Dental fluorosis caused by volcanic degassing in West Ambrym, Vanuatu

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ABSTRACT

Fluorosis, both dental and skeletal, is a disease afflicting millions of people worldwide and is caused primarily by the ingestion of fluoride-rich drinking water. Usually, this is groundwater that has leached fluoride from underlying rock deposits. In West Ambrym, Vanuatu, however, the indigenous people live in close proximity to a degassing volcano and harvest rainwater for their potable water needs. The current project investigated two hypotheses; firstly, that dental fluorosis existed in West Ambrym and secondly, that it was caused by the ingestion of rainwater contaminated by the degassing volcanic plume.

A dental survey was undertaken of children aged 6 to 18 years using the Dean's Index of Fluorosis. A total of 835 children participated; 253 of whom came from the target area of West Ambrym. For comparative analysis and a more regional perspective, the remaining 582 surveyed were from other nearby locations. Drinking water, non-drinking water and food samples were collected for fluoride analyses.

Dental fluorosis prevalence was found to be 96% in West Ambrym, 85% in Malakula, 71% in North Ambrym, 61% in Southeast Ambrym, 36% in Tongoa, 43% in an 'incidental islands' group, and 100% on Tanna. Drinking water samples from West Ambrym ranged from 0.7 to 9.5 ppm F (average 4.2 ppm F). Groundwater sources ranged from 1.8 to 2.8 ppm F (average 2.2 ppm F). Of the 158 drinking water samples, 99% were over the World Health Organisation recommended concentration of 1.0 ppm F. It was found that pH was not a suitable proxy for fluoride concentration. That painted and/or rusted corrugated iron roofing may play a role in lowering fluoride concentration of stored rainwater was a tentative finding. Coconut juice was a rich source of fluoride. Food samples ranged from < 6 ppm F to over 100 ppm F.

The current research has shown that the semi-continuously degassing of Ambrym volcano is introducing significant levels of fluoride into the drinking water of the local Ni-vanuatu. This geo-meteorological process has resulted in the development of widespread dental fluorosis in West Ambrym. The pathway of fluoride-enriched rainwater identified in this study has not previously been recognised in the aetiology of fluorosis. Defluoridation, or accessing an alternative water source, accompanied by modified rainwater harvesting practices, are means by which the prevalence of the disease can be markedly reduced.

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He aha te mea nui o te Ao?

Maku e kī atu, he tangata, he tangata, he tangata.

Māori Proverb

What is the most important thing in the world?

I say to you, it is people, it is people, it is people.

"At the beginning, this investigation was conceived of
as having but two purposes; the first to satisfy a scientific curiosity
as to what was producing this damage to the teeth, and, second,
if the cause could be found and if preventive measures could be
provided, to save future generations from this disfigurement;
a humanitarian effort"

Frederick S McKay, 1942

CHAPTER 1: INTRODUCTION

1.1 Introduction and objectives

Volcanoes can release significant quantities of fluorine compounds into the environment. Fluorine transported on volcanic ash has been implicated in animal morbidity and mortality as a result of pasture contamination, most notably in Iceland during the Laki fissure (1783-1784) and Hekla (1947 and 1970) eruptions (Thorarinsson, 1979), and the Ruapehu eruptions of 1995-1996.

In the Southwest Pacific, the island volcano Ambrym has been recognised as having one of the largest discharges of volcanic gases in the world (Bani *et al.*, 2006). Although these are dominantly sulphur compounds, it was recognised that airborne volcanogenic fluoride may be a significant component affecting the local population's health by becoming incorporated into drinking water supplies (Cronin *et al.*, 2002).

In humans, digested fluoride is deposited primarily in bones and teeth. Dental fluorosis, evidenced by white discolouration of teeth, is the first visible sign of prolonged over-exposure to ingested fluoride. Increased and continued over-exposure can result in damage to skeletal tissues. Numerous previous studies worldwide have elucidated that fluorosis is primarily a water-borne disease, where water with elevated levels of fluoride is used for drinking and cooking. Most of the known dental and skeletal fluorosis occurs in environments where communal drinking water supplies access groundwater that has leached fluoride from minerals in the underlying geological strata. Fluorosis is endemic in a number of countries because of this (e.g. in India and Africa), but can be a consequence of other causes such as indoor coal burning (e.g. in China). It can also be augmented by practices such as tea drinking, artificially fluoridated water supplies, and the use of fluoridated toothpastes or dentrifices.

Hence, the aim of this study was to elucidate whether the semi-continuous degassing of Ambrym volcano is causing dental fluorosis amongst the indigenous population of West Ambrym, Vanuatu. This has not previously been recognised as a pathway whereby fluoride enters potable water supplies with subsequent impacts upon health.

