ASSESSMENT OF THE HAZARDS AND RISKS ASSOCIATED WITH THE SOUFRIERE HILLS VOLCANO, MONTSERRAT

Twelfth Report of the Scientific Advisory Committee on Montserrat Volcanic Activity

Based on a meeting held between 9 and 11 March 2009 at the Montserrat Volcano Observatory, Montserrat

Part I: Main Report

Issued on 3 April 2009

Summary

(i) The episode of explosions and lava extrusion on the west side of the dome between 2 December 2008 and 3 January 2009 added a new lobe of lava to the dome and produced pyroclastic flows that reached the sea to the west, east and south. Explosions from 2 to 5 December were non-pumiceous and generated ash columns up to 15 km high, whilst those of 3 January were pumice-rich and produced an 11 km-high column. The activity probably initiated in the vent produced by the 28 July 2008 explosion above Gage's Wall. During the course of the lava extrusion between 10 December and 3 January the vent for the growing lobe moved eastwards closer to the position of the old, central vent. Since January incandescence and gas release has been more central, suggesting that any resumption of extrusion may be from there.

(ii) The consecutive episodes of explosions and extrusions: July-August 2008 and December 2008-January 2009, suggest that the volcano may have changed its mode of extrusive behaviour from long- to short-period episodes of extrusion and pause. We think that the large lava dome sitting on the feeder conduit may be acting as a pressure valve, inhibiting magma rise and shortening the duration of the magma flow, and that this behaviour, rather than a resumption of the long-period extrusive episodes, is more likely to continue. An alternative explanation, which we think less likely, is that the short eruption episodes result from a reduction in the pressure in the deep magma reservoir. Such a scenario could be the precursor to the end of the eruption. However, we see no signs yet that this is the case.

(iii) The resumption of lava extrusion, probably from a central vent high on the dome, is the most likely significant event over the next year. As in the last two episodes lava extrusion may begin with an explosion. An eruption from a central vent could send pyroclastic flows to the north and into Tyer's Ghaut, as we saw in January 2009. The lava dome is now larger than ever and the risk of major dome collapse resulting in large pyroclastic flows or lateral blast to the north and west remains, but at low levels of probability. Each time the magma tries to make its way to the surface through the large lava dome after a pause, there is the danger of increased instability within the dome. However, the probability of this leading to whoesale collapse of the dome into the Tar River Valley is reduced to about 1-in-5.

(iv) Using a quantitative risk assessment method for the Hazard Zones (Fig.1), we have estimated the annual risk of death to individuals from the volcano, and find that it has risen slightly from that calculated six months ago. For a full-time resident of Zone A the risk level is 1-in-9,100 (up from 1-in-11,000 six months ago). For a full-time resident in Zone B the risk level is 1-in-720 (up from 1-in-900 six months ago). Risk levels north of Nantes River remain extremely low (about 1-in-4 million).

