Volcanic Ash from the 1999 Eruption of Mount Cameroon Volcano: Characterization and Implications to Health Hazards

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ABSTRACT

Volcanic ash from the 1999 eruption of Mount Cameroon volcano has been characterized for its particle size and shape (by scanning electron microscopy, SEM), and mineralogy (by X-ray diffractometry, XRD). Also the total fluorine (F) content of the ash was determined by the selective ion electrode method. The results show that the Mount Cameroon ash particles have a variety of shapes including fibrous, rounded, subrounded, irregular, angular, eleongated and bladed. All the ash samples have a significant proportion (~ 30%) of ash < 4 μm in size and this is classified in occupational medicine as 'thoracic' and 'respirable' ash that is considered harmful to health. The XRD patterns show that the ash contains plagioclase feldspar, enstatite, augite and chromite, which, if fine enough may cause irritation of the respiratory tract, but they are relatively insoluble in the alveolar region. The ash lacks free silica, the main mineral in volcanic ash responsible for causing silicosis. The F concentration in the ash ranges from 46 μg/g to 189μg/g. This is high considering that the lethal dose of F is set internationally at ~ 100μg/g. This study forms the basis for a long term monitoring of volcanic ash risk and possible mitigation measures of the Mount Cameroon volcano.

Keywords: volcanic ash, Mt. Cameroon, health hazards

RESUME

Cendre de Volcan de L'Eruption de 1999 du Mont Cameroun: Caracterisation et Implications aux Risques Sanitaires.

La cendre de volcan de l'éruption de 1999 du mont Cameroun a été caractérisée pour la dimension et la forme de ces particules (en utilisant la microscopie électronique a balayant, SEM), et minéralogie (diffractométrie a rayon X, XRD). En outre toute la teneur en fluor (F) de la cendre a été déterminée par la méthode sélective d'électrode d'ion. Les résultats prouvent que les particules de cendre du mont Cameroun ont une variété de formes comprenant : les fibreux, les arrondies, les sous arrondies, les irréguliers, les angulaires et les ovales. Tous les échantillons de cendre ont une proportion significative de (~ 30 %) de cendre ayant la taille < 4 m et ceci est classifié dans la médecine du travail comme la cendre 'thoracique' et 'respirable' qui est considérée nocif à la santé. Les modèles de XRD montre que la cendre contient le feldspath de plagioclase, l'enstatite, l'augite et la chromite qui, s'ils sont assez fins, peuvent produire l'irritation de la cavité nasale mais sont relativement insolubles dans la région d'aveolaire. La cendre manque de la silice libre, qui est le minerai principal de la cendre volcanique responsable d'engendrer la silicose. La concentration de F dans la cendre s'échelonne de 189 g/g. Ceci est élevé considérant que la dose mortelle de F est placé internationalement aux environs de ~ 100 g/g. Cette étude forme la base pour une surveillance à long terme du risque volcanique et des mesures possibles de réduction du volcan de mont Cameroun.

Mots clés : cendre de volcan, Mont Cameroun, risques sanitaires

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1. INTRODUCTION

Volcanic eruptions commonly emit a cloud of volcanic ash that can rise to several kilometres into the atmosphere. The resulting ash umbrella cloud can be carried to great distances over a wide surface area by the prevailing wind. Following the Mt. St. Helens (USA) eruption in 1980 (Raub et al., 1985), for example, a plethora of case studies focusing on health effects of volcanic ash at different volcanoes have been undertaken (e.g. Cronin and Sharp, 2002; Cronin et al., 2003; Cullen et al. 2002; Dollberg et al., 1986; Forbes et al. 2003; Horwell and Baxter, 2006; Horwell et al., 2003). Despite these efforts, there still exists a wide gap between volcanologists who typically examine volcanic ash with little or no attention to the < 4 μm size fraction that is considered the most hazardous to health (Horwell and Baxter, 2006). The inhalation of volcanic ash and the resulting health problems to humans and animals is an emerging important theme of occupational medicine. Interest in this domain of research heightened after the Mount St. Helens eruption that caused an extensive ashfall in the Western United States in 1980 (Dollberg, et al. 1986). Volcanic ash can cause respiratory health problems, irritation of the eyes (e.g. Fraunfelder et al., 1983) as well as mental health problems, trauma, and death. The health effects of inhaling volcanic ash depend on its characteristics which include presence or absence of condensed volatiles, notably F, electrical charges, grain size, grain shape and the mineral composition of the ash. In occupational medicine, ash that is <10μm in diameter is classified as thoracic whereas ash that is < 4 μm is classified as respirable (Horwell and Baxter, 2006). Fibrous ash particles can cause respiratory health problems similar to those caused by asbestos; thus the width-length ratio of individual ash particles is important in air quality studies at active volcanoes. Although particles of various sizes and shapes can be inhaled, the < 4 μm fibrous fraction readily penetrates to the non-ciliated airways of the lungs (alveolar region) causing the most harm to health (Horwell et al., 2003). Silica in volcanic ash can cause silicosis and therefore it is important to determine the mineralogical make up of volcanic ash (Baxter et al. 1999).

