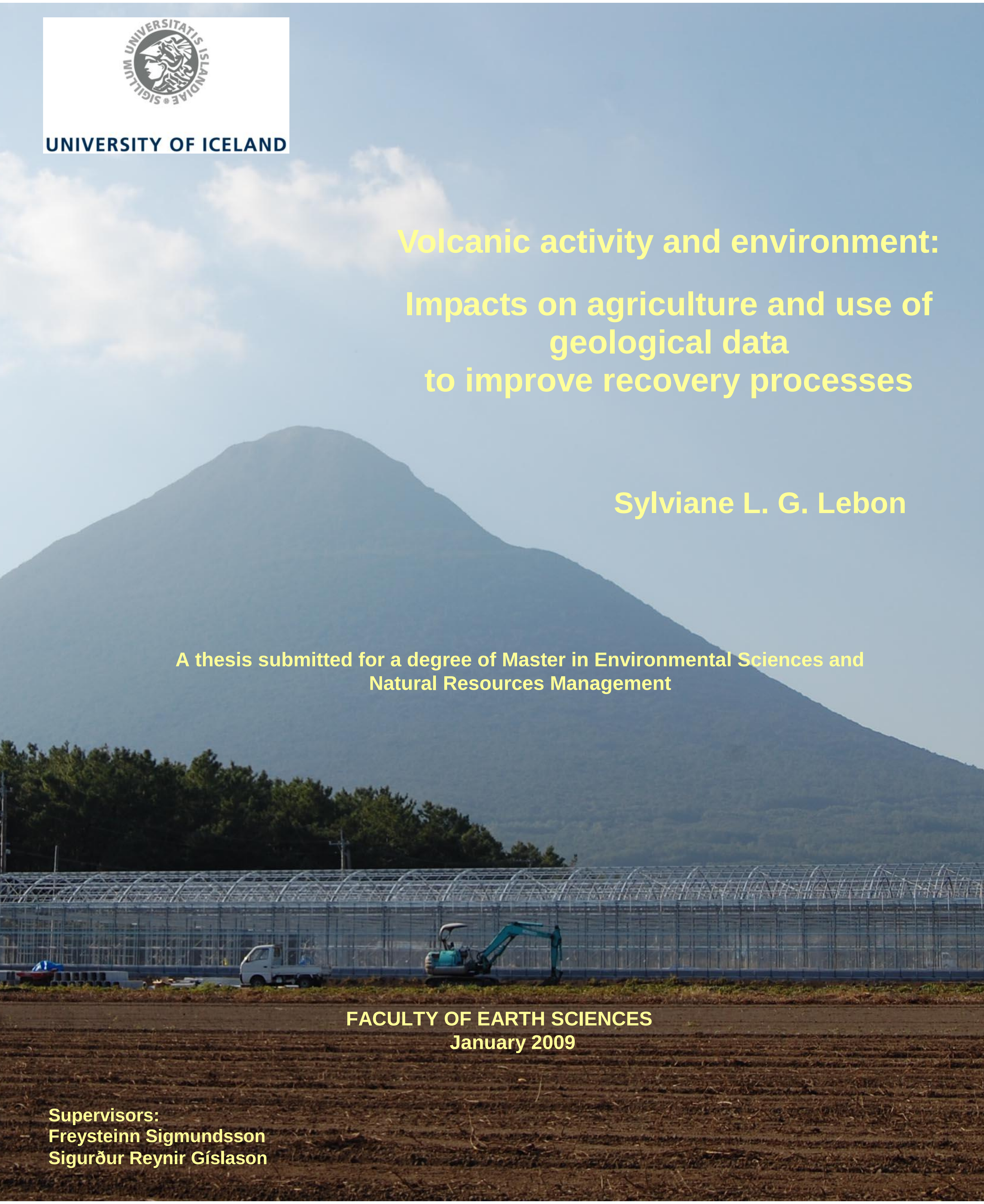

UNIVERSITY OF ICELAND

Volcanic activity and environment:

Impacts on agriculture and use of geological data to improve recovery processes

Sylviane L. G. Lebon

A thesis submitted for a degree of Master in Environmental Sciences and Natural Resources Management

FACULTY OF EARTH SCIENCES
January 2009

Supervisors:
Freysteinn Sigmundsson
Sigurður Reynir Gíslason

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Abstract

Volcanic eruptions are dramatic events that can significantly affect the livelihood of surrounding populations, in particular since the fertility of volcanic soils results in them often being used for agricultural purposes. Therefore, when volcanic crises occur, the livelihood of farmers can be strongly affected. The actions taken both by farmers and the authorities during recovery phase from a volcanic eruption are important and will have a strong influence on the ability of local population to regain their financial equilibrium and independence. This study evaluates factors that are critical in the improvement of recovery processes for agricultural areas affected by natural hazards, and in particular volcanic activity. Work was carried on the basis of sites visits, focusing on interviewing scientists involved in the crises and/or local residents and authorities, as well as documentary reviews of past case histories of the handling of natural hazard crises. Four main field visits were carried out: Mts. Pinatubo and Mayon (Philippines), Mt. Unzen (Japan), Mt. Taranaki and heavy snowfalls of 2006 in South Canterbury (New Zealand) and Volcán de Turrialba (Costa Rica). The study reveals that scientists collect information throughout a volcanic crisis that can be used effectively to improve recovery response times in agricultural areas. In order to contribute positively to the recovery of an area, the information supplied needs to be relevant to the area affected which implies a pre-existing knowledge of the specifics of the region depending on the type of crops or animals being raised, as well as of the climatic and seasonal components. In addition, it is important to have already established trusted communication channels between scientists, authorities and local communities through which this information can be transmitted to ensure efficient exchanges of this information. The case studies also show that communities that are organised around a strong support network achieve higher levels of resilience and thereby fare better not only throughout the emergency phase but also at recovery stage.

Ágrip

Eldgos eru dramatískir atburðir sem hafa mikil áhrif á lífskjör fólks í nágrenni þeirra. Mikil frjósemi eldfjallajarðvegs veldur því að á heimsvísu er mikil landbúnaður stundaður í hlíðum eldfjalla og næst þeim og hamfarir á eldfjöllum geta því haft mikil áhrif þar. Aðgerðir bænda og yfirvalda á enduruppbyggingartíma eftir eldgos eru mikilvægar og þær móta hvernig samfélögum næst eldfjöllum tekst til við að ná fyrra fjárhagslega jafnvægi og sjálfstæði. Þessi ritgerð fjallar um hvaða þættir geta styrkt enduruppbyggingarferli á landbúnaðarsvæðum næst eldfjöllum þar sem náttúruhamfarir verða og þá sérstaklega eldgos. Rannsóknin fór fram m.a. með vettvangsferðum þar sem lögð var áhersla á að fá upplýsingar með viðtölum við vísindamenn sem komið höfðu að vinnu við hamfarir og/eða viðtölum við íbúa og yfirvöld á viðkomandi svæðum. Einnig voru metin birt gögn um fyrri tilvik um viðbrögð við náttúruhamförum. Eftirfarandi áherslusvæði voru heimsótt: Mt. Pinatubo og Mt. Mayon á Fillipseyjum, Mt. Unzen í Japan, Mt. Taranaki á Nýja Sjálandi og jafnframt metin viðbrögð við mikilli snjókomu í South Canterbury á Nýja Sjálandi, og loks Volcán de Turrialba í Kostaríka. Rannsóknin sýnir að gögn sem vísindamenn safna meðan á hamförum stendur má nota til að bæta og efla uppbyggingarferli á landbúnaðarsvæðum. Til að slík gögn nýtist best þurfa upplýsingar sem veittar eru að taka mið af staðháttum viðkomandi svæðis. Þekking fyrir hamfarir á sértækum þáttum hvers svæðis svo sem landbúnaðarháttum ásamt veðurfari og árstíðabundnum sveiflum er mikilvæg. Rannsóknin bendir á mikilvægi þess að fyrir hamfarir séu til staðar traustar samskiptaleiðir milli vísindamanna, yfirvalda og íbúa á eldfjallasvæðum. Meðan á hamförum stendur og eftir þær á uppbyggingartíma skipta slík „samskiptanet“ sköpum við miðlun upplýsinga. Rannsóknin bendir einnig til þess að samfélög þar sem öflugt tengsla- og stuðningsnet íbúa er til staðar auki mjög hæfni samfélaga til uppbyggingar og þar með farnist slíkum samfélögum betur, ekki aðeins meðan neyðarástand varir, heldur einnig á endurbyggingartíma eftir náttúruhamfarir.

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Chapter 1:

Introduction

1.1. General introduction: rationale for this study

In the last few decades significant progress has been made towards understanding volcanoes and the hazards they might cause to local populations. The majority of countries where volcanoes are located have been working on and/or are working on prevention and mitigation measures to ensure that the impact of eruptions or other volcanic activity on local communities is minimised.

For the purpose of this study, relief work is defined as the work carried out in order to help populations victim of a natural hazard.
Emergency is defined as the interval during which assistance to populations is provided at the time when the natural hazard strikes and immediately thereafter.
Rehabilitation, on the other hand, is the time after emergency where work is carried out to bring the living and working conditions to normal. In this study, recovery is used as a synonym of 'rehabilitation'.
The term crisis in the context of this study is taken in a wide sense. When used in the expression 'volcanic crisis' it refers to the fact that volcanic activity can impact on agriculture even if the volcano is not erupting per se (e.g. through degassing). Crisis on its own will refer to the whole cycle from the onset of the hazards to the end of rehabilitation.

The rationale for this research stems from the fact that it appears, for volcanic hazards, as well as for other natural hazards, that the support provided decreases rapidly after the emergency phase is over. This means that in the case of a significantly long crisis or when recovery work has to be undertaken, resources may be scarce and external support limited as the attention of the media and aid network has turned to other matters. As a consequence, entire communities may be in poor living conditions, often with limited sources of income.

The problem can become particularly acute in the case of volcanic eruptions. The length and intensity of a volcanic crisis can vary vastly and so can its impacts. An important additional factor is that in many cases volcanoes are surrounded by agricultural areas. Support to farming has in any cases not been a priority for governments, who have shown a tendency to provide assistance to industry and urban areas due to their greater economic importance and higher density of population.

The importance of agriculture, however, should not be underestimated. The availability of cheap intensely grown products has led a significant number of countries to disregard the importance of their own agriculture due to the low competitiveness of locally-produced goods. The fluctuations of food and oil prices over the last two to three years shows that no country can afford to exceed a certain level of dependence on imports if it wants its economy to remain sustainable.
For example, the Philippines, who used to be a net exporter of rice, are now net importers. Rice is now reported as one of the three major import products of the Philippines (FAO 2004). The area around Mt. Pinatubo used to produce important quantities of rice before the eruption of Mt. Pinatubo in 1991; seventeen years later production has still not been re-established at pre-eruption levels and farmers are struggling to increase yields. Even though post-eruption support was provided to farmers, it appears inadequate to support the re-implantation of high yield crops.

This study aims at evaluating how information collected by the scientists in times of volcanic activity can assist farming communities (being traditional or modern agriculture) in order to overcome the negative effects of an eruption as fast as possible. Also, wherever possible, leveraging the potential beneficial effects that volcanic products could bring to agricultural activities.

The main focus of this study is agriculture, even though people are, of course, both agents and beneficiaries of the results of the present research.

1.2. Objectives

The objectives of the study were defined as follows:

1. Summarize understanding of interaction between various volcanic products and the environment. Consider the hindrances and/or opportunities they bring to societies where agriculture is key to the livelihood of the local population;
2. Evaluate the use of geological information for early assessment of likely environmental impacts of a volcanic event on soils and possibly water resources and establish the nature of the rehabilitation work required;
3. Determine the nature of the information required to enable early planning;
4. Consider appropriate integration of the results from such inter-disciplinary (i.e. information cross-overs between geology and agronomy) work within the wider scope of prevention and mitigation plans in order to secure the awareness and commitment of the various parties.

1.3. Methodology

The initial phase of the research focused on gathering existing information on the impacts of volcanic products on agricultural activities, since an overview of such impacts was needed in order to proceed with the study.

The study was initially designed to be mostly based on documentary research. However, the difficulty in finding relevant published information both about recovery in general and more specifically on actions taken in respect of rehabilitation of agriculture affected by volcanic activity led to the need for site visits.

The core of the research on recovery processes was carried out using a combination of a review of the documentary evidence of case studies and of site visits that have been, or currently are, affected by volcanic crises.

Interviewee pool consisted of a mix of local authorities, scientists and local residents. Interviews were partly pre-arranged, and partly organised on site. Information on sites was gathered on the basis of unstructured interviews (i.e. not based on pre-designed questionnaires) where interviewees were invited to share their experiences. The information gathered regarding the different case studies was then compared and analysed. Part of this analysis was based on discussions with other scientists involved in the field of volcanic hazards; this includes extensive discussions with New Zealand scientists carrying out research on the potential impacts of volcanic eruptions on the dairy industry.

This methodology allowed access to information which could not have been obtained otherwise due to language barriers (this applies essentially to the case of Japan). Furthermore, this approach provided information from persons that do not publish their opinion, such as farmers and local residents.

The focus was set on the recovery aspect of volcanic crises. Preparedness, prevention and mitigation phases were also considered in order to assess their potential importance in the recovery process. Similarly, where relevant, the response to non-volcanic hazards was also looked at and evaluated. Such cases can bring valuable lessons that can be used in the context of volcanic crises.

The main sites visited for the purpose of this study are situated in a variety of volcanic settings. The main locations are highlighted in Table 1.

Country	**Volcano/other hazard**
Visits with a strong emphasis on agricultural activities	
Philippines	- Pinatubo - Mayon
Japan	- Unzen
New Zealand	- Ashburton South Canterbury: for the 'snow event' of 2006 - Taranaki: 2007 drought - Taranaki: volcanic hazard - Ruapehu
Costa Rica	- Turrialba
Iceland	- Hekla
Other visits	
Philippines	- Taal - Bulusan
Japan	- Izu-Oshima - Miyake-jima - Sakura-jima - Kaimondake
Costa Rica	- Poas - Arenal - Irazu

Table 1: Country and location visited. The table also includes description of non-volcanic hazards where appropriate

This study was based at the University of Iceland in Reykjavík. Iceland, due to the specificities of the Icelandic climate, volcanic activity and agriculture, was not selected, however, a full case study but a summary of key lessons learnt from the Icelandic experience can be found in Chapter 4.

Documentary evidence was gathered in respect of the eruption of Paricutín (Mexico), Mt Hudson (Chile/Argentina), Tungurahua (Ecuador) and Mt Merapi (Indonesia).

As and where relevant, experience from other eruptions was also taken into account.

1.4. Thesis outline

Chapter 2 focuses on the description of the most frequently observed impacts of volcanic activity on agriculture. Chapter 3 takes this review further by listing some of the factors that can influence the impact of eruptions on agricultural activities. These two chapters aim to fulfil objective 1 set above.

Chapter 4 presents the field studies conducted and the events subject of documentary reviews. The sites visited for the purpose of this study are given, along with a description of eruption and recovery for each case. Chapter 5 focuses on comparison and analysis of all cases and draws lessons from them, contributing towards objectives 2 to 4 described in section 1.2 above.

Chapter 6 gives final conclusions of this study and perspectives for future work.

