SHAKEN, BUT NOT STIRRED

The 2004 Eruption of the Tristan da Cunha Volcano

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Abstract

Overnight on 29-30 July 2004, Tristan da Cunha, a remote volcanic island in the South Atlantic Ocean, was shaken by an intense earthquake swarm. The tremors felt by many of the island's population evoked memories of events leading up to the 1961 volcanic eruption and the subsequent evacuation of the whole island. Shortly after this, fresh pumice was found floating near the island. Concern was immediate, and the population watched the site of the 1961 eruption, known locally as "the volcano". Administrator Mike Hently sought advice from the UK's Foreign and Commonwealth Office - Tristan is a dependency of the UK Overseas Territory of St. Helena - requesting a scientific assessment of the situation. It was in direct response to this request that the author visited the island in September 2004. Events were reconstructed from the islanders' accounts and, following requests from the local community, reassurance and advice were given. Both direct observations and subsequent analysis of seismic data are consistent with a small parasitic eruption having occurred on the lower (submarine) flanks of the Tristan volcano, whilst the sub-aerial portion of the volcano had not stirred. This event reiterates the responsibility of the scientific community to provide meaningful advice on potential hazards and hazard mitigation to those living with active volcanoes. It also illustrates the disproportionate vulnerability of small, remote island communities to natural hazards.

Keywords

Tristan da Cunha, volcanic eruption, earthquake, vulnerability, natural hazards

Introduction

Tristan da Cunha (hereafter "Tristan"; Figure 1) - the so-called "Lonely Island" (Rogers, 1927), lying in the South Atlantic at 37° 05' S, 12° 17' W, 2820 km (1750 miles) WSW of Cape Town and 1,900 km (1,180 miles) SSW of St. Helena - is the most remote inhabited island on Earth. The island remains a dependency of the UK Overseas Territory of St. Helena and has been occupied since 1816, when a British military garrison was temporarily stationed there. The island has a stable population of around 300 and remains in contact with the rest of the world via satellite communications and by ship - approximately 6 days sailing from Cape Town.

Tristan is part of an archipelago comprising five islands, including the smaller uninhabited islands of Inaccessible and the Nightingale group. Tristan itself is an almost circular island, with an area of 98 sq. km, rising to a central peak at 2,060 m (6,760 ft) above sea level from a plateau truncated by steep cliffs rising to around 300-650 m (1,000-2,000 ft) (Figures 2,3). This morphology is instantly recognisable to the volcanologist as a shield volcano and the island is entirely volcanic in origin, consisting of a series of basanitic lava flows (Le Roex et al, 1990). The only habitable part of the island is a small plateau at the foot of the cliffs on the northwest side where the only permanent settlement, Edinburgh of the Seven Seas, lies.

Figure 1 - Tristan da Cunha, the "Lonely Island", the first view in the early morning on arrival, the Nightingale islands in the foreground. (Photograph by the author)

The 29-30 July 2004 earthquake activity, which resulted in tremors felt by many of the island's inhabitants, was recorded by two seismometers installed in March 2004 by the Comprehensive Test Ban Treaty Organisation (CTBTO) as part of the International Monitoring System (IMS). This activity lasted approximately six hours and peaked around 21:00-22:00 (Coordinated Universal Time) on 29 July (BGVN, 2004). At their strongest, these reached 4.8 on the Richter scale (NEIC, 2004). The tremors caused widespread alarm, as similar events had preceded the last eruption of the Tristan volcano in 1961 when a trachy-andesite[1] tholoid[2] erupted over a period of 4 months (Harris, 1964) immediately adjacent to the settlement, resulting in complete evacuation of the island. Subsequently, on 3 August 2004, freshly erupted pumice was found floating on the surface of the sea around 1.5 km (1 mile) to the east of the island. These events precipitated the assessment by the author, which comprised eliciting and interpreting the sequence of events from the islanders themselves, and a survey of the island itself to identify any physical indications of volcanic unrest.

This paper documents the author's observations made during a field season on Tristan between 10 September and 3 October 2004, the overall objective of which was to ascertain whether there was any likelihood of further volcanic unrest and/or any potential threat to the islanders. Some analysis of the islanders' perceptions of these events is also presented, and potential impacts on vulnerability and resilience to further unrest examined. Throughout, the author tried to be aware of the islanders' perception of the facts about *their island* and *their volcano*.

