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Re-assessing volcanic hazard maps for improving volcanic risk communication: application to Stromboli Island, Italy

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Abstract

Hazard and risk maps are tools for both mitigating against risk and informing and preparing the general public. Recent studies have highlighted that volcanic hazard and risk maps used during emergencies can be difficult to interpret. Our research focuses on evaluating and improving the efficacy of currently available maps of Stromboli volcano on Stromboli island (Italy) for the communication of volcanic hazard and risk information. Stromboli is an active volcano characterised by persistent explosive activity, sporadic lava effusions and landslides on the volcanos northwestern flank, which sometimes generates tsunamis, most recently in 2002. This study used semi-structured interviews conducted with local legislators, administrators and 'enforcers' to understand their perceptions of available risk information; to evaluate the respondents mental spatial maps; and to determine the most important components in encouraging risk-reducing behaviour in a hazardous situation. Respondents were asked to evaluate a contour map, an aerial photograph, a digital elevation model (DEM) and an innovative 3D tsunami risk map. These results enabled the development of different volcanic risk maps for use by 'experts' and 'tourists' using a contour map and a DEM (Scale 1:12.500). A 3D map focused on the tsunami risk (Scale 1:6.500) area was also produced.

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1. Introduction

Volcanic hazard maps usually display the current or potential extent of volcanic phenomena that can affect an area. The likelihood of the occurrence of the phenomena and severity of impact are considered to produce hazard zones which are often then transformed into risk zones depending on the vulnerability of the area in question. The relationship between volcanic phenomena, topography and surrounding human infrastructure can be complex and the resultant geospatial information not easily decoded or understood by non-expert users. Further, these maps are often widespread sources of information and fulfil a variety of functions including explaining and displaying the distribution of hazards, the risk levels of the areas likely to be affected and, in times of crisis, areas where access should be denied. Particularly, recent studies have shown that volcanic hazard and risk maps are difficult to interpret, limit understanding and consequently preparedness to react both to changes in volcanic activity and the management of the emergency may be compromised, even when users have high levels of education (Haynes et al., 2007; Moen and Ale, 1998; Newhall, 2000). However, the development of different cartographic solutions such as contour, aerial photo and 3D maps in combination with Geographical Information Systems (GIS) have highlighted their role in improving the quality of hazard maps (Lantzy et al., 1998; Vaijala and Feischbeck, 2000). The aim of our investigation was to assess the efficacy of available hazard and risk maps of Stromboli Island through testing map comprehension, volcanic hazards understanding, and to elicit opinions about existing maps and suggestions in order to produce new, more suitable, maps if necessary. Our study serves also as an evaluation of their use in 'way-finding' activities and particularly in optimising the task of making the 'agent intelligent' (Freska, 1999) and thus enhancing the map's potential as a decision-making tool during volcanic crises.

2. Research Methodology

Stromboli Island is the emergent part of an active volcano (Rosi et al., 2000). This is characterised by a persistent low-to-moderate magnitude explosive activity and sporadic high magnitude explosive events and lava effusions. The volcano's North-Western flank shows clear evidence of instability, having been affected by several landslides events, both in the submerged and inland sector, sometimes generating a tsunami as occurred in December 2002 (Tinti et al., 2006). Although the island population is about 500, many thousands of tourists visit Stromboli every year, the majority of them lured by the attraction of the active volcanic cone near the summit of the island. After the last two volcanic crises in 2002-2003 and 2007 the Italian Civil Protection Department produced and published new maps. In particular a tsunami hazard map was developed to show the escape routes from beach areas. This used a contour map as a base. A high quality aerial photo map showing safe walking paths and rules to follow while visiting the volcano was also developed. The only volcanic hazard zoning map available at the time of this study was part of a scientific paper published by Barberi et al. (1993) (Figure 1).