Chapter 2:

Impact of volcanic products on agriculture and soils

Volcanic soils, often referred to as andisols, are known for their high level of fertility (Takahashi and Shoji 2002, FAO 2001, Neall 2008). Land around volcanoes throughout the world is often heavily cultivated in order to reap the benefits from the natural fertilising effects of terrestrial volcanic products (Ugolini and Dahlgren 2002, Shoji and Takahashi, 2002). On a worldwide basis, over 40% of the labour force is occupied in agricultural production (WRI, 2008). Around 1% of the surface of the Earth is covered by volcanic soils, supporting more than 10% of the world's population (Ping 2000).

The initial section of this chapter will give a brief description of what makes volcanic soils unique and so favourable for agricultural activities. Subsequent sections of this chapter will treat of volcanic ash and gases and how they can impact soils, crops and livestock following an eruption. Section 2.2 focuses on the mechanical effects of volcanic ash and section 2.3 on the chemical impacts of volcanic products. Section 2.4 summarises potential other and longer-term effects of volcanic activity.

Other volcanic products such as ballistics, lava flows and density and pyroclastic flows do not form part of the focus of this research.

As this study focuses on the effects of volcanic products on agriculture, it does not specifically highlight any of the potential impacts on human health. For analysis of the impacts of volcanic activity on human health, refer to the work of Peter Baxter (Institute of Public Health, University of Cambridge).

2.1. Volcanic soils

Soils of volcanic origin have unique properties (Takahashi and Shoji 2002). It is those that give the soils their known high level of fertility and are as a result used extensively for agricultural purposes.

The key characteristics of volcanic soils (andisols) for agriculture are their water retention capacity and their ability to fix elements, in particular phosphates.

Water retention:
Volcanic soils have very specific water retention properties in that the size and shapes of the particles it is made of will allow the creation of capillaries, giving the soil a low bulk density and high porosity (Ping 2000). These are critical for the circulation of water. Limited capillaries generally reduce the availability of water to plants and hence can hinder growth (Masujima and Mori 1962, quoted in Maeda et al 1977, p253). However, in environments affected by fresh ash falls, water retention can become an issue due to the homogeneity of particle size (Maeda et al 1977); practical implications and solutions applied will be discussed in section 4.2.3.

Phosphorus retention:
The propensity to retain phosphorus of volcanic soils is very high, due to high content of Al and Fe compounds (Ugolini and Zasocki 1979, Ping 2000). This makes them highly suitable for agricultural activities as it reduces the need for added fertilisation and hence leads to better yields and potentially lower costs of production of agricultural products.
This strong fixation can, however, lead to problems; these can be resolved by applying corrective measures (FAO, 2001, Brady and Weil 2004)

pH:
Volcanic soils have pHs between 5 and 7 (Ping 2000). This has significant implications with respect to the ability to fix elements and fluorine sorption is maximal at pH 6.0 (Cronin et al, 2000). As a result volcanic soils can sometimes show excessive concentrations of fluorine which will impact on animals and humans feeding of its products.

Nanzyo (2002) indicates however that newly reclaimed soils can show low productivity due to low content in nutrients and micronutrients, toxic aluminium content and possibly the necessity for stabilising the soil organic nitrogen; as a result these soils might require amelioration. Such observations were made at the site of the 1991 eruption of Hudson volcano (Besoain et al. 1995).

2.2. Mechanical effects of volcanic ash on land and agriculture

During an eruption, volcanic ash is ejected from the volcano up into the atmosphere and subsequently falls to the ground in the form of ash falls. Volcanic ash is composed of fine-grained rock and mineral fragments and glass shards, commonly with acid droplets and soluble salts coating the ash-grain surfaces. The properties of the ash depend mostly on the relative proportions of their main constituents. Ash results from fragmentation of foamy magma (following decompression) and of country rock (during rapid expansion of steam) and from explosive mixing of magma with water. Shard shapes and sizes depend upon the shape and size of gas bubbles in the magma immediately before eruption and fragmentation of the magma. (adapted from Miller and Casadevall 2000 and from Jones and Gislason 2008)

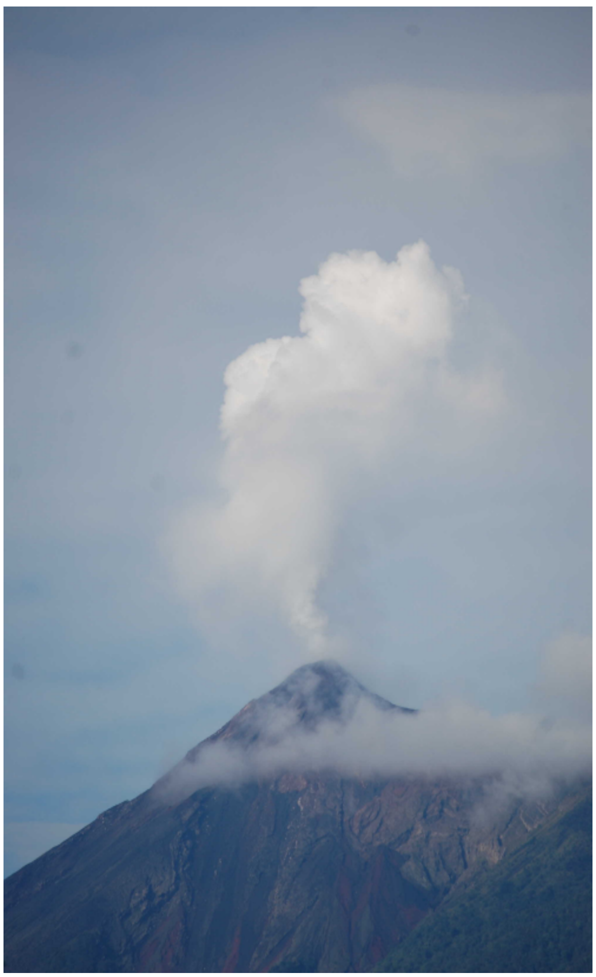


Figure 2.1: Volcán de Fuego (Guatemala), 2008. The volcano's ash column. At the time of the visit, the volcano was ejecting ash on a quasi permanent basis, which was then dispersed through the effects of the wind and subsequently settled on surrounding fields and on nearby villages and towns such as Antigua. Picture taken in October 2008

This study also refers to tephra. This term is used here in accordance with the definition proposed by Thorarinsson (1944, quoted in Larsen and Eiríksson (2008)) describing tephra as "all pyroclasts that leave a volcanic vent by air, regardless of type, size and shape". "A pyroclast is a fragment of magma" (Wolff and Sumner 2000)

Most of the ash is deposited close to a volcano but as a consequence of buoyancy in the eruptive column some of it will be transported for distances up to hundreds or thousands of kilometres in an ash plume. Areas downwind will generally be more severely affected than any other direction; however in areas proximal to the volcano, ash will fall 360° around the volcano. Particle size decreases as the distance from the volcano increases, as does the thickness of the deposition layer. Particle size and amount of fallout is highly dependent on the vigour of the eruption.

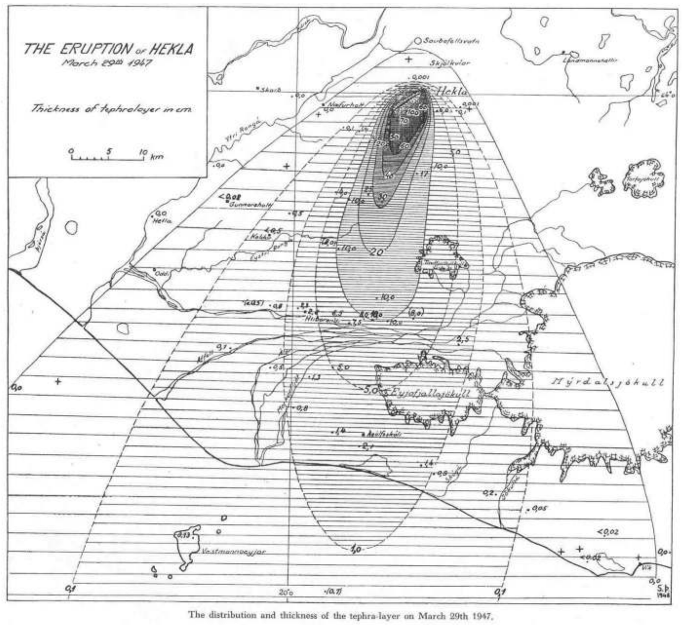


Figure 2.2: Hekla, Iceland, 1947. Isopach (distribution of ashfall as ash layers, thickness in cm) map of the eruption of 1947-48, ashfall of 29 March 1947.
Source: Thorarinsson 1967.

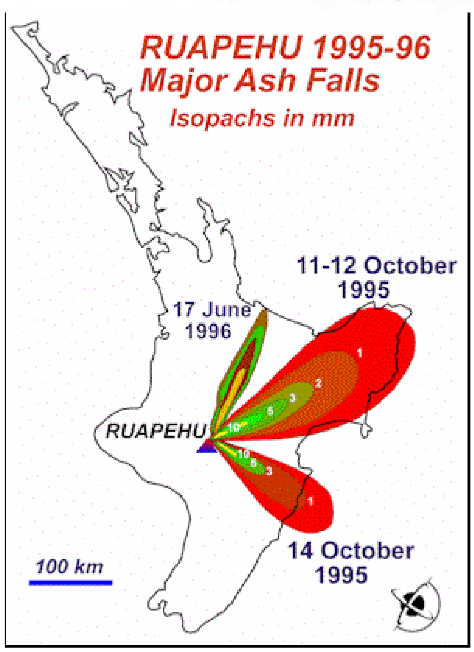
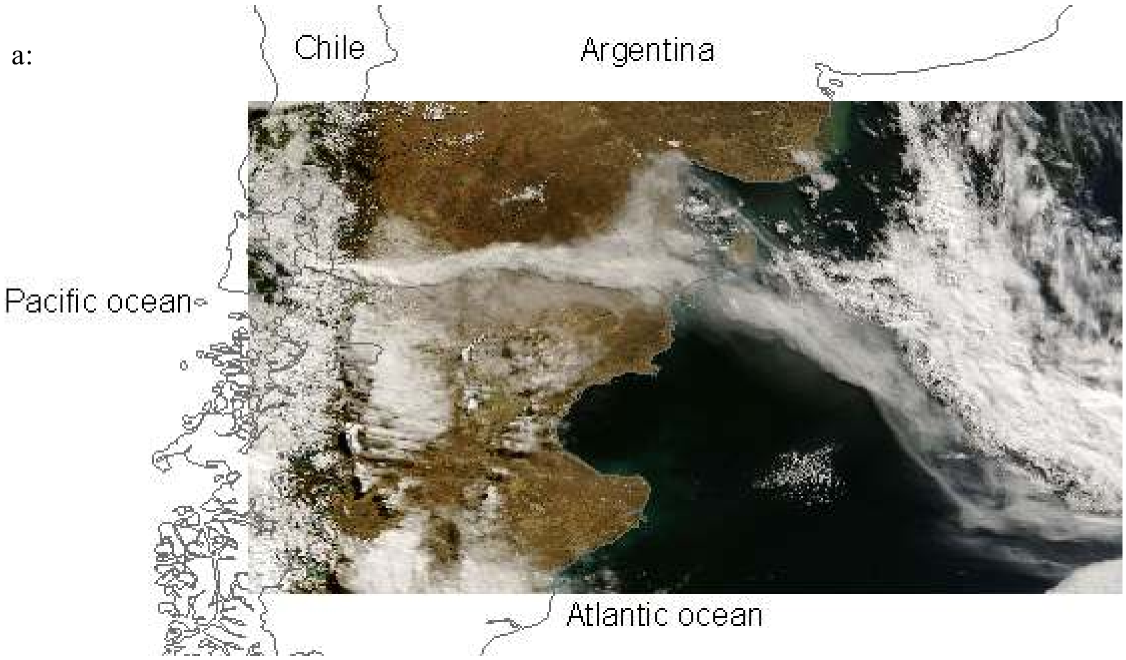


Figure 2.3: Ruapehu, New Zealand 1995-96. Isopach map (in mm) of the eruption of 1995-96.
Source: GNS 2008a.

Figures 2.2 and 2.3 show examples of isopach maps (ash distribution) for Hekla (Iceland) and Ruapehu (New Zealand). Ash distribution is dependent on the predominant winds at the time of the eruption as well as on the height of the eruption column. Figure 2.4 shows how an ash plume can be carried over long distances.

a:



b:

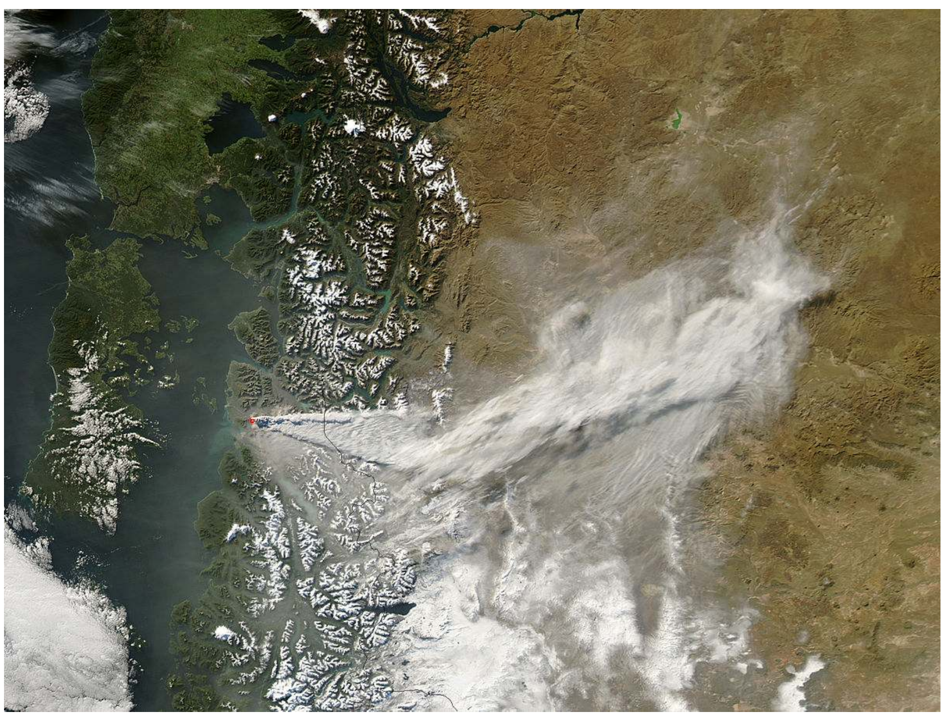


Figure 2.4: Chaitén, Chile, 2008.

- a: The ash plume of Chaitén on 5 May 2008. The picture shows how the ash plume is carried by winds over very large distances thereby affecting regions situated hundreds or even thousands of kilometres from the volcano itself) (Picture dated 5 May 2008, at 14:25, from NASA Modis gallery (http://rapidfire.sci.gsfc.nasa.gov/gallery/?search=chaiten&date=, modified by author in ArcGIS to add location).
- b: The ash plume from Chaitén on 31 may 2008. The picture shows how the ash plume is affected by winds in different manners on the Western (left of the picture) and Eastern (right of picture) slopes of the Andes (Raw image from NASA Modis gallery http://rapidfire.sci.gsfc.nasa.gov/gallery/?search=chaiten&date=).

