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RESEARCH ARTICLE

Volcanic hazard communication using maps: an evaluation of their effectiveness

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Abstract Hazard maps are considered essential tools in the communication of volcanic risk between scientists, the local authorities and the public. This study investigates the efficacy of such maps for the volcanic island of Montserrat in the West Indies using both quantitative and qualitative research techniques. Normal plan view maps, which have been used on the island over the last 10 years of the crisis, are evaluated against specially produced three-dimensional (3D) maps and perspective photographs. Thirty-two demographically representative respondents of mixed backgrounds, sex, education and location were interviewed and asked to complete a range of tasks and identification on the maps and photographs. The overall results show that ordinary people have problems interpreting their environment as a mapped representation. We found respondents' ability to locate and orientate themselves as well as convey information relating to volcanic hazards was improved when using aerial photographs rather than traditional plan view contour maps. There was a slight improvement in the use of the 3D maps, especially in terms of topographic recognition. However, the most striking increase in effectiveness was found with the perspective photographs, which enabled people to identify features and their orientation much more readily. For Montserrat it appears that well labelled aerial and perspective photographs are the most effective geo-spatial method of communicating volcanic risks.

Keywords Volcanic hazard map · Volcanic risk map · Montserrat · Volcanic risk communication · Evaluation · Geo-spatial

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Introduction

> *"Although maps are everyday tools for volcanologists, they are often too abstract and difficult for many users of volcano warnings".* (Newhall 2000, p1190)

A map is an illustration of the space and environment around us, coded and simplified to allow communication (Muehrcke 1978; Monmonier 1996, 1997). Hazard maps have become a fundamental means of communicating volcanic risk to the public. They are used to explain and display the distribution of hazards, risk levels of areas likely to be affected and areas where access may be denied in times of crisis. Maps also form an integral part of emergency plans and response where they are considered vital for the coordination of preventative, protective and rescue evacuations (Dymon and Winter 1993; Nourbakhsh et al. 2006). This study examines the effectiveness of such maps for communicating volcanic risk on the island of Montserrat in the West Indies.

Volcanologists and other scientific professionals are trained to interpret geospatial information in many different contexts. There is little empirical research to support the assumption that a lay audience will be able to read and interpret a topographic hazard map with the same skill (Handmer 1985) or that presenting the information in this way modifies public behaviour or attitudes towards that hazard. If, for example, non-scientific users were reluctant to confess to map reading difficulties and have a different spatial 'reality' to the scientists, it is likely that misunderstandings and confusion will prevail (Newhall 2000). This would have serious consequences for risk communication.

No systematic studies exist which evaluate how non-specialists decode and comprehend the information contained within volcanic hazard maps. However, limited research in the case of flood map comprehension has shown that standard contour-based maps are not an effective method for communicating hazard and risk information (Handmer and Milne 1981). To make matters worse, volcanic maps often become a 'work in progress' due to changing volcanic activity and knowledge, causing the hazard and risk zones to be in a constant state of adjustment, thereby adding to the confusion.

The purpose of this study was to pilot a methodology for the systematic evaluation of the effectiveness of maps as methods of risk communication and to provide *evidence* for ways in which maps could be improved if necessary. Both qualitative and quantitative methodologies were used to test map comprehension on a representative sample of local residents on the volcanically active island of Montserrat in the Caribbean. Different map formats were used to appraise their impact on understanding. As the first study of its kind dealing with volcanology, we also present a brief review of the use of volcanic hazard maps and a summary of literature relevant to testing map comprehension. Much of the relevant literature comes from the use of maps for communicating risk information about other natural hazards, in particular flooding.

Volcanic hazard maps

Volcanic hazard maps usually display the current or potential extent of dangerous volcanic flows (lava, pyroclastic or lahar) together with the potential distribution of tephra. Topography is a major factor controlling the distribution of many volcanic hazards, therefore the presentation of relief, traditionally displayed with contour lines is a very important component. Maps also often show main areas of housing and road networks.

Hazard maps relating to volcanic activity can be extremely complex. Volcanic eruptions, as distinct from many other natural hazards (e.g. earthquakes, tsunami and floods) may subject any one particular location to a range of different hazards. A town, for example, could be at high risk from ash fall but low to moderate risk of pyroclastic flows. The differing types of activity are usually either represented as separate hazards or as zones where the assigned hazard status is an accumulation of the hazard from each of the potential types of activity. Hazard maps are very often combined with socio-vulnerability information to produce risk maps.

The use of hazard maps on Montserrat

Simplified topographic maps have been used by the Montserrat Volcano Observatory (MVO) as the base for hazard maps throughout its recent and ongoing eruption (Young et al. 1997). These maps have been used to communicate hazard zones to local government officials and the general public. Together, the MVO and local authorities have used these hazard maps as the basis for risk maps.

Between May 1996 and July 1997 the island was 'micro-zoned' into a number of hazard zones whose risk status varied in accordance with the status of the current Alert Level (see Kokelaar (2002) and Aspinall et al. (2002)). The purpose of these geographic divisions was to allow continued utilisation of as much of the island as possible, whilst reducing the need for evacuations. The large number of small zones reflects this pressure for precision (Kokelaar 2002). The states of the zones were associated with five alert levels that reflected changing volcanic activity and determined access to the zones. Eleven different maps were produced over a 13-month period, thus complicating the communication to a lay audience of an already difficult emergency management tool (Pattullo 2000; Kokelaar 2002). Whether understood or not, the changing restrictions on access were often treated loosely by the authorities and islanders (Kokelaar 2002). In response to the event of the 25th of June 1997 (when 19 people were killed in a series of Pyroclastic flows—see Loughlin et al. (2002)) and the escalating volcanic activity, the maps were greatly simplified (Kokelaar 2002) and reduced to an Exclusion Zone, Daytime Entry Zone and Safe Zone. With the exception of some limited movement of the zone boundaries, these remain unchanged until the time of writing (February, 2006). Simplified topographic maps still form the basis for the visual communication of the location of the zones by the MVO and the authorities.

Previous work on natural hazard map comprehension

Despite the increasing use of maps to convey spatial risk information, evaluations of their effectiveness, in particular, their comprehension by the public has largely been neglected (Handmer and Milne 1981; Dymon and Winter 1993; Moen and Ale 1998). The limited literature that exists is largely based on the behavioural response after the release of flood hazard maps and not the comprehension of the map itself. This does not adequately address: (1) whether people can decode the map to understand the information as intended by the communicator; and (2) whether the information, once decoded and understood, will alter the receivers' risk perceptions, awareness and behaviour to conform to that of the communicators.

Roder (1961) evaluated the use of maps on the residents of the Topeka flood plain, in Kansas (USA). The study identified that most people had not received or seen the map before, those that had found problems interpreting contours and even those who knew the area well found it difficult to orientate and locate themselves on the map. Respondents stated that they would rather rely on their own observations and experience of floods than the map.

A literature review by Handmer and Milne (1981) described a slim and embryonic research area that included five studies (including that of Roder (1961)). They concluded that flood maps had a low utility as a source of public information. Problems encountered were partly to do with the level of public interest in the maps as well as their comprehension. However, even if understood, it was clear from the five studies that the relationship between the comprehension and behavioural change in relation to the risk was very weak. This relationship was also confirmed by McKay (1984) who concluded that the perception of flood risk was improved by maps but that this had no impact on the willingness of participants to seek out similar risk information in the future. This study did not evaluate people's ability to use and interpret the map and therefore the positive impact on perceived flood risk cannot be separated from other background information the participants may have received.