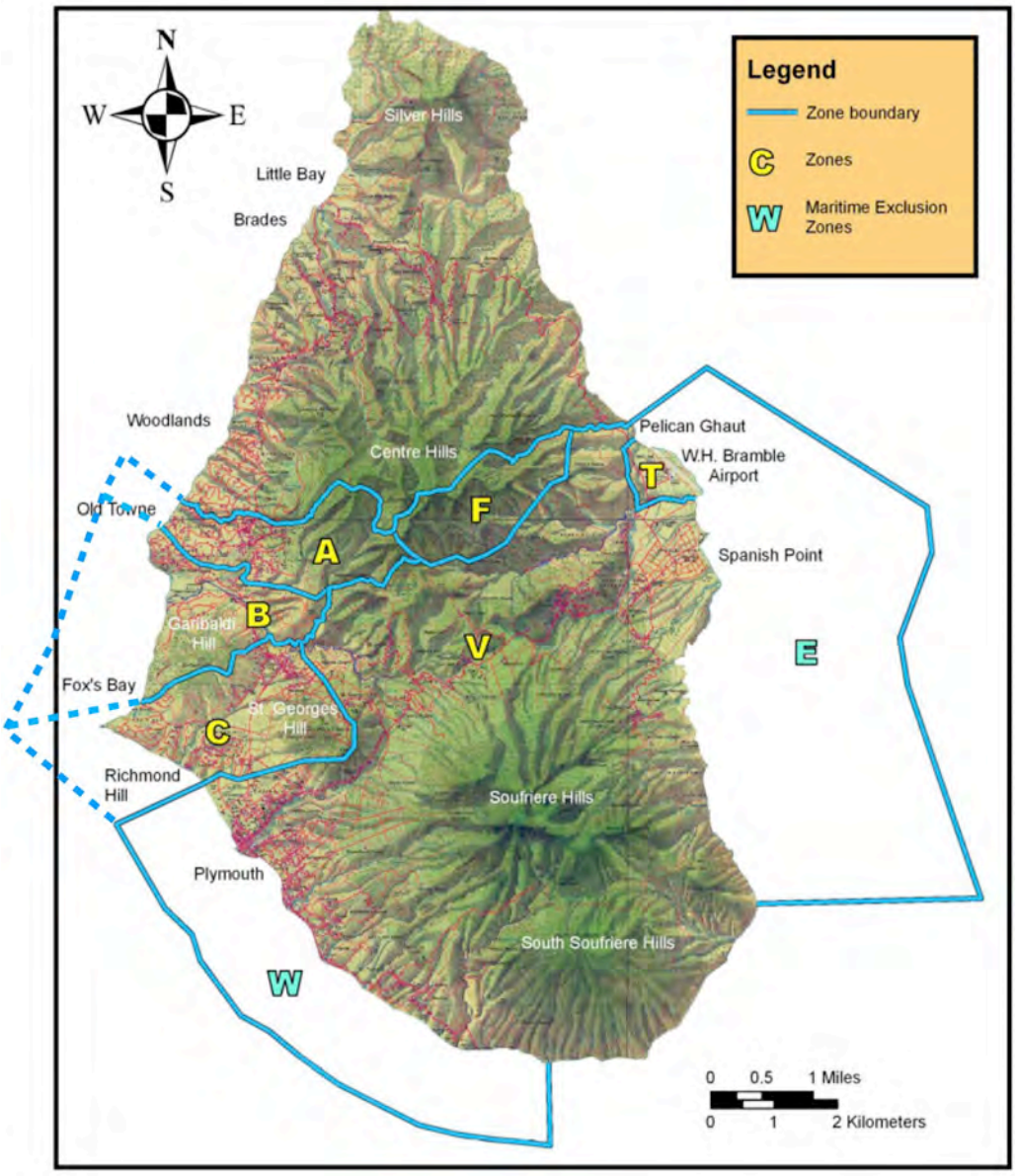

Fig.1 Hazard Zone boundaries of the Hazard Level System. The suggested extension of the boundaries offshore western Montserrat within the Maritime Exclusion Zone is shown.

Contents

Introduction

1. The twelfth meeting of the Scientific Advisory Committee (SAC) on Montserrat Volcanic Activity took place at the Montserrat Volcano Observatory (MVO) from 9 to 11 March 2009. This report is the main product of that meeting. The Committee was commissioned by the Foreign and Commonwealth Office and operates under the Code of Practice for Scientific Advisory Committees issued by the Office of Science and Technology. The Terms of Reference for the Committee are presented in Appendix 1, and the agenda of the meeting is given in Appendix 2.

2. There are two parts to this report: Part I contains the main findings and Part II contains the technical aspects of the assessment. A Preliminary Statement from the full SAC meeting was issued on 11 March 2009 (Appendix 4). A public meeting was held on the evening of 12 March at the Primary School in Salem to explain the preliminary findings to the public under the chairmanship of Mr Keith Dyet of the DMCA. A radio interview of Wadge and Acting Director Stewart by ZJB's Kafu Cabey based on the findings of the meeting was recorded on 11 March 2009. Appendix 5 provides a glossary of technical terms, and Appendix 6 gives a version of the Chief Medical Officer's (CMO) scale of risk.

3. We were made to feel most welcome at MVO by Acting Director Roderick Stewart and the rest of the staff. As usual there was a free and beneficial exchange of ideas and opinions. The explosions and lava extrusion of December 2008 and January 2009 have prompted reappraisal of the way we think the volcano is likely to behave during a resumption of magma supply to the surface. This issue dominated the meeting.

Recent Volcanic Activity

4. The period from December 2008 to January 2009 saw the second short-lived episode of explosions and lava extrusion since the end of the last long-lived period of lava extrusion in April 2007 (the first was in July-August 2008). Most of this activity was from the western side of the lava dome above the Gage's Valley, though small collapses of the dome lava, increasingly exposed by erosion of the talus on the eastern side, occurred regularly.

5. Unlike late July 2008, when there was a sustained swarm of precursory seismicity prior to the explosion that initiated that episode, there was very little seismicity before the explosion at 9:35 pm on 2 December 2008 and no warning could be issued. A pyroclastic flow derived from a collapse of the lava dome reached the sea at Plymouth starting fires whilst a 15 km high ash cloud released a pulse of sulphur dioxide into the stratosphere. The flow collided with the southeastern side of St George's Hill producing a surge that reached the summit but did not flow down the other side. Surges also reached Aymers Ghaut and Richmond. Three smaller explosions occurred on 3, 4 and 5 December near the 28 July 2008 vent and above the Gage's Wall vent that had been active since early 2006. The rocks ejected did not include pumice.

6. By 10 December 2008 lava was extruding and producing rockfalls and pyroclastic flows into the Gage's Valley while the seismicity changed from being dominantly hybrid events to rockfall events. By 19 December a substantial new lobe of lava had grown onto Chances Peak. As the elevation of the point of extrusion increased so did the ability of dome collapses to generate flows to both north and south. From then until early January rockfall seismicity increased slowly as lava extruded at a rate of about 5 cubic metres per second. Pyroclastic flows into the White River in the south reached the sea, whilst a flow on 2 January reached as far as Lees in the upper Belham Valley via Tyer's Ghaut.