The effects ash can have on agriculture results from both its physical and chemical properties. The physical effects are the result of the deposition of particles, which will affect plants and livestock through loading. The angularity of remobilised particles can lead to abrasive damage, subsequent to the eruption. In addition, the propensity of particles to fix volcanic gases can give them particular chemical properties which can have implications –positive or negative- for soils, plants and livestock.

2.2.1. Impact on plants

Physical impacts of ash falls on plants can be various. Vegetation is essentially affected through smothering/burial, breaking of stems and leaves, ability to photosynthesise and limitations created to pollination. Table 2 summarises the most common physical impacts of ash on vegetation.

Process	**Impact**
- *Smothering/burial*:	The accumulation of ash on the ground will lead to the smothering and the burial of the smallest plants. Plants closest to the volcano are generally affected most as thickness of ash deposited can often reach 50-100 cm in relatively short amounts of time. (Neumann 1996, Volcano Hazard Website 2008)
- *Breaking of stems and leaves*:	The ash accumulation will also affect higher plants due to large quantities of ash falling on the leaves. This can lead to breakage due to the additional weight; similar phenomena have been observed for stems of trees and shrubs. (Rees 1979, Volcano Hazard Website 2008)
- *Limitation to photosynthesis*:	Even small amounts of ash can have adverse effects on leafy plants. When ash covers the leaves of plants, this reduces the surface that can capture the light in order to nurture photosynthesis processes. If the layers of ash get too thick this can seriously hinder the ability of the plant to maintain its vital functions. (Rees 1979, Volcano Hazard Website 2008)

Process	Impact
- *Limitation to pollination*:	Flowers can be covered with ash. This will affect the ability of pollinator to access and transfer pollen from plant to plant thereby potentially limiting the amount of fertilisation taking place. (Rees 1979, Cook et al 1981, Volcano Hazard Website 2008)

Table 2: Overview of physical impacts of ash on vegetation and the effects these can have on crops. The references mentioned in the table are only examples of studies where such effects where reported. The literature gives several other examples which are not mentioned in this study. For more information see for example Blong (1982) and Dale et al. (2005).

By far, the most common damages are the burial and breaking of stems, which are a simple consequence of the quantity of fallen ash. However, it is important to be aware that even small quantities of ash can have detrimental effects in the life cycle of individual plants. Such effects might not be as critical for natural vegetation as for agriculture where the species of plants are growing in an area is important to produce edible/marketable products.

Ash can also cause minor damage such as tissue bruising. Whilst this will not on its own be life threatening to any plant, it can weaken the tissues in such a manner that it will favour the settling of fungus which will cause damage to tissues. This was observed for example at Paricutín (Mexico) after the 1943 eruption (Rees 1979).

In the medium- to long-term (durations of up to 10 years have been observed), further damage can be caused by remobilisation of tephra by the wind. The abrasiveness of the particles can hinder plant growth and damage plant tissues and can slow down the recolonisation of environments by natural vegetation and/or crops. Younger and smaller size plants will be most vulnerable to abrasion and hence an environment affected by tephra remobilisation can remain desert for quite a long time after an eruption (e.g. Paricutín (Rees 1979), Hekla (Thorarinsson 1979), Hudson (Bitschene 1995 and Inbar et al. 1995)).

In wetter environments and seasons, ash can also be remobilised mixed with water, creating lahars. High density mud and rock flows can flood large expanses of agricultural land, destroying any existing crops and leaving behind significant amounts of material that can hinder future crops.

The impacts of a given thickness of ash deposited will also depend on the type of crop being grown in the area affected. For example, at Rabaul (Papua New Guinea) in 1995, larger trees such as cocoa plants and coconut trees were barely affected (Neumann 1996). Similar observations were made for coffee trees after the eruption of Santa Maria (Guatemala) (Thornton 2000). In both cases, other plants were severely affected.

2.2.2. IMPACTS ON SOILS

As mentioned previously, andisols have fairly unique properties that make them highly suitable for use in agricultural production. However, these properties are not necessarily achieved immediately after an ash fall and time might be required to enable the soils to yield the benefits from newly added volcanic material.

The main impacts of loading of ash on top of existing soil relate to its interaction with water.

Adding a large quantity of ash of one dominating particle size will have implications for the water retention and circulation properties of the soil, as ash properties are fairly different from that of already cultivated soils (Maeda et al 1977). The formation of capillaries that would facilitate the circulation of water through the soil requires the presence of particles of a range of sizes. Where one size dominates, the absence of capillaries may lead to the creation of a hard crust as observed at sites affected by the 1991 eruption of Mt. Hudson (Inbar et al 1995). Such crust prevents water infiltration and plants are often unable to grow through the crust. Pre-existing plants will only survive if they have a deep root system that enables them to absorb water from the lower layers, and the supply of water to these layers can be maintained through some other source than rain.

On the other hand, the presence of an ash layer on top of the soil can sometimes act as mulch (i.e. a protective cover for the soil that will protect it from the negative impacts of the climate) that will protect the moisture within the soil and prevent or limit evaporation, thanks to the thixotropic (i.e. gel-like, does not spill yet expands easily) properties of volcanic soils (Ugolini and Dahlgren 2002, Ping 2008).

From a water retention point of view, the impact the addition of ash can have on soils is very dependent on the thickness of the ash layer and on whether the vegetation relies mainly on ground moisture or on rainfall for survival.

In this context, the thickness of the ash layer will be of high importance. For example, after the Hudson eruption of 1991, Besoain et al. (1995) estimate that areas covered with 10 to 15cm of ash would recover in a matter of years, whilst their estimate for recovery of areas covered with thicker deposits can take hundreds or even thousands of years.

Another modification of soil properties that has been observed in the past is an increased soil reflectance resulting from the ash layer deposited on top of the pre-existing soil (Oppenheimer 2003). The colour of volcanic ash depends predominantly on its composition and silicic ash can have a fairly light grey colouration. Since it can be deposited over relatively vast areas, the impact of a change in surface colouration can be significant for plants as increased reflectivity induced by the lighter colouration can result in lower temperatures in the top layers of the soil. Soil temperature can be a significant factor in the growth of certain plants and if it is reduced noticeably, the ability to grow the most temperature sensitive species might be affected.

2.2.3. IMPACTS ON ANIMALS

The main hazard caused to livestock by ash is that of ash ingestion either in their respiratory system through inhalation or in their digestive system by eating ash-coated vegetation.

Ingestion through respiratory processes can lead to excessive production of mucus (protective lubricant within an animal and human body) within the lungs, or more severe lung infection (Rees 1979, Bitschene 1995). Livestock will be particularly vulnerable where the grain size of the ash is medium to small, which is generally in slightly more distal areas from the volcano. Larger particles are unlikely to be breathed in and reach the lungs as airways are generally designed to prevent inhalation of foreign objects. Smaller particles will represent a higher danger in a similar manner to that represented by dust particles from vehicle traffic in cities known as PM2.5/PM5/PM10 in environmental monitoring. However, as ash grains can be of glass-like nature, the health risk involved is higher due to their sharp edges that can damage internal tissues of the lungs potentially triggering severe infections.

Livestock will also ingest ash when they are eating ash-coated forage. Ash can then accumulate in the animal's stomach and, in the longer term, form a compacted block, similar to a brick, which will weigh on the digestive system of the animal and can severely impair its ability to digest food (Inbar et al. 1995, Bitschene 1995).

Even in small quantities, ash can have adverse effects on livestock. A thin layer of ash on the grass and forage consumed by animals during prolonged periods will have abrasive effects on the teeth and hooves of the animals (Bitschene 1995). In the long term, it can seriously affect the animal's ability to eat as its teeth will no longer be sharp enough to process the grass. Hooves can get damaged thereby affecting the animal's ability to walk and hence to find suitable sources of food.

The presence of ash in the air can also lead to eye infections as ash is blown in the air. This can severely impair the vision of animals (Bitschene 1995).

In special cases, sheep can also be affected through accumulation of ash in their wool (Inbar et al. 1995, Bitschene 1995). If ash falls have already reduced the availability of forage, weakened animals might not be able to carry the additional weight of the ash in their coat. In extreme cases, sheep will no longer be able to roam in search of forage and could die of exhaustion and starvation.

As ash can be remobilised by the wind throughout long periods of time (remobilisation of up to 3 years have been reported in the areas of Argentina affected by ash fall after the Mount Hudson (Chile) eruption in 1991), hence, some of the effects described above can last for extended periods of time.

For livestock, it is also important to take into consideration the effects the ash fall has on vegetation as this can limit the availability of forage. In extreme cases, it might be necessary to feed them from external sources of forage such as hay. However, these might need to be sourced from areas very distal from the volcano as vegetation collected close to the volcano is likely to carry a certain quantity of ash.

Livestock are not the only animals important for agriculture that can be affected by eruptions; insects and birds will be too. Humans can of course be affected too but this is outside the scope of this study. Even though these are not necessarily directly linked to agricultural production, they can be critical contributors -both positive and negative- in the growth of crops. Insects and birds are pollinating agents, critical to the development to maturity of plants, flowers and fruits. If they do not play their role actively at the time pollination is required, the harvest will be adversely affected limiting the yield from food crops and horti- and fruiti-cultural activities (e.g. Paricutín 1943 (Rees 1979) and St Helens 1980 (Cook et al 1981)).

Ash can also affect parasites thereby leading to higher production and/or reduced need for pesticides. This was the case after the Paricutín eruption where the number of fruit flies dropped, the eruption having acted as an insecticide (Rees 1979). Similar effects were observed around Mt St Helens in 1980 (Thornton 2000).

2.2.4. IMPACT ON INFRASTRUCTURE AND EQUIPMENT

Infrastructure and equipment can also be heavily affected by ash falls. Significance of this type of damage will be greater in the context of modern agriculture since it is heavily dependent on technology to harvest crops, milk livestock and conserve products. Road access will be critical too as it is necessary to access cultivated areas and to transport the products to market. In traditional agriculture, as most processes are manual, dependence on technology is much lower and therefore losses due to failure of infrastructure and equipment are lower.

During initial ash falls, the ash cover can hinder circulation of vehicles due to reduced visibility. Remobilised ash will cause more important problems for quite a number of years after the eruption.

Infrastructure such as electric distribution network is particularly sensitive to ash falls and small amounts of ash can lead to complete shut-downs of power plants and transmission stations due to the risk of flashovers (= unintended electric discharges) (Bebbington et al. 2008, Bitschene 1995).

The presence of ash in the air can also have impacts on the working of refrigeration equipment (required to conserve products such as milk) as particles will enter the cooling mechanisms. The sealing and air filtering are critical to avoid contamination of edible goods by ash.

The wear and tear of water pumps can be heavily increased by the presence of ash in the water. This can have significant implications in situations where water supplies are contaminated by ash and the agricultural exploitation is dependent on water pumping to nourish livestock and crops. (Barnard et al 2007)

2.3. Volcanic gases and gas-derived salts: chemical impacts of volcanic products

The most common and abundant volcanic gases are: H_2O, CO_2, SO_2, H_2S, HCl and HF (Delmelle and Stix 2000). HF is not always present, whereas in most cases the others are, but is important in the context of this study as fluorine can have significant impacts on agricultural activities. The quantity and nature of gases emitted by volcanoes depend on the amount and composition of magma.

2.3.1. VOLCANIC GASES

Volcanic degassing will affect plants and animals if they have direct contact with the gases.

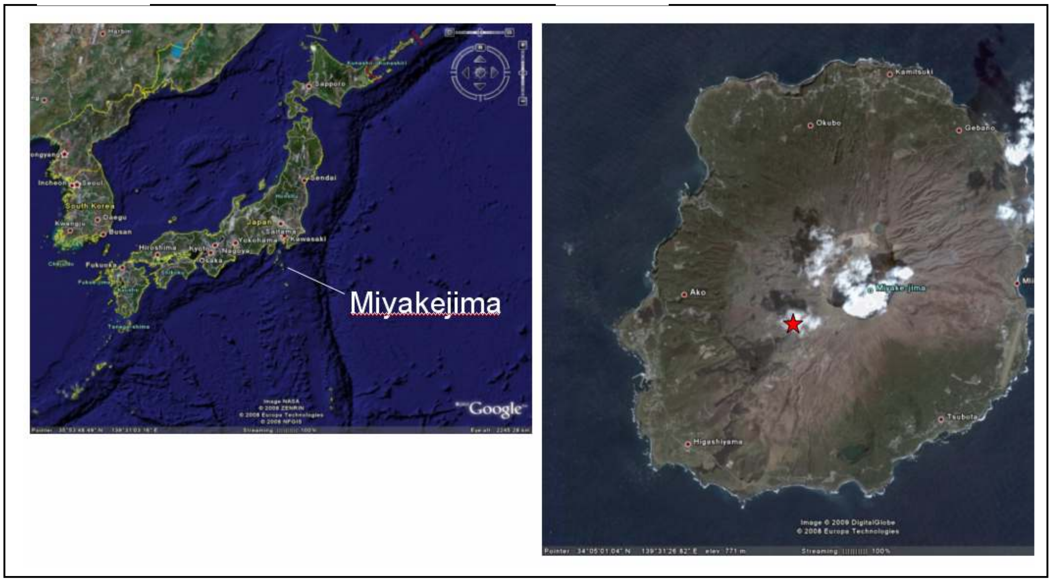
However, impacts of degassing on agriculture are normally of fairly limited spatial extent as significant impacts are generally limited to areas proximal to the summit of the volcano where most degassing occurs.

Only in extreme events, such as the case of sulphur degassing from Miyakejima (Japan) in the period 2000 to 2003, or that of sulphur and fluorine from Laki/Eldgjá in 1783-84 (Thordarson and Self 2003), will the gas emission be sufficiently important to have significant impacts on agricultural activities.

High concentrations of SO_2 in the air are known to disturb plant stomatal respiration (i.e. through the pore situated on the plant leaves) and cause necrosis (death of cells on the leaves) (Williams-Jones & Rymer 2000). Limited growth has been noted in the coffee plantations situated downwind from Poas in Costa Rica (Rymer and Harris (2002)). Delmelle et al. (2002) reported similar problems around Masaya in Nicaragua.

Leguern et al. (1980) report some black spots on the skin of bananas following the eruption of Souffriere of Guadeloupe in 1976-77, making them unsuitable for commercialisation. However, research in the field of long-term impacts of moderate degassing is still in its early stages.

Exposure to sulphur dioxide for prolonged periods can also result in deep corrosion. This can be extremely damaging to equipment and infrastructure located in the area affected by the gases. Such damage has been observed in Japan (following the eruption of Miyakejima – see figure 2.5c) and in Nicaragua in the surroundings of Masaya volcano (Williams-Jones and Rymer 2000) a: b:



c:

Figure 2.5:
a: Japan, overview map. Aerial view of Japan showing the location of Miyakejima island (Image from Google Earth).
b: Miyakejima, Japan, overview map. Aerial view of Miyakejima island. The island has a diameter of approximately 8 km. The red star shows the location at which figure 2.5c was taken, at approximately 1.5 km from the centre of the crater (Image from Google Earth).
c: Miyakejima, Japan, 2007. Container corroded by the continuous degassing of Miyake-jima (Japan) since 2000. Picture taken in November 2007.