Handmer (1985) summarises two studies in Australia where respondents were asked to determine whether their properties lay inside or outside a particular flood zone. He concludes that the general map skills of the interviewees were adequate enough to either locate or approximately locate their houses successfully. However, they had problems interpreting the flood risk information and comprehending flooding probabilities.

The release of hazard maps in advance of experience or visible evidence of the hazard is often met with scepticism and fear by the local authorities, government and also the public (Handmer 1985). This is due to the threat of potential negative effects on house values, insurance rates and the local economy (Yeo 2004). Although there exists some evidence of negative economic effects, there is also evidence to suggest these maps actually have no effect (Yeo 2004). Earthquake and flood risk maps were also not found to have an effect on house purchasing decisions or the take-up of flooding insurance in California (McKay 1984).

Improving the efficacy of maps

Limited literature has shown the value and superiority of aerial photos in aiding spatial comprehension. For example, Delucia (1978) asked respondents to locate, identify, count and estimate features and then answer verification (true/false) statements about features and routes. Aerial photographs were found to be most effective for all tasks except the count and estimate questions where the map was superior. It was inferred that the obliquity of aerial photos presented the interpreter with a view that is much more like a scaled down version of reality.

A study in the New Guinea Highlands found that those who had received some education could interpret aerial photographs despite being unable to read maps (Handmer 1985). This was explained by a combination of improved cognitive skills and the rugged topography that enabled the inhabitants to experience actual aerial views of the landscape. This increase in effectiveness is similar to that attributed to an information filtering difference by Monmonier (1996); in drawn maps the cartographer does the filtering for the user, but with photographs the user filters their own information. Thus, the spatial items are in their correct relative scale, critical to a lay person's understanding. Handmer (1985) points out the importance of recognising the function of the geospatial information; if the purpose is for the public to plan evacuation routes then oblique aerial photographs may be best suited.

A good example of tailoring spatial information to suit different audiences is demonstrated by Lantzy et al. (1998) in which different groundwater contamination maps are used by: (a) scientists for recognising the extent of the problem; (b) environmental and site managers for evaluating remedial options; and (c) a 3-D computer animated model used for the public in an open forum. Although these researchers recognised the need to tailor the information to the needs of their target audiences, they did not evaluate the effectiveness of the information transfer and simply assumed that because they had made it simple, then it must be giving the intended message to the public. Other studies cited above might justify some scepticism as to whether this was really the case.

Participatory map design

Handmer (1985) lists four limitations of standard maps as communication tools: (1) information may not reach the target audience; (2) it may not be understood; (3) it may not change attitudes; and (4) it may not change behaviour. Therefore, even if maps are understood they are unlikely, like most risk reducing education campaigns, to alter perceptions and/or behaviour. However, some recent advances have been made to produce spatial information in a deliberative process with those at risk, reducing some of the limitations outlined above. Cognitive or mental maps work on the assumption that information about the environment is passed through a series of spatial filters (e.g. knowledge, experience, and personality) to form a mental (i.e. cognitive) representation (Downs and Stea 1973, 1977; Gould and White 1986). With these 'mind maps' people code, store, recall and decode information about the relative locations and attributes of phenomena in their everyday spatial environment. Deliberative maps created from these mental images can incorporate people's unique perceptions of hazards and risks and help depict information that is important and relevant to the local population, e.g. evacuation routes, emergency supply locations and more suitable measures of scale, such as walking time between locations.

Until recently the obvious potential for the use of mental maps in the perception of spatial hazards, where situations are dynamic and changing, has been largely overlooked since their inception in human geography in the 1960s (Dymon and Winter 1991, 1993; Monmonier 1997; Alexander 2004; Cronin et al. 2004). Local residents are usually the best source of on-site knowledge and information, therefore, *the reflection of individuals' voices is essential to improve hazard maps* (Asian Disaster Reduction Centre 2005, p78). A recent volcanic example includes that of Cronin et al. (2004) where participatory mental mapping techniques were used with indigenous populations on the island of Ambae, Vanuatu to produce trusted user-friendly risk and hazard maps.

Cognitive maps have also been used to improve the communication and understanding of complex GIS maps in resettlement projects (Vajjhala and Fischbeck 2000), where respondents needed to get the 'feel' (risks and opportunities) of an area they may move to. Respondent's activities, perceptions, and memories were included on the map in symbol form with the incorporation of walking and cycling time-scales rather than traditional scale bars. GIS maps were then constructed, dramatically transforming the display and increasing public comprehension. A user-friendly map was thus constructed by utilising the benefits of the computer software but incorporating elements of traditional and participatory mapping to *bridge the gap between information and communication* (Vajjhala and Fischbeck 2000, p2).

Clearly maps cannot be produced which meet everyone's unique spatial appreciation of their surroundings. However, with input and feedback from the public, a single more optimum map can be produced which helps the majority of potential users (Dymon and Winter 1993).

The study area

The island of Montserrat is 16.5 km north to south by 10 km east to west (Fig. 1) and sits at the northern end of a chain of volcanic islands known as the Lesser Antilles island arc. The arc is formed by the westward subduction of the Atlantic plate beneath the Caribbean plate, producing volcanoes that typically erupt relatively small volumes of highly viscous lava in the form of lava-domes. They are characterised by explosive activity that also produces pyroclastic flows and surges (Kokelaar 2002).

The Soufrière Hills volcano began erupting in July 1995 and has been characterised by cycles of dome growth and collapse with some limited explosive activity. A dramatic increase in activity on the 25th of June 1997 led to 19 fatalities within a defined exclusion zone. At the time of writing (September, 2006) the dome is in its third cycle of dome growth. More extensive summaries of eruptive activity up to the third cycle can be found in Kokelaar (2002) and Herd et al. (2005).

The small size of the island had constrained pre-crisis development to the gentler slopes of eroded pyroclastic flow and lahar deposits from the Soufrière Hills volcano, which sits at the southern end of the island. Thus, the capital town, Plymouth (only 4 km from the volcano summit), the airport on the east coast (5 km) and numerous communities on the northern flanks were in highly vulnerable positions and are now destroyed (Fig. 1, Kokelaar 2002). The majority of the 4,500 strong population[1] now live in the recently developed northern and (previously established) central areas of the island. Approximately 300 families still inhabit the south central area bordering the Belham Valley, which was most recently evacuated in October 2002 for 10 months (Fig. 2a). Nationals make up 82% of the population, with non-nationals defined as those who have settled on the island since 1991. Prior to the start of the eruption, the health and education infrastructure on Montserrat was of a good standard with some of the highest standards of living in the Caribbean and a well educated population (Clay et al. 1999; Possekel 1999; Skelton 2000).

Methodology

The assessment of the effectiveness of risk communication is a complex process as many different variables, e.g. cultural and societal contexts, respondent attitude and experience, may affect research findings in a variety of subtle ways. (This is analogous to the complex physical behaviour of the volcanic phenomena themselves where any one of several interdependent variables (e.g. magma

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[1] Data from the 2001 population and housing census May, 2001, Statistics Department, Montserrat. The 1991 census reported a population of 10,625 that has been slowly decreasing since its post war high of 14,333 (Clay et al. 1999).