7. Two explosions at 4:47 and 7:07 am on 3 January 2009 produced mainly pumice, unlike the similar-size explosions of 2 December. The pumiceous nature of the rocks indicates an origin deep within the conduit. By this time the vent was higher on the dome, near the long-term location of extrusion from the conduit. Following the explosions activity stopped abruptly. Later observations show that the old Gage's Wall vent was buried by lava and apparently blocked. Evidence for a shift in vent location was provided by observations of incandescence and degassing from the central, older (2007) part of the dome.

Monitoring Results

8. Seismicity has been at generally low levels since August 2008, apart from the December 2008 - January 2009 episode. During this episode volcano-tectonic events increased initially, though not sufficiently to give any precursory warning of the explosion on 2 December, and were followed by hybrids events. These were replaced by long-period and rockfall events as lava extrusion increased after 10 December. From about 21 December until the episode-ending explosions of 3 January 2009 the seismicity showed increasingly cyclic behaviour with a period of about 4 hours.

9. The GPS data continued to show the inflationary behaviour seen since April 2007, until December 2008. Because of access problems the data from the South Soufriere receiver have not been available for much of the time. However, a new scheme for processing the GPS data now means that the whole-island pattern of deformation can be assessed more readily without focussing on one baseline (MVO1-SOUF) as before. These data show a clear change to deflation during the December 2008 – January 2009 explosive and extrusive episode, as we might expect as magma moves from the deep reservoir-conduit system to the surface.

10. The volcano continues to emit considerable quantities of gas as it has for most of the eruption. Daily rates of sulphur dioxide output have been above the long-term average for most of the past year. The main exceptions to this have been during the two short extrusive periods (July-August 2008 and December 2008-January 2009) when flux levels fell noticeably.

11. Detailed petrological analysis of samples from the 28 July 2008 event shows that the pumice came from a depth of at least 2 km. This answers one of the questions posed at the last SAC. The magma involved in this event clearly did not come

solely from the dome but involved new magma rising from depth. We cannot yet answer the equivalent questions about the 2 December explosion, which was non-pumiceous, though the pumice-rich 3 January explosion was probably also sourced from deep within the conduit.

Probable Future Behaviour

12. Whilst there is little surface activity at the time of writing, the evidence from the seismicity, gas and deformation monitoring over the last 6 months is that the deeper volcanic system is still active and that the eruption cannot be considered to have stopped.

13. Up until now much of our thinking about the long-term behaviour of the volcano has come from the observed pattern of 1.5 to 3.5 year-long periods of lava extrusion separated by similar periods of no extrusion, or pause. It is now two years since the end of the last major eruptive episode and there have been two episodes of short-lived lava extrusion in July-August 2008 and December 2008 – January 2009 within that period. The second of these involved a much larger volume of magma extruded at a moderate rate and generated an abrupt deflationary signal detected by GPS. What do these two events represent and will this new type of behaviour continue?

14. In previous reports we had emphasized that this was the first time that lava would be extruded through a large dome. We think that the overburden pressure exerted by this dome on the rising magma may be the reason why the two extrusive events were relatively short-lived. The dome may be acting like a pressure valve, necessitating the magma within the conduit to achieve extra pressure to be released. The source for the magma involved could be a deforming dyke. An alternative source for the short-period extrusions could be the magma reservoir itself. It may be that long-term, falling magma pressure within the deep reservoir means that flux to the surface cannot be sustained for longer periods.

15. If the magma reservoir is the source of the short-period episodicity then this may mark the decline in the ability of the volcanic system to erupt at all, effectively heralding the end of the eruption. However, we think the dome-as-pressure-valve mechanism is more likely. One consequence of this latter hypothesis would be that if the dome collapsed entirely (as in July 2003 and May 2006), it is more likely then that protracted extrusion would be re-established.

16. We estimate that the probability that over the next year the next significant event will be the resumption of lava extrusion is 47% and that when that happens it is about twice as likely to be of the short-duration type than reverting to the long-duration extrusion. Wholesale dome collapse into the Tar River Valley remains likely (21% probability it will be the next significant event). Every time lava has to re-establish a pathway through the dome it has the potential to intrude sideways and perhaps de-stabilize the edifice, resulting in major collapse.

Assessment of Volcanic Hazards

17. The serious nature of the threat posed by the volcano was clearly demonstrated again during the December 2008 – January 2009 episode. The explosion of 2 December occurred without any short-term warning being possible, ejecting ballistic blocks of lava up to 2 km away to Lee's Yard. The surge derived from the pyroclastic flow that hit the southeastern side of St Georges Hill reached the summit and could have killed anyone there. Pyroclastic flows reached the sea at Plymouth on two occasions and also at the White River and Tar River deltas. Up to the time the episode stopped, pyroclastic flows of increasing runout were occurring in Tyer's Ghaut, reaching as far as Lee's. Had the episode continued, such flows may well have reached further down into the Belham Valley. So, even this relatively modest episode of lava extrusion at moderate extrusion rates was capable of threatening many parts of western Montserrat.