Three primary objectives were:

1. To determine the existence, and, if existent, the prevalence and severity of dental fluorosis in West Ambrym.
2. To ascertain the concentration of fluoride in drinking waters of West Ambrym.
3. Based on the outcomes of objectives 1 and 2, a third objective was to identify appropriate methods to reduce levels of fluoride in drinking waters, thereby reducing the fluorosis risk.

1.2 Study area – West Ambrym, Vanuatu

1.2.1 Geological and environmental setting

Ambrym is one of the 83 islands in the Y-shaped, northwest-southeast trending archipelago of Vanuatu, formerly known as the New Hebrides (Figure 1.1). Located on the Pacific Ring of Fire, between the Equator and the Tropic of Capricorn, these Melanesian islands are of both tectonic and volcanic origin. The dominant geological process in their genesis is the subduction of the Australian plate beneath the Pacific plate along the New Hebrides Trench (Pelletier *et al.*, 1998; Christova *et al.*, 2004; Schellart *et al.*, 2006).

Ambrym has several active vents located within a central, summit caldera and volcanic plateau, known as the 'Ash Plain' (Figure 1.2). Two of these vents, Marum and Benbow, rise to 1270 m and 1159 m a.s.l., respectively. Lava is basaltic andesite to basalt in composition (Monzier *et al.*, 1997), and the structural geology of this shield volcano is described in a paper by Robin *et al.* (1993). Protuberant headlands to the west, north, and southeast give the island

its distinctive tri-lobate shape. Each region is thus identified according to this natural geographic division as West, North, and Southeast Ambrym, respectively.

Ambrym vents have been semi-continuously active for over two hundred years at least. Captain James Cook, when sailing past Ambrym on his second voyage in 1774, recorded that "we observed two very large columns of smoak, which I judge ascended from Volcanos (*sic*)" (Beaglehole, 1961). By January 2005, the Ambrym plumes were emitting SO_2 at a rate of 14 000 – 20 000 tonnes/day, with a fluoride output estimated to be up to 1100 tonnes/day (Oppenheimer, unpublished data, 2005). The Melanesian volcanoes, along with those of Iceland, appear to be some of the most fluoride-rich systems on Earth (Witham *et al.*, 2005).

Any rain that falls through a volcanic plume usually scavenges volcanogenic solutes and ash particles. Thus, the distribution and dispersion of volcanogenic fluoride in rainfall will naturally be influenced by wind strength and direction, as well as plume flux. The famous 'Southeast Trades' are the prevailing winds in Vanuatu. These predominate during the dry season from May until October and are known locally as the 'tokelau' (D. Charley, pers. comm. 2005). During the wet season, from November until April, winds are more variable and cyclones often occur. During each 12 month period, this wind variability ensures no area of Ambrym is entirely free from volcanic emissions.

Vanuatu's tropical to sub-tropical climate sustains lush forest vegetation; trees, ferns, and vines, as well as cash or subsistence fruit, and vegetable crops such as coconut, banana, and yam. Growth and productivity of horticulture is often compromised on Ambrym due to volcanic emissions causing acid rain and ash fall. An area of damaged vegetation can be seen in Figure 1.2b.