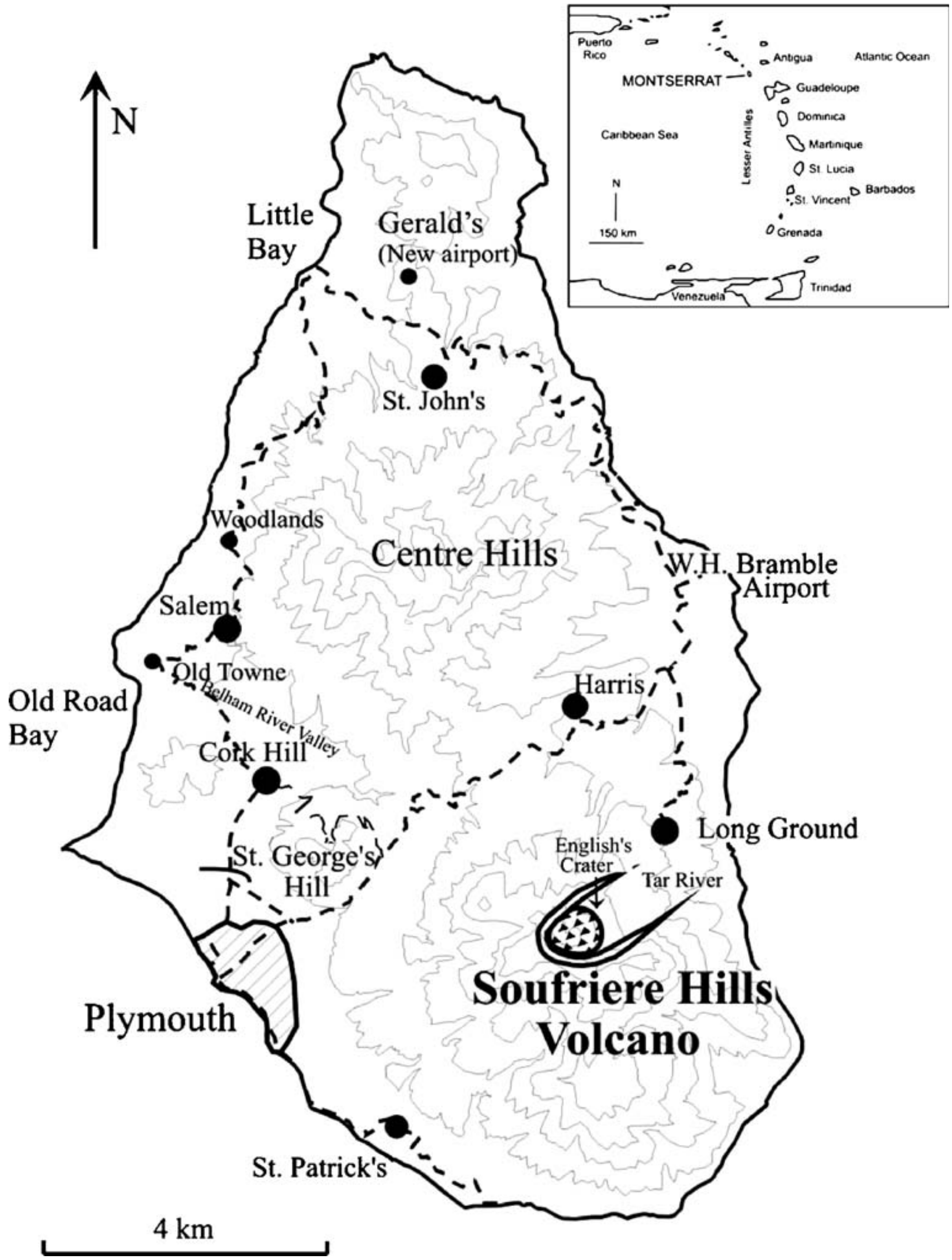


Fig. 1 Map of Montserrat as it was before the volcanic eruption. Insert shows the island's position in relation to the wider Caribbean. Figure is reproduced from Young et al. (1998 p.3390)

viscosity, rate of degassing, stress regime) may govern changes in behaviour at any one time). With the risk communication process, however, it is not really possible to investigate any one of these variables in isolation, therefore a holistic methodology must be employed that will allow the influence of all of these factors to be studied collectively in a way that is sensitive to the context in which the measurements are made.

Quantitative methods, e.g. statistical analysis of questionnaire responses, are highly effective in measuring the 'cause and effect' of individual variables and circumstances and have been used with some success in other areas of volcanic risk perception (Johnston et al. 1999; Gregg et al. 2004). However, results can be difficult to interpret when trying to understand the underlying reasons for behaviour (Henwood and Pidgeon 1992). It has become increasingly clear that questionnaire-based research alone cannot capture the complexity of risk perception and that methods more sensitive to the context are needed (Krimsky and Golding 1992; Horlick-Jones et al. 2003).

Qualitative methods, on the other hand, involve rich, detailed and penetrating accounts of the incidents and subjects under investigation (Bryman 1988). Their small sample sizes mean that the results are often location and time-specific and difficult to replicate with a heavy reliance on the subjective interpretations of the researcher (De Vaus

2004). Nonetheless recent researchers have successfully taken a more interpretive stance in areas vulnerable to volcanic activity by employing deliberative qualitative methodologies (Cronin et al. 2004; Mitchell 2006).

We have chosen to use both quantitative and qualitative methods in our research design. The qualitative research involved the taking of written notes that recorded details of respondents attitudes, commentary and spatial interpretative abilities during the interview as well as their answers to specific questions. Questions that could be 'scored' were deliberately asked during the survey in order to statistically test relationships between differing variables. Due to the lack of precedent in this field, the questions were based on some previous work in related areas but were also experimental, being finalised in the field with the pre-test respondents. This 'mixed' methodology approach allows us to more fully identify the complexity of the issues that relate to risk perception and map comprehension and permits more confident conclusions (Horlick-Jones et al. 2003). For more details see Hammersley (1996).

The sample population

Forty-five people were interviewed individually at various locations and times around Montserrat. While the sample tested was purposefully orientated towards a range of demographics, in order to examine their influence on map comprehension, the final sample was fairly representative of the Montserrat population in terms of age, gender, education and racial origins (Table 1). In qualitative work it is common to use such a sampling strategy, which is oriented towards a purposefully defined aim (Pidgeon and Henwood 2004). People who had arrived on the island post June 1997 were not interviewed, due to their limited first-hand geographical knowledge and experience of the evacuated areas.

Map tools used

One regular contour map, six 3D maps, and two perspective photographs of Montserrat were used during the interviews, all printed on A4 card (Fig. 2a–g). The contour map (Fig. 2a) was the same as the regular topographic map used by the MVO for all of their outreach activities. The map used included colour (see legend to Fig. 2a for details) however, for simplicity we have reproduced it here in black and white. Based on information available in January 2004, this map included: contour lines; squares for the location of the main villages and towns; roads; lines to indicate larger river valleys; a scale bar; a north arrow and the exclusion zone. Volcanic deposits were also included. To discourage respondents from simply identifying features and locations through textual cues, no key was given or any written labels.