18. The main sources of hazard remain: pyroclastic flows and surges derived from collapses of the dome, explosions raining ash and rocks and producing column-collapse pyroclastic flows, lateral blasts following removal of the side of the dome, tsunamis and mudflows.

19. The focus of initial extrusion in December 2008 was on the western side of the dome, sending pyroclastic flows into Gage's Valley. Later, the point of extrusion moved further east, closer to the original central vent of the dome, and sent flows to both south and north. We think the next new point of extrusion is most likely to be from such a central location. If the lava is directed northwards, pyroclastic flows could move into the Belham Valley via Tyer's Ghaut quite readily. Flows in other directions would be much less hazardous.

Assessment of Risks to People

20. In this assessment we continue to use the fixed zone approach in which we take each hazardous process identified above, estimate the probability that they will occur and affect a given area of Montserrat and then calculate the risk to which a given number of people in that area will be exposed. The Zones defined by the Hazard Level System (August 2008) are the ones used to define individual risk levels. We use the modified UK Chief Medical Officer's (CMO*) scale (Appendix 7) to convey a qualitative description of the degree of the annualised individual risk based on the numerical estimates, but we also provide some alternative risk measures to add further perspective. Details of the probability and risk calculations are presented in Part II of this report. These risk estimates have large uncertainties and so the reader should not attribute detailed meaning to small numerical differences in quoted risk values. The descriptive CMO scale categories, as reported here, better capture these differences. We have also calculated the increased risk faced by individuals from the volcano by referencing it to the general "background" risk of accidental death thought to be typical for people living in Montserrat (a rate numerically equivalent to 28 per 100,000 people per year).

21. Across the area of central western Montserrat vulnerable to volcanic hazards, the general level of risk has risen slightly since the last assessment. This is due to the

addition of new lava mass to the summit of the volcano in December 2008, the increased likelihood of renewed lava extrusion over the next year that may emerge from a more central vent, and the potential for dome instability arising from internal stresses during re-start.

22. *Risks to people living in Zones A and B*
On the basis of our quantitative risk modelling, the level of annualised risk of death (IRPA) due to volcanic hazards for an individual in each of the populated Zones (A and B) of Fig. 1 is:

Zone A (full-time resident): 1-in-9100, C on the CMO* scale, 1.4*x* background risk level of accidental death

Zone B (full-time resident): 1-in-720, B on the CMO* scale, 6*x* background risk level of accidental death.

For Zone A the individual risk exposure level has increased when compared to that determined at the last, SAC11 assessment, from 1-in-11,000; for Zone B the individual risk exposure level has also increased, from 1-in-900. The IRPA for the Woodlands area remains extremely low, about 1-in-4 million (for SAC11 the corresponding risk was 1-in-5 million). Zone C is unoccupied and we have not calculated a general risk level.

23. *Risks to workers in Zone F (Corbett Spring-Locust Valley)*
This area is one designated for agricultural production with controlled access of limited daytime workers. The individual risk exposure to a person working normal hours in this area is about 1-in-8500 (in the CMO* C band).

24. *Risks to workers in Zone T (Trants)*
Workers extracting sand and gravel from Trant's beach and neighbouring flow deposits are at risk from pyroclastic flows. The probability of a major collapse to the NE, such as would generate big flows towards Trants, is now assessed marginally lower than it was in previous SAC meetings (3% probability in next 12 months). Assuming relevant mitigation measures are used (as discussed in SAC11 report, for example) the Trants workers' situation produces an IRPA of about 1-in-8300, or about 3.1x higher than the occupational risk level for the (UK) extractive & utility supply industry and similar to the exposure in Zone F without mitigation measures. If these protection measures fail, or are not implemented, then the IRPA would be considerably elevated, and closer to 1-in-3300 (as shown for conservatism on Figure 6), or about 6*x* the UK exposure rate.

26. *Risks to workers at Fox's Bay and at Isles Bay*
The construction of a ramp somewhere on the south-western coast of Montserrat would enable barges to be loaded with aggregate trucked from mining sources. One proposal has been to build the loading stage at Fox's Bay. There, the present risk exposure for a worker would be about 1-in-1100 per annum equivalent, or about 19*x* the corresponding UK occupational risk (see Table 2). If the loading stage is located on the coast in the accessible southern part of Isles Bay, behind Garibaldi Hill, the worker risk is estimated to be about 1-in-1730, which is about 12*x* the equivalent UK occupational risk (and currently roughly the same as the

SAC11 risk estimate was for Fox's Bay, back in October 2008). Thus, there is a modest margin of additional safety associated with the Isle's Bay site relative to the Fox's Bay option. This said, worker exposures relating to the transportation of aggregate to the ramp would need to be considered also, but more detail of any proposed operations would be required to address this aspect of the risk discussion.