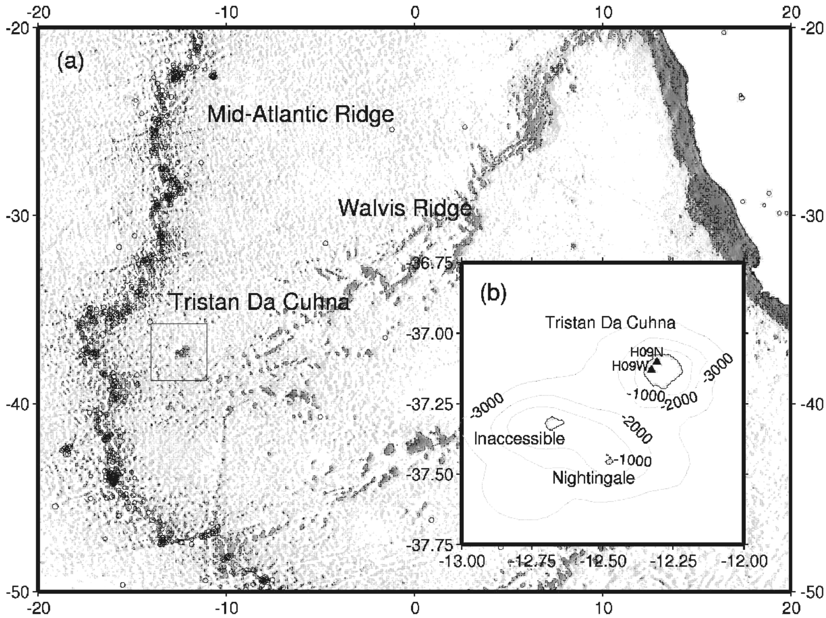

Figure 2 - A bathymetric map of the South Atlantic showing the location of Tristan da Cunha with inset showing the locations of the CTBTO's two seismometers which recorded the felt events and subsequent seismic activity. (Modified from O'Mongain et al [2007]).

Isolation and the island's vulnerability

With isolation and small size can come vulnerability to both exogenous and indigenous (natural) hazards, as defined by Lewis (2009, this issue). In the case of Tristan, for an example of an indigenous hazard, the entire population lives within one settlement on the limited area of flat land in the northwest of the island. Having lived for many years on an island, in virtual isolation, islanders also become more vulnerable to introduced disease (exogenous hazards). As recently as the autumn of 2007, visiting ships brought flu-like viruses that infected a significant proportion of the Tristan population, and an appeal had to be made to get adequate supplies of drugs to the island (Brock, 2007).

A volcanic eruption, even a minor event, could affect the entire settlement and it is in those terms that the risk posed by the volcano and the 2004 tremors must be viewed. The small area of land on which the islanders live could easily be made uninhabitable - affecting the entire population with one event, along with the lack of space for temporary location and the difficulty of a rapid evacuation of the island - a vulnerability of 1.0 out of the 0-1 scale on the United Nations Department of Humanitarian Affairs scale (UN DHA, 1992). Tristan, being associated with the colonial power of the UK, is also vulnerable to decisions potentially irrevocably affecting the islanders' lives (such as evacuation) being made by people remote from the situation (Lewis, 2009, this issue).

Figure 3 - Tristan da Cunha from the West with the main features labelled.
(Photograph by the author)

Communication pathways

Today most people in the developed world are accustomed to relying on accessing outside help, be it help reaching them, or having access to emergency services. Nevertheless, Tristan remains remarkably isolated. In 2004, and at the time of writing, communications were limited to passage and freight on the crayfish trawlers *Kelso* and *Edinburgh* from Cape Town, scheduled to call nine times a year, and the *SA Agulhas* calling once a year (www.tristandc.com). Cruise ships and other vessels also call each year, either bringing tourists or seeking medical assistance. There is no airfield. The government office on Tristan has only had telephone and fax links (in the Administrator's office, via satellite) since 1992, and email and the internet (in the Administrator's office) since 2000. This meant that in 2004 rapid communication was possible, such as for seeking help from UK (in contrast to the situation in the 1961 volcanic crisis) but physical help reaching Tristan, or evacuation, was still difficult, relying on nearby ships. Communication within the community is not a problem. Although Tristanians did not have telephones at the time, the alarm could be raised using VHF radios, or the "gongs"

– old gas cylinders suspended at various parts of the settlement – that are banged to call the men to fish on fine mornings or in case of fire.