The 3D maps (Fig. 2b–e.) were constructed using ARC VIEW GIS software by the integration of a pre-eruption digital elevation model of Montserrat (supplied by Geoff Wadge, University of Reading). The pre-eruption topography was modified using ARCVIEW to produce a topography that closely resembled that at the time of the fieldwork and was coloured in green with similar colours used for the volcanic deposits as the topographic maps. The aerial photographs (Fig. 2f, g) contained no additional information and did not cover the whole island but rather the areas most recently

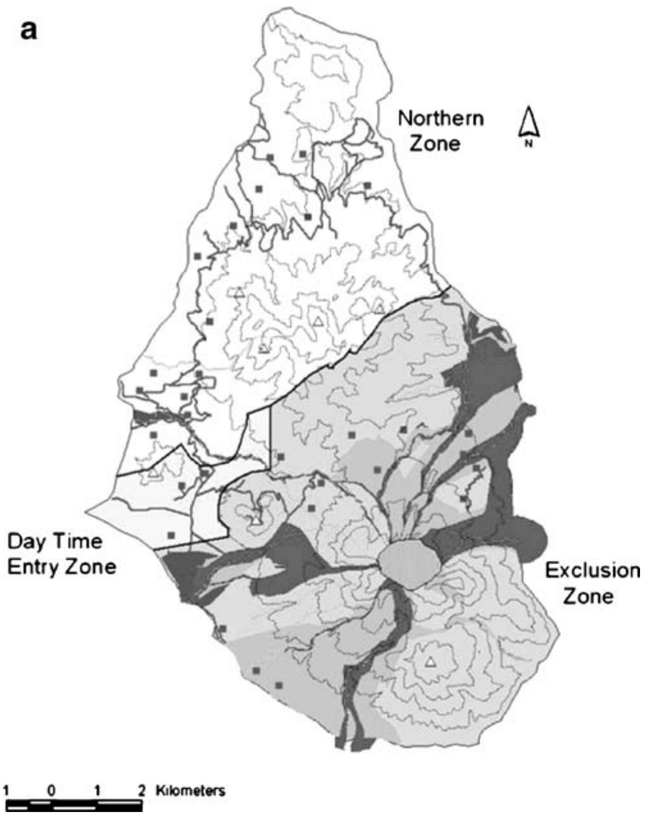


Fig. 2 **a** The contour map showing the risk zones and volcanic deposits at the time of Survey (March 2004). On the original map *contour lines were black*; *road lines were dark red*; *larger valleys were shown with blue lines* and the *exclusion zone was pink bounded by a thick black line*. The *extent of surge deposits was shown in pale yellow*, *pyroclastic flow deposits in red* and *lahar deposits in brown*. Figure is adapted from Cole et al. (2002 p.233). **b** 3D view up the Belham Valley (looking SE). **c** 3D view from the SW looking NE over the western side of the island. **d** 3D view from the NE looking SW over the eastern side of the volcano. **e** 3D view from the south east looking over the southern and eastern side of the island, (the pre–eruption digital elevation model of Montserrat used to create these 3D images (2b–2e) was kindly supplied by Geoff Wadge, University of Reading). **f** Photograph of the eastern side of the island looking towards the volcano, taken in February 2004. Kindly supplied by the Montserrat Volcano Observatory (copyright MVO). **g** Photograph of the western part of the island looking down the Belham Valley, taken in February 2004. Kindly supplied by the Montserrat Volcano Observatory (copyright MVO)

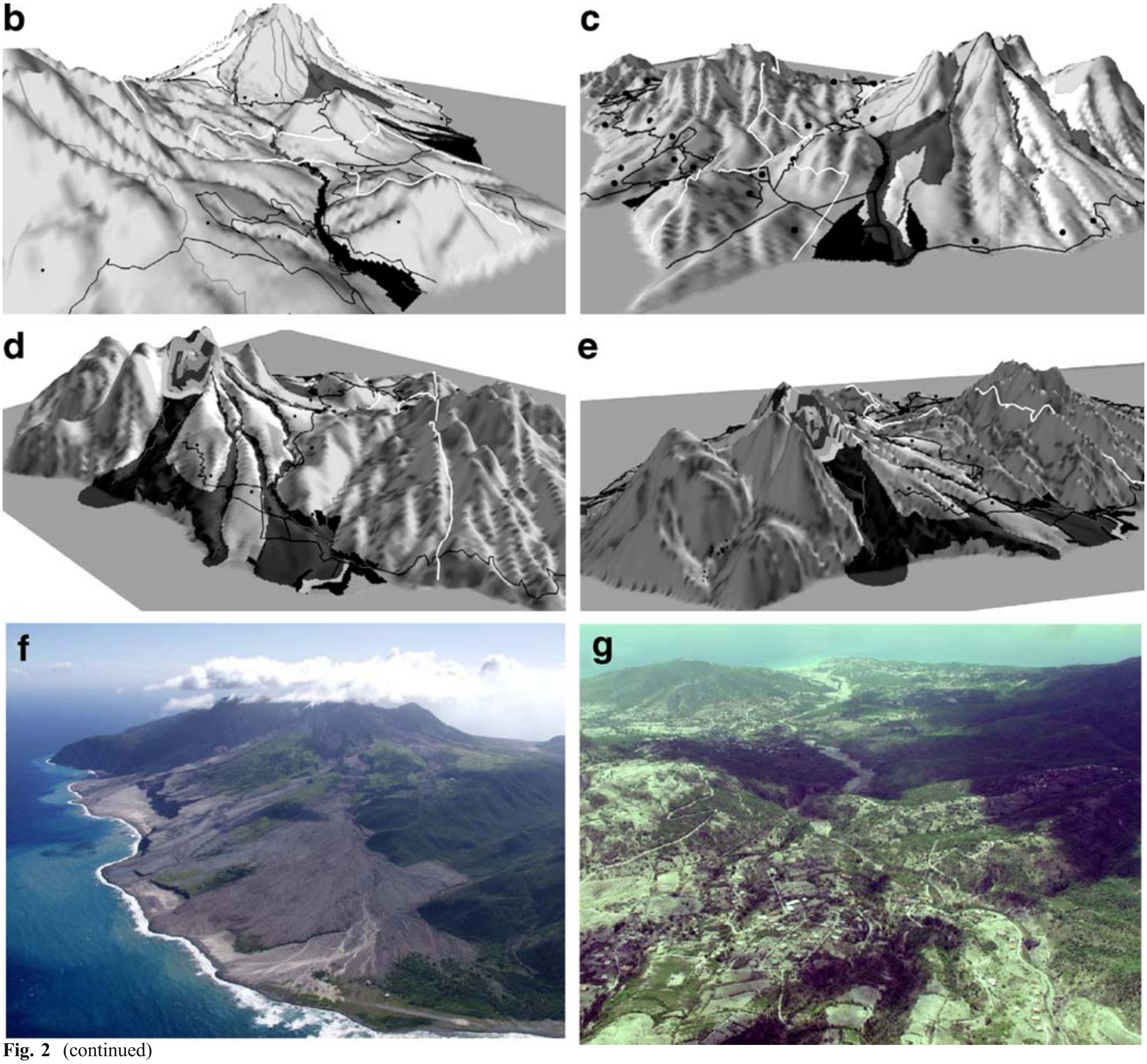


Fig. 2 (continued)

affected by the volcanic activity and another view to show the western portion and part that had been most recently evacuated. This choice was governed by the availability of images at that time and unfortunately slightly limited some of the questions associated with the photographs.

Six views of the 3D model were chosen as, in comparison to the flat contour map, one image did not completely show the 3D relief of the whole island. The six images gave an optimum representation of the island's main features, as if the island could be tilted and spun within the hands of the respondent. These images were two slightly oblique aerial views—N/S and S/N perspective (not shown here) and therefore very similar to the view in the contour map; two oblique views of the western side (Fig. 2b, c); and two oblique views of the eastern side of the island (Fig. 2d, e).

Questionnaire

Respondents were asked questions that tested both basic map reading skills and also how this related to comprehension and understanding of the volcanic hazards. The justification for each grouping of questions is summarised in Fig. 3 and the variables and themes used (other than demographic variables) in the statistical analysis are summarised in Table 2. A full copy of the questionnaire is available from the first author on request.