Releases of carbon dioxide can also have effects on fauna and flora. During the eruption of Hekla in 1947-48, a number of sheep were killed by carbon dioxide suffocation due to this gas accumulating in low lying badly ventilated areas, such as ditches (Thorarinsson 1979). For flora, even though tree kills due to high CO_2 concentrations have been reported, for example in Mammoth Mountain, Long Valley Caldera, USA (Gerlach et al. 2001), this project found no reports of similar degassing effects on farmland or crops at any location. The presence of concentrations sufficient to cause death of plants or trees seems to be a relatively rare event. Such events appear limited in time and very localised as carbon dioxide dissipates easily with wind and concentrations can rapidly be brought back below levels where it could be lethal.

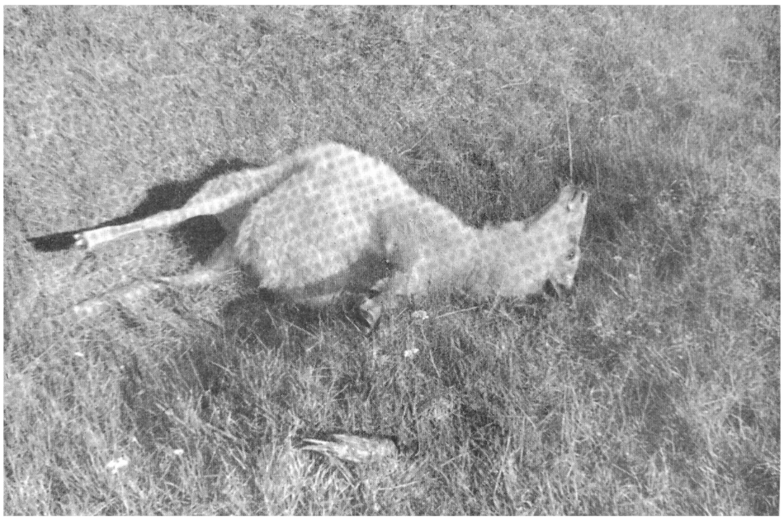


Figure 2.6: Sheep suffocated by CO2, Loddavötn (Hekla), Iceland, 1948. (Photo Thórarinsson, quoted in Kjartansson 1967)

Although a number of human fatalities from CO_2 exposure have been reported over the last few decades such as the lake overturn at Nyos and Monoun (Cameroun), at Mammoth Mountain (USA), in the Azores (Portugal), in the Alban Hills (Italy), etc. (Lebon, 2006), this is outside of the scope of this study.

With respect to effects on agricultural activities, Hekla is the only case that this study came across where death of livestock was attributed directly to excess concentration of CO_2 has been reported. This could be attributable to the fact that degassings of high concentration of CO_2 have remained fairly small localised events.

In exceptional cases, very large degassings of a combination of gases have been known to have had devastating effects on all forms of life over very large areas. This was the case during the eruption of Lakí in 1783-84, which killed a 70% of the livestock (Thornton 2000), vegetation and population of Iceland and disturbed agricultural activities throughout Europe. (Thordarson and Self 2003, Grattan et al. 2003)

2.3.2. GAS-DERIVED SALTS AND VOLCANIC ASH

Ash particles ejected by the volcano can become the support for transport of elements released during the eruption (Óskarsson 1980, Frogner et al 2001, Oppenheimer 2003 and Jones and Gíslason 2008). Condensed salts of fluorine acids and heavy metals may in particular be transported by this mechanism. The adsorption of gases, aerosols and salts onto ash takes place in the eruption column and volcanic cloud. This process is dependent on gas solubilities, level of magma degassing, particle size (see section 3.1) and the time particles spend in the volcanic cloud (Óskarsson 1980, Jones and Gislason 2008).

The ash is then carried away by winds over distances that can exceed hundreds of kilometres. The leaching of these elements, which are highly soluble on contact with water (Frogner et al 2001, Flaathen and Gislason 2007) into the soil and water can then lead to chemical effects on surface and ground water as well as changes in soil chemistry.

One of the most direct hazards caused by gas/salt-coated ash is that of fluorine poisoning (Georgsson and Pétursson 1972, Óskarsson, 1980). Generally livestock is first affected through consumption of ash-covered fodder but recovery has been observed for livestock that has been moved away from affected areas. It has to be noted too that the physical presence of ash on livestock feed can lead to weakening of the livestock, making it more sensitive to poisoning by the elements carried by the ash.

Fluorine, chlorine and sulphur, which are the volatiles most readily adsorbed and condensed onto tephra surfaces (Delmelle et al 2000 and 2007, quoted in Jones and Gíslason 2008), can act as irritant to the respiratory system of animal (IVHHN (International Volcanic Health Hazard Network), 2008). Fluorine and sulphur, in the form of H_2S or SO_2, and salts can also lead to poisoning, dental lesions, loss of teeth, etc.

Sheep are generally more tolerant to fluorine contamination than cattle (Cronin et al 2000). Concentrations above 25 micrograms per gram of ash of readily soluble fluorine can lead to acute fluorosis whilst concentrations between 40 and 100 micrograms per gram could lead to chronic fluorosis (Cronin et al 1998). Chronic fluororis can take weeks to months before becoming apparent.

2.4. Potential other and longer term effects

The injection of gases and ash into the atmosphere can lead to environmental effects that will, in turn, impact on agricultural activities.

2.4.1. ACID RAIN

The injection of volcanic gases such as SO_2, HCl and HF into the atmosphere through the plume can lead to chemical reactions that can lead to the formation of acid rains (Bischene 1995, Williams-Jones and Rymer 2000, Flaathen and Gíslason 2007). This has been observed on numerous occasions in location with volcanoes showing heavy degassing such as in Central America (Masaya, Poas, Turrialba, etc.). However, the conversion of SO_2 into H_2SO_4 and other acid rain components is heavily dependent on climatic conditions and seasonality (see sections 3.1. and 3.2. below)

Figure 2.7: Volcán de Turrialba, Costa Rica, 2008. The effects of acid rain on vegetation around Turrialba. The brown areas on the leaves show burns by acid rain. These plants are situated about 100 m below the summit of the volcano, where active degassing is taking place.
Picture taken in October 2008.

2.4.2. CLIMATIC CHANGES

In the case of very large eruptions, the gas injection can reach the stratosphere causing climatic changes (Self et al. 2005).

The effect of aerosols injected into the stratosphere can be that of cooling the average global temperature instead of contributing to its increase. The eruption of Mt Pinatubo in 1991, for example, is estimated to have caused a cooling of surface temperature of 0.5 to 0.6°C through injection of SO_2 into the lower stratosphere (Self et al. 1996).

On a more local basis, volcanic eruptions can also produce volcanic smog, also called ‘vog’ (USGS 2008a), which can have a significant health impact for humans and animals in the area affected.

Volcanoes also emit large amounts of greenhouse gases such as CO_2 and water vapour. These are known to have a greenhouse impact on the climate by absorbing the infrared thermal energy emitted by the Earth surface. As a result, volcanic eruptions could be a contributor to the increase in global surface temperatures. The review of such an effect on climate is, however, outside the scope of this study.

2.4.3. Sedimentation downstream

The deposition of ash and its remobilisation through lahars can lead to increased sedimentation downstream along main waterways. This can seriously affect ecosystems and potential for agricultural activities in areas of redeposition of the sediments carried by the rivers.

To date, the detailed impacts of these movements of sediments on plant growth have apparently attracted limited attention from research scientists.

Figure 2.9: Pinatubo, Philippines, 2007. View of enlarged and new river channels following the eruption of Mt Pinatubo of 1991 and the lahars in subsequent years. The photo was taken in June 2007.

2.4.4. Ash remobilisation

Ash can be remobilised by winds for very long periods (up to 10 years) after the eruptive event. This can significantly impair the ability of vegetation to grow and affect animal health due to the presence of particles in the air.

In Iceland, it has now been ascertained that the process of desertification which affects part of the country is not only the consequence of excessive deforestation or overgrazing but is also the consequence of tephra remobilisation. The abrasive particles of tephra attack young plants potentially hindering their growth. This means that in unprotected areas, plants have difficulties re-settling as their tissues get damaged by wind-blown particles at their most fragile stage of growth. (Gísladóttir and Erlendsson, 2008)

Ash remobilisation is an issue that was particularly acute in Argentina following the eruption of Mt. Hudson. Mt. Hudson is situated in Chile but prevailing winds in Southern Chile blow towards the East meaning that most of the ash gets blown to

Southern Argentina. In the case of the 1991 eruption, remobilisation of ash by wind was observed for at least 10 years after the eruption. In some areas, this caused significant problems and hindered greatly the re-establishment of agricultural activities in the region (Bitschene 1995).

2.4.5. Delayed fluorosis

Past examples of eruptions in the Chilean Andes show that livestock can develop fluorosis some time after the end of the eruption. Araya et al. (1993) and Araya (2003) observed the occurrence of fluorosis up to one year after the end of the eruption in the area surrounding Lonquimay.

In the case of the eruption of Hekla in 1947-48, dental fluorosis sometimes developed 9 to 13 months after the tephra fall (Thorarinsson 1979).

Chapter 3:

Factors influencing the impact

The impacts of volcanic products on agriculture can vary vastly depending on the location of the volcano. This is a consequence of the importance of climatic and seasonal conditions, as well as of the different sensitivities of the various species of vegetation to the effects of ash and gases.

3.1. Particle size

Particle size is of high importance when considering impact on livestock. Animals are more likely to ingest smaller particles both through respiratory and digestive processes. Smaller particles will also enter the mechanical parts of equipment.

In addition, smaller particles will provide a larger surface for coating by aerosols due to their higher surface area to mass ratio (Óskarsson 1980, Jones and Gíslason 2008) They can therefore can lead to higher risk of poisoning by elements such as fluorine (Thorarinsson 1979, Thornton 2000). As they will get carried further away from the volcano, they will extend the hazardous area. For example, in the case of eruptions from Hekla, areas more distal from the volcano in the North of Iceland were more hazardous for livestock than proximal areas (Óskarsson, 1980). This can make livestock management difficult as the area to evacuate can become fairly large and dependent on wind direction when the ash plume is ejected from the volcano.

The fact that smaller particles can cause a higher risk than larger and hence risk levels can increase with distance from the ash source can be rather counterintuitive. In case of a volcanic crisis, specific information with respect to this might need to be communicated in order to ensure that the hazard is managed adequately.

3.2. Seasonality

The season at which an eruption takes place can largely affect the size of the impacts. Both plants and livestock have very different sensitivities at different stages of their development cycle (Thornton 2000).

Plants will be particularly sensitive during flowering. And the presence of ash during the phase of early development of fruits can give rise to necrosis (=death of cells) on their skin. It might make them unsuitable for consumption or simply for commercialisation (as they would not meet the aesthetical expectations of customers for example).

Ash falls can also affect pollinators and if they are depleted at critical times then, further development of flowers into fruits might not take place. In the case of the eruption of Mt St Helens (USA) in 1980, the damage to the development of fruits was largely avoided because pollinators were destroyed just after the flowering period (Cook et al 1981). As plants had been fecundated, damage to crops was limited.

The impacts of the eruption of Paricutín (Mexico) in 1943 on agriculture were also largely reduced by the fact that the onset took place after completion of the harvest (Rees 1979).

Livestock will also have different levels of sensitivity depending whether the ash falls take place during pregnancies, lactating periods, etc. (Rubin et al 1994).

The process of oxidation of SO_2 to H_2SO_4 is largely dependent on light availability, which means that eruptions taking place at high latitudes in the wintertime are less likely to give rise to acid rain due to limited daylight hours (Flaathen and Gislason 2007).

3.3. Climate

Climatic conditions at the time of an eruption can affect the acuteness of impacts. For example, if ash falls take place in the winter on snow covered areas, the ash and salts will be, at least in part, washed away by the first snow melt. As a result, it will have limited impacts on vegetation and/or crops despite the high concentration of soluble salts in the first snow melt. So in cold climates, seasonality will be even more important.

Wet climates will also wash away ash rapidly, through heavy rain, but in places where extreme weather such as typhoons and hurricanes occurs, it can lead to further issues by causing large ash remobilisations such as lahars (e.g. Mayon and Pinatubo in the Philippines).

In the case of the eruption of Mt Hudson in 1991, Inbar et al. (1995) state that the predominant climatic conditions in Southern Argentina are largely to blame for the prolonged remobilisation and the quantity of ash in suspension, as winds blow particles in the air, creating a form of haze for years after the eruption.

Delmelle et al (2002) also found that SO_2 and HF are more solute in fog and clouds than in rain; this will have serious implications depending on where eruptions occurs and also which season they take place in.

3.4. Presence of vegetation, species sensitivity and life cycle

Various researches indicate that the presence of certain types of vegetation in areas affected by volcanic products can act as a mitigating factor.

The presence of tall vegetation can limit the remobilisation of tephra over long distances and hence the damage to newly growing plants as larger plants act as a shield. Delmelle et al. (2002) suggest that coffee plantations downwind from Masaya (Nicaragua) be sheltered by the presence of evergreens such as *Eugenia jambo, Brosimum utile* or *Clusia rosea*, which are more resistant to volcanic gases; these would then act as a fence, limiting the concentration of damaging gases reaching the coffee-trees.

Different species will have different sensitivities to the various volcanic products and will be able to adapt more or less well to the changes occurring in the environment following a volcanic eruption. It is thus very important to understand the changes that are taking place in order to foresee any need for change of crops or new requirements for fertilisation and/or fumigation.

For example, in the area affected by ash falls from Tungurahua (Ecuador), farmers have had to change crop types from traditional Ecuadorian crops to potatoes and onions; this is due to the changes taking place in the soil chemistry and these are now the only species that grow readily in the area (Linda Rutherford, University of Florida, Pers. Comm., January 2006). Similarly if an area is affected by lahars following a large eruption, it might be relevant to change crop type to crops with fast yields that enable harvest before the rain season, instead of commercial crops that span throughout the year or require multi-years investments (e.g. area around Mt Pinatubo following the 1991 eruption).

As mentioned in section 3.2, the life cycle of plants is also important as their sensitivity can change according to the season during which they are exposed to volcanic ash and gases. It is therefore important to take this into account, whenever possible, when making decisions as to what action is required to minimise impacts and/or recovery time.

3.5. Dependence of activity on technology-based assets

The dependence on infrastructure and equipment will also be a key factor to take into account when assessing the needs of the recovery period.

Different types of agriculture will have different needs. Traditional agriculture, with small farms, generally relies more on manual production and aims for local markets; the availability of technology and infrastructure is thus generally not critical to its survival. On the other hand, modern agriculture tends to rely heavily on machinery and infrastructure for production, storage and access to market.

As a result, the smooth running of machinery and infrastructure will become a priority in order to initiate recovery in areas where agriculture is intensive and heavily mechanised. Neglecting that aspect of the recovery will lead to slow returns or even failure of the recovery.

Chapter 4:

Case studies and field visits

This study was carried out partly on the basis of field visits and partly on the basis of documentary reviews of field reports, books and peer-reviewed articles, press articles, relating to events during and after volcanic eruptions.

In one of the cases, New Zealand, the response to a different natural hazard, unusually heavy snow fall, was considered as it provides an example of successful management of a crisis.