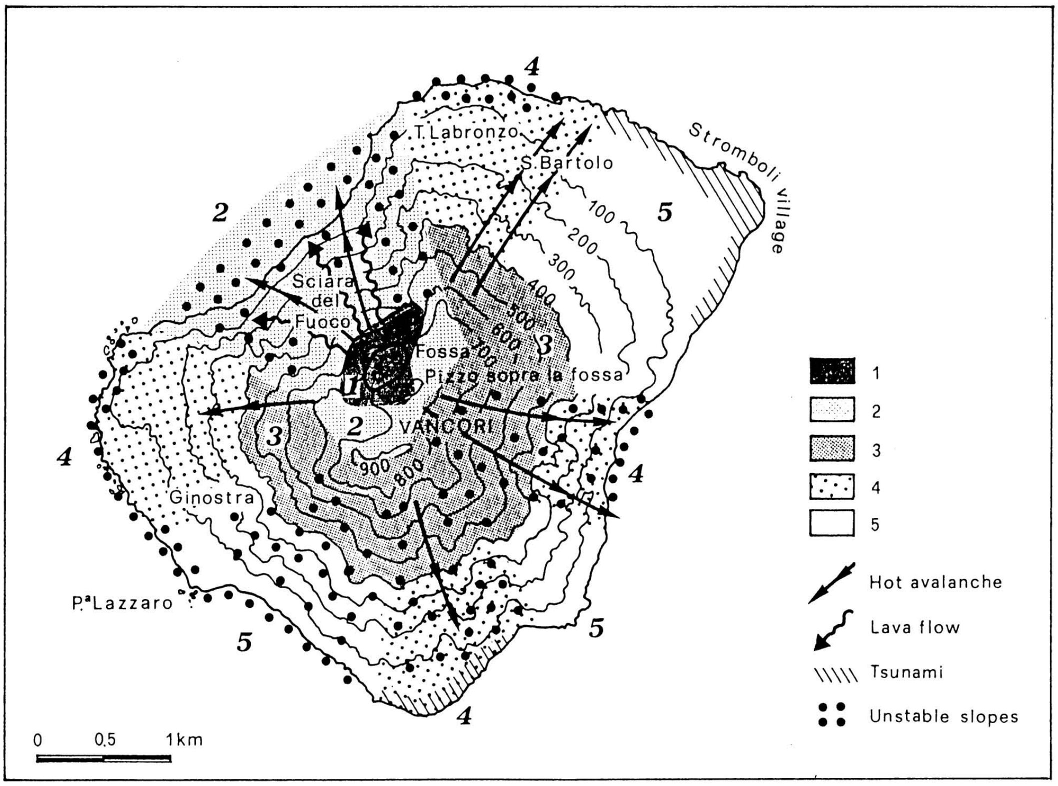

Figure 1. Volcanic Hazard map (Barberi et al., 1993)

The purpose of our research was to evaluate the use of these maps in informing the appropriate authorities of the hazard, evaluating the information of most relevance to these users and subsequently ensuring that this information was available with the greatest clarity and accuracy. Our research thus focussed on those people who would be passing on or acting on risk-related information during times of crisis, this included the civil protection officers, local administrators and various types of police officers as well as volcano-guides and hoteliers (referred to as the 'elites'). This was split into three phases: (i) the efficacy of the current maps and information were assessed via semi-structured interviews; (ii) the development of maps based on findings from phase one and (iii) re-testing of these maps with elites from phase one to produce the best final product. During phase one a contour map (Figure 2) and an aerial photograph (Figure 3) of Stromboli Island were shown and tested along with the Walking Trails map (Figure 4) and the Tsunami Risk map (Figure 5). Interviewees own spatial understanding and ability to locate key features (infrastructural, morphological and volcanic) was tested for each map type. Answers to these questions were scored based on accuracy. They were also asked to describe features most useful to visitors to the island and some general framing questions about their knowledge of the volcanic hazards and how they might improve the maps themselves.