27. *Risks to workers in Plymouth*

The MVO risk assessment for the salvage of barges beached at White River in October 2008 considered in detail the risk of operations at the Plymouth Jetty under conditions at the volcano at the time (see Komorowski et al., Appendix 3 of MVO Open File Report 09/01). To give a measure of context to that assessment, the annualised individual risk for a worker at the Plymouth Jetty, working normal hours for a whole year under those particular circumstances, would equate to an IRPA of about 1-in-10, given the risk exposure at Plymouth Jetty estimated by MVO in October 2008. Such a level of risk is unconscionably extreme, by any standard, exceeding the exposure of a soldier in a major war. Although the situation at the volcano has changed somewhat since the events of December 2008 to January 2009 (the ensuing further destruction of Plymouth having been admirably anticipated by the MVO risk assessment), similar conditions could return to the volcano very rapidly. Thus even with the quieter, less active conditions at present, it would be imprudent to think in terms of returning to an IRPA of about 1-in-500 per year, which was the value determined for SAC11, prior to the escalation of activity in the western part of the crater. From the elicitation, the chances of a collapse down Gage's towards Plymouth are assessed about 1.6*x* greater than they were last October, so an IRPA of about 1-in-300 might strike the right balance now; any resumption of activity in the west would immediately precipitate the risk exposure in and around Plymouth. As with the Plymouth Jetty situation in late 2008, in all the estimates of worker risk just discussed exposure levels could rise significantly and rapidly if renewed activity develops in an unfavourable location on the volcano. Thus the individual risk estimates should be taken simply as comparative, and each case needs to be assessed on its own particulars and with an eye to how fast conditions could deteriorate.

28. *Risks in the Maritime Exclusion Zone*

The pyroclastic flows and surges of 29 July 2008 almost reached the sea at Plymouth and two of those of the December 2008 – January 2009 episode did reach the sea there and at the White River delta, showing the value of the western component of the Maritime Exclusion Zone. Whilst the probability of flows entering the sea via the Belham Valley at Old Road Bay is much smaller than at Plymouth it is not negligible. Presently, if the hazard rises to Level 4 and Zone B is evacuated, then the area offshore Zone B would not be in the Exclusion Zone. It would be better if this offshore area were to become part of the Maritime Exclusion Zone automatically as the Hazard Level increased. Thus we re-iterate our recommendation from SAC11 that the Hazard Zone boundaries of Zones A, B and C be extended offshore for 2 km as in Fig.1 and the sea areas be subject to the same restrictions as the rest of Maritime Zone W (i.e. daytime transit, at Levels 2 and 3 and essential workers only at level 4 and above) when the adjacent land Hazard Level changes (Fig.1).

The Operation of MVO

29. This meeting was Dr Nico Fournier's last interaction with the SAC before taking up his new post in New Zealand. We thank him for his contribution to the MVO as Acting Director and for making major improvements to the GPS network.

30. Even after one year, the new contract with the Government of Montserrat had not been signed at the time of the meeting and has created a planning and implementation barrier that has affected MVO over the last year. The six vacant posts (Director, seismologist, two volcanologists, software engineer and outreach officer) had been advertised, and candidates short-listed. It is hoped that the Director position will be filled by June 2009. However, there is a danger of losing interested candidates during any further delay. We look forward to the implementation of the plan set out in the original proposal once the contract is in place.

31. Caribbean Helicopters has been able to re-instate a minimum 2-hour/week service since the end of February 2009 after a hiatus of five months since their fleet of helicopters was damaged by Hurricane Omar. Whilst some helicopter flights were made with a Lynx from Royal Fleet Auxiliary HMS Waveruler, with a French military helicopter from Guadeloupe, and with some fixed-wing observations flights during the interim, a major backlog of work had built up. A 3-month trial dispensation to use a single-engine rotary-wing aircraft had been granted (no twin-engine aircraft being available). It is hoped that this will be extended at the end of this period.

32. Towards the end of the December 2008 – January 2009 episode when larger pyroclastic flows were entering Tyer's Ghaut it became increasingly apparent that the ability to detect such flows in real-time, and raise an alert, was limited – especially at night. The seismic network, which should be able to determine the location of most pyroclastic flow signals, is relatively insensitive to flows in Tyer's Ghaut. The thermal camera mounted at MVO had proved a valuable addition in this regard. Installing the new visible, fixed cameras and using the acoustic flow meters (from the Barclay project) would also help. The yet-to-be-installed crater rim tiltmeters (perhaps including one on Gage's Mountain) could also give some real-time contextual information. A number of other technologies that could potentially help to monitor the dome and its immediate surroundings were discussed: photogrammetry, lidar, satellite radar, AVTIS ground-based radar, airborne platforms (drones, tethered balloons), "spider" frames, ash trays, temperature gauges in Plymouth.

