A Volcanic Hazards Assessment Following the January 1999 Eruption of Submarine Volcano III Tofua Volcanic Arc, Kingdom of Tonga

by

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SUBMARINE VOLCANO III

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LOCATION

Tonga Islands, 35 kms northwest of *Ha'atafu* village on *Tongatapu* at latitude 20.85° South; longitude 175.53° West (Fig. 1). This volcanic centre forms part of the Tofua Volcanic Arc (TVA).

FORM AND STRUCTURE

Although no details are available concerning the form and structure of this submarine volcano, This volcano is likely to be the summit of a large submarine stratovolcano which rises from a NNE-SSW trending plateau, 1500 m below sea level (Fig. 1). A shoal has existed at the site during historic times.

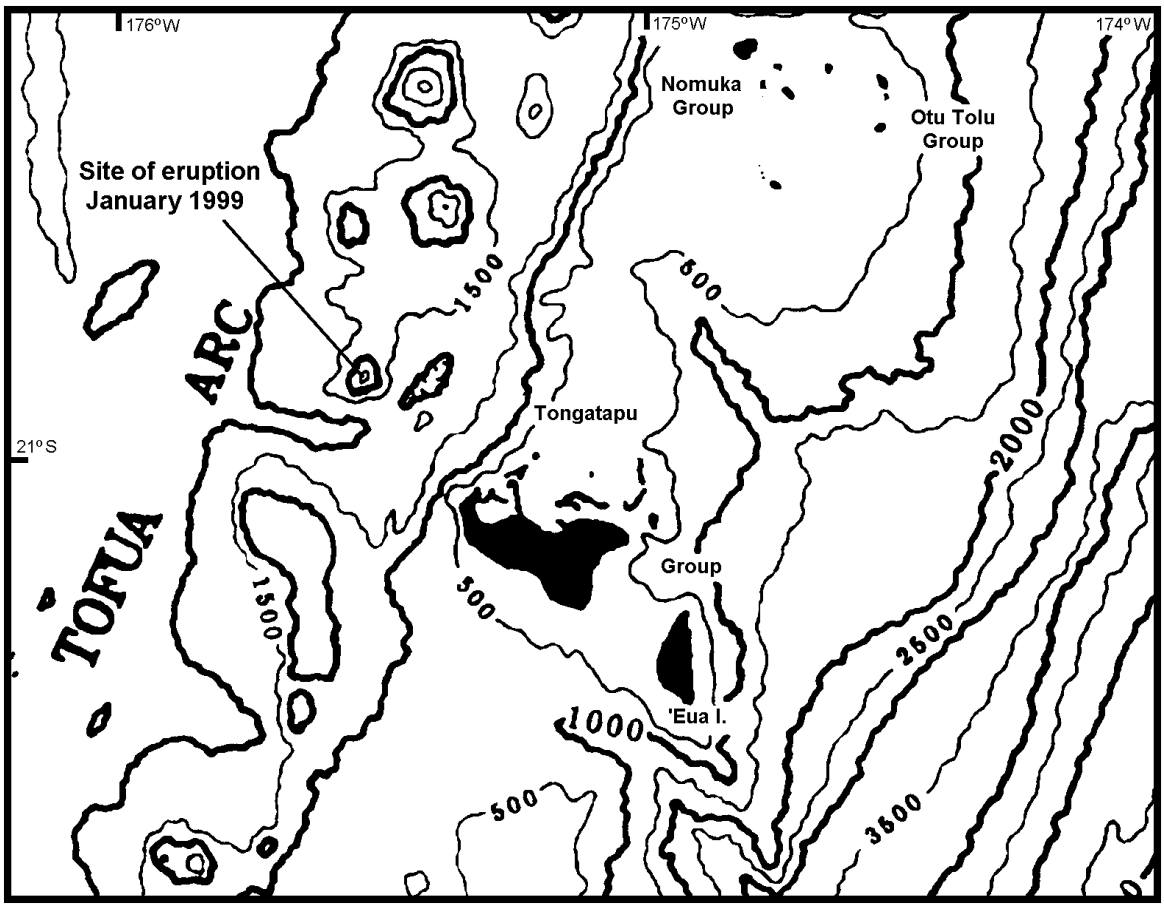

Figure 1: Locality map of the southern part of the central region of the Tonga Platform and Tofua Volcanic Arc showing the site of the current (January 1999) volcanic activity. Note the NNE-SSW trending trough-like feature that separates the volcanic arc and the Tonga Platform in this region that may be a southerly extension of the Tofua Trough. Bathymetric contours are at intervals of 500 m.