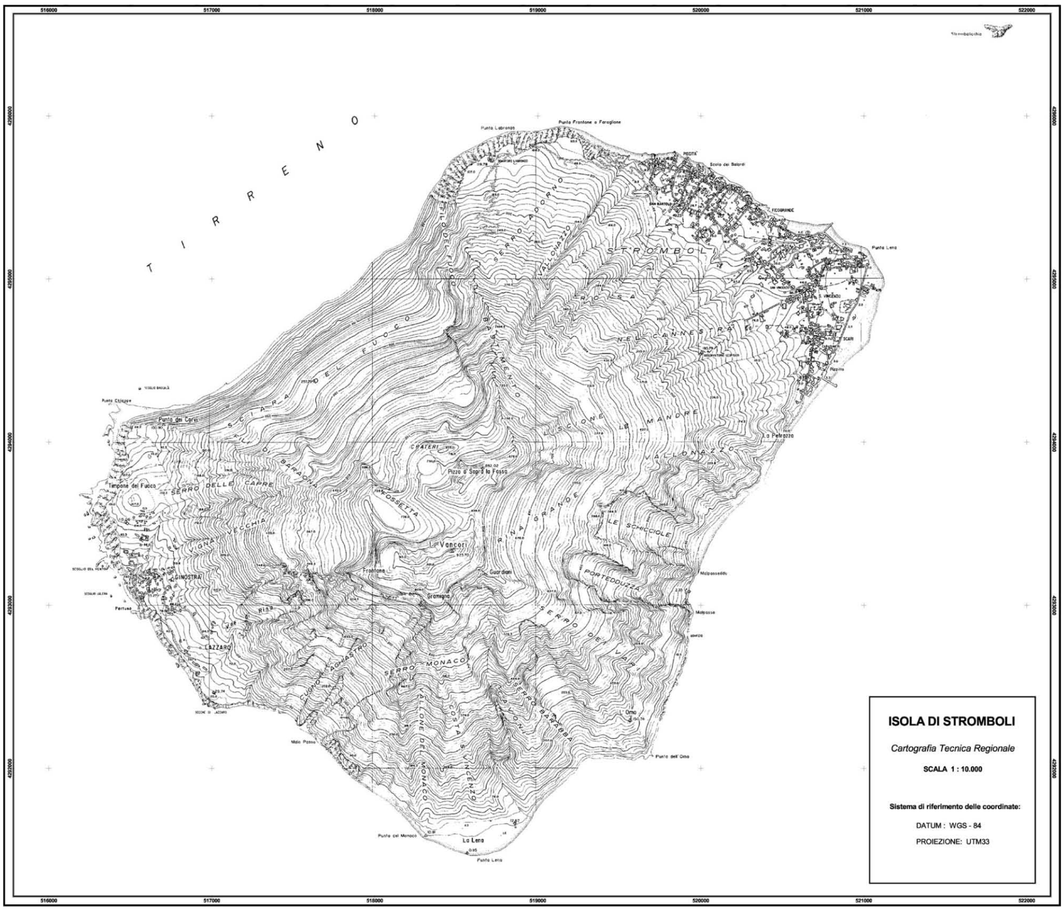

Figure 2. Contour map. Scale 1: 10.000 (Sicilia Region Technical Service)

During phase three respondents were asked further questions relating to interpretation and utility of the new maps developed in phase two as the results of the early interviews. These new maps included a revised contour map, an aerial photograph and a DEM all containing hazard-related information, walking routes, and rules for visitors. An innovative 3D tsunami hazard map was also presented and tested for its communication efficacy (within main map sheet accompanying this article). There were 18 questions focussed largely on the utility of these maps (readability, clarity). A few questions assessed how well respondents could use the new maps to locate the key features in phase one. The full questionnaires and interview protocol can be obtained from the corresponding author.