In terms of exposure to the world media and news, the islanders have had television (and the accompanying advertising) since 1994 (cable) and the British Forces Broadcasting Service (BFBS) since 2001. Media coverage of natural hazards, however, tends to focus on high impact events and their victims, thus a mature understanding of available information is still potentially lacking. Email and the internet finally reached Tristanians in their homes in September 2007, thus at the time of the first tremors in July 2004, there was not this ready source of information (both good and bad) 'at the islanders' fingertips'.

The Tristan Volcano

The Tristan Archipelago represents the uppermost parts of large volcanoes, of which only Tristan remains active. While it lies just 200 km east of the Mid Atlantic spreading ridge crest (Figure 2), it is generally accepted to represent the current surface expression of a deep-seated hotspot (eg Bowin et al*,* 1984, Duncan, 1981, O'Connor and Le Roex, 1992). The formation of the subaerial portion of the Tristan volcano occurred between 0.1 and 0.2 Ma (million years) ago (McDougall and Ollier, 1982) and the most recent eruption from the central peak ~ 20,000 years ago - yielded a small scoria cone. The cone's crater is now occupied by a shallow lake. In the last 20,000 years volcanic activity has been restricted to small 'parasitic' vents on the flanks of the volcano and in the recent past (3-4,000 years), activity has been further confined to the coastal plains, where there have been two types of eruption: (1) explosive, yielding scoria cones, eg Hillpiece, in which case the risk to the inhabitants would be from ash deposition and ejecta (volcanic bombs); or (2) effusive, resulting in lava domes or tholoids such as the two most recent centres, Stony Hill to the SSE (pre-habitation) and the 1961 tholoid (known locally as *the volcano)* adjacent to the Settlement in the NNW (Figures 4, 5, 6). While voluminous outpouring of lava from the peak itself is considered unlikely (Dunkley, 2002), both types of recent eruption, if they occurred on the Settlement plain (between Pigbite and Big Sandy Gulch), would potentially necessitate evacuation. Unfortunately, given that the most recent eruption occurred here only just over 40 years ago, this probably remains a less-resistant, preferable route for magma to ascend.

The 1961 volcanic crisis

The eruption began with earthquake activity resulting in tremors felt by the islanders, and landslides on the cliffs directly behind the Settlement during August and September 1961. By 10 October, a new volcanic cone 250 ft (80 m) high, emitting clouds of ash and red-hot lava, had risen adjacent to the Settlement (Figure 5) and the decision was taken by Administrator Peter Wheeler to evacuate all 268 Tristanians. Fishing boats immediately evacuated the islanders to Nightingale Island before they were able to depart aboard the Dutch ship, *Tjisadan* (which happened to be in the region at the time) on 11 October, beginning their journey to the UK (Wheeler, 1962). The islanders' vulnerability, inherited from their isolated existence, was demonstrated as the islanders subsequently suffered during their time in the UK: a pensioner was mugged and the islanders lacked immunity from a 'flu epidemic, causing the only fatalities associated with the period. Despite the islanders' requests, the UK Colonial Office decided in mid-1962 not to repatriate the islanders as the viability of the island had been the subject of debate for several years previously. This decision illustrates just how vulnerable island populations are to the decisions of distant colonial powers.

Fortunately, this was not enforced, and repatriation was finally completed by 10 November 1963 (Lewis et al, 1970; Munch, 1964).

Figure 4 - Map of Tristan da Cunha indicating the location of the settlement plain and the most recent subaerial volcanic activity, the 1961 tholoid

The July 2004 earthquake event

Interviews with the islanders[3] revealed that first tremors were felt in the late afternoon on 29 July in houses on the eastern side of the Settlement adjacent to *the volcano* causing immediate concern of its reawakening (Figure 6). Later, some residents reported hearing rumbling noises preceding further tremors as seismic activity intensified. Although reports differ slightly as to which direction they originated from, the general consensus appears to be that they came either from the cliffs behind the Settlement or *the volcano*. Tremor intensity peaked late evening when most reports were received from the other areas of the Settlement. Each shock, or shaking episode, lasted around 20 seconds. In the worst cases windows rattled, furniture shook, and mirrors were observed moving on dressing tables. At their most intense, the tremors possibly reached equivalent force to "B" to "C" grading on Administrator Wheeler's scale from the 1961 event (Wheeler, 1962)[4]. Two residents admitted to the author that they were so alarmed that they had even packed up their belongings in readiness for a hasty departure, and indicated that they were not alone in their level of concern.