DEPTH DETAILS

During a survey in 1943 the summit was reported to be 13.7 m below sea level. A later survey, however, indicated that the summit was 12.8 m below the surface. During the most recent eruption several reports suggested that a small island had formed, no island was observed when the site was visited on 14 January 1999.

VOLCANIC ACTIVITY

Four reports of activity are known at this centre (Table 1). Details of the character and extent of the activity that was reported during 1911, 1923 is unknown, however, it was probably submarine and explosive in character, similar to the current eruption. Admiralty records also indicate that activity may have also occurred during 1970, which was probably also submarine and explosive in character. Several views of the current activity are given in Figure 2.

TABLE 1: VOLCANIC ACTIVITY *AT SUBMARINE VOLCANO III*

Year	Month/Date	Character of Activity	References
1911	Aug	Submarine activity; no other details are known.	Thomson, 1926; Sapper, 1927; Richard, 1962; Simkin and Siebert, 1984.
1923	Jul 1	Submarine activity; an eruption column of steam was rising to a height of 30 m above sea level and was reported 1 km in extent from the vent; no other details are known.	Thomson, 1926; Richard, 1962; Simkin and Siebert, 1984.
1970	3 Jan	Submarine activity?; large area of discoloured water covering area estimated to be 500 acres; no other details are known	Anon. 1959; 1976; 1984; Centre for Short Lived Phenomena, 1970.
1998	27-31 Dec	Submarine activity?; series of earthquakes felt on *Tongatapu*	Anon. 1999; Cable and Wireless report, 1999; Defence Video, 1999; Fonua, 1999; Mafi, pers. com 1999; Samani, pers. comm. 1999; Scott, pers. comm. 1999; Shackelford pers.comm. 1999.
1999	7 Jan	Submarine activity?; area of shallow water reported over "the Sea Mount", the colour of water had changed from blue to green.	
	8 Jan	Submarine activity; eruption column reported to be rising from the sea, large area of discoloured water present in vicinity.	
	12 Jan	Submarine activity; eruption column composed of pre-dominantly steam was being emitted to a height of 100-200 m; molten lava was reported to be present in a small fissure-like vent that appeared to be located within a small crater that measured 50 m in diameter; a small island-like structure of pyroclastic material was reported to be present at the site of eruption; the island appeared to emerge/submerge periodically, when above sea level it was about 3 m high and when submerged it was about 1 m below the surface; hot and steaming scoria was floating on the surface around the site of the eruption; an area of discoloured water 1000 x 300 m was present around the eruption site.	
	14 Jan	Submarine activity continues; a circular area of turbulent water present around a shoal, little or no discolouration of the water in the region was observed; the island reported earlier had receded to just below the surface; the active vent was producing a small eruption column of mainly steam that was reaching a max height of 10-15 m with the plume being dispersed to the NW by the prevailing winds; pumice was observed floating on the sea surface in vicinity of eruption site, and rare lava fragments were also reported to have been ejected from the vent area; strong continuous "vibrations" (volcanic tremor) were felt at distances of less than 200 m from the vent area. Tongan officials issued a warning to shipping transiting the area and a "precautionary" NOTAM was issued by the Nadi ACC warning of the possible hazard to aircraft.	

