converted into lahars when they entered the adjoining rivers. Exposure of the cryptodome generated a series of vulcanian explosions producing a sequence of andesitic lapilli fall deposits exposed at Morne Prosper, and block and ash flows from the gravitational collapse of the dome. Where exposed together the latter overlie or pass into the lahars. Wood collected from laharic deposits that interfinger with the block and ash flows associated with this eruption give dates of 1,350 and 1,270 years B.P (Demange et al. 1985). As a result of these eruptions a conical-shaped crater, partly filled by coarse block and ash flow deposits, was formed between Robinson and Du Mas estate. Like the Micotrin dome and the Babillard Estate crater, this crater lies on or near the margin of the Wotten Waven caldera, and extrusion of the cryptodome may in fact have been more closely related to the most recent activity of the Wotten Waven caldera than to Watt Mountain itself.

Historical eruptions

There have been no reports of historical eruptions from Watt Mountain.

Future activity

Although two phases of young explosive activity (1.3 and 10 ka) may have been sourced from this volcano, there is no concrete evidence that it has been active in the recent past. However, the proximity of recent seismicity together with the vigour of the adjacent Valley of Desolation hydrothermal field does suggest that an eruption may occur from this centre in the future. Past activity from Watt Mountain appears to have been largely effusive, resulting in lava flows and domes, with associated block and ash flows. This is considered the most likely style of activity for a future eruption.

Morne Trois Pitons

Morne Trois Pitons is a large volcanic structure located within the Central Graben. Its summit is now occupied by three coalesced Pelean domes with a volume of approximately 1.5 km^3 (Wills 1974).

Past eruptive activity

Demange et al. (1985) divide the eruptive history of Morne Trois Pitons into three phases. Rocks of the undated oldest phase are exposed on the west coast north of Roseau and on the northern side of the Boeri River, where they lie on top of andesitic lava flows of Pliocene age. Characteristic of this phase are thick, coarse-grained block and ash flow deposits which are interbedded with conglomerates that represent their reworked equivalents. The conglomerates are well exposed near Canefield on the west coast. Locally these deposits are overlain by young reef limestones. Deposits of phase 2 are pumiceous in character and reflect a shift from Pelean to Plinian-style activity. Ignimbrites from these eruptions cover an area of 62 km^2 and are mainly exposed in two tongues, one extending northeast towards the valley of the Pagua River and the other northwest to reach the west coast at Layou, where at least three flow deposits are exposed. One of these deposits has been dated at >40,000 years B.P. (Wadge 1989). Further inland, the ignimbrites are much thicker, reaching thicknesses of >180 m in the upper reaches of the Layou river (Wills 1974). The eruption that led to these pumiceous deposits is thought to have produced a caldera of diameter of about 6 km within the northern part of the Central Graben (Demange et al. 1985; Roobol and Smith unpublished data). During the third phase, the current complex of Pelean domes was extruded into a large 3.5 km diameter crater with a rim preserved to the east. Another crater rim to the southwest of the domes possibly represents the margins of a younger and smaller crater associated with the Pelean activity. Eruptions associated with these domes produced an extensive apron of block and ash flow deposits. These deposits have yielded radiocarbon ages of 17,240 (Wadge 1989) and 25,310 (Roobol et al. 1983) years B.P.

Historical eruptions

There have been no reports of historical eruptions from the Trois Pitons centre.

Future eruptions

There is no evidence for recent activity at the Trois Pitons centre, but occasional shallow seismicity beneath the volcano together with its youthful appearance indicates it may erupt again. Future eruptions could be either dome-forming or explosive, and are likely to originate from the summit region. Until more detailed work has been done on this centre it is impossible to determine the likelihood of a future eruption.

Grand Soufrière Hills

The Grand Soufrière Hills is a poorly-studied, major volcanic center situated on the southeast coast. It is deeply dissected, but has a distinct circular crater 1.9 km in diameter that opens to the east. A Pelean dome occupies the centre of the circular crater, and pyroclastic deposits mantle the southeastern flank of the volcano. Lava flows and dikes forming headlands protruding into the Atlantic Ocean on its southeastern flanks may be exposed remnants of the underlying Miocene basement.

Past eruptive activity

Sigurdsson and Carey (1991) describe a pyroclastic fan extending southeast from the breached crater, and outcrops at Corossol reveal a sequence of block and ash flow deposits, a thin blast deposit, a mudflow deposit and pumiceous pyroclastic flow deposits (ignimbrite), indicating a range of past-activity at this centre. To the southeast of the Grand Soufrière Hills centre on the coast there are a number of unconsolidated valley-fill block and ash flow deposits suggestive of relatively recent activity. A megabreccia of large (up to 3 m) flow-banded andesite clasts set in a semi-lithified medium-grained ash matrix exposed at Pointe Mulatre is also thought to have been derived from the Grand Soufrière Hills (Sigurdsson and Carey 1991). Two dates have been obtained from samples from block and ash flow deposits from this center, a K-Ar age of 0.8±0.4 Ma (Wadge 1989) and a radiocarbon age of 10,320 years B.P. (Smith and Roobol unpublished data). A further radiocarbon date of 11,000 years B.P. was obtained from the blast deposit at Corossol (Sigurdsson and Carey 1991). The 0.8 Ma age is thought to reflect 40Ar contamination from magmatic gases and thus may be too old (Wadge 1989).