The next felt tremor episode occurred on the morning of 31 July. Subsequently, seismic activity remained at an elevated level, with some stronger events being felt in parts of the settlement throughout August and into September. Nothing reaching the initial levels has been felt again (consistent with seismic records). Given that the monitoring station was only installed in March 2004, it is not possible to say if the ongoing low-level seismicity is anomalous or simply representative of normal background levels.

Figure 5 - Inclined view of the Settlement (Edinburgh of the Seven Seas) with the 1961-2 eruptive centre [the "*volcano*" to the inhabitants] in the background. Until the last two years, steam was seen hanging in the air over the top of the dome towards the cliffs, however, the slight grey haze visible in the vicinity here is due to incineration of the island's rubbish on the far side. (Photograph by the author.)

Detailed retrospective analysis of the July event data and ongoing monitoring of near-real-time-data from the Tristan stations was subsequently carried out by scientists at the British Geological Survey and others, and although nothing was felt by the islanders, seismicity remained elevated for many months. The 2004 Tristan earthquakes can be classified as "volcano-tectonic" earthquakes [VTs] (Stewart et al, 2005, O'Mongain et al, 2007). Such earthquakes are thought to result from brittle failure of the country rock in response to pressure of magma injection from depth and subsequent slippage along fault planes (eg Miller et al, 1998). With only two closely spaced seismometers on Tristan, data available are insufficient to resolve hypocentre locations although the location of these events was estimated to be between 37 and 53 km (23 to 33 miles) offshore to the SSE (O'Mongain et al, 2007). That the tremors were felt predominantly in the eastern sector of the Settlement may be explained by local ground conditions. It is recognised that buildings on unconsolidated ground often sustain more damage from earthquakes than those on solid rock (FEMA, 2004).

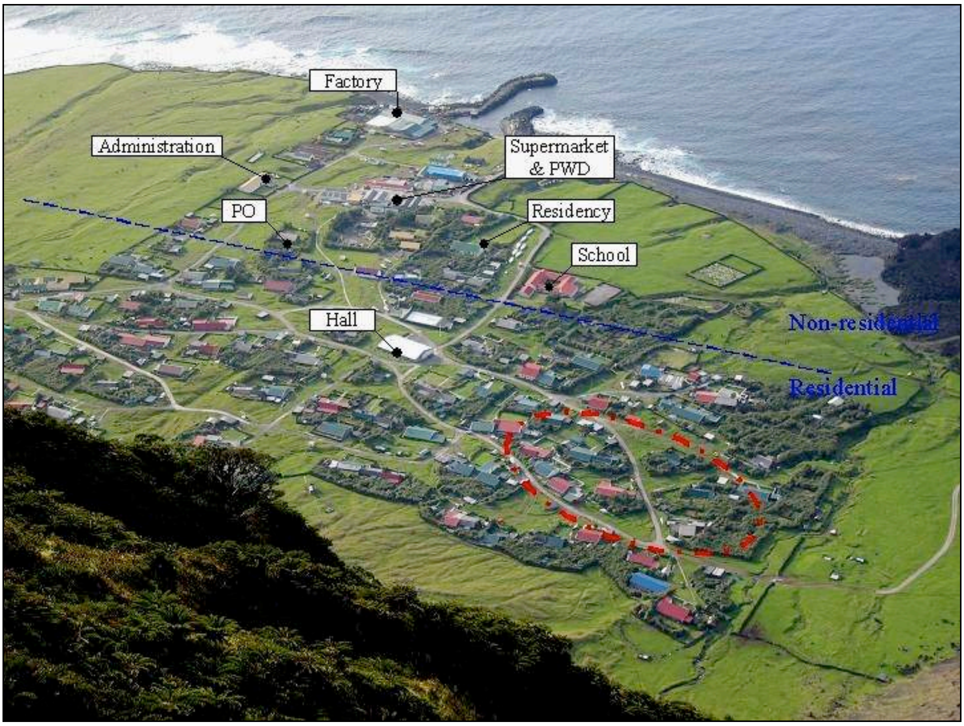

Figure 6 - Detail of the Settlement with the main public buildings annotated. The approximate delineation between residential and non-residential sectors is also shown in blue. The red ellipse shows the area where tremors were felt most intensely. (Photograph by the author)