As shown in Fig. 3 there is some overlap between the main themes: *map skills* and *locating*, both test *topographic* skills although *locating* also tests knowledge of the geographic area and ability to manoeuvre around the map. Map skills concentrate on the ability to decode mapped

Table 1 Demographics of the survey respondents

	Map type					
Map type	3D + photo		Contour + photo		Total maps + photo	
Number of respondents	19		13		32[a]	
Percentage	59		41		100	
Age	%	No	%	No	%	No
<20–29	11	2	23	3	*16*	*5*
30–49	47	9	62	8	*53*	*17*
50–>70	42	8	15	2	*31*	*10*
Total	100	19	100	13	*100*	*32*
Education						
No formal qualifications	27	5	61	8	*41*	*13*
GCSE/CSE/CXC	21	4	15	2	*19*	*6*
A levels/diplomas	26	5	8	1	*19*	*6*
Higher Degrees	26	5	15	2	*22*	*7*
Total	100	19	100	13	*100*	*32*
Sex						
Male	53	10	46	6	*50*	*16*
Female	47	9	54	7	*50*	*16*
Total	100	19	100	13	*100*	*32*

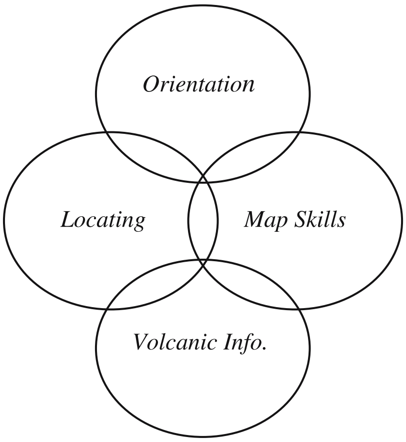
[a] Only those respondents who had answered sufficient questions to be included in the quantitative analysis are included in the demographic analysis. However the demographic breakdown of those involved in the developmental stage of the research is very similar to that shown here.

symbols. Locating and orientation are also closely related and it was surmised that ability to identify volcanic information would be related to abilities with the other three themes.

As the photographs cover a reduced area and contain less volcanic information than the other two map types, the number of questions asked covering the 'locating' and 'volcanic' themes had to be reduced. However, the compar-

'**Orientation**' – The skill of being able to identify the different compass directions on the map or photograph, this was felt to be a basic skill for map comprehension and usability.

'**Locating**' – The ability to locate personally significant locations, such as one's house and interview site and also named places such as villages and familiar topographic features. This task contained the largest number of variables to make it fair for the respondents who would perhaps know certain areas where they had lived or worked more than others. This task was partially based on the work reported by Handmer (1985) where respondents were asked to locate their home.



'**Map skills'** – The ability to identify and decode traditional mapped information, such as contour lines into relief and other information such as roads. This task was partially based on the work of Roder (1961) and also that reported in Handmer (1985) where difficulties with coded mapped information were reported.

'**Volcanic Information'**. – The ability to identify, interpret and understand the volcanic information on the map such as the exclusion boundary, hazard information and areas routinely affected by volcanic activity.

Fig. 3 Description of the four task categories tested in this study

Table 2 Variables used, overall themes and relationship to the different map types

		Map type		
	Skills tested	Contour[a]	3D[a]	Photos[a]
No. of respondents interviewed		13	19	32
Variables				
The North	Orientation	X	X	X
The South		X	X	X
The East		X	X	X
The West		X	X	X
Any Hill	Map Skills	X	X	X
Any Valley		X	X	X
Roads		X	X	X
Island identification	Locating	X	X	X
Location of respondents house		X	X	
Current location		X	X	
St Georges Hill		X	X	X
Garibaldi Hill		X	X	X
Belham		X	X	X
Centre Hills		X	X	
Silver Hills		X	X	
Plymouth		X	X	
St Patrick's		X	X	
Cork Hill Village		X	X	X
Lees Village		X	X	X
Old Towne		X	X	X
Whites Ghaut		X	X	X
Tuitts Ghaut		X	X	X
Paradise Ghaut		X	X	X
Long Ground		X	X	X
Harris Village		X	X	X
Tuitts Village		X	X	X
Spanish Point		X	X	X
The volcano	Volcanic Information	X	X	X
Exclusion line		X	X	
Pyroclastic Flows		X	X	
Surge Flows		X	X	
Volcano Ghauts[b]		X	X	X
Tar River Valley		X	X	X

[a] These answers were encoded and given a numeric value during the questionnaire: 1 = correct, 2 = close (within 500 m, unless the topography was very different) and 3 = wrong (more than 500 m or misinterpreting topography).

[b] Includes the valleys affected by pyroclastic and surge flows in the photograph

isons involving the photographs with the other maps only used the variables available to all (Table 2).

As this was an exploratory study, the interview protocol was developed and pre-tested with 12 respondents. From these trial interviews, a more robust protocol was developed for the remaining interviews. While one respondent was re-interviewed (only with new questions so there would be no learning effects through repetition), the other 11 interviews contained too many missing variables and were not included in the statistical comparisons. The refined protocol was used to interview a further 33 respondents. Data from two of these respondents was not included in the analysis due to the absence of accompanying photographic data in one case, and the lack of light available to make the interview conditions fair in another. Thus, in all, data from 32 respondents was used for the final analysis.

The respondents were divided into two groups, one group of 19 completing questions on the 3D maps followed by the photographs, while the other group of 13 was presented first with the contour maps followed by photographs. Different groups were chosen for the contour and 3D maps as it was thought that once they had filled-in and discussed one map type with the interviewer, their responses could be biased for the next map type. It was hypothesised that the respondents would fare better with the photographs (due in part to the findings by Plester et al. (2002), who found that children performed better with maps if they had seen photographs of the area first). Therefore, it was decided to start the interviews with a map, reducing the bias of a respondent orientating themselves on a photograph first. It was also hoped this would help the interviews end on a more positive note. All the respondents completed one map type and the photographs.

The interviews took place during March 2004, each taking about 25 min and following the same protocol, with one investigator asking the questions and marking down a code on a prepared table and the other writing notes. A code (Table 2) was employed in order to analyse answers statistically but it also meant that the respondent could not deduce whether they were answering correctly or not, thus reducing a learning bias and possible embarrassment.

Interview notes were taken for all the respondents. As well as complementing the quantitative part of the survey, these notes also provided a method of cross-checking locations marked by the first investigator and helped in refining questioning techniques as time went on. The qualitative data were coded according to similar themes and issues that respondents discussed by respondents when answering the questions and is presented in the discussion alongside the quantitative data, with direct quotes from the respondents and the interviewer's notes where relevant.

Statistical analysis

Although the data were normally distributed, it was decided to use non-parametric tests due to the small sample size in the study. These tests provide a more conservative test of differences, giving results and relationships that are more robust when significance is found. The ‘Wilcoxon Signed Ranks Test’ (or ‘Wilcoxon Matched Pairs Signed Ranks Test’) was used to explore the difference between the results of the use of the 3D maps and the photos, and also between the contour maps and the photos. This test is similar to the traditional *t* test, but rather than simply comparing the means, it converts scores to ranks.

To investigate the difference between the contour and the 3D maps the ‘Mann-Whitney U test’ was employed as there are two independent groups with a continuous measure of map understanding. This is also a non-parametric alternative to the t-test, but it compares medians rather than the means, which it converts to ranks and then tests whether the ranks for the two groups differ significantly (Pallant 2001). Both tests produce a Z-score similar to a t-score in the *t* test and is an overall evaluation of rank differences that are used to estimate statistical significance.