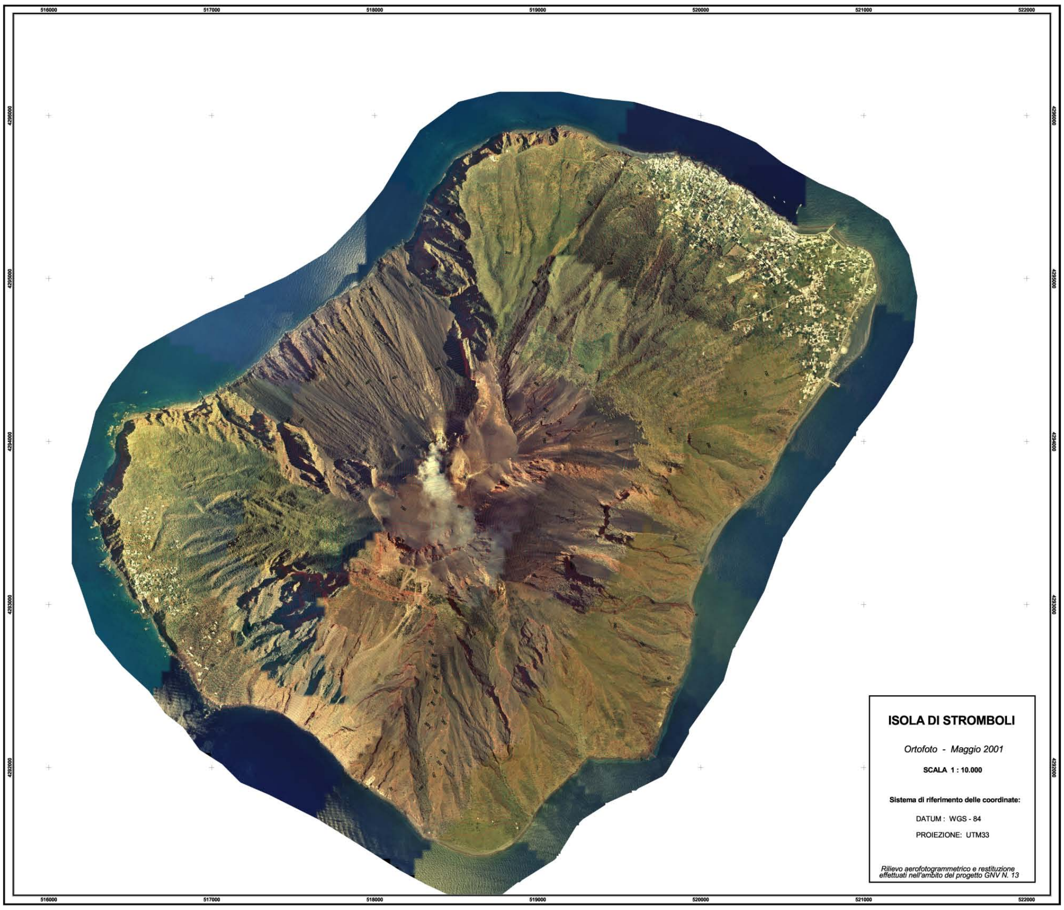

Figure 3. Orthophoto 2001 (courtesy of M. Marsella, Universit La Sapienza - Roma, GNV Project 13)

3. Results

Phase One: testing the existing maps

With a group of respondents trained in understanding and interpreting traditional contour maps it is not surprising that there was no significant difference in respondents between reading and interpreting the contour map and aerial photographs. Most respondents (12 out of 13) expressed a preference or a strong preference for personally using contour maps, but suggested the aerial photograph was more suitable for distributing information to the general public (8 out of 13). Those with regular interactions with volcano tourists (e.g. Civil Protection officials, volcano guides) also emphasised the need to clarify the link between topography and changing volcanic hazard. Respondents tended to view hazards in a multi-disciplinary way, mentioning the need to convey information about vegetation fires and slope instability. Adding symbols to the maps that indicate specific hazard and risk features was a frequent request. A