The 2004 volcanic eruption

The Tristan cray fishing season starts at the beginning of August and the pumice was first found by the fishermen to the east of Sandy Point (the eastern tip of Tristan) at some 3-4 miles distance on Tuesday 3 August when they reached this location. The pumice reached Tristan's beaches over the next few days, a particular abundance being noted on the beach at Cave Point (Seal Bay side; Figure 4) where the beach was described buy islanders interviewed as having "turned white." Given the prevailing ocean currents and the wind reported by the fishermen that day, it can be inferred that the source was further to the south or south west of Tristan, towards Nightingale island. The pumice was very pale grey, very angular in shape, very low density and highly vessicular. Much of it was also extremely fragile (Figure 7) leaving no doubt that it was the product of a very recent eruption. Detailed examination showed the vesicularity to be >75% by volume, with individual vesicles often showing cuspate forms from breakage of earlier vesicle walls, indicative of rapid exsolution of volatiles typifying explosive eruption (Figure 8). Explosive eruptions are rare in the submarine environment at depths of greater than a few hundred metres due to the pressure of the overlying water column suppressing juvenile gas exsolution, thus excluding magmatic disruption (Head and Wilson, 2003), thus restricting the number of possible vent locations.

Figure 7 - Pumice clasts. Left-hand-side: fresh pumice collected from the surface of the sea by the island's fishermen on 3 August 2004. The striated surface appearance on the fresh pumice is due to its tubular structure (orientation indicated by the blue arrow). Right-hand-side: pumice found around the high-tide mark on the beach at Cave Point on 23 September, by which time only the more resistant, slightly denser material remained. Note the increased rounding over time from the left to right pumice. (Photograph by the author)

Samples of the 2004 pumice were analysed for both major and trace elements and were found to be phonolitic in composition (Reagan et al, 2008). Comparison with published analyses for Tristan (Le Roex et al, 1990), and the older (1 Ma) Inaccessible island succession (Cliff et al, 1991) suggests that the pumice has greater affinity with the (younger and more strongly alkaline in geochemical terms) Tristan lavas, suggesting its derivation from the same parental magma type. The evidence presented above is consistent with an eruption from a small vent below sea level on the flanks of the Tristan Volcano. Bathymetric data shows a fairly large seamount, the summit of which reaches a depth of "500 fathoms" (<1000 m) approximately 6 miles to the north-east of Nightingale (Baker et al, 1964), presenting a possible location for the vent. The trigger may have been an injection of new magma from great depth or movement along faults intersecting the magma chamber. On bathymetric maps of the South Atlantic, oceanic fracture zones are clearly visible as pronounced approximately east-west trending lineaments either side of the Mid Atlantic Ridge (Figure 2).