Results

Contour vs. photo

A total of ten (from 33) tasks (variables) were carried out significantly more successfully on the photographs than on the contour map (Table 3) and only the ability to point out north (marked on the map, see Fig. 2a) was significantly easier on the contour map. When these variables are grouped into their overall themes, Map Skills, Locating and Volcanic skills are found to be significantly easier on the photographs than on the contour maps (Table 6).

3D maps vs. photos

Four variables are found to be significantly easier to place on the photographs than the 3D map (Table 4) with no overall grouped variable being significantly easier on the photos (Table 6). No variables were significantly easier on the 3D maps than the photographs.

3D maps vs. contour maps

When the 3D and contour maps are tested against each other, the placing of the two variables ‘Valley’ and ‘Volcano Ghauts’ (valleys leading from the volcano) are significantly more correct on the 3D map than the contour map (Table 5). When examined as group variables, the overall task of ‘Map skill’ is found to be significantly easier for the respondents on the 3D map than the contour map (Table 6).

The pattern of spatial responses

The patterns of correct and incorrect responses for five locations were mapped for the contour map and the photographs (Fig. 4). The five locations shown are important because they represent significant topographical differences and places important to the edge of the Exclusion Zone at the time of survey. The results plotted include all those interviewed and not just those chosen for the statistical analysis, although some respondents were unable even to attempt to identify some of the locations. The mapping of the spatial responses in Fig. 4a, b do not show a complete record of responses but rather illustrate the pattern of ‘mis-location’ for the contour maps and the photograph. The comparison between the 3D map is not shown.

Confusion over different landmark features demonstrates clearly that some people were not interpreting the contour information correctly. For example, St. Georges Hill was often placed within a valley and the Belham Valley placed on a hill. However, while locations were sometimes confused (e.g. St. Georges Hill mistaken for nearby Garibaldi Hill, Richmond Hill or the Centre Hills), respondents were better able to identify topographic features using the photographs. In addition, people generally felt more confident locating themselves on the photo than on the map.

Table 3 Variables which indicate a significant difference between the contour map and the photographs

	Orient.	Location						Map skills		Volcanic info.	
	The North	St Georges Hill	Garibaldi Hill	Paradise Ghaut	Belham Valley	Spanish Point	Cork Hill	Roads	A valley	Tar River Valley	Volcano Ghauts
Z	−2.121[a]	−2.236[b]	−2.828[b]	−2.428[b]	−2.887[b]	−2.373[b]	−1.994[b]	−2.000[b]	−2.530[b]	−2.309[b]	−2.121[b]
Sig. (2-tailed)	0.034	0.025	0.005	0.015	0.004	0.018	0.046	0.046	0.011	0.021	0.034

[a] Based on negative ranks = contour better than photo.

[b] Based on positive ranks = photo better than contour map.

Table 4 Variables which indicate a significant improvement between the 3D map and the photos

	Locating			Volcanic info.
	Garibaldi hill	Belham valley	Whites ghaut	Tar river valley
Z Sig. (2-tailed)	−2.955 0.003	−2.181 0.029	−2.183 0.029	−2.194 0.028

Based on positive ranks = photo better than 3D map

Discussion

The ability to decode a mapped message into information and meaning is assumed to be a learned skill. However, it cannot be assumed that all educated individuals will possess this ability, because of varying study interests, or cognitive differences, such as that often noted between men and women. In addition, the less well educated cannot be labelled as spatially unaware as they often have very complex understandings of their surrounding environment.

A correlation of 0.51 was identified between age and education (p=0.003). This reflects the 'brain drain' on Montserrat due, in part, to the volcanic crisis. It also mirrors a wider social situation found in many small islands and rural communities where the more gifted young leave to find better prospects and employment abroad, with an inward migration of educated but older individuals to retire.

Table 7 shows the variables from the questionnaire that correlate with the education of the respondents. Those who have a higher education can more easily orientate themselves on the photograph by identifying north and west directions and also have an improved ability for 'locating;' (a) where they live; (b) Garibaldi and (c) Centre Hills on the contour maps. When the grouped variables were examined, the only significant correlation with education is with the skill of *Orientation* on the photographs. As this grouped variable is not found to be significantly different between the three map and photograph types, it can be concluded that education is not a major influence on the understanding of the different map types. This is exemplified by the fact that more educated people made up the group that was tested on the 3D maps and these attained the lowest percentage of correct answers.

No correlations were found in the overall data to support any gender differences noted by other researchers (Downs and Stea 1973; Monmonier 1996).

Table 5 Variables with a highly significant improvement between the 3D and contour map

	Map skills Valley	Volcanic info. Volcano ghauts
Z Exact Sig. (2-tailed)	−3.197 0.001	−2.819 0.008

Based on positive ranks = 3D map better than contour

Orientation

The skill of being able to orientate oneself on a map or photograph or to identify compass directions was found to be similar for all the map types and photographs. No single method stood above the others with respondents scoring on average just over 50% of correct answers. Photographs scored the highest percentage of correct answers (59.4%) and the 3D map the lowest (47.4%) but this difference was not significant (Table 5). The only single variable to show any significance was the ability for respondents to correctly locate 'North' on the contour map. This may be due to people being more accustomed to viewing the island from a north–south perspective with the north at the top. However, as they were not similarly able to locate the other compass directions with such ease, this is more likely attributable to the small compass rose in the top right side of the contour map which was not present in the 3D maps or photographs.

Locating

The task of locating various well-known features around the island, from villages to valleys and hills, was easier for respondents using photographs. Almost two thirds (62.5%) of those tested obtained correct answers compared to only 31.6% of respondents tested on the 3D maps and 23.1% of those tested on the contour map. The average scores for the contour and 3D maps were the lowest for all the different group variable tasks (Table 5). This demonstrates that it was the task the respondents found most difficult on maps; in contrast, it was significantly easier to do this correctly on photographs.

However, respondents were much more competent at identifying where they lived on contour maps (50% of respondents as opposed to only 21% using 3D maps). This may indicate that respondents were used to seeing the contour map of Montserrat and can remember where their house is located on this shape, not that they were actively interpreting the map. This is demonstrated by the very low percentage of correct answers identifying the location of the interview using both the contour map (15%) and the 3D map (26%). No significant difference was found for these variables between the two map types.

Using prominent features to locate and orientate themselves on the map and reference themselves to other

Table 6 Percentage correct answers for each of the group variables and their significant differences

	% Correct answers			Significance of comparisons		
				Wilcoxon signed ranks		Mann-Whitney u test
Group Variable	Photo	Contour	3D	C vs P	3D vs P	C vs 3D
Orientation	59.4	53.8	47.4	Z=−1.273 *p*=0.203	Z=−1.194 *p*=0.233	Z=−1.244 *p*=0.226
Locating	**62.5**	23.1	31.6	**Z=−3.063 *p*=0.002**	Z=−1.711 *p*=0.087	Z=−1.040 *p*=0.295
Map Skills	**96.9**	53.8	**100**	**Z=−2.555 *p*=0.011**	Z=−0.687 *p*=0.492	**Z=−2.763 *p*=0.005**
Volcanic	–	76.9	78.9	–	–	Z=−1.298 *p*=0.194
Volcanic (photo—reduced variables)	**96.9**	61.5	94.7	**Z=−2.536 *p*=0.011**	Z=−1.443 *p*=0.149	Z=−1.808 *p*=0.071

Figures in bold are those which the statistical tests demonstrated had a significant difference

features and locations was a skill used by six out of the 16 males. No females used this technique to answer the questions. Four males used this technique on the 3D maps and two on the contour map. One used the volcano, while the other five used Bransby Point, a finger of land in the exclusion zone pointing out to the west. These male respondents used the features to navigate themselves successfully around the map. Interview notes for Respondent 3, for example, state that he *initially mistook SGH* [St Georges Hill] *for Garibaldi* [Hill] *and then corrected himself and used Bransby Point as a locator although put SGH (St Georges Hill) a little far north*.