33. The CALIPSO strainmeters/dilatometers have never been of day-to-day use to MVO. The ability to detect secular trends even with substantial post-processing is limited. However, the detection of events (such as strain associated with the GPS-detected December-January event) should be achievable. The MVO GPS network will be further improved when the Spring station (recently destroyed) is replaced and the Roche's Yard relay for the SSOUF station is fixed. The new, ITRF-based

processing scheme (using GAMIT software) is nearly complete and should allow automated daily solutions. Forward and inversion modelling code should also be available soon for timely analysis. The upgrade to the DOAS-based sulphur dioxide monitoring system with new instruments, possibly two new stations and a new wind model (now being developed at Leeds), is now planned for completion by the end of 2009. There has been no progress on dome surveying since the departure of Dr Ryan. Infrasound from microphones at MVO, Waterworks Estate and St George's Hill should help resolve explosion dynamics. Dr Humphrey's petrological analyses are yielding interesting results, which would be more useful from a monitoring and assessment standpoint if the time for sample collection and processing could be reduced.

34. The collaboration with the University of Florence on the thermal camera and infrasound sensors has been very beneficial. Gravimetry, via a continuous instrument at Olveston and surveys in conjunction with the University of Bristol is ongoing. The TerraSAR-X monitoring of the volcano with change-difference radar imagery with the University of Reading has proven helpful during times of explosive and extrusive activity and will be continued.

35. The Hazard Level System has been used to change public access to areas around the lower Belham Valley twice in the last six months. A new, detailed photo-map of the A-B-C Zone boundary lines that makes the status of individual houses clear has been produced. Consultation with individuals in the construction of this and in the implementation of controlled access appears to have helped lower the general level of resentment usually felt when reduced access measures have been applied.

36. The new outreach initiative effort: "Living with our Volcano", has been well-received. New signs to the observatory and a new logo have been created. Re-design of the main web pages is now overdue. The Interpretation Centre will be re-deployed elsewhere, probably in Salem, and will require management from the new outreach officer, once in post. Similarly the Business Development Plan can be activated when more staff time is available to drive it forward.

SAC Membership

37. There are no anticipated changes to the SAC membership.

Next Meeting

38. Given the potential for more stop-start activity we see the need to meet again in six months. The period 7-9 September 2009 is the proposed time.

Appendix 1: Constitution of the Scientific Advisory Committee on Montserrat Volcanic Activity

This document outlines the main responsibilities of the Scientific Advisory Committee (SAC) on the Soufriere Hills Volcano, Montserrat. The document includes the terms of reference for the SAC and a membership template. The SAC is to replace the Risk Assessment Panel and is commissioned by the Overseas Territories Department (OTD) of the Foreign and Commonwealth Office (FCO). The SAC will work according to the Office of Science and Technology (OST) Code of Practice for Scientific Advisory Committees.

Terms of Reference

The main responsibilities of the SAC are:

1. to carry out regular hazard and risk assessments of the volcano in co-operation with the Montserrat Volcano Observatory (MVO) and to report its findings to HMG and the Government of Montserrat; and

2. to provide scientific advice at a strategic level to HMG and the Government of Montserrat outside these regular assessments in co-operation with the MVO.

NB: The "Government of Montserrat" will normally mean, in the first instance, the Governor as s/he has the constitutional responsibility for the safety of the Montserrat population. The Governor will be responsible for ensuring appropriate dissemination of SAC assessments or recommendations to the Government and people of Montserrat.

The SAC is also required to perform these additional functions:

3. to provide independent advice on the scientific and technical operations of the MVO to ensure that the work matches the level of risk;

4. to provide scientific advice and assistance to the MVO as required by the MVO Director; and

5. to offer advice on new developments that were not foreseen when the TORs were set up, and if appropriate make recommendations for changes to the TORs.

The SAC will carry out its activities within the OST Code of Practice for Scientific Advisory Committees. The SAC will be responsible to the UK Government through the FCO (OTD). The SAC will not incur expenditure without prior FCO (OTD) authority.

These general terms of reference are supplemented with the following specific points:

(a) The work of the SAC concerns scientific assessment of the volcanic activity and related hazards and risks. This scientific work is an input to decisions made by the HMG and the Government of Montserrat related to the safety of the people of Montserrat (such as evacuation and extent of Exclusion Zones), to issues of planning and sustainable development of Montserrat and to the mitigation of external hazards (e.g. to civil aviation).