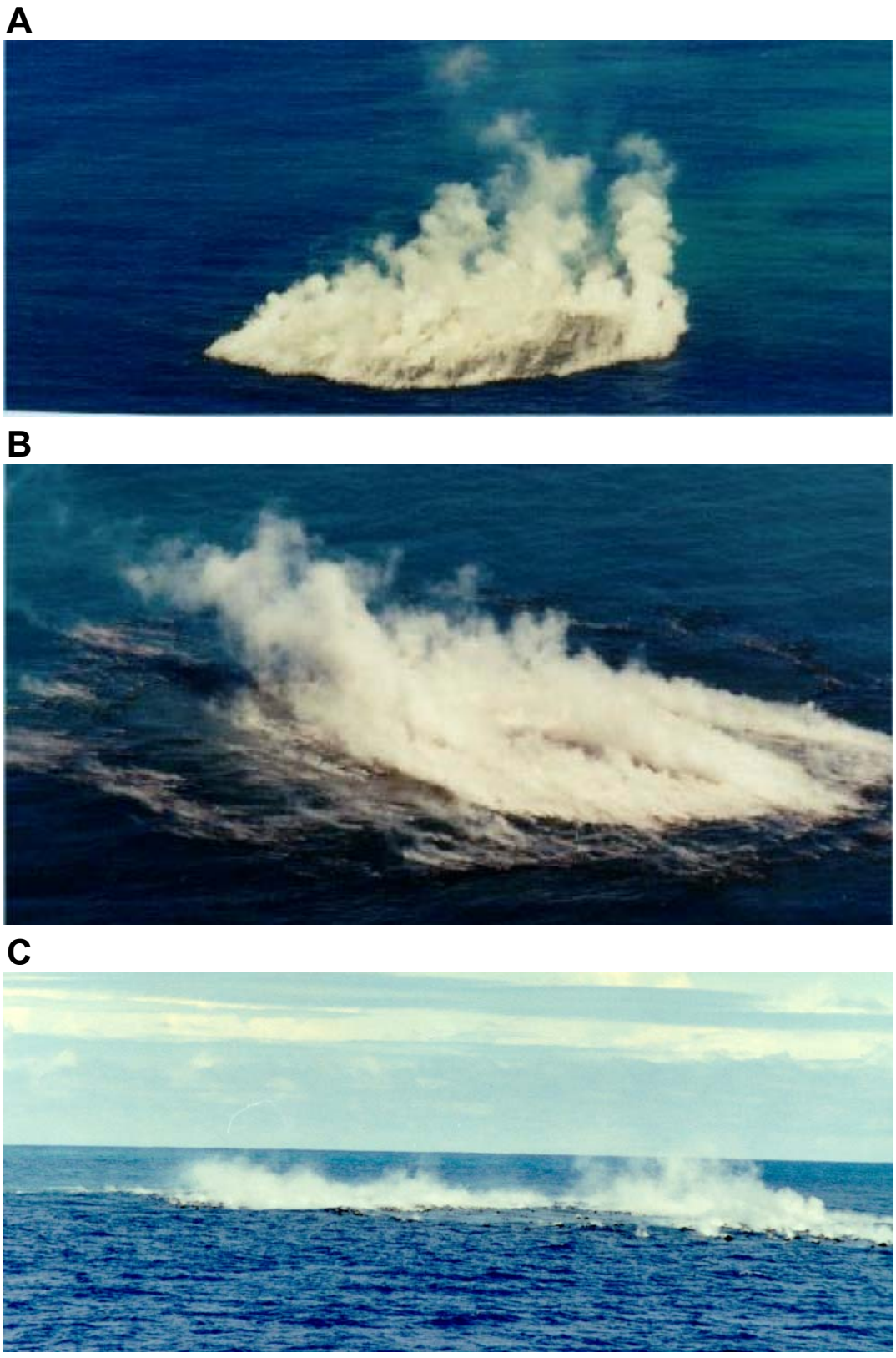

Figure 2: Views of the eruption of Submarine Volcano III taken on 12 January 1999 (photographs A and B) and 14 January 1999 (photograph C). **A.** The small "island-like" structure formed during the eruption. It was reported that the island was periodically rising above the surface, then receding. **B.** Boiling sea around the vent. Fragments of hot pumice are present around the vent area. This view also suggests that the "island" had receded. (both photographs B Hutchins after Cable and Wireless, 1999). **C.** Eruption site showing the turbulent water and the steaming pumice present around the vent. (photograph Tonga Chronicle).

VOLCANIC HAZARDS

Submarine volcanic eruptions are the most common forms of activity that have occurred along the Tofua Volcanic Arc during historic times. Recent eruptions have occurred near *Hunga Tonga* and *Hunga Ha'apai*, at *Falcon Island*, *Metis Shoal*, *Home Reef* and in the region of *Curacoa Reef*. Assessments of the volcanic hazards that occur at submarine volcanic centres are sometimes difficult to accomplish due to remoteness of many of the centres and the incomplete record of activity. It is common that only a small number of eruptions that occur at the centres are detected, and even fewer are actually observed. It is only those eruptions that produce a structure that actually reaches the surface are observed and can be assessed.