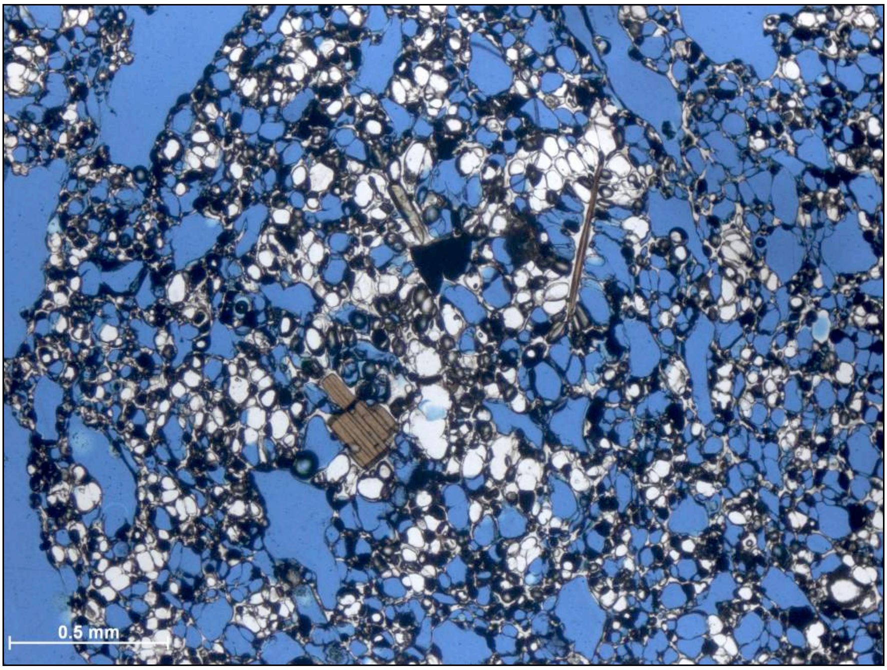

Figure 8 - Photomicrograph of the pumice with blue dye impregnation illustrating the extremely high vessicularity (porosity) and cuspate shapes of the vesicles. (Photograph by the author)

No sign of further activity was found during the author's survey. Nevertheless, further tremors resulting from volcanic activity anywhere on the island could de-stabilise the high cliffs behind the Settlement resulting in large rockfalls or landslides, or alter the flow of streams potentially affecting the islanders' water supply (Figure 9), another concern regarding the island's isolation. Rising gas bubbles in the ocean accompanying a further submarine volcanic eruption could also represent a hazard to shipping, and could even sink smaller craft such as the islanders' long boats.

Hazard communication – reassurance and education

In addition to making direct physical observations, the approach taken was to ascertain what people themselves wanted to know, which can be summarised as "you tell me". Their questions were then analysed and addressed as directly as possible. Misconceptions were also addressed to ensure that people were appraised of the full situation and, importantly, felt their concerns had been addressed. Scientific information to non-scientists can seem unrelated to their concerns (the author's experience both working in Tristan and elsewhere; see also Cronin et al, 2004 and Haynes et al, 2008). On finding no signs of immediate crisis, information was made available formally three weeks into the visit, allowing time for further questions to be raised prior to the author's departure from Tristan. Paper copies of "FAQs" (Frequently Asked Questions) and answers were distributed, and informal question-and-answer sessions held in the local bar. Tristan is a close-knit community and information travels rapidly by word of mouth.

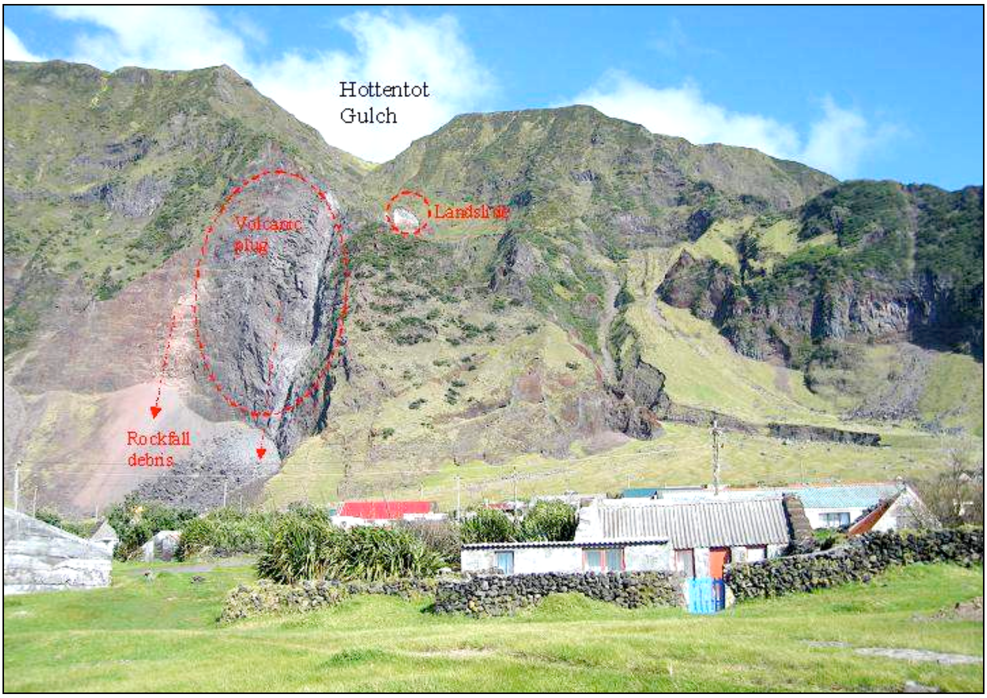

Figure 9 - The Main Cliffs behind the settlement with the areas most vulnerable to rockfalls annotated, most notably the volcanic plug previously identified by Dunkley (2002) as a potential hazard. The recent landslip scar (August 2004) at around 400m in Hottentot Gulch is also marked. (Photograph by the author)