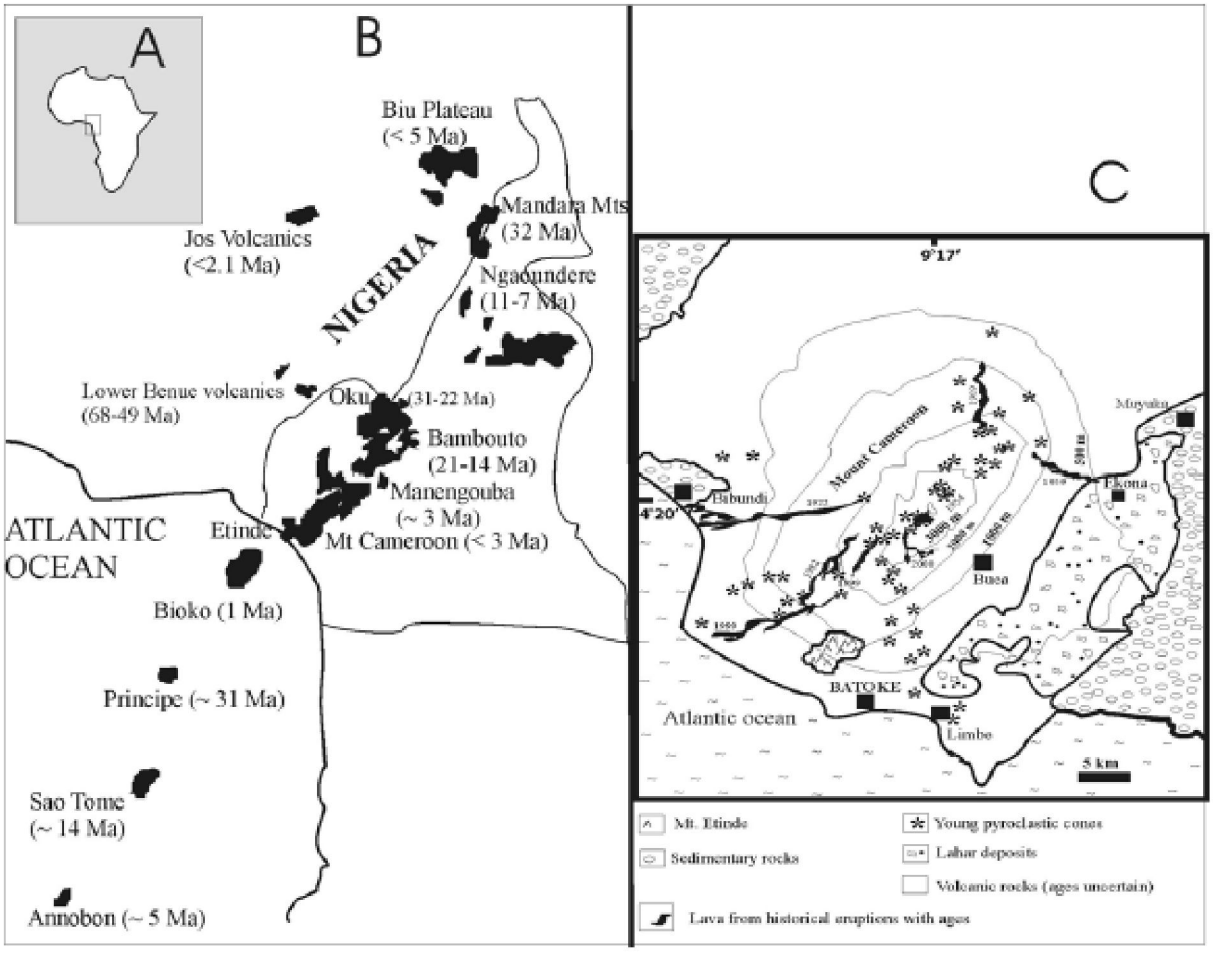

Fig. 1: Regional geological setting of Mount Cameroon and sketch geology of the volcano. Note the location of the batoke Health area where the samples were collected.