Four countries were visited for the purpose of this study, each with one or more sites. They are:

- The Philippines – June 2007: for exploring the effects of the eruption of Mt Pinatubo of 1991-1993 and subsequent lahars until 1997 and the ongoing eruption of Mt. Mayon.
- Japan – November 2007: for the eruption of Mt. Unzen of 1990 to 1995. Site visits were also carried out to Sakura-jima, Izu-Oshima, Miyake-jima and Kaimondake.
- New Zealand – March-April 2008: for the hazards to agriculture around Mt. Taranaki and the very heavy snow fall of the winter of 2006 in South Island, and to observe the setting of the eruption of Ruapehu 1995-96.
- Costa Rica – October 2008: for the ongoing degassing of Mt. Turrialba and resulting damage to surrounding vegetation.

These field visits and some analysis of findings from each of them are described in sections 4.1 to 4.4 below.

Figure 4.1: Map showing location of field visits.

The last three sections of this chapter look at lessons learnt from a number of other cases. Section 4.5 focuses on key volcanic events, known to have had significant impacts on local agriculture, which were reviewed through documentary reviews.

Section 4.6 highlights a number of lessons that can be drawn from experience in Iceland following the eruptions of Mt. Hekla over the last 60 years. Section 4.7 looks briefly at three non-volcanic events to determine how these experiences can help in the handling of volcanic crises.

4.1. Field visit 1: Philippines (June 2007)

4.1.1. PHILIPPINES: DETAILS OF THE FIELD VISIT AND GEOLOGICAL SETTINGS

Dates of the visit: 11 to 24 June 2007
Locations visited: University of the Philippines, including extensive research of documentation held at the University library (Quezon City-Manila), Mt. Pinatubo and surrounding area, Angeles City, Taal Volcano and surrounding area, Mt. Mayon and surrounding area including Philvolcs (Philippines Institute of Volcanology and Seismology) office, Legaspi City, Mt. Bulusan and surrounding area including Philvolcs office.

Geological setting:

a:

b:

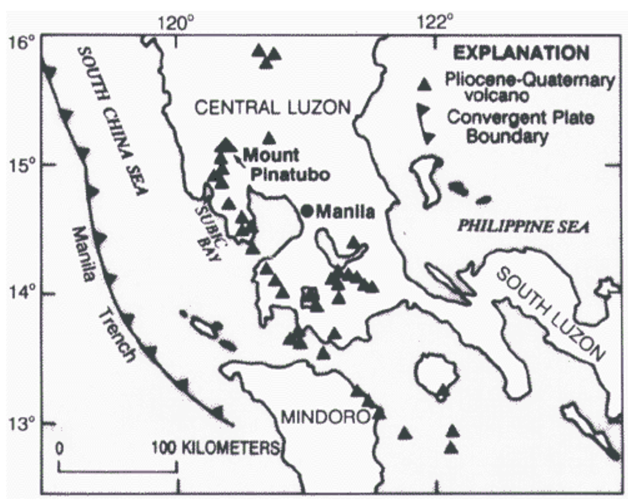
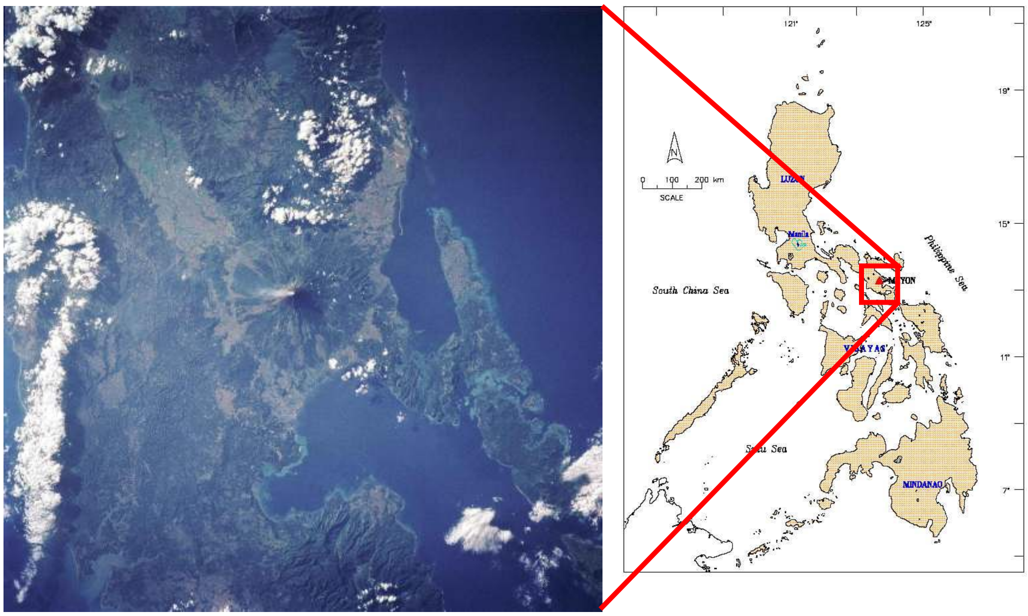


Figure 4.2: **a: Philippines** (CIA (Central Intelligence Agency) 2008a).
b: Location map Mt. Pinatubo, Philippines (from Newhall et al. 1996).
c: Location map Mt. Mayon, Philippines (next page) (from Corpuz, 2005).

c:



All sites visited are situated on Luzon island (Fig 4.2), one of the most Northern islands of the Philipines, where the capital city, Manila is located. Mt. Pinatubo is situated in Central Luzon, approximately 80 km North of Manila. Mt. Mayon is located in Southern Luzon, approximately 300-400 km South-East of Manila.

Taal volcano is situated on the island of Luzon (near Batangos, see figure 4.2a) above). Mt. Bulusan is situated at the Southern end of the island of Luzon.

At the time of the visit, Mt. Pinatubo was in a quiescent period. Taal volcano showed some fumarolic activity as well as increased temperatures in the main crater lake. Philvolcs issued warnings relating to a risk of explosion at the main crater. Mt. Mayon was emitting a small amount of ash/smoke (however, not recorded as actively erupting). Mt. Bulusan has showed sporadic seismicity and explosions followed by punctual ash emissions throughout 2007.

Taal volcano and Mt. Bulusan are not referred to specifically in the remainder of this study. However, a number of discussions with local residents and Philvolcs staff were held in order to obtain views of local population on risks and on impacts on local agricultural activities.

Over 54% of economy of the Philippines is service-related (occupying 49% of population), and 14% linked to agriculture (occupying 36% of population) (CIA 2008a).

Main contacts and interviewees during the visit:
Hannah Mirabueno, researcher, Philvolcs (Philippines) and University of Kagoshima (Japan).
Gloria Luz Nelson, Professor of Sociology, Population Studies, University of the Philippines, Los Baños.
Cynthia Banzon-Bautista, Professor of Sociology, University of the Philippines, Quezon City.
Doracie B. Zoleta Nantes, Professor of Geography and Asia Research Fellow, University of the Philippines, Quezon City.
Local residents around the four volcanic areas visited.

4.1.2. PHILIPPINES: THE ERUPTIONS AND SUBSEQUENT HAZARDS

Mt. Pinatubo (Central Luzon) began erupting in April 1991 after nearly 500 years of inactivity (Smithsonian 2008). The strength of the eruption has been recognised as VEI (Volcanic Explosive Index) 6, putting it on par with the largest eruptions of the last century. The eruption lasted for nearly three months and was followed in 1992 and 1993 by two eruptive episodes of much lower explosivity (VEI 1).

Even though the eruptive activity only lasted until 1993, the area was directly affected by the aftermath of the eruption until 1997 through the occurrence of lahars (Figs. 4.3 and 4.4). The Philippines are situated on the path of a significant number of typhoons and as a result are annually affected by heavy rainfalls in the latter part of the year. These, following the eruption of Mt. Pinatubo and the creation of thick deposits of ash, triggered large lahars up to six years after the initial eruption. The presence of lahars made it difficult to re-establish long term commercial crops such as sugar cane (a cane plant can be productive for up to 8 years) and significantly reduced the productivity of rice paddies.

Figure 4.3: Mt. Pinatubo. Philippines, 2007. A view of the channels and the agricultural area on the Southern side. Picture taken in June 2007.

In addition to the impacts resulting from the direct deposition of ash on the fields (i.e. burial, smothering, etc. of vegetation), the injection of gases and ash in the atmosphere had severe global climatic consequences. It is estimated that the eruption caused an average decrease in temperature of 0.5 to 0.6°C in the year that followed the eruption (Self et al. 2000).

In this project, however, no evidence was found of specific impact of the climatic changes on agriculture in the Philippines. This may be attributed to the fact that the damage caused by ashfall was so large that climatic impacts would have been secondary in the region.

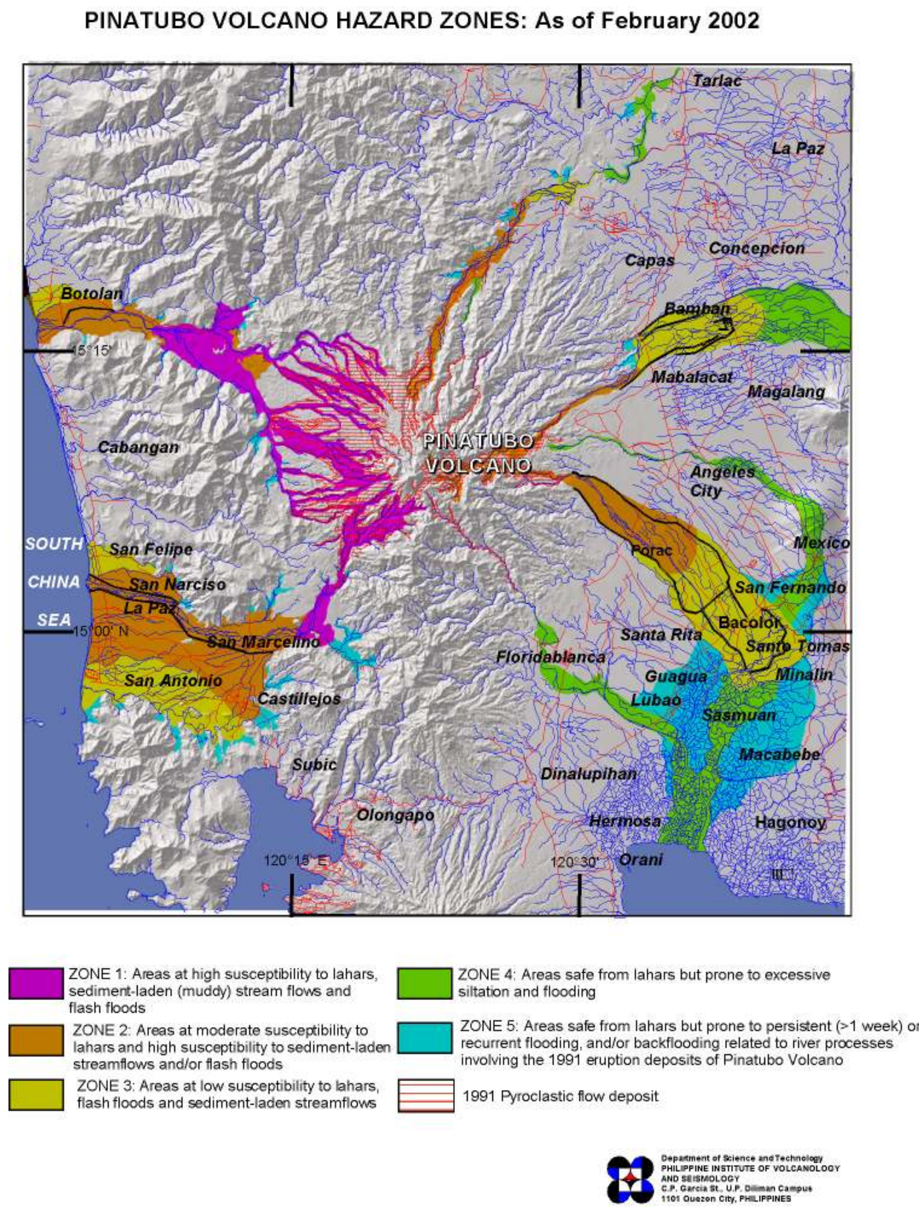


Figure 4.4: Pinatubo hazard zones, Philippines, 2002. The map show the zones around Mt. Pinatubo identified as at risk of volcanic hazards by Philvolcs. This map was drawn up in 2002 and hence includes all the changes having affected the area following the 1991-93 eruption of Mt. Pinatubo (Source: Corpuz 2005)

Dr Gloria Nelson reports that, a year after the onset of the eruption, in, Pampanga (Eastern and South Eastern side of Mt. Pinatubo, fig. 4.5),11,270 ha of crops had been damaged and 14,605 farmers affected (Gloria Nelson, pers. comm., June 2007).

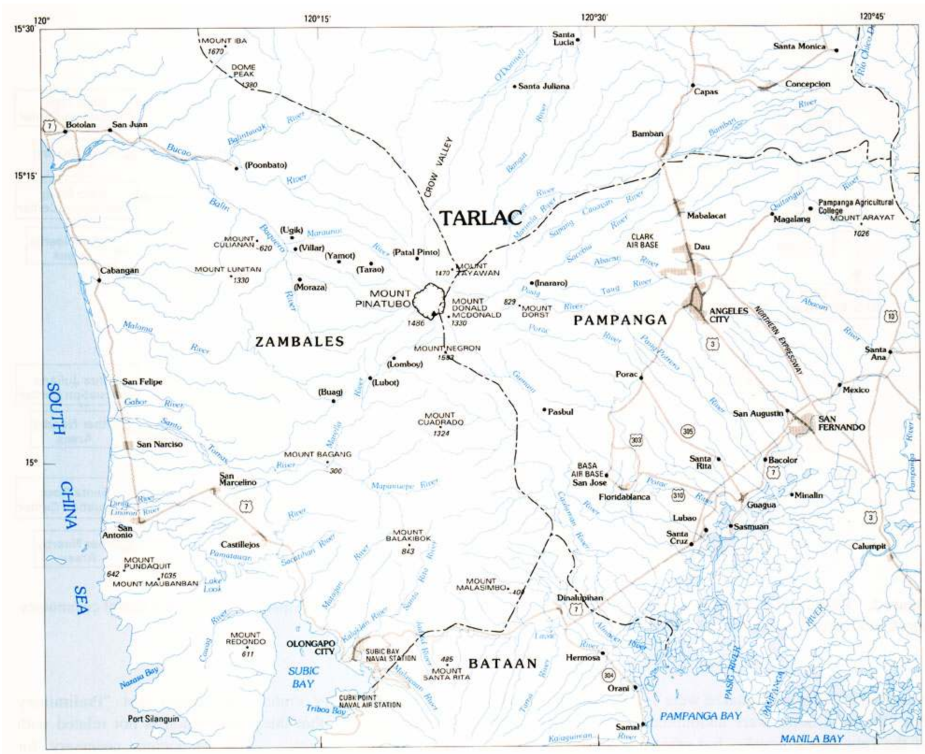


Figure 4.5: Districts surrounding Mt Pinatubo, Philippines, 1996. (Source: Punongbayan et al. 1996)

The damaged caused by the eruption to the agricultural sector was estimated at 57 million US dollars, essentially due to the destruction of farmland and death of livestock (Mercado et al. 1996).

Statistics issued by the National Statistics Office of the Philippines show that the number of farms in Pampanga diminished by 19% (from 47,521 to 38,699 farms) between 1991 and 2002 but increased by 9% (from 26,049 to 28,314 farms) in Zambales (Western side of Mt. Pinatubo) (National Statistics Office Philippines, 2008). Area of farms decreased from 91,241 to 64,959ha (-29%) in Pampanga and from 47,850 to 35,979ha (-25%) in Zambales (National Statistics Office Philippines, 2008). It is however not possible to infer a direct correlation between this evolution of number of farms and of cultivated areas with the eruption as other factors might have affected this evolution.