The six principal concerns expressed by the Island's inhabitants were:

i. Were the tremors volcanic in origin?

ii. Was *the volcano* (in the sense of the 1961-2 centre) re-awakening?

iii. Why were the tremors felt most strongly closest to *the volcano* (in the east of the Settlement)?

iv. What was the floating rock? (Many referred to it as "sulphur"), where did it come from, and was it poisonous?

v. Reassurance was sought that the situation would not change for the worse after the author had departed. (Reassurance was apparently given by a visiting scientist that 'nothing more would happen' after the initial tremors in 1961. After his departure the eruption took place.)

vi. If there was an eruption, what would happen? Where could they go?

Answers were supplied to the population in September 2004 and inherent challenges in communication were identified:

i. Yes, the tremors were volcanic but a significant eruption was not imminent and there was no immediate threat to the Settlement. Here the concept of the volcano being the entire island had to be communicated without causing further alarm.

ii. There was no sign that the 1961 "volcano" was about to re-awaken. Steam emanation was as expected for a volcano cooling down more than 40 years after its last eruption[5]. The complete absence of sulphurous gases and sulphur minerals observed is also indicative of a lack of new lava. This would therefore seem to exclude imminent eruption at higher levels on the volcano. Analysis of the data from the two earthquake monitoring stations indicates that the source of these earthquakes was at a distance of some 25-30 km (15-20 miles) away, possibly offshore to the SE (preliminary analysis: BVGN (2004)).

iii. Local site conditions can make a big difference as to whether an earthquake can be felt or not and very similar buildings may be affected in different ways. Buildings on unconsolidated ground may shake more than those on solid rock.

iv. The pale grey floating rock found at the beginning of August was pumice, a volcanic rock. Old deposits - a creamy-coloured horizon near the base of the cliffs SW of Hottentot Gulch - were pointed out. Assurance was given that it was not poisonous. Children were perfectly safe playing with it.

v. Scientists at the British Geological Survey would continue to analyse near-real-time data from earthquake activity in the region from the CTBTO seismometers on Tristan.

vi. Should an eruption take place, on the far side of the island, the threat to the settlement would be limited to the danger posed by the accompanying tremors, direct damage to property and potential disruption of power and water supplies, rockfalls from the cliffs behind the settlement.

Aftermath and analysis

The author's visit, aimed at establishing whether this was indeed the first stages of a volcanic crisis and providing necessary advice, was typical of crisis response. This was a significant responsibility for a single scientist in the absence of other voices. On the other hand, adherence to the general guidelines for scientists at times of volcanic crisis (Newhall et al, 1999) and relaying a consistent, unconfused message was made easier. One overwhelming conclusion drawn from this work was the importance of being aware of the islanders' perception of the facts about *their island* and *their volcano*. In Tristan there is a community with past experience of what can happen. In living memory, also, is a time when they had to fight for the right to return home. In all communication with the public, trust in scientists and the authorities is paramount (Haynes et al, 2007). The approach taken in this instance, appears to have gone a long way towards maintaining trust. It also allowed answers to be tailored to questions and revealed perceptions and misconceptions allowing these, too, to be addressed. The luxury afforded in a small and close-knit community was the chance to speak personally with people and if not with each individual, with a family member or with someone in the community that they trusted. An approach recommended by Haynes et al (2007) was to identify trusted members of the community in addition to figures in authority. It has been previously established that assessing risk from a purely physical perspective without taking in the communities' perceptions may result in subsequent communication problems. Ultimately this may increase the vulnerability of the population to hazards through failure to adopt appropriate mitigation measures (Paton et al, 2000). In this case, there was a failure to realise that islanders perceived *the volcano* to be simply the 1961 eruption site and not their entire island.