In this study, volcanic ash collected downwind during the 1999 eruption of Mount Cameroon volcano, West Africa, has been analysed for its particle size and shape (by scanning electron microscopy, SEM) as well as its mineral content (by X-ray diffractometry, XRD). These data allow for the comparison of ash at Mount Cameroon to that of earth's other volcanoes and it is a significant milestone in the investigation of health effects of volcanic ash at this edifice.

BACKGROUND

Studies on the respiratory health effects of the volcanic activity of Mount Cameroon are sparse. Baxter and Kapila (1989) evaluated the respiratory and other health status of the survivors of the Lake Nyos gas disaster (this event is regarded as a form of eruption). Following the 1999 eruption of Mount Cameroon, a number of studies were performed on the health of the populations in the Bakingili-Batoke health districts. These studies reported irritation of the eyes (Afane et al. 2001) and respiratory problems (Afane et al. 2001). These investigations however failed to explain the nature of the ash (ash particle characteristics, F content etc.) responsible for these health effects. Environmental and health hazards linked to F in volcanic ash have been noted at other volcanoes (e.g. Cronin et al., 2003). Also, a large data base on physical characteristics of volcanic ash and their implications to health hazards has recently been compiled (Horwell and Baxter, 2006). Data from this present study at Mt. Cameroon will add to this resource and identify the possible specific attributes of the ash that can enhance the understanding of the health effects noted by Afane et al. (2000, 2001) after the 1999 eruption.

Mount Cameroon (Fig. 1) is one of Africa's most active volcanoes and it is situated along the Atlantic coast of West Africa. This volcano rises to a height of ~ 4095 m making it the most prominent topographic high along this coast. It is typically a basaltic volcano that forms part of a long line of volcanoes referred to regionally as the Cameroon volcanic line (Fig. 1) or Hot line (Deruelle et al., 2007). Volcanic lakes along this line have emitted CO_2-rich gases leading to the death of over 1800 people (notably Lake Nyos in 1986 and Lake Monoun in 1985). Details of these lake disasters are given in Le Guern and Sigvaldason (1989) and the causes of the deaths remain enigmatic to occupational health experts. Mount Cameroon is the only active volcano along this line having erupted quite recently in 1999 and 2000 (Njome et al., 2008, Suh et al., 2003, 2008). Considering that the focus of this article is volcanic ash and health, the interested reader is referred to the references cited above for a full discussion of the geology of Mount Cameroon although an outline of the geology is provided in Figure 1. During the 1999 and 2000 eruptions, volcanic ash emitted from the active vents affected large areas of the southern slope of this volcano.

MATERIALS AND METHODS

During the 1999 eruption of Mount Cameroon (28th March - 22nd April, 1999) volcanic ash was collected at Batoke (see Fig. 1 for its location), one of the major health districts in the downwind direction on the south western flank of the volcano. Batoke is ~9 km away from the eruption site or source of the ash. The ash was collected in cleaned open domestic dishes placed away from possible secondary contamination by roadside dust. Representative samples of the ash were analyzed for particulate size, shape and mineralogy by combined SEM and XRD techniques at the University of Botswana, Gaborone. The SEM and XRD techniques are described elsewhere (Shemang et al. 2007). The F content of the ash was analysed by the selective ion electrode method which involves adjusting the pH of F as well as the total ionic strength of the buffer which has a high affinity for the fluorine ion (Asobo, 2008 and references therein). F analysis was accomplished at a commercial laboratory.

RESULTS AND INTERPRETATIONS

The ash particles from the 1999 eruption of Mount Cameroon have a wide range in particle size and shape (Fig. 2). Most (> 60%) of the samples fall between 3μm - 69μm in size. The ash particles have a variety of shapes including, rounded, subrounded, angular, elongated, bladed and irregular. Some of the elongated particles qualify as fibrous in shape as defined by Horwell et al. (2003) and can therefore easily reach the alveolar region. Particle sizes, expressed as length/wide ratios (over 200 measurements; details can be obtained from first author upon request), show that 30% of the ash falls within the < 10μ but > 4μm range. A small proportion, ~ 10%, of the ash fell under the category of respirable ash fraction i.e., < 4μm.