Mt Mayon (Southern Luzon) (Fig. 4.6) has had active phases every year since 1999 (except in 2007). Intensity and size of eruptions have varied, as well as eruptive products. They are mainly ash and pyroclastic flows, but lava flows have also occurred. The eruptions in themselves caused limited damage due to their low intensity.

Figure 4.6: Mt. Mayon, Philippines, 2007. Mt. Mayon and surrounding agricultural areas. The plains at the foot of Mt. Mayon are mainly used to grow rice. Picture taken in June 2007.

However, due to the geographic location of the volcano, volcanic ash is remobilised throughout the rainy season, causing lahars that damage crops and disrupt agricultural activities (Fig. 4.7). The area is also affected by extreme events such as Super Typhoon Durian (Category 4) in 2006 (Figs. 4.8, 4.9 and 4.10). The typhoon hit the area on 30 November 2006 and killed over 1100 people and led to the temporary displacement of 1 million people. Associated damage to agriculture is estimated at 45 million US dollars (Fano, 2007).

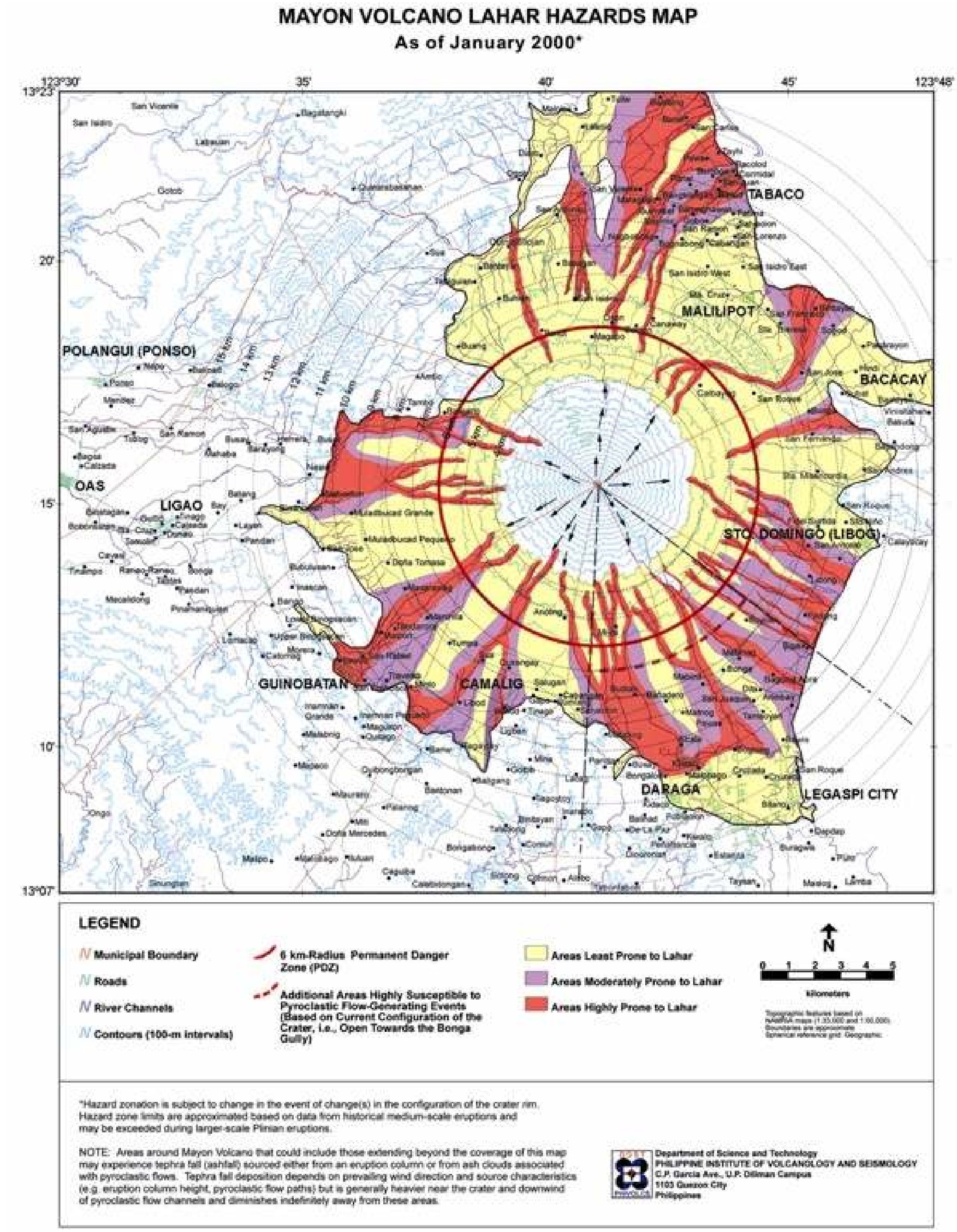


Figure 4.7: Mt. Mayon hazard map, 2000 (Source: Philvolcs)**.** Hazard map for Mt. Mayon showing the areas that can potentially be affected by lahars. The map shows that there is a significant risk of lahars on all sides of the volcano with exception with the North West flank. Following Typhoon Durian, the largest lahars and most important damage were observed from the South West side to the East side of the volcano.

The event had a significant effect on the topography and as a result new hazards maps have to be drawn to reflect the modification in the hazard zones (Mirabueno, pers. Comm., 2007).

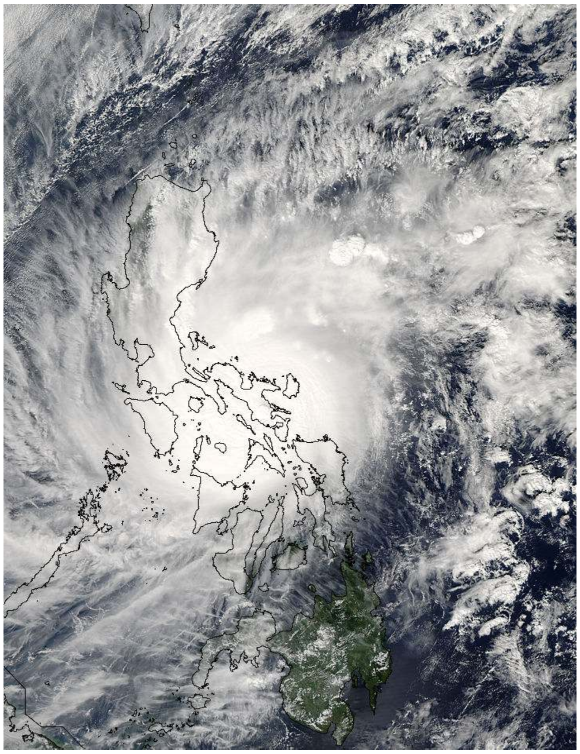


Figure 4.8: Typhoon Durian, Philippines, 2006. MODIS satellite photograph of Super Typhoon Durian on 30 November 2006. The eye of the typhoon is situated just a few kilometres from Mt. Mayon. (adapted from 2006/334 - 11/30 MODIS - http://rapidfire.sci.gsfc.nasa.gov/gallery/?2006334-1130/Durian.A2006334.0500.2km.jpg)

Figure 4.9: Fields at the foot of Mt. Mayon. Philippines, 2007. Area affected by the lahars from typhoon Durian at the foot of Mt Mayon (in the background). Picture taken in June 2007 (7 months after the lahars)

Figure 4.10: Mayon lahar channel. Philippines, 2007. Side of one of the lahar channels showing a house buried nearly up to the roof by sediments deposited by the lahar flow. Picture taken in June 2007.

The large number of casualties of this typhoon (1100 to 1200 people depending on the source (Fano 2007)) is partly due to the fact that high alert levels had been raised earlier in the season but limited damage ensued; as a result population paid limited attention to the later warnings issued.

Typhoon Durian was not the only one affecting the area in 2006; a rapid succession of typhoons occurred which resulted in the clogging up of the river beds. These are generally engineered (widened and empty of any material) during the dry season so as to accommodate the fairly large lahars that can affect the area. However, when clogged up, overflows occur and inhabited areas can be severely affected by the mudflows. This situation occurred in 2006; the channels where unable to absorb the unusually large flow so late in the season.

No recent official statistics from the National Statistics Office of the Philippines are available reporting the current number of farms or the area they cover as the last census was carried out in 2002. However, scientists working on populations issues around Mt. Mayon indicate that migratory movements towards the capital city to the detriment of agricultural activities have been observed (Zoleta Nantes, pers. comm., June 2007). It is however, as in the case of Mt. Pinatubo, difficult to draw a direct correlation between these movements and volcanic activity.

4.1.3. PHILIPPINES: THE RECOVERY

One of the key differences between the case of Pinatubo and that of Mayon is the amount of external assistance they have attracted. Massive international involvement occurred following the eruption of Mt. Pinatubo with assistance money from the local government and also from all over the world, both for emergency and recovery.

At the emergency level, assistance was provided through the construction of alternative housing and creation of alternative jobs in manufacturing in order to provide occupation for the population that would have to be displaced from the areas affected by lahars for the 6 years following the eruption.

Figure 4.11: Drainage channel of Mt. Pinatubo, Philippines, 2007. Side of a drainage channel of Mt. Pinatubo, showing clearly the area affected by floods (where no vegetation grows). The green lowland area is used as agricultural land and was inundated by lahars in the years subsequent to the eruption. Picture taken in June 2007.

International assistance was also provided for emergency. A significant proportion of the external money was however used to study the eruption and its impacts, including agricultural research, publishing of manuals advising on how to re-start agricultural production in areas affected etc. (Thomas Wilson, University of Canterbury, New Zealand, pers. comm. 2007). However it seems that the diffusion of this information was limited and accounts from local communities show that even though they were given seedlings to re-plant their fields, technical advice as how to handle crops in the newly created environment was too scarce (e.g. in Barangay (village) Moraza, Garcia et al 1993).

As large lahars were anticipated for a number of years after the eruption, the authorities decided to implement a ‘technocratic top-down planning’ model and build new towns in which they were hoping to relocate displaced populations (Bazon

Bautista et al, 1996). The idea was also to attract investment in factories that would provide employment while agricultural land would be unavailable for cultivation; this did not materialise and there was a poor uptake of relocation to the resettlement areas. Instead populations remained in lahar-affected areas and had to develop their own strategies to ensure the livelihood of their families. Some farmers changed crop types to seasonal crops that would grow outside of the rainy season (often finding suitable crops by trial and error), sometimes supplemented by new activities such as pumice-gathering –used in the jeans industry to create the 'stone-washed' effect for example - for resale to wholesalers (Fig. 4.12).

Figure 4.12: Pumice gatherers, Mt. Pinatubo, Philippines, 1993. Pumice gatherers awaiting the collection truck to sell the bags of pumice they have collected close to Mt Pinatubo. Picture courtesy of Henry Pradin.

In the areas surrounding Mt. Mayon assistance has been limited to evacuation to tented camps and support during volcanic crises (including subsequent lahars). When it comes to re-establishing crops the population is generally left to handle the situation on their own (Mirabueno, pers comm., 2007). This self-reliance also means that during crises, the population is tempted to return to attend to their fields since they cannot afford to lose their crops.

A review of the actions taken following the eruption of Mt. Pinatubo shows a clear lack of communication between the various teams of researchers in the field at the time. Numerous duplications of studies have been observed by this author whilst reviewing documentation available at local libraries during fieldwork. Furthermore, studies which were too limited in scope to have any real significant impact in the rehabilitation work required following the eruption. Some funding was even used by teams of researchers in agronomy to determine the nature of the ashes emitted by the volcano when this type of information had been held by the teams of volcanologists from the onset.

A review of the Filipino press at the time of the crisis reveals that the overall attitude of the government promising aid appears to have led to a general lowering of resilience levels in the population. By 1992, the press was relaying the message of farming communities complaining of the lack of assistance (Cadahing 1992a and 1992b). The expectation was that the government would provide them with seedlings, fertilizers, equipment, etc. to re-establish agriculture. At the other site, at Mt. Mayon, this has not been the case. There farmers did not receive any assistance over that of emergency sheltering and food. Yet poverty levels seem to have risen around the two volcanoes. In fact, it appears that the governmental plans of temporary resettlement providing jobs in industrial activities have mainly had the effect of destroying the agricultural activities in the area. And, despite the assistance provided, ten years after the last lahar, agriculture was still producing very low yields and most farmers aim at providing their children with opportunities to leave rural areas and find jobs in industry (Nelson pers. comm. 2007, Zoleta Nantes pers. comm. 2007).

Nelson (pers. comm. 2007) reported that farmers members of local farmers associations reached higher productivity and income partly thanks to the availability of the help of farm technicians. These groups acted as a support network to farmers during and after the crisis.

These two cases, even though taking places in the same country, show very different handling of a crisis and its aftermath. The eruption of Mt. Pinatubo mobilised a large amount of resources, whilst for the eruptions of Mt. Mayon, intervention was limited to the emergency phase. Yet in both cases, a pauperisation of rural populations was observed (Zoleta Nantes pers. comm. 2007).

In the case of Mt. Pinatubo, information relating to the volcanic products and the evolution of the eruption (and possible subsequent events such as lahars) could have been used better to the benefit of local populations. The following would have been of use for a smoother handling of the crisis:

- ash dispersion pattern and expected lahar paths: these are already used for emergency management but they can assist in determining the areas that can be resettled and cultivated rapidly after the eruption as well as those that will only be available on a seasonal basis (i.e. outside of main lahar season – June to November);
- ash composition and thickness *during* the crisis: this can help identifying the most suitable crops in the intermediate period between eruption and complete recovery;
- ash composition and thickness *after* the crisis and potential long term impacts through changes in soil mechanical and chemical properties: this would be required to establish the best remedial actions as soon as possible after the end of the event.

Similar information would be of use around Mt. Mayon, with a stronger emphasis on the first point, as no evidence of significant changes in soil properties was encountered during the field study.

4.2. Field visit 2: Japan (November 2007)

4.2.1. JAPAN: DETAILS OF THE FIELD VISIT AND GEOLOGICAL SETTINGS

Dates of the visit: 14 to 28 November 2007

Locations visited: Izu-Oshima and Miyakejima volcanoes (part of the Izu volcanic arc, off the East coast of Honshu Island), the City of Shimabara (Kyushu), attendance to Cities on Volcanoes 5 conference 19-23 November 2007 (incl. poster presentation), Mt. Unzen, Sakurajima and Kaimondake volcanoes on Kyushu, Kagoshima city (Southern Kyushu).