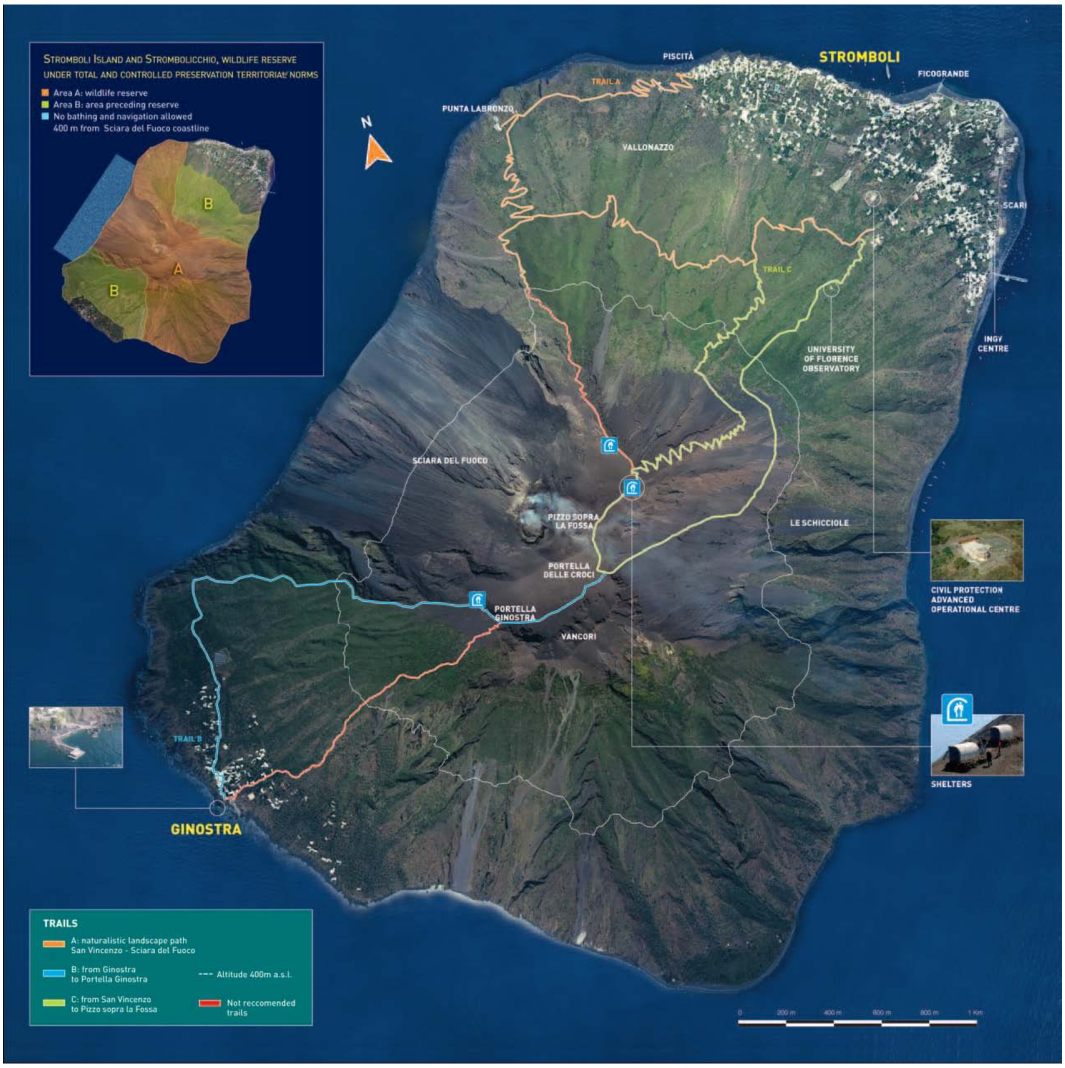

Figure 4. Walking Trails map 2004 (Italian Civil Protection Department, 2007)

clear sense also emerged that while additional hazard-related information was useful the maps needed to remain clear and concise. Symbols were the preferred choice for this but the use of colour and demarcation of local features such as paths and vegetation were also frequently suggested.

Testing the tsunami hazard map, the tension between the need to show narrow streets and other locational elements as exit routes and the fact that many respondents struggled a little to interpret this level of detail in the map became clear as even the expert respondents found location tasks challenging on this map.