(b) The provision of scientific advice to the Governor and Government of Montserrat is the responsibility of the MVO and its Director. The SAC has the

function of assisting the MVO in its major missions in all respects of its activities and to assist in matters relating to the provision of long-term and strategic matters.
(c) The MVO Director (or scientific staff designated by the Director) participate in all SAC activities except for ToRs 3 and 4.
(d) The SAC has the function of giving advice and assistance to MVO and the management contractor relating to scientific matters as required by the MVO Director. Such independent advice to the MVO may include appraisal of the technical expertise of staff, evaluation of the monitoring systems, assessment of proposed research projects by external groups, and advice on technical matters.
(e) With respect to ToR 3 the Chair of the SAC will be a member of the MVO Board of Directors and can provide independent advice to the Board as required. The Chair will be expected to attend MVO Board meetings (currently twice a year).
(f) Given the special circumstances of Montserrat as a United Kingdom Overseas Territory, reports of the SAC would be provided for both Governments. Reports would also be given to the MVO Management Board.
(g) The SAC will be required to present its findings in a manner suitable for release to the public. It will also be required to assist the Governments and the MVO in explaining the activity of the volcano and the scientific information pertinent to decision-making by the authorities.
(h) The SAC will liaise with other relevant scientific organisations or committees as required, which might for example include regional scientific institutions and the Department of Health Committee on health hazards from volcanic ash.
(g) The Chair of the SAC will make an annual report to the MVO Board of Directors.

MEMBERSHIP
Membership of the SAC will be at the invitation of the FCO (OTD) and will cover the key areas of expertise required to assess the hazards and risks of erupting volcanoes. Expertise will include such areas as volcanology, volcano geophysics, and hazard analysis. The SAC will continue the approach of the former Risk Assessment Panel that was endorsed by the UK Chief Government Scientist in December 1997. Thus the Committee requires a facilitator as a member for applying expert elicitation methods to estimate volcanic risk. These considerations imply a minimum of four members, excluding the Director of the MVO. Additional experts can be invited to participate as required by the Chair, with prior agreement from the FCO (OTD), if a lack of expertise becomes apparent on a particular issue. As required by the Code the SAC is expected to consider external opinion. The membership will be considered on an annual basis with a view to regular changes and refreshment of membership.

MEMBERSHIP TEMPLATE
Members invited to serve on the SAC for the Montserrat Volcano are expected to attend all hazards and risk assessment meetings and to participate in the formalised elicitation procedure. Members have the responsibility to use their scientific judgement and expertise to meet the Terms of Reference. Opinions of the Members on scientific matters should be expressed through participation in the work of the SAC. Divergences of scientific opinion will normally be reported in terms of scientific uncertainty through the formal expert elicitation procedure. Differences that cannot be incorporated through the elicitation methodology

should be included in the reports of the SAC as required by the OST Code. The Chair of the SAC, or his or her delegate from the Committee, will be responsible for presenting the findings of the SAC's work to the Governments of Montserrat and the United Kingdom and to the public in co-operation with the Director of the MVO. Any disagreement or divergence of opinion with the Director of the MVO that cannot be reconciled or incorporated through the elicitation method should be reported through the MVO Board of Directors.

SECRETARIAT

The FCO (OTD) will provide a Secretariat for the SAC, as set out in the Code of Practice. FCO (OTD) will reimburse premium economy travel costs, reasonable hotel accommodation, meals and professional fees (once agreed) in full. The SAC will not incur additional expenditure without prior FCO (OTD) authority. The Secretariat's main point of contact is Alison Marshall, Desk Officer for Montserrat in OTD. His contact details are as follows:

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Tel: +44 20 7008 3123
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Appendix 2: Agenda SAC12 9-11 March 2009

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3. December 2008- January 2009 episode
    - TerraSAR-X data
    - Significance in terms of system dynamics
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    - Monitoring
    - Collaboration
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    - Outreach
14. SAC Matters
    - Risk Management Study
    - Membership
    - Next meeting

Appendix 3: List of Participants

Chairman

Prof. G. Wadge	ESSC, University of Reading, UK

Committee members

Dr. W.P. Aspinall	Aspinall & Associates & Bristol University, UK
Prof. J. Neuberg	Leeds University, UK
Prof. B. Voight	Penn. State University, USA
Prof. K.V. Cashman	University of Oregon, USA

People present in an advisory or observer capacity

Mr. R. Stewart (Acting Director, MVO, SRC)
Dr. Richard Roberton (MVO, Director SRC)
Dr Nicolas Fournier (MVO, SRC)
Dr. E. Jospeh (MVO, SRC)
Mr. T. Christopher (MVO)
Mr R. Syers (MVO)
Mr. C. Williams (MVO)
Mr. F. Dondin (SRC)
Ms L. Chardot (IPGP)
Ms A. Donovan (U. of Cambridge, UK)

Appendix 4: SAC12 Preliminary Statement, 11 March 2009

After three months of relatively little surface activity following the explosion of 28 July 2008, there was a period of one month of lava extrusion that was preceded by explosions on 2 December 2008 and culminating in further explosions on 3 January 2009. This new lava was extruded from a vent high on the western, Gages, side of the dome. Pyroclastic flows from this activity reached the sea at Plymouth, White River and entered the Tyer's Ghaut reaching as far as Lees. The new lava added to the dome on the western side increases the mass available to any collapse to the west or north. Since early January there has been no further lava extrusion. It appears from the current degassing and incandescence that the lava vent has become more centralised.