Geological setting:

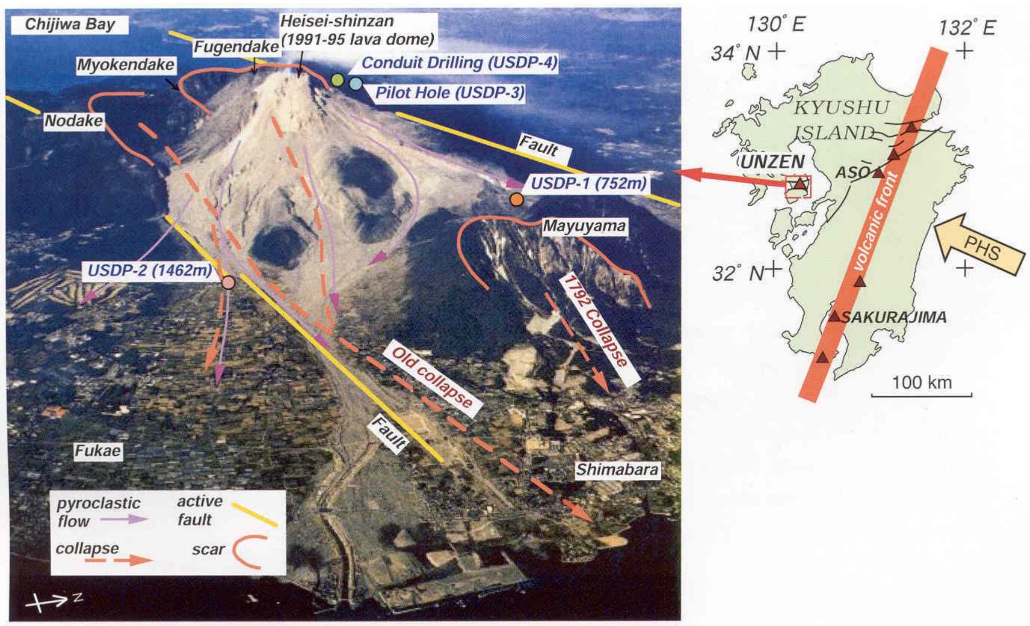
a:

Figure 4.13:

a: Volcanoes of Japan (Source: USGS, 2008b)

b: Unzen and Sakurajima, Kyushu Island, Japan. (next page) On the right side, position of Unzen and Sakurajima on Kyushu Island. Kaimondake volcano is represented by the triangle south of Sakurajima. The left side of the figure shows the respective locations of Mt. Unzen, Shimabara and Fukae towns. (Source: Shimizu et al 2007)

b:



At the time of the visit, Unzen, Izu-Oshima and Kaimondake were quiescent. Miyakejima was actively degassing SO_2 but at lower rates than those observed during the very active period of 2000-01 (when rates reached 40000-50000 t/day (Tsukui et al. 2007). Sakurajima was emitting low amounts of ash.

Experience following the eruption of Mt. Unzen of 1991-95 forms the core of the analysis below but experiences from other volcanic areas visited in Japan will be mentioned where relevant.

In Japan (total population 127 million people), 73% of economy is service-related (occupying 68% of population), and 1.5% linked to agriculture (occupying 4.6% of population) (CIA 2008b)

Main contacts and interviewees during the visit:

Koji Hata, Director Unzen Restoration Project Office - Nagasaki prefecture
H. Kawaguchi - Nagasaki Prefecture
Laura Hart, Coordinator for international relations – Nagasaki Prefecture. L. Hart kindly acted as an interpretor for the meeting with Koji Hata and H. Kawaguchi; she also provided the written translation (from Japanese) of documents from the Nagasaki Prefectural government.

Hannah Mirabueno, researcher, Philvolcs (Philippines) and University of Kagoshima (Japan)
Masashi Tskukui, Yoshihisa Kawanabe, Kohei Kazahaya, Hitoshi Yamasato and Kenji Niihori, field trip leaders for trip to Izu-Oshima and Miyakejima.
Setsuya Nakada, field trip leader for trip to Mt. Unzen.
Tetsuo Kobayashi, Masato Iguchi and Yoshihisa Kawanabe, field trip leaders for trip to Sakurajima and Kaimondake.

4.2.2. JAPAN: UNZEN: THE ERUPTION

The last large eruption of Mt. Unzen took place from 1990 until 1995, after nearly 200 years of inactivity (Nakada 2008). The eruption led to more than 9400 Merapi-type pyroclastic flows affecting the area surrounding Unzen, leading to the need to evacuate part of the local population (Figs. 4.14 and 4.15). At the peak of the crisis, over 160 thousand people were evacuated, nearly six thousand of them for a period of up to four and half years (Shimizu et al. 2007).

The extensive evacuation programme operated by the Japanese authorities was relatively successful as there were no casualties among local residents. However, a group of 44 people died and 12 were injured (Shimizu et al, 2007). They were for most part scientists (including Katia and Maurice Krafft and Harry Glicken) and journalists who were taken by pyroclastic flows on 3 June 1991.

Figure 4.14: Shimabara, Japan, 2007. Aerial photograph of Shimabara and surrounding area taken from above the summit of Mt Unzen, showing the importance of agriculture. This picture was taken from a helicopter flying directly above the summital area of Mt. Unzen. This is the reverse view from that showed on figure 4.13b. The pyroclastic flow channel visible on figure 4 13b is situated immediately to the right of this picture. Picture taken in November 2007.

The main areas affected were those of the city of Shimabara and Fukae town. Total damage was evaluated by the city of Shimabara in 2002 as amounting to over 2 billion US dollars, thereof 176 million US dollars being direct damage to agriculture and 200 million US dollars direct damage to animal husbandry (Shimizu et al. 2007). Around 600ha of agricultural land was affected (Nagasaki Prefectural Government, 2007a).

Mt. Unzen is currently the site of Unzen Scientific Drilling Project (USDP) for which holes have drilled into the volcano and its conduit in order to get a better understanding of its eruptive history (Nakada 2008).

4.2.3. JAPAN: THE RECOVERY

Recovery after disasters in Japan is a heavily organised process and authority to act is delegated down to the local authorities by the central government.

In the case of the 1990-95 eruption of Mt. Unzen, the Prefecture of Nagasaki took charge of all emergency, reconstruction and rehabilitation work.

A large change in the type of crops and agricultural technique before and after the eruption took place. Before the eruption, tobacco and dairy livestock were predominant; this was replaced by greenhouse horticulture (Fig. 4.17 below shows the current agricultural landscape in the suburbs of Shimabara) and dairy farming was relocated to other neighbouring areas (Nagasaki Prefectural Government, 2007a).

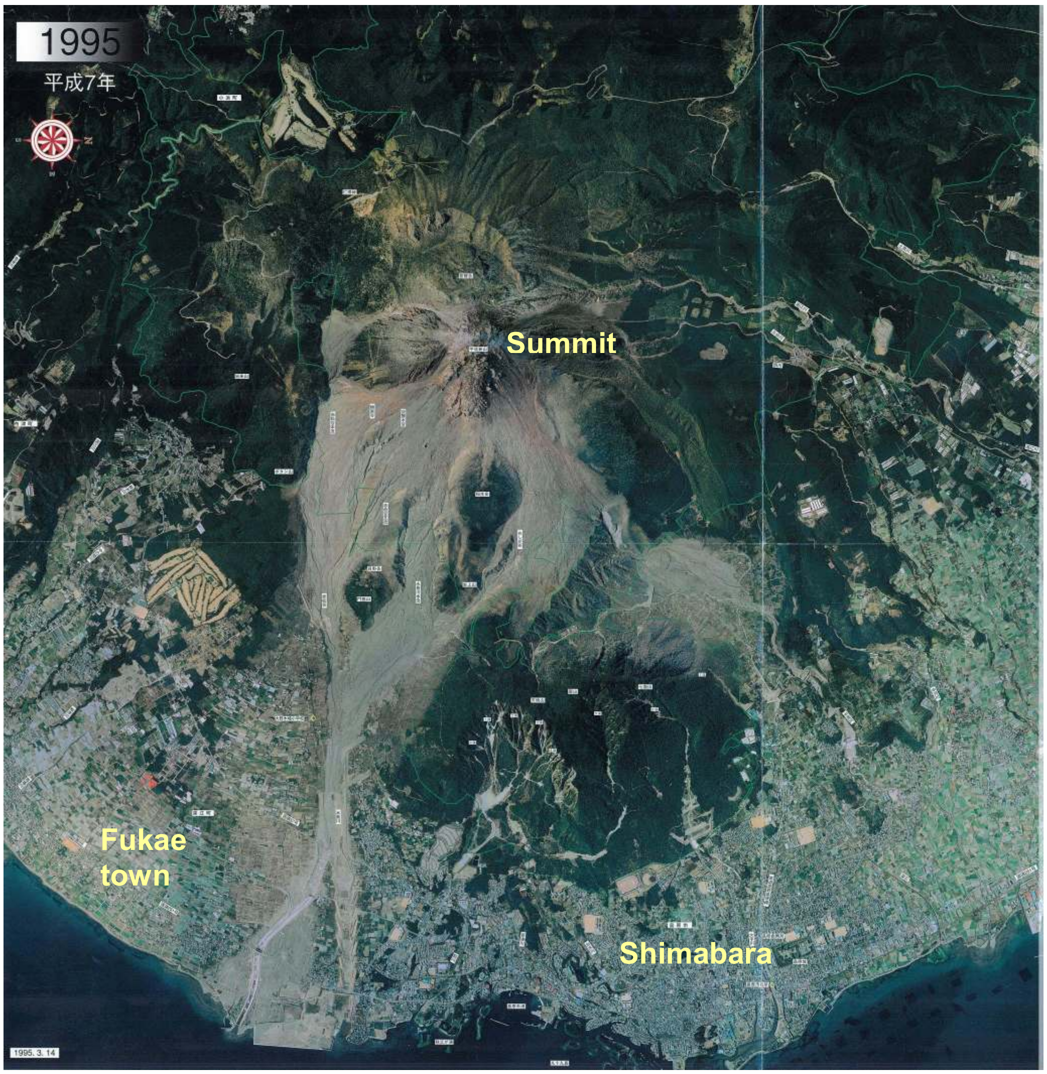
Even though very substantial governmental support was provided to local farmers during the recovery phase, of the 667 farms damaged during the eruptions only 374 farms recommenced farming (Nagasaki Prefectural Government, 2007a) and the average farm size was increased (Koji Hata, pers comm., 2007). However, of the 600ha having undergone damage, only 331ha were rehabilitated (Nagasaki Prefectural Government, 2007b)

The rehabilitation of the farming land was performed through a number of steps. First, soil was brought from other regions and was used to cover the deposits after the passage of the pyroclastic flows. Local officials report that the gradient of the fields was altered to 0.5% (see figure 4.16) in order to counteract the effects of falling ash on greenhouses. Drainage and irrigation channels were subsequently built in order to ensure that damage from future floods would be minimised whilst crop irrigation would also be guaranteed. (Nagasaki Prefectural Government, 2007a) The rehabilitation process started in 1993 and was completed in 2000 (Nagasaki Prefectural Government, 2007a).

The recovery process in the case of the 1990-95 eruption of Mt. Unzen was thus essentially government-driven. Very substantial amounts of money and technical assistance were provided in order to enable the farmers to start agricultural activities as rapidly as possible.

Figure 4.15 (following 3 pages): Mt. Unzen, Shimabara and Fukae town, Kyushu, Japan. The distance from the summit to the centre of the city of Shimabara is approximately 7 km.The pictures show the evolution of the area down the East side of Mt. Unzen over time. a- shows the area in 1991 prior to the onset of the eruption, b- shows the area immediately after the eruption in 1995, c- shows the area after recovery has been completed in 2006. (Source: Unzen Restoration Project Office, 2007) a-

b-



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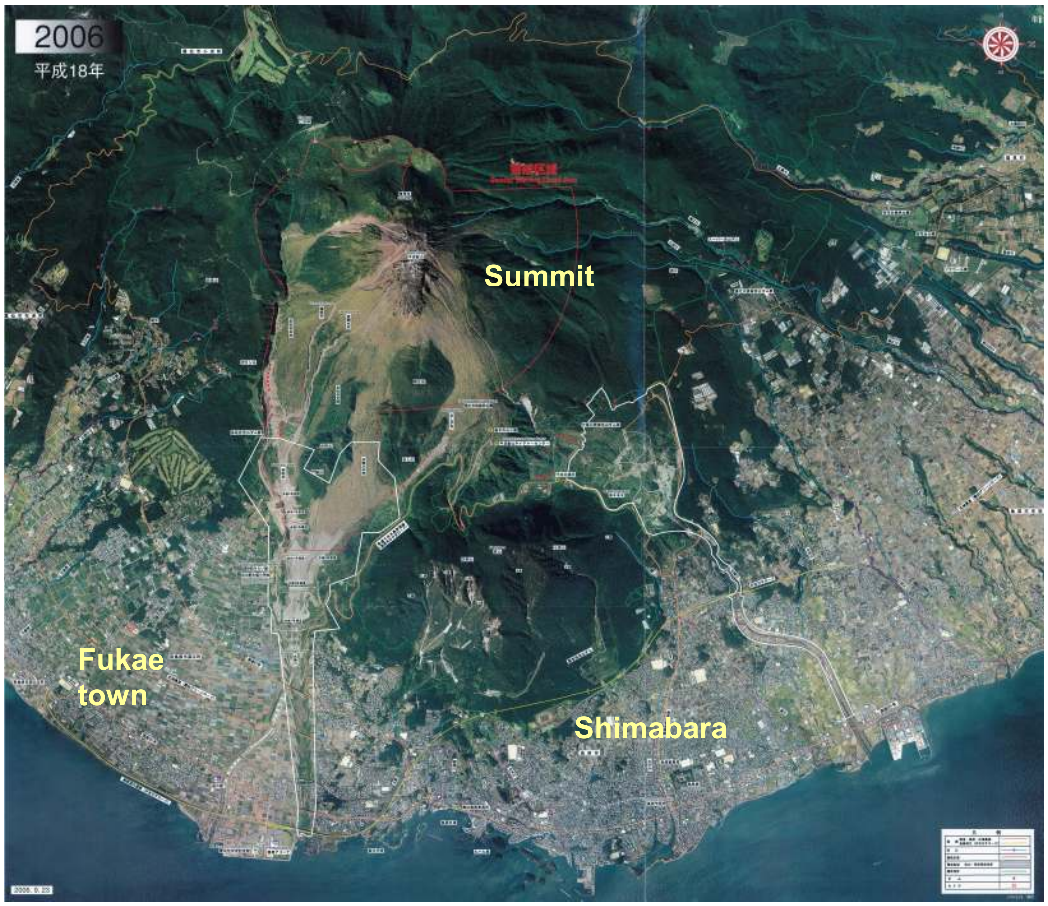


Figure 4.16: Agricultural recovery, Shimabara. The left picture shows an area devastated by pyroclastic flows. The picture on the right shows how the same area looks after the completion of recovery work. (Source: Nagasaki Prefectural Government)

Similar governmental interventions have been reported in other sites visited such as Miyake-jima Island during the eruption of 2000 and the area surrounding Sakura-jima (during the continuing eruption).

Near Sakura-jima, on-site interview of a local farmer revealed technical assistance was provided after volcanic crises and that agronomists would be on hand to give advice on the best way to improve soils after tephra falls. He mentioned, for example, having received advice to mix different size particles in order to improve the water retention properties through the formation of capillaries.

Farming is an important economic activity around four of the five volcanoes visited: Unzen (1995), Sakura-jima (continuing in 2008), Kaimondake (885AD) and Miyake-jima (2006). The exception is Izu-Oshima (1990), where agriculture is of lesser importance than in the other areas. (The dates between brackets indicate the end of the last eruption. All dates are from Smithsonian Institute, 2008.)