Volcanologists refer to volcanic crisis as the sequence of events from the first signs of a volcano stirring, through the eruption to the aftermath as the region recovers (Johnston and Ronan, 1999). Accordingly, risk education is divided into distinct time frames: non-eruptive, pre-eruptive, eruption and aftermath. While during a crisis period, risk education and intervention are essential, the most effective time for education can be just after a crisis. The event should be used to raise awareness, and to aid education.

Extra materials were subsequently supplied to the school to enhance the volcanology section of the school students' 'Tristan Studies' course. It has been demonstrated elsewhere that schools can play a vital role in hazard education as children share what they have learnt with parents and other carers (eg Paton et al, 2000). With increasing exposure of Tristan and its children to world media, this kind of education will become more important as the media are biased toward reporting the rare, high impact events and the affected people, thus possibly giving a skewed perception of the hazards faced on Tristan itself.

A synopsis of standard earthquake precautions was additionally left with the Administrator to allow appropriate action to be taken should further tremors occur since, as discussed above, these not only represent a direct threat to the physical safety of the population; but even lesser activity could disrupt infrastructure and utilities. Changes in the watercourses could affect the water supply to homes and the crayfish processing factory – key to the island's economy.

Conclusions

The earthquake swarm felt on Tristan over 29-30 July 2004 appears to have been associated with magma rising prior to a submarine eruption from a location to the SSE of Tristan itself. The timing of the eruption itself can only be constrained to before August 3, at a location > 5 km (3 miles) offshore, to the south of Tristan. The composition of the pumice suggests a common parent or source end to the Tristan lava succession. The sequence of events was established predominantly from separate observations by members of the community, who also needed answers and, where possible, reassurance, to allay their fears for their homes and the future of their community. The evacuation of 1961 is still in living memory and provided a backdrop to this event. Although no conclusive evidence of recent or imminent sub-aerial volcanic activity on Tristan was found, it provides a stark reminder that this remains an active volcano and plans must be in place to mitigate hazards posed to the community. What was most noticeable in the seismic data was the abrupt onset (O'Mongain et al, 2007) suggesting that there may be little warning prior to more energetic earthquake activity or effusive volcanic activity. The event highlights the importance of continued monitoring, especially given that activity between 1961 and 2004 was not monitored and no baseline exists for comparison.

This event also reiterates the volcanological community's responsibility in hazard assessment and communication with both the civil authorities and the public. It emphasises not only the importance of listening and addressing immediate concerns, but also the differences in language used by scientists, authorities, and residents. For example, it was critical to distinguish between the Tristan Volcano (the surface expression, ie the island itself) and the 1961-2 eruption site (the tholoid adjacent to the settlement, Edinburgh of the Seven Seas). In the absence of escalating volcanic activity, no further intervention or action was required but this event raised awareness of volcanic hazards.

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Endnotes

1. A lava type with little or no free quartz, mineralogically-dominated by alkali feldspar and sodic plagioclase along with one or more of the following mafic minerals: amphibole, biotite or pyroxene. Small amounts of nepheline may be present and apatite is a common accessory mineral.

2. Dome-like structures produced when only limited flow of viscous lava away from the eruption site occurs.

3. Interviews were carried out very informally taking in as many of the population as possible; from the Administrator, those in administrative positions, men, women and children, and including the elderly and housebound. Questioning was kept open, and interviewees were simply asked to recount what they had experienced over the past two months, without first introducing any leading information such as dates or times for events. Questioning always aimed at determining what they had experienced. The tremor events had obviously been the topic of much debate and some people's experiences and interpretation had circulated widely, thus care was taken to ensure that only the individual's own experiences were noted. Third parties were subsequently approached to verify the second-hand portion of the information.

4. Administrator Wheeler compiled this scale in order to keep some form of consistent record during the two months of felt tremor activity preceding the eventual eruption of the volcano adjacent to the settlement. The eruption led first to the movement of the population to the Patches prior to their final evacuation to the UK. The scale also enabled the accounts of the individual islanders to be put into perspective in 1961 and in the more recent 2004 episode.

5. A thermal probe was left in Tristan and instruction given to allow the local population to continue monitoring the fumarole temperature and cooling of the 1961 tholoid. This enabled the local population to take (albeit limited) action, helping them to feel ownership of decisions and major factors affecting the course of their lives.

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