In terms of ash mineralogy, the samples contain no crystalline silica but are rich in other minerals such as fayalite (olivine), augite, chromite, plagioclase feldspar and enstatite represented as various peaks on the XRD patterns shown in Figure 3. The relative proportions of these phases in each sample can be deduced from

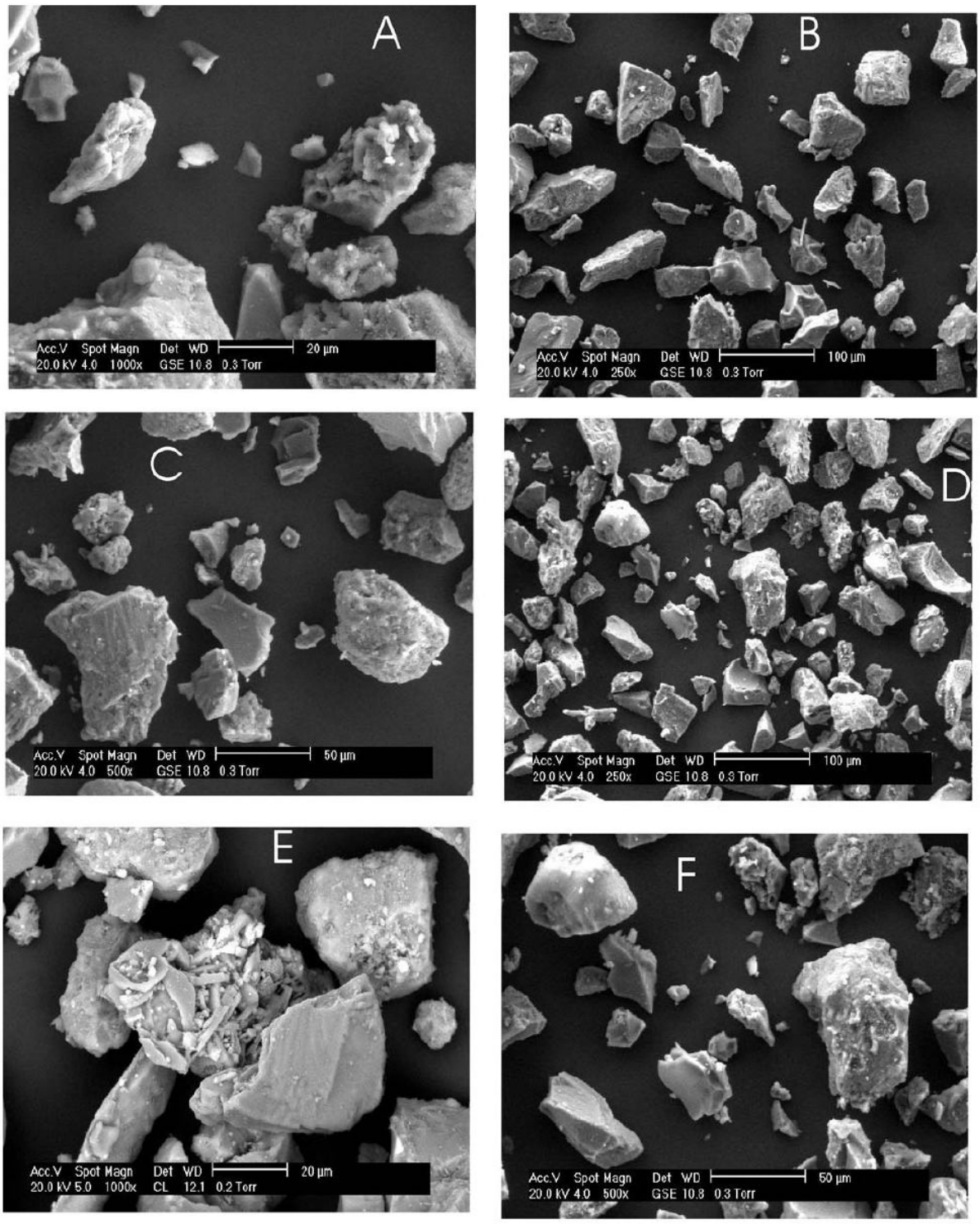

Fig. 2: Backscattered secondary electron images of ash samples (taken with the scanning electron microscope) showing the variations in particle shapes and sizes of the ash from the 1999 eruption of Mount Cameroon.