Historical eruptions

There have been no reports of historical eruptions from the Grand Soufrière Hills centre.

Future eruptions

Very little is known about the Grand Soufrière Hills centre, and until more detailed work has been done it is impossible to determine the likelihood of a future eruption. Currently there is no evidence of a voluminous magma reservoir beneath this centre and the probability of a large-scale magmatic eruption is considered remote. However, two 10 - 11 ka ages indicate there has been some activity here in the not so distant past, and we believe it should be regarded as potentially active until new information becomes available to clarify its eruptive history.

Seismicity

At least half of all the seismic swarms that have occurred in southern Dominica in historic times have been associated with the Plat Pays volcanic complex. The most recent major volcanic earthquake swarm in Dominica occurred between September 1998 and July 2000, and was associated with the Plat Pays volcanic complex and the Morne Anglais/John centre (Seismic Research Unit 2000). By July 2000 over 1,500 shallow volcanic earthquakes had been recorded by the seismograph network, many of which were felt. Activity decreased after July 2000, but earthquake frequency remained above pre-swarm background levels and is currently (2004) still elevated. The swarm consisted mainly of about 19 earthquake sequences each 1-3 days in duration spaced at intervals of a few weeks to months, with smaller, more widespread events between these main pulses (Stasiuk et al. 2002). Over the course of the swarm, the summation of the sequences delineated a dominant, subvertical sheet-like central zone to the swarm in the Bellevue Chopin - Loubiere area at a depth of 2 to 6 km, with arcuate extensions extending north toward Morne Trois Pitons, and southwest and south, roughly parallel to the margin of the Soufrière depression. The swarm is interpreted as a result of fracturing and fault slip on an existing weak zone, as a form of strain release resulting from magma pressurization in the vicinity of Morne Anglais (Lindsay et al. 2003).

From September 1998 to July 2000 Dominica experienced a major earthquake swarm associated with the Plat Pays volcanic complex and the Morne Anglais/John centre. Details of this swarm are discussed above in the section on seismicity of the Plat Pays volcanic complex.

Much of the pre-1997 seismicity in southern Dominica appears to underlie the Wotten Waven caldera. Occasional volcanic earthquakes also occur beneath Micotrin.

Although most of the historic earthquake swarms in Dominica have occurred in the south of the island, there have also been several periods of intense activity in the north; in 1841, 1893, and more recently in 2000 and 2003. The most intense of these occurred in April 2003, when more than 500 earthquakes were recorded in less than a week. It is likely that the earthquakes recorded (and also strongly felt) during both this swarm and that of 2000 were volcanic in nature.

Most epicenters cluster in an arcuate zone measuring 10 km from north the south and which opens to the west. This zone includes the Morne aux Diables volcano as well as the north-western flanks of Morne Diablotins, and may represent a ring fault associated with Morne aux Diables. Although some of the larger events do plot near the central vents of Morne aux Diables, the lack of unambiguous association with either of these two centers does make it difficult to determine the significance of these events.

Monitoring

Continuous instrumental monitoring of earthquakes in Dominica began in 1953 when the first seismograph was installed in the Botanical Gardens. This equipment was in operation until 1979 when it was damaged by hurricane David. In 1974 a temporary network of 4 additional seismographs was installed to record and locate the earthquakes occurring in southern Dominica at that time. In 1980, when monitoring capability was being restored after the hurricane damage, the permanent station was moved to Morne Daniel. Four additional permanent stations were installed in response to the 1985/86 swarm. A major network upgrade was completed in 1998, just prior to the most intense seismo-volcanic activity in Dominica since instrumental monitoring began. Two further stations were added in 2000 and

2003, and the network now (2004) comprises 11 permanent stations. Ten of these stations transmit their data to two complete seismograph network base stations at Morne Daniel and Wesley. The Guadeloupe Volcano Observatory operates one seismograph in the northwest of the island; data from this instrument are included in the Dominca network.

Between October 1998 and April 1999 a 19-station GPS network was established in southern Dominica, and in early 2004 a network of 8 stations was installed around Morne aux Diables in the north. These networks are reoccupied at regular intervals to monitor for ground deformation. Gases and fluids from geothermal areas in Dominica are collected and analysed at roughly half yearly intervals to look for thermal or compositional variations which may reveal changes in the behaviour of the volcano.

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