Two types of submarine eruptions have occurred at centres along the TVA during recent times:

i) Explosive eruptions which commonly result in the production of pyroclastic cones around the vent regions which are quickly eroded by the ocean. Subaerial lava flows or lava domes are not formed during this type of eruption. This type of eruption is caused by the exsolution of magmatic gases from the magma within the conduit below the vent. As these eruptions are volatile-rich they commonly produce highly vesicular pumice, which when it reaches the surface forms extensive rafts which move away from the vent under the influence of wind and ocean currents. In some cases where the eruption does not reach the surface, pumice rafts are commonly the only phenomena that may be observed. Examples of this type of activity includes recent eruptions at *Curacoa Reef* (1973), *Home Reef* 1984, *Metis Shoal* (1979) and *Falcon Island* (1927-36).

ii) Effusive eruptions which commonly result in the formation of lava domes or rocky shoals. Phases of explosive activity may occur during this type of eruption. They are, however, caused by the explosive fragmentation of lava during its interaction with the seawater. Islands that are formed during this type of activity commonly remain above or near the surface for long periods after activity has ceased. As these eruptions are relatively volatile-poor pumice is not produced. Examples of this type of eruption includes recent eruptions at *Metis Shoal* (1967-68, 1995) and at a vent near *Hunga Tonga* and *Hunga Ha'apai* (1988).

Based on the reports of activity, the recent eruption that occurred at *Submarine Volcano III* appears to be entirely explosive in character, ie. eruptive type i) above, although no large pumice raft has been formed to date.

Specific Hazards

The are a number of specific hazard types that are observed during submarine volcanic activity, or may occur as a result of the activity. These hazards have the potential to affect the immediate area surrounding the centre or even affect a much wider area, which may include islands several tens of kilometres away or the islands of neighbouring countries. The hazards of concern have been listed on Figure 3 and include:

Volcanic **explosions** that occur within the vent region will produce **ballistic ejecta** which may be propelled several hundred metres. Larger explosions may eject blocks up to 1 - 1.5 kms from the vent. Reports of the activity indicated that lava blocks were being ejected during the early stages of this eruption.