A few respondents, both male and female, used real locations and features in the surrounding environment where the interviews were taking place to locate themselves and then attempted to transfer this information to the maps.

A large number of respondents had either not heard of the names of some of the valleys and villages or had forgotten where they were. This may be reasonable if the respondents were new to the island and because of

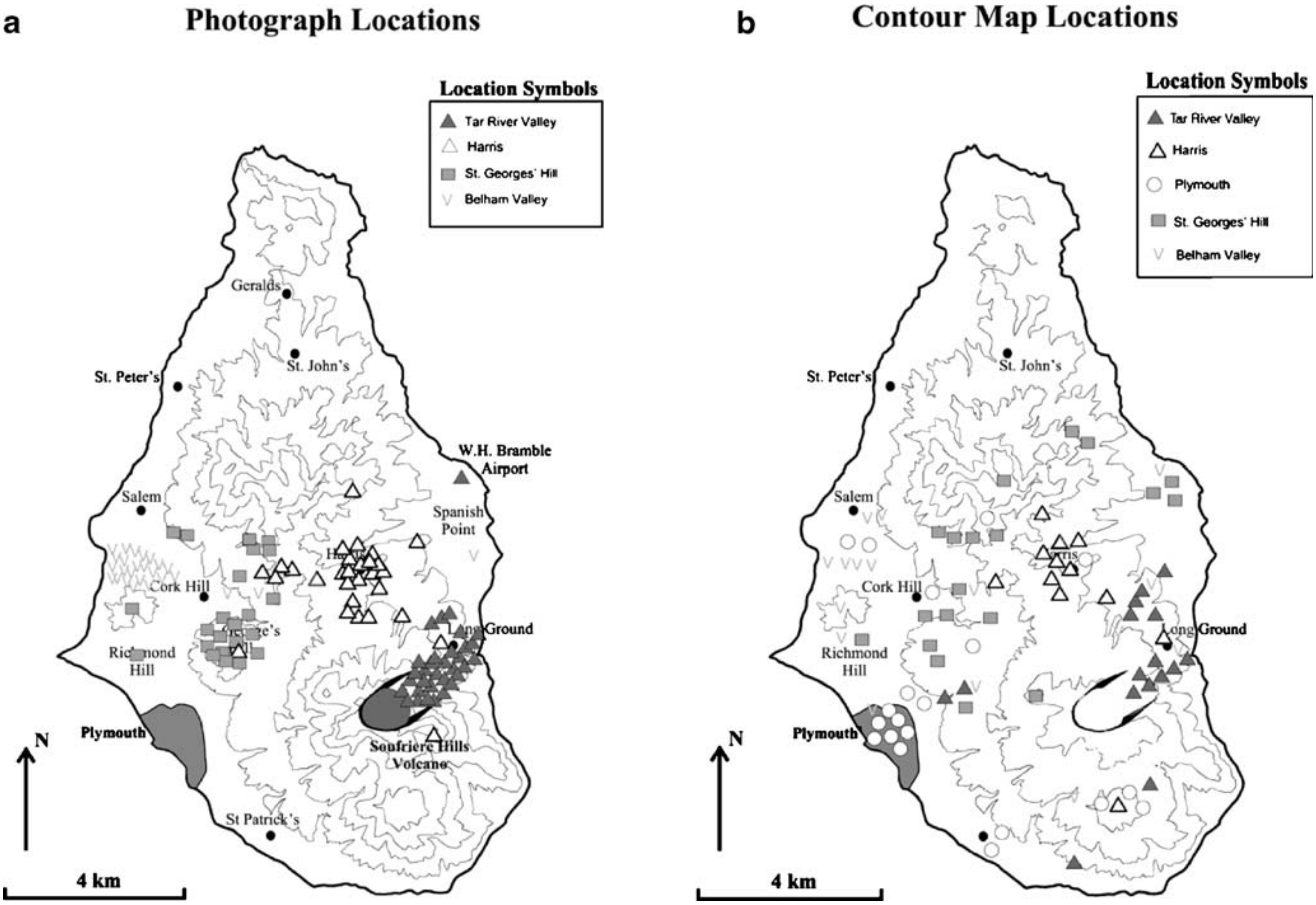


Fig. 4 A comparison of the pattern of locational responses between the contour and photographs (underlying map is reproduced from Young et al. (1998 p.3390))

Table 7 Correlation results for the influence of education

Variable	Group	Correlation	Significance
Photo—North	Orientation	0.385	0.030p
Photo—West		0.358	0.044p
Contour—Live	Locating	0.619	0.032p
Contour—Garibaldi Hill		0.575	0.040p
Contour—Centre Hills		0.685	0.010p
'Orientation'		0.400	0.023p

exclusion zone restrictions had been unable to explore certain areas of the island. However, as stated in the methodology only those who had been on the island prior to June 1997 were interviewed and therefore, this problem of 'locating' ran beyond the few relative newcomers interviewed; not only identifying problems with map reading but also a cultural phenomenon of people limiting themselves to quite small areas on the island. Montserratians have never liked travelling 'distances' and have deep attachments to their home villages (Pattullo 2000). The relevance of this becomes apparent for the theme of *volcanic skills* and *locating* areas near the volcano. When questioning people about the locality of certain valleys down which volcanic hazards flow, respondents, although recognising the valley name, commonly could not give a direction or location for the valley. Therefore, they did not know if the dangers the scientists were talking about were coming towards the north and the safe zone or the east, west or south!

> "....[I have] *never been to Long Ground or spent any time on the east side,"*

Respondent 39, Montserratian, who has always lived on the island.

The mis-locations in Fig. 4 exemplify this pattern, with respondents mixing up the valleys, hills and settlements. Although some respondents were matching up the correct features or representations on the map, their inaccurate locations show a difficulty with *locating* and *orientating*.

General map skills

The ability for respondents to interpret topography was found to be significantly easier for those using the photographs and the 3D maps; both attaining very high average correct scores of 97% for the photographs and 100% for the 3D maps. This indicates that both of these formats are easier to interpret in comparison to the contour maps where a score of 54% was achieved. Although the 3D maps obtained the highest score, no significant difference or improvement was found between them. This improvement over the contour map is due to the almost total inability for respondents to interpret contours and therefore topography on the traditional map. The qualitative observation notes support this quantitative finding with many respondents notably not using the topography on the map to locate and identify features.

When using the photographs and the 3D maps, respondents did not have to decode mapped symbols as the relief stands out much as it does in reality. This can also explain why roads are easier for the respondents to interpret on the photographs than the 3D maps. The roads were misidentified by respondents (5 from 32) who pointed to the contours and on one occasion the exclusion line. A further three respondents confused valleys with contours, roads and the exclusion line. It therefore seems imperative that if standard type maps are to be released to the public, then the marking of dissimilar linear features should be strongly differentiated—e.g. that contours, roads and (exclusion zone) boundaries must be plotted in clearly distinctive ways.

Occasionally, respondents would confuse prominent features or colours for topography. For example, the westward pointing finger of land Bransby point or the markings used to display pyroclastic flow deposits as the highest points on the island. The mis-location patterns in Fig. 4 also show this confusion, with respondents confusing the high point of the South Soufrière Hills as Plymouth, and the colours over the village of Spanish Point as the high ground of St. Georges Hill.