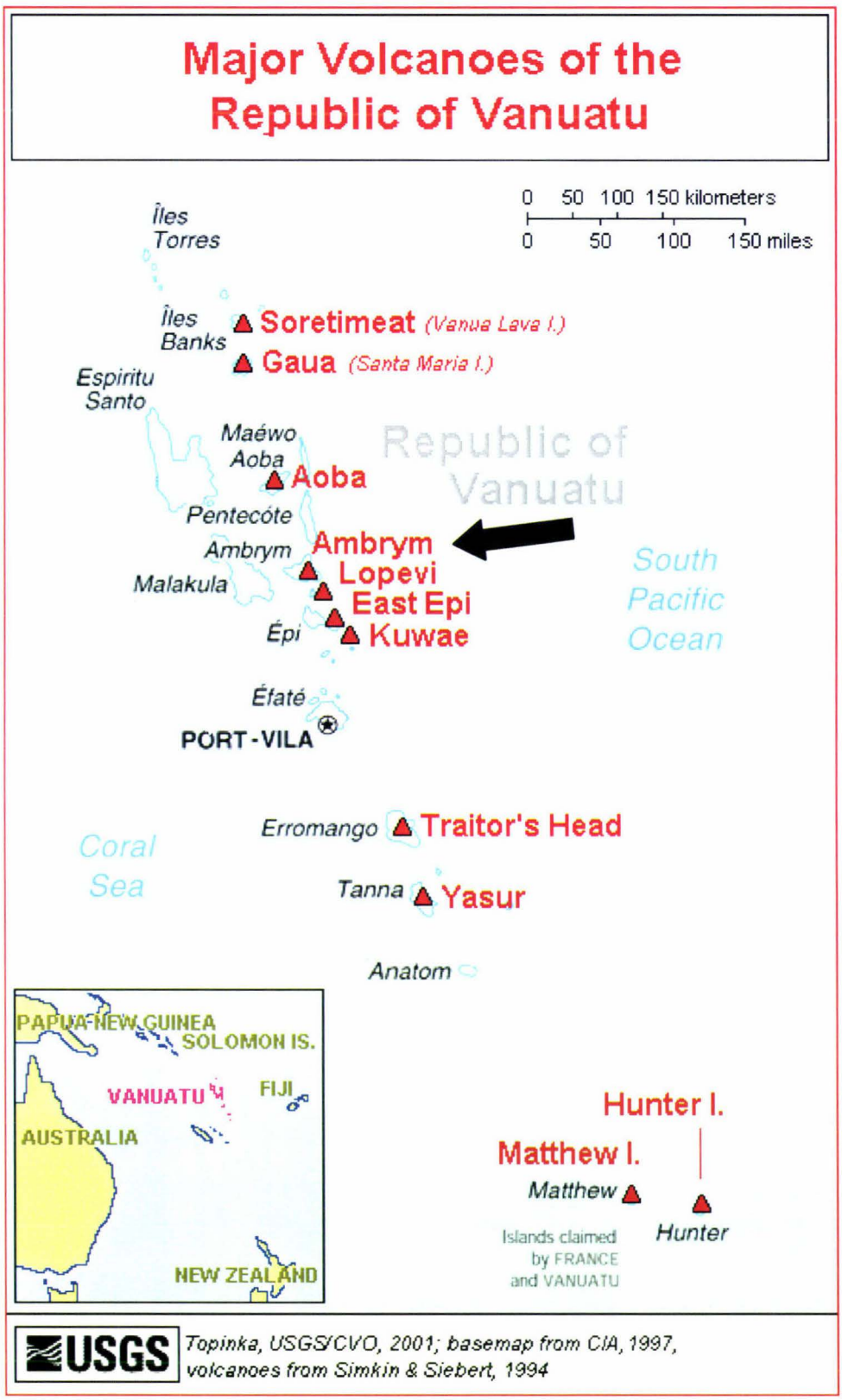

Figure 1.1: Map of Vanuatu; attention is drawn to Ambrym and the other major volcanoes in this archipelago. Ambrym is located at 16°25' S and 168°07' E. Inset shows Vanuatu's location in the southwest Pacific. (Source: Smithsonian Institution)