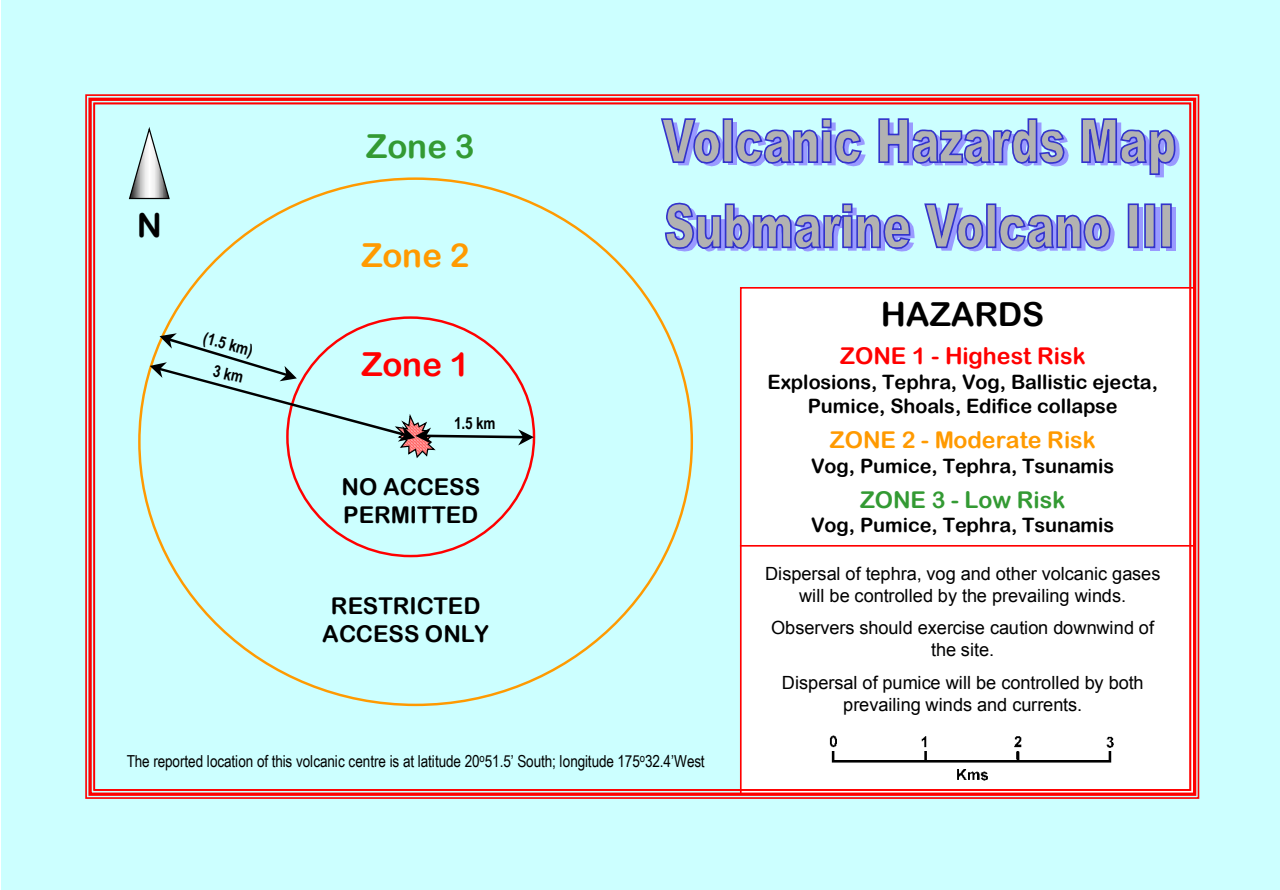

Figure 3: Volcanic Hazards map for Submarine Volcano III showing the three zones of relative risk around the centre and the hazards that are likely to affect each zone (after Scott, 1995). It also indicates the recommended restrictions on access to each zone.

The eruption column produced during an eruption is composed of a mixture of **tephra** and volcanic gases, including SO_2. The tephra produced during the eruption consists of small fragments of rock produced during the explosive disruption of the magma. Volcanic gases, steam and boiling seawater can combine to form **volcanic fog** or **vog**. Both tephra and vog are dispersed under the influence of the prevailing winds, to be deposited at localities, sometimes tens to hundreds of kms downwind of the vent. Vog which can include a highly corrosive form of acid rain may affect many structures that encounter it downwind. Tephra-laden eruption columns, if injected to upper tropospheric levels have the potential to affect aircraft transiting the region. An eruption column was reported during the early phase of this eruption and resulted in a “precautionary” NOTAM being issued by the Nadi ACC.

Because of the entirely explosive character of the activity **pumice** may be produced during the eruption. The pumice produced forms rafts which may drift great distances from the vent under the influence of the prevailing ocean currents and winds. Pumice rafts are commonly washed up on the shore of neighbouring islands or disrupt shipping transiting the region. Pumice was reported on the surface of the sea in the vacinity of the vent during the eruption.

Because of the explosive character of the activity sometimes large amounts of pyroclastic material is produced which results in **shoals** or in some cases islands being formed. Most of the shoals formed are highly unstable and are quickly eroded by the sea. While these structures are present either during or after the activity they cause considerable hazard for

shipping transiting the area. Shoals were reported in the area of the centre prior to the eruption. Furthermore, the vent region for this eruption was reported to be within a shoal composed of pyroclastic material. From reports available to date, no significant island was formed during this eruption.

Due to the unstable nature of the structures formed during eruptions of this type, large explosions or seismic activity that will occur during activity may initiate a volcanic **edifice collapse**. This results in the movement of large amounts of material down the submarine slopes of the volcano. This mechanism may cause volcanogenic **tsunamis** to be generated. Small tsunamis may also be produced by the shock waves produced during the submarine explosions occurring within the vent. Tsunamis produced by either of these mechanisms have the potential to affect regionally extensive areas. Volcanogenic tsunamis have not been reported during the current eruption.

Hazard Zones

The volcanic hazards map shown in Figure 3 indicates three (3) hazard zones around the volcano. The boundaries between the zones are based on hazard assessments conducted at other submarine volcanoes both along the TVA, eg. Scott (1995), and elsewhere in the world. The zones indicate the relative degree of risk from specific volcanic hazards around the volcano. In general terms the degree of overall risk decreases with distance from the volcano, this is the case for risk from volcanic explosions, ballistic ejecta and the presence of shoals. The risk of the affects from some hazards, ie. volcanogenic tsunamis, may increase with distance from the volcano.

For other hazard, including vog, tephra and pumice, the dispersal of which is controlled by the prevailing winds and currents, areas at risk from these hazards will be located downwind/downcurrent of the volcano.

Because of the nature of volcanic hazards that may occur on and around this volcano it is **strongly recommended** that no access be permitted to zone 1 (Figure 2), ie. within 1.5 km of the volcano. Furthermore, it also **strongly recommended** that access to zone 2 (Figure 2)**,** ie. between 1.5 km and 3 km of the volcano, be restricted. Because of the unpredicability of many volcanic phenomena it is also **recommended** that extreme care be taken when approaching the volcano within distances of less than 5 km.

ACKNOWLEDGMENTS

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