Volcanic information

No significant improvement was found between the contour and the 3D map in terms of the interpretation of the full range of volcanic information. Both maps yielded a similarly high percentage of correct answers with scores of 77 and 79% respectively, with no one map type proving significantly better over the other. When the reduced variables are compared against the photographs, both the 3D maps and the photographs yield very similarly high percentage correct scores of 94.7 and 96.9% respectively. For the contour map, this drops to 61.5%. Therefore, there is a significant improvement between the contour and the photographs' ability to communicate the volcanic information.

Respondents were asked to locate the markings on the map that represented pyroclastic flows, surges and mud flows and also to discuss their location in relation to the topography; testing comprehension and knowledge but also the application of that knowledge. Many of the respondents took some time deliberating because of confusion about the physical properties of these hazards and the different geographic locations they affect. However, this can also be attributed to difficulty in interpreting the colours, features and topography of the map.

Colour was a common factor which the respondents used to try and interpret the mapped hazards, particularly the colour red, which they commonly associated with the high temperatures of pyroclastic flows and surges. The respondents were trying to match up the colours they saw around them rather than recognising them as false colour symbols and decoding them relative to their topographical position. For example:

> *"me thinks the red is the lava, the lava is like fire and the pyroclastic flow is like smoke"*
>
> Respondent 21
>
> *"where the red is danger"*
>
> Respondent 22
>
> *"the surge is the red colour because it is hot"*
>
> Respondent 42

Some respondents were able to use their knowledge to decipher the patterns into topographic meaning and hazard identification, however many were not.

A correlation between the ability to score highly on the *Volcanic Skills* variable was found with the *Map Skills* and *Locating* variables for all map types indicating that in order to interpret the volcanic information people need to be able to locate themselves and decode the map symbols. A correlation for the two map types and the photographs was also found between the *orientation* variable and the *locating* variables as those who can orientate themselves will be more able to locate themselves.

Although most respondents were able to locate the exclusion line, when asked for the possible reasons for it being located here, only two were able to relate its position to the terrain. The majority of the respondents persisted in describing the exclusion line as the line separating safe and unsafe areas, even after much prompting to expand and describe why. This is an accurate but basic description, showing a lack of understanding and knowledge of the relationship between the hazards and topography and why some areas are dangerous and others safe. It also exemplifies the problems highlighted above in *map skills* and an apparent inability to decode topographic information in order to explain the pattern of the meandering exclusion line by many respondents.

Danger recognition

Two respondents actually re-evaluated their perceptions of danger after looking at the photographs. Respondent 39 was shocked when she looked at the aerial photograph of the Belham Valley area as she could clearly see that the Valley was on a direct path from the volcano down which hazards could flow. Previously she couldn't understand why the Belham area had been evacuated.

Concluding comments

Future work

While piloting this work we attempted to ask respondents to draw 'mental maps' of their area. Approximately eight respondents drew their own sketch map on a blank sheet of paper. The respondents were told that a friend was visiting the island and needed a map to guide them from Salem, (within the safe zone), to Plymouth, (within the exclusion zone). They were asked to mark out the safest route and the areas or dangers to avoid. However, this was abandoned as after the map comprehension interview (the priority for this research) respondents were rapidly tiring and were generally unhappy to cooperate. The findings from our study strongly suggest that the richer and more realistic information available on the aerial photographs were providing cognitive cues to the interpreter. In the absence of respondents' mental maps we can only guess at what these cues were and whether there was some commonality to them among respondents (e.g. Bransby Point was important to some male respondents as a locating feature). Future work should therefore examine people's cognitive maps and their proposed emergency escape plans using a dedicated methodology. This could offer two avenues for improved risk communication: (1) a comparison of their maps with those produced by the scientists could identify misconceptions and problems to address; and (2) the mental maps can be used as the basis for the hazard maps, thus overcoming problems with decoding issues, usability and also increasing their efficacy at raising awareness by incorporating the public's needs, views and perceptions of the local geography to produce trusted and user friendly maps or GIS photo-maps.

Although improved GIS mapping will aid communication among volcanologists, it has been shown that during a rapidly evolving crisis, emergency managers tend to rely on less technical options, sometimes preferring hand-drawn maps to the more complex GIS versions (Alexander 2004). For example, following the Boxing Day Tsunami in 2004, technical difficulties forced emergency managers to abandon their GIS maps in favour of hand drawn maps (Dr. Tom Mitchell, Institute of Development Studies, UK, 2005, personal communication). Thus, it would be very valuable future research to compare between the lay public, emergency managers and the authorities the efficacy of GIS photo maps (photographs draped over DEM data) with the more simple oblique photographs, labelled to make them more 'map like,' and hand drawn maps. It would also be prudent to explore a similar interview aproach with school children as modern educational methods are increasingly supplimented with graphical/computer imagery. This may mean that the younger generation could be more familiar and comfortable with maps or photos draped over 3D visualisations of DEM's.

Implications for emergency management

Photographs were found to be significantly better than the contour maps on three of the four key skills; Map Skills, Locating and Volcanic Skills. No significant difference was found between the photographs and the 3D maps, although the percentage of correct answers for the photographs in the Locating' skill was almost twice that of the 3D maps, the variability of the other scores and the rigorous tests chosen reduced the apparent significance of the difference. The 3D maps were found to be significantly better than the contour maps for 'Map Skills.'

It can be concluded that for the sample tested, photographs are an improved method for the communication of spatial hazard information. In a rapidly evolving crisis situation, where there has been little preparation or planning, photos can be quickly produced and annotated electronically or by hand.

This improvement of spatial comprehension with aerial photographs is similar to that reported in Handmer (1985) and Plester et al. (2002). Respondents did not have to decode contours, symbols or false colours and were able to filter their own information. As stated by Delucia (1978, in Handmer 1985, p84), a photograph "is much closer to being a scaled down version of reality." This is also shown in the increased effectiveness of the 3D map compared to the contour map for the general 'map skill' as respondents do not have to decode contours.

The locating task also revealed a limited knowledge of the wider geography of the island confirming a Montserratian cultural phenomenon of people sticking to and limiting themselves to quite small areas on the island. This was also common with those who were new to the island preferring compass directions rather than unrecognisable names of the areas affected. Demographics did not have a significant influence on map comprehension, although some men were using notable topography to orientate themselves, which was a technique not used by women.

Many respondents also showed difficulty in demonstrating an understanding of the properties of the hazards, their topographic controls and defining the topographic positioning of the exclusion line, which was compounded by their inability to decode the contours on the contour map. However, the relationship between increased map comprehension and perceived risk is unknown and requires further work; although a couple of respondents did demonstrate increased risk perception on viewing the photographs.

It is difficult to extrapolate the direct applicability of this study to regions outside of the Caribbean as variations in the socio-cultural and geographic setting will cause mapped information to be interpreted in different ways. However, this exemplifies and reiterates the point that one approach does not suit all situations. The notion that everyone can or should understand traditional hazard maps, with education the key to increased comprehension, should be rejected. At the very least, evaluation of new hazards and risk maps must become usual practice so that they can be adapted and their efficacy measured. Ideally, improved methods should be developed with those at risk, to produce an effective and trusted tool. However, if this means the production and use of more than one map type (e.g. scientists continue to use a more detailed topographic map), care needs to be taken to maintain transparency and avoid any suspicion that information is being withheld or the public map "doctored." Intstilling and promoting trust is as important for the management of the crisis as effectively communicating the geospatial hazard and risk information.

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