the relative abundance of the various mineral peaks on the representative XRD patterns provided in Figure 3. If these mineral grains are fine enough, they can cause irritation in the eyes and lungs (Afane et al. 2000, 2001) but there is no medical evidence, to the best of our knowledge, of health effects caused by chemical reaction of these phases with respiratory tract fluids considering that these crystalline phases are relative insoluble.

Table 1 shows the F concentration in the eleven ash samples analyzed. The F content ranges from 46 µg/g

Table 1: Fluorine concentration (μg/g) of volcanic ash samples from the 1999 eruption of Mount Cameroon. F measured by selective ion electrode method.

Sample Number	F (μg/g)
1	125
2	64
3	89
4	101
5	55
6	45
7	89
8	95
9	46
10	189
11	145

Table1. Atanga et al.

to 189μg/g. Aerosols from volcanic plumes usually contain F and acutely lethal doses of F for most mammals are > 100μg/g (Cronin et al 2003) and most grazing animals actually show immediate health impacts with F values higher than this upper limit.

DISCUSSION AND CONCLUSIONS

Volcanic eruptions are amongst the many hazards occurring in the world today which place a risk on mankind's own very existence (see, for example, Gaillard and Dibben, 2008). Consequently, for communities whose proximity to active volcanoes renders them susceptible to experiencing adverse impacts from volcanic activity such as ashfall, the actual evaluation and management of associated health risks is essential (Blong, 1996; Paton et al. 2008). This study has provided a basis for evaluating some of the main factors that can influence the exposure of humans to volcanic ash. The main factors considered in this contribution are the size distribution, shape and mineralogical