Phase Two: developing new maps

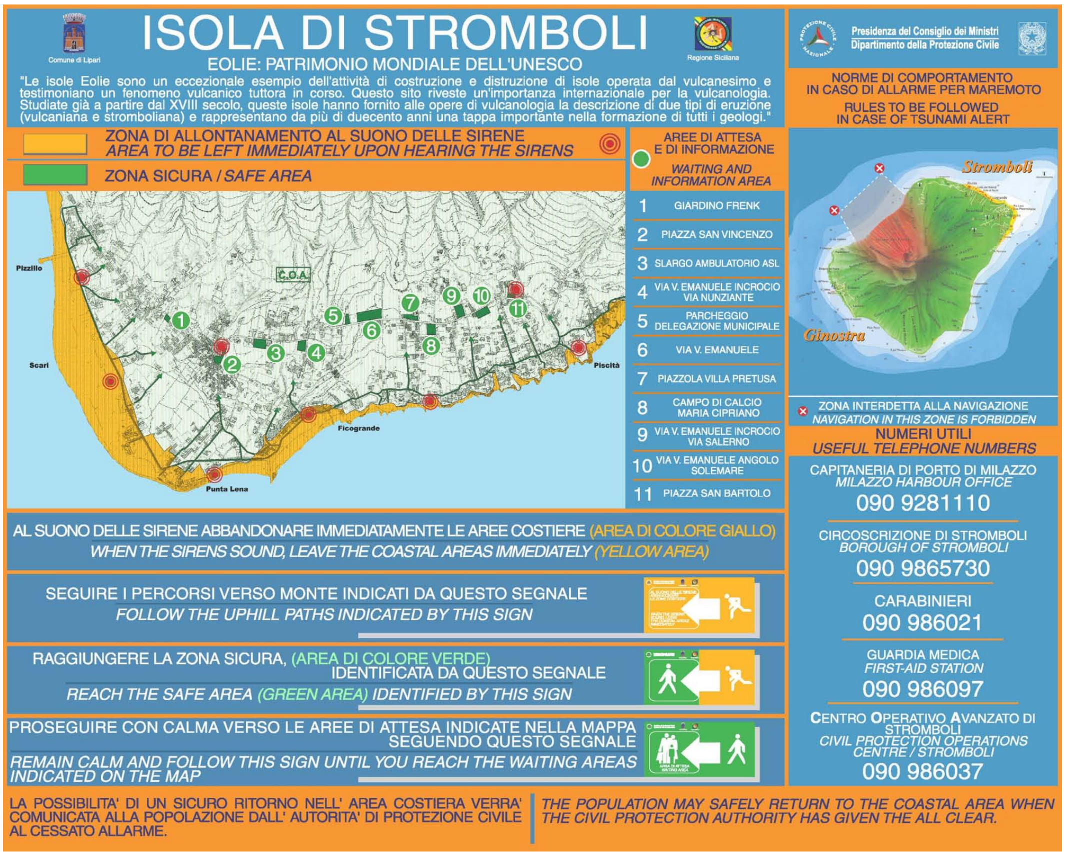

Figure 5. Tsunami Risk map 2003 (Italian Civil Protection Department, 2007)

We used the findings from phase one to develop four different maps using a GIS of Stromboli. The first three maps have volcanic hazard zones superimposed on them along with the differing walking trails also coded for safety.

These maps included:

1. a hazard map with a contour base
2. a hazard map with a black and white aerial photograph base
3. a hazard map with a shaded relief DEM base
4. a 3D perspective map with tsunami hazard zoning and other relevant features

The main map sheet accompanying this article titled "Volcanic and Tsunami Risk Maps of Stromboli Island (Italy)" has been compiled by combining all the information available in the literature with the results from our study. The map sheet is subdivided into two sectors showing the geocoded volcanic and tsunami hazard and risk maps and their related legends. The location of Stromboli Island is shown and a legend with bibliographic references and useful information is also enclosed.

Phase Three: testing and enhancing the new maps

The ability to read and interpret topographic maps among the selected group of interviewees lead to a continued preference for contour maps for their own professional use (eight out of twelve). Where respondents differentiated between their own use and those of non-elite users they tended to think that non-elites would understand the 3D DEM better than the contour maps. All respondents liked the additional hazard information on all of the maps, describing it as a useful working tool during an emergency (contour map) or very clear information (all maps) with a clear connection between the hazards and the walking trails (contour maps). So, the connection between hazard and location on the island was welcomed both for its value in helping technical experts make decisions and in conveying to the general public the relationship of walking trails to the volcanic hazards (both warning and informing). One of the features most commented on for the second generation of maps was the use of colour. The most frequent comment was that red should be associated with the most hazardous phenomena and that colour should be used very sparingly so as not to confuse the map. The DEM map was regarded as an appealing and attractive way to convey information to non-elite users, with some expert users highlighting its utility in checking for damage as the topography and vegetation is extremely distinct. With the tsunami hazard map, three different perspective maps were shown.

4. Conclusions

Based on our findings the following conclusions might be drawn:

1. The expert users on Stromboli preferred contour maps to aerial photographs as a base for hazard-related information. This may not be the case in regions where administrators etc., are less familiar with these maps (see e.g. Haynes et al., 2007).

2. The addition of volcanic and tsunami hazard zones was universally liked and was seen as a useful educational tool. There is also evidence that this enhanced communication and potential utility of the maps for expert users.

3. 'Attractive' GIS-based maps, particularly the 3D DEM, were seen as very useful educational tools (e.g. in visitor centres). They were also believed to make the spatial relationship between terrain and hazard more understandable to non-elites.

4. It is important to consult locally on the details of maps, such as colour and to be aware of popular perception before producing a map.

5. Clear, concise maps with simple graphics but accurate topographic detail are efficient tools that could be used for a variety of purposes.

All of the interviewed people on Stromboli Island clearly indicated that working with hazard maps was very important in both increasing their own knowledge (of volcanic and tsunami risk) and to optimize communication of volcanic hazards information to the general public.

The obtained results and above all the tested methodology suggest the viability of our approach to assess hazard and risk mapping in other areas. A more effective communication of the value of science, particularly with maps, can have a huge impact on policy and decision makers, and consequently on human safety.

Software

All of the produced 2-D maps were developed with ESRI ArcGIS 9.2. ERDAS Imagine 9.3 was used to create the 3-D perspective view tsunami map. Interview questions and protocols are available on request from the corresponding author.

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