The July and December episodes of explosive and extrusive activity are unusual compared to the longer duration periods of extrusion and pause that we have seen in the past. They may reflect the way the volcano is responding to renewed magma rise beneath the large existing dome. The volcano may be entering a period of shorter episodes of extrusion and accompanying explosions with intervening shorter pauses. We think lava extrusion on the dome will be the most likely next development. Whilst the volcano appears to be quiet at the surface the MVO measurements of seismicity, deformation and gas indicate that the volcano remains active. Thus there is no sign of the end of the eruption yet and we estimate that the likelihood of that occurring during the next year is about 6%.

For people living in Zones A and B the risks have risen again slightly. The more frequent stop-start character of the dome growth will make the management of the risk levels more trying.

Appendix 5: Glossary of Terms

Andesite: The name given to the type of magma erupted in Montserrat.

Basalt: The type of magma entering the magma reservoir below Montserrat.

cGPS: Continuously-measured Global Positioning System for repeated measurement of ground deformation.

Conduit: In a volcano magma flows to the earth's surface along a pathway known as a conduit. The conduit is usually thought to be a cylindrical tube or a long fracture.

Dyke: Vertical, tabular body of magma within a fracture below the volcano that can act as the conduit for flow to the surface.

EDM: Electronic Distance Measurements made by laser ranging to reflectors gives length changes of a few millimetres accuracy over several kilometres.

Hybrid/LP Seismicity: Varieties of earthquake signal often indicative of magma motion in the upper part of the conduit.

Lava: Once magma gets to earth's surface and extrudes it can be called lava. Below ground it is always called magma.

Lateral Blast: An energetic sideways-directed explosion from a lava dome that can generate highly fluid pyroclastic flows.

Magma: The material that erupts in a volcano is known as magma. It is not simply a liquid, but a mixture of liquid, crystals and volcanic gases. Magma must contain enough liquid to be able to flow.

Magnitude: The magnitude of an explosive eruption is the total mass of material erupted.

Mudflow: A flow of rock debris, ash and mud that occurs on many volcanoes particularly during eruptions and after very heavy rain

Pyroclastic flow: These are flows of volcanic fragments similar to avalanches of rock in landslides and snow avalanches. They can be formed both by explosions and by parts of an unstable lava dome avalanching.

Pyroclastic surge: These are also flows, but they are dilute clouds rather than dense avalanches. A surge is a rapidly moving mixture of hot particles and hot gas and their behaviour can be compared to a very severe hurricane. Surges can be formed above pyroclastic flows or directly by very violent explosions.

Swarm: A large number of, in this case, earthquakes occurring in rapid succession with characteristics indicating they are generated from a similar region in the earth. Can merge into tremor.

Volcanic ash: Ash particles are defined as less than 4 millimetres in diameter. Respirable ash consists of particles less than 10 microns (a micron is one thousandth of a millimetre) in diameter.

Appendix 6: Modified Chief Medical Officer's Risk Scale (CMO*)

Negligible (F)*:* an adverse event occurring at a frequency below one per million. This would be of little concern for ordinary living if the issue was an environmental one, or the consequence of a health care intervention. It should be noted, however, that this does not mean that the event is not important – it almost certainly will be to the individual – nor that it is not possible to reduce the risk even further. Other words which can be used in this context are 'remote' or 'insignificant'. If the word 'safe' is to be used it must be seen to mean negligible, but should not import no, or zero, risk.

Minimal (E)*:* a risk of an adverse event occurring in the range of between one in a million and one in 100,000, and that the conduct of normal life is not generally affected as long as reasonable precautions are taken. The possibility of a risk is thus clearly noted and could be described as 'acceptable' or 'very small'. But what is acceptable to one individual may not be to another.

Very low (D)*:* a risk of between one in 100,000 and one in 10,000, and thus begins to describe an event, or a consequence of a health care procedure, occurring more frequently.

Low (C)*:* a risk of between one in 10,000 and one in 1,000. Once again this would fit into many clinical procedures and environmental hazards. Other words which might be used include 'reasonable', 'tolerable' and 'small'. Many risks fall into this very broad category.

Moderate (B)*:* a risk of between one in 1,000 and one in 100. It would cover a wide range of procedures, treatment and environmental events.

High (A)*:* fairly regular events that would occur at a rate greater than one in 100. They may also be described as 'frequent', 'significant' or 'serious'. It may be appropriate further to subdivide this category.

Unknown*:* when the level of risk is unknown or unquantifiable. This is not uncommon in the early stages of an environmental concern or the beginning of a newly recognised disease process (such as the beginning of the HIV epidemic).

Reference: On the State of Public Health: the Annual Report of the Chief Medical Officer of the Department of Health for the Year 1995. London: HMSO, 1996.