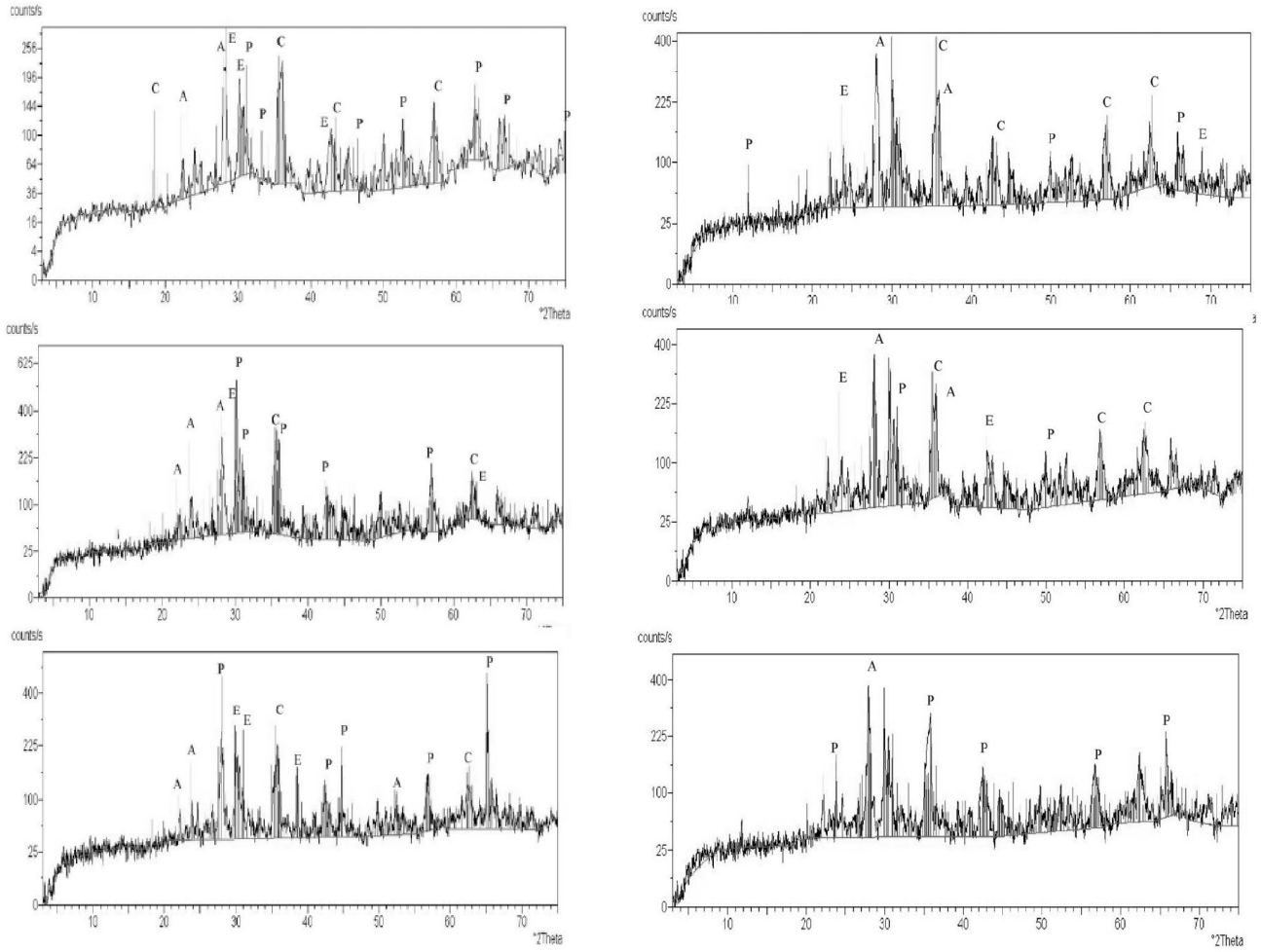

Fig. 3a and 3b: X-ray diffraction patterns of ash samples from the 1999 eruption of mount Cameroon volcano. P+plagioclase feldspar; A+ Augite, C= Chromite, E= Enstaatite

composition of the ash as well as the F content. The results show that the ash contains a significant fine fraction that can easily be inhaled. Also fibrous particles, noted for their respiratory health problems are also present. The results also show that the F content of some of the ash samples exceeds 100μg/g; the upper limit beyond which chronic fluorosis was noted in cattle at Lonquimay volcano in 1989 (Araya et al., 1993) and at Ruapehu volcano in 1995 (Cronin et al. 2003). Fluorine is highly soluble and readily bioavailable (National Research Council, 1974) and can cause respiratory health problems in humans. Freshly erupted ash has unweathered particles and electrical charges can be generated on ash particles which may affect reactions in the lungs when inhaled, especially in the presence of halogens such as F (Williamson et al., 2001; (Horwell et al., 2003).

Assessment of the mineralogical composition of volcanic ash is a crucial step in health hazard assessment. Studies have shown that volcanic ash often contains crystalline silica as quartz, cristobalite or tridymite polymorphs. Exposure to crystalline silica has been known to cause silicosis, a fibroic lung disease. It may also cause lung cancer in some persons who have developed silicosis (International Agency for Research on Cancer, 1997). Cristobolite is the most toxic mineral in volcanic ash and it is considered to be a human carsinogen. This study shows that cristobalite is absent in the 1999 ash. Medical records have no evidence that the other mineral phases present (fayalite, enstatite, augite, plagioclase feldspar, chromite) can cause similar health effects.

Acute and chronic health effects of volcanic ash depend, amongst other factors, on the particle size particularly the respirable-size material and mineral composition (especially the crystalline silica content) (Horwell et al., 2003). The grain size of ash particles is of critical importance and is conventionally defined in terms of the aerodynamic diameter or length/width ratio. In terms of occupational health, such ash is classified as thoracic and respirable if < 4?m (Quality of Urban Air Review Group, 1996). Recent studies showed that fibrous fine particles (1?m) and ultrafines (0.01?m) are likely to be the most toxic (Expert Panel on Air Quality Standards, 1995). Insoluble fibre may represent respiratory hazards similar to asbestos depending upon fibre length and width. Hazardous fibres are those whose length-diameter ratio is greater than 3 and length greater than 5?m (Horwell and Baxter, 2006). In this study, a significant part (~ 30%) of the 1999 ash has these charactersitics indicating that the ash that can be inhaled into the lungs. These results might explain the health impacts noted by Afane et al. (2000, 2001) in this area. Consequently, there is a need for action to be taken to prevent the exposure of the population to volcanic ash as well as raise awareness and educate those who are more exposed to potential health effects.

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