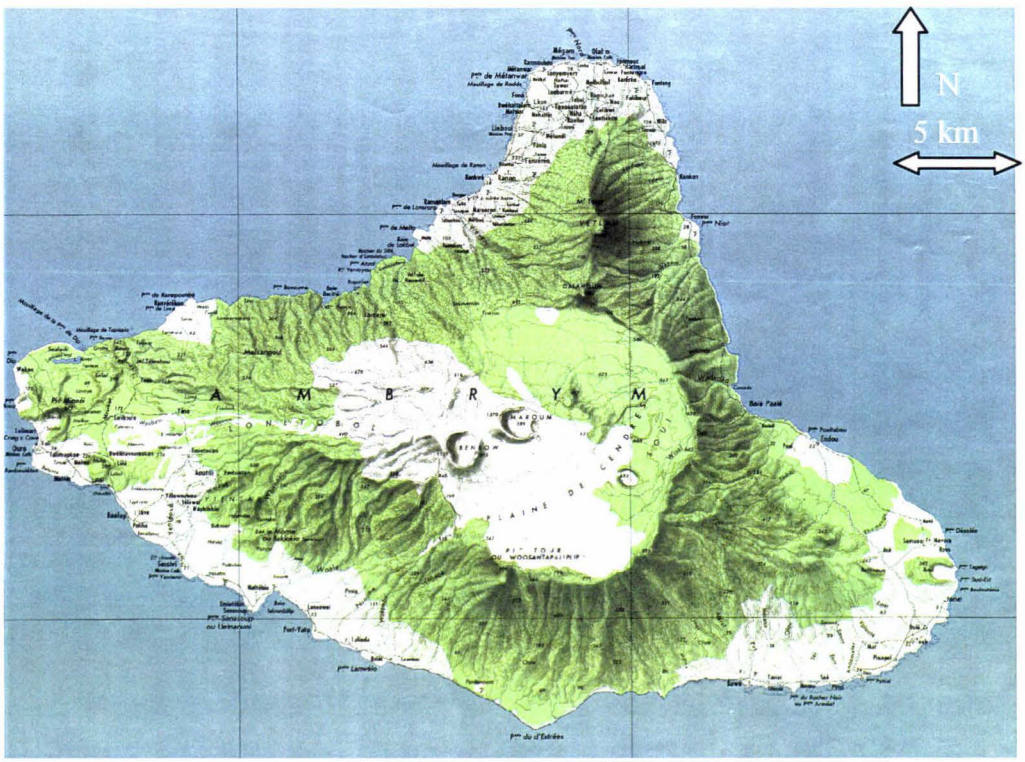

Figure 1.2a: Ambrym contour map. Note the central summit volcanic Ash Plain plateau ('Plaine de Cendres') and main vents of Benbow and Marum. (Source: The World of Maps).

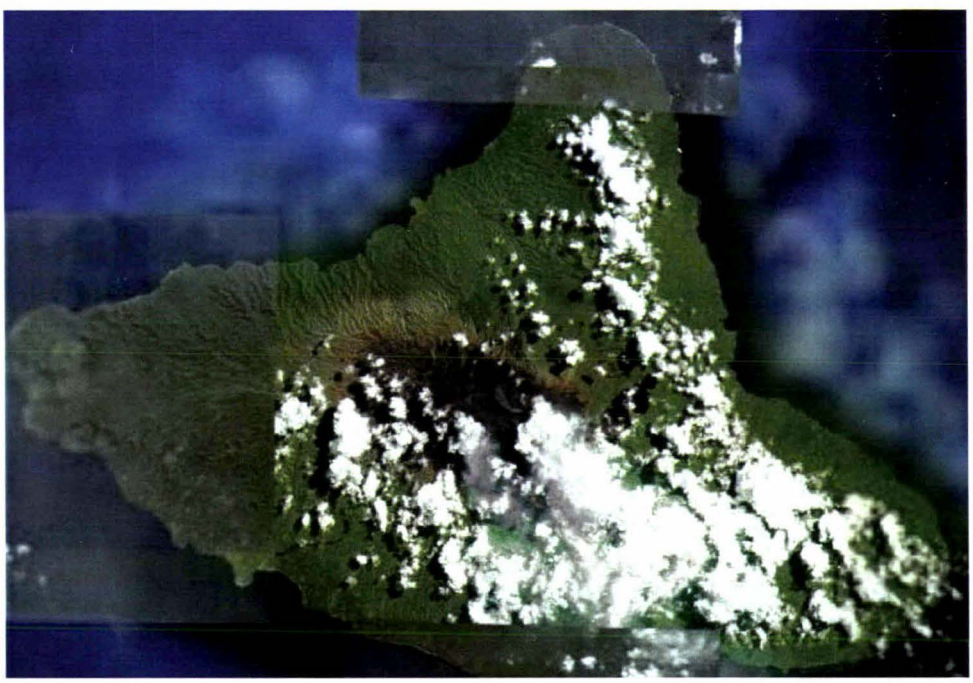

Figure 1.2b: Volcanic plume emanating from the vents in the dark brown Ash Plain is barely visible as it mixes with meteoric cloud. The pale brown and pale green area northwest of the Ash Plain indicates vegetation damaged by acid rain and volcanic emissions. (Source: Google Earth).

1.2.2 Sociocultural setting

The indigenous people of Vanuatu are called Ni-vanuatu or Ni-van, meaning 'of Vanuatu'. There are six provinces in Vanuatu. Ambrym is administered in the Malampa Province, along with the islands of Malakula, Paama, several smaller islands, and the now uninhabited Lopevi. Ambrym's population of over 7000 live a traditional lifestyle including subsistence farming and gardening. Rainwater is harvested by the majority of residents for drinking and cooking purposes and stored in tanks alongside households or in shared community tanks. About 20% utilise a piped water supply (Bakeo, 2000). Locally grown root crops and other vegetables, fruit, bread, and coconut are important staple foods (Carlot-Tary, 2000), while water, tea, and coconut juice are the most regularly consumed fluids (UNICEF, 2001). It is populations like this that live subsistence lifestyles and rely on local food and water sources that are often more at risk of elemental deficiencies and toxicities (Plant *et al.*, 1998).

Acid rain, ash fall, and successive volcanic eruptions and lava flows that have occurred within living memory have all damaged villages and forced evacuation and relocation (D. Charley, 2006; pers. comm.). Daily life for the Ambrym Ni-vanuatu, geographically at least, centres around this active, degassing volcano which is the heart and foundation of their island (Figure 1.3).

Figure 1.3: Degassing of Ambrym volcano with the two major plumes coming from the vents of Benbow and Marum. View is from West Ambrym, January 2005.