In the case of Unzen, all the recovery was handled by local government-driven process with very little involvement of local populations, which had been evacuated from the area. Solutions were designed and implemented at high level. They clearly took consideration of the fact that soils would be affected (hence new soil was brought to cover the ash-covered pre-existing soil) and that the eruption would be continuing beyond the large eruptive phase of 1991. Agricultural recovery work started in 1993 i.e. halfway through the eruption (which ended in 1995) and involved a shift from outdoors crops to greenhouse-based production (Fig. 4.17). This allows sustained production even in case of ash fall, as crops in greenhouses are protected from ash damage.

However, the application of similar solutions to eruptions in other countries is probably fairly limited. This solution requires financial resources that very few states can afford to allocate to recovery from natural hazards. More importantly, a specific socio-cultural context where the population affected is amenable to the government making most decisions relating to the recovery for them is required.

a:

b:

Figure 4.17: Fields in Shimabara, 2007.

a: Shows open field crops and, in the background, greenhouses in which melons are grown

b: Shows open fields crops. The outline of Mt Unzen can be seen in the background.

The Japanese society works in a way which is pretty much unique. Japanese are fairly resilient as a whole. There is overall an acceptance of the authority exerted by the government and the decisions made by them. In the context of natural hazards management, this means that, for example, if an evacuation order is issued, it is generally followed and people accept temporary relocation. This is helped by the fact that the government provides the necessary support in terms of housing, etc.

In the context of the recovery from the Unzen disaster, agricultural rehabilitation plans were designed by the government with the involvement of specialist advisors. Farmers were then given the opportunity to either agree with the proposed solution and recommence farming (as mentioned above only 374 out of 667 chose to do so) or take up other economic activities.

4.3. Field visit 3: New Zealand (March-April 2008)

4.3.1. New Zealand: Details of the field visit and geological settings

Dates of the visit: 18 March to 7 April 2007
Locations visited:
The visits to New Zealand focused on two main sites: the region around Mt. Taranaki (North Island) for the volcanic risks from future eruptions and Ashburton District (South Canterbury – South Island) for the unusually large and sudden snowfall affecting the area in June 2006 (Southern hemisphere winter). A brief trip to the area around Ruapehu was also carried out to observe the setting of the 1995-96 eruption.
Another key part of the visit was a number of meetings held with the Ministry of Agriculture, the Ministry of Civil Defense and Emergency Management, GNS (Geological and Nuclear Sciences), Massey University, University of Canterbury and with Federated Farmers.

Geological setting:

a:

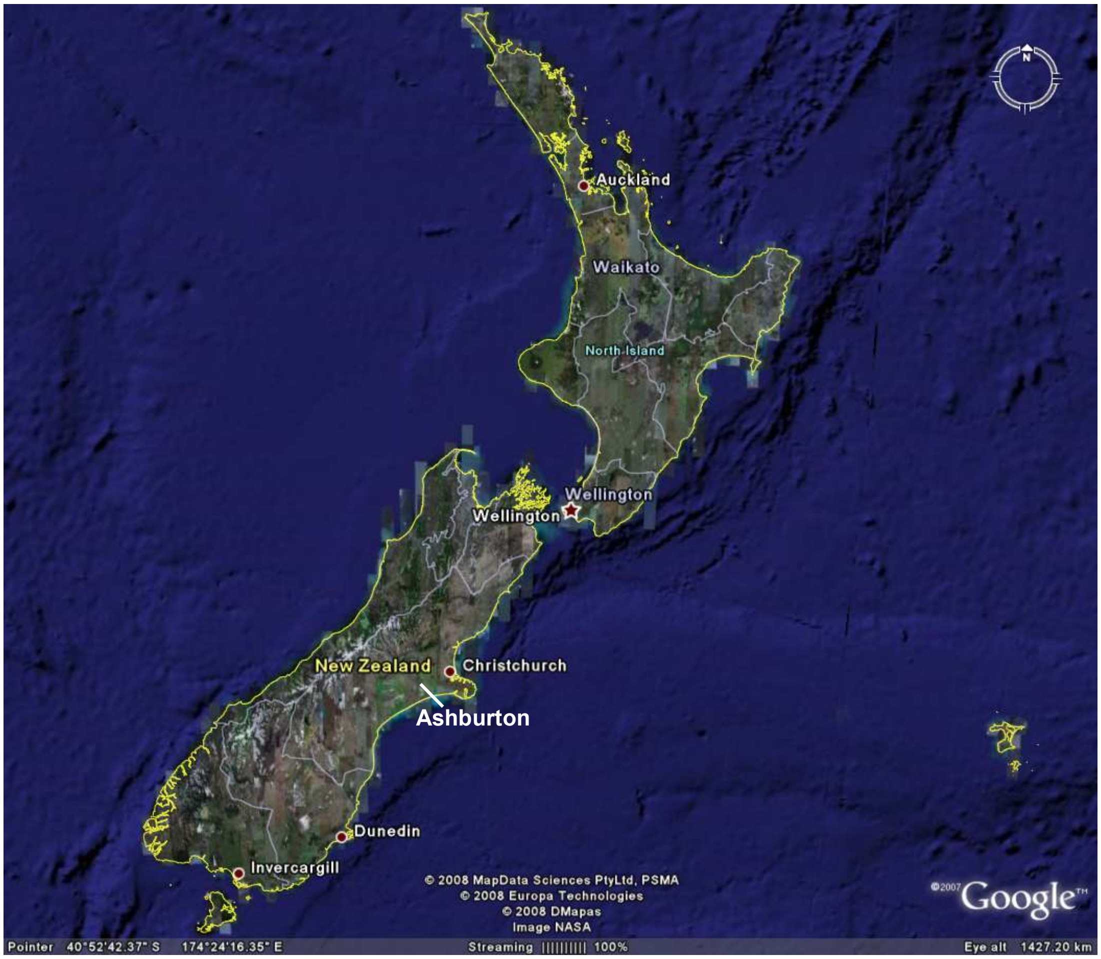
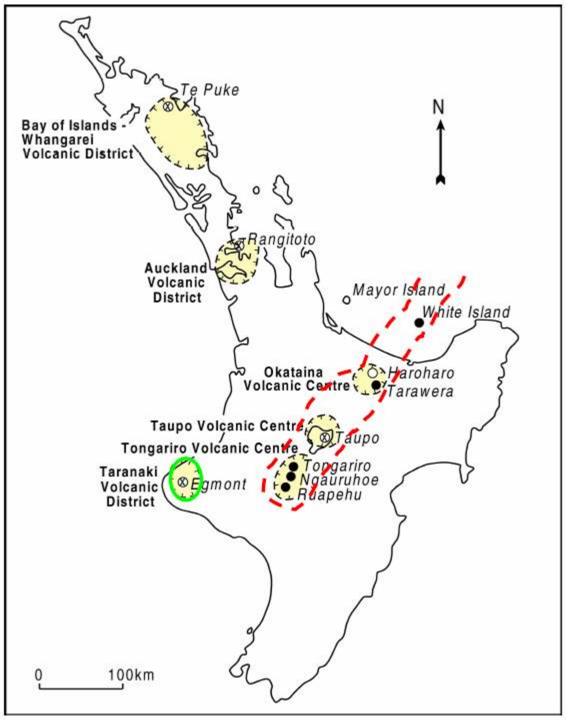


Figure 4.18: **a: Map of New Zealand** (Source: Google Earth)
b: (next page) Volcanic centres and districts in North Island, New Zealand (Source: Wilson and Kaye, 2007)

b:



The main volcanic centres of New Zealand are found on North Island (Fig 4.18) and off its coast.

At the time of the visit, none of the mainland New Zealand volcanoes where erupting. However, the region around Mt. Taranaki (also known as Mt. Egmont). The area was affected by an other hazard, as it was affected by a period of severe drought that was putting farmers under stress.

Agriculture in New Zealand (total population 4.1 million people) represents 4.5% of the GDP and employs 7% of the active population (CIA, 2008c); key export products of this activity are dairy products and lamb meat and products.

Main contacts and interviewees during the visit:

Thomas Wilson, Researcher, University of Canterbury, Christchurch and GNS Lower Hutt

David Johnston, Scientist, GNS, Lower Hutt.

Jim Cole, Professor, University of Canterbury, Christchurch.

Desiree Paulsen, Emergency Management Officer – Taranaki Regional Council, Plymouth.

John Greer, Regional Team Leader, MAF (Ministry of Agriculture and Forestry) Policy – Ministry of Agriculture and Forestry, Christchurch

Terry Donaldson, National Service Manager, Biosecurity Services – AsureQuality, Christchurch

Richard Smith, Emergency Management Research Analyst – Ministry of Civil Defense and Emergency Management (MCDEM), Wellington

Philip Journeaux, Manager North Islands Regions, MAF policy – Ministry of Agriculture and Forestry, Wellington
Alan Walker, MAF Policy, Crisis management centre, Ministry of Agriculture and Forestry, Wellington
Fiona Duncan, MAF Adverse Events Team, Ministry of Agriculture and Forestry, Wellington
Hugh Callen, Earthquake Commission, Wellington
John Leadley, Federated Farmers, Ashburton, South Canterbury
Kevin Geddes, Federated Farmers, Ashburton, South Canterbury
Shane Cronin, Associate Professor, Massey University, Palmerston North
Ian Chapman, Compliance Analyst, Powerco

4.3.2. NEW ZEALAND: SUMMARY OF EXPERIENCES AND CURRENT RESEARCH

The last eruption of Mt. Taranaki (Fig 4.19) took place about 200 years ago but it is predicted that an eruption could take place in the next 100 years (GNS, 2008). It is expected to bring the following types of hazards: lava flows, pyroclastic flows, landslides, lahars, floods, ash falls and volcanic gases (GNS, 2008)

Even though the area has not been subject to any recent eruption, it has been the focus of scientific research and of the civil defence and Ministry of Agriculture as it is one of the greenest areas of North Island. It is heavily used for livestock grazing (both sheep and cattle) with approximately 24% of the herds of the country in 2002 (Wilson, 2006). It is also one of the largest dairy producing areas of North Island and the region around Mt. Taranaki is key to the economy of the country as a whole.

Figure 4.19: Mt. Taranaki, New Zealand, 2006. (Source: Wikipedia, 2008)

As a result, studies have been carried out to assess the vulnerability of agricultural activities in the Taranaki region to volcanic eruptions. Scenarios have been designed in order to assess the feasibility of cattle evacuation (current research by Thomas Wilson) and resistance of infrastructure to volcanic ash falls (current research by Ian Chapman). In the short term, it is unlikely that agricultural activities would recover rapidly from medium or large eruptions. Cattle evacuation does not appear feasible and a significant number of weaknesses to ash have been identified in the infrastructure (electrical, gas, industry), which would probably lead to the need of a total shut-down of operations during ash falls. (Wilson, pers. comm.. 2008 and discussions held at the Ministry of Agriculture)

Figure 4.20: Merino sheep, New Zealand, 2007. (Source: Wilson and Kayes, 2007)

Due to its high exposure to natural hazards, New Zealand has one of the most advanced and best funded emergency management system in the world. However, the local emergency management officer the author met during the study acknowledges that recovery, albeit part of the theoretical working framework of the New Zealand civil defence, the 4Rs (Reduction, Readiness, Response, Recovery - Fig. 4.21), is not yet practically integrated into the field work (Desiree Paulsen, pers. comm. 2008). In fact, at the time of the visit, Taranaki Regional Council was actively recruiting a recovery manager for its operations. According to the New Zealand Civil Defense, the management of emergency phases seemed however to be under control, as attested by the successful management of the drought that was affecting the area at the time of the visit (March 2008).

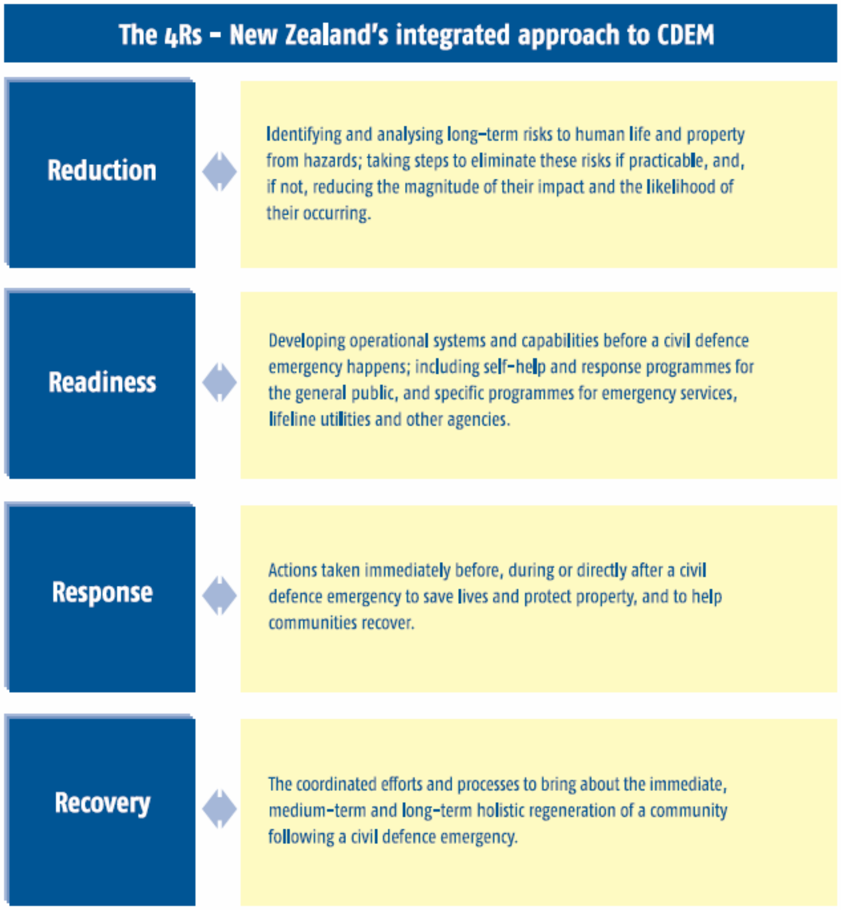


Figure 4.21: The 4 Rs of Civil Defence and Emergency Management (CDEM), New Zealand, MCDEM. The four Rs as defined by the Ministry of Civil Defence and Emergency Management of New Zealand are: Reduction, Readiness, Response and Recovery. According to MCDEM, these are the four steps that should be followed for the successful management of any crisis. At the end of every process cycle, feedback should be encouraged in order to improve Reduction and hence reduce exposure in subsequent crises. (Source: Department of Internal Affairs, 2008)

New Zealand has had what is recognised by the local authorities as a case of extremely successful emergency and recovery management in the last couple of years, which is often cited as a model for further development of the civil defence/emergency management activities (Wilson, Paulsen. Greer, Smith, Journeaux, Walker and Duncan, pers. comm. and meetings held in March/April 2008).

One event that was specifically discussed during the visit is the response to heavy snowfalls in 2006 in Ashburton (South Island). This event provides insights into the successful management of agriculture in New Zealand in an area affected by a sudden natural hazard.

On 11 June 2006, South Canterbury (South Island) was affected by unusually heavy snow falls, much earlier than normal for the Southern hemisphere winter. Of all the districts affected, Ashburton showed a particularly high level of resilience due to the existence of a close knit-community that pooled together to take action, and only specific support was required from the Civil Defence and District Authorities. Sheep and pigs were rescued in a timely and organised manner using helicopters and hay was provided to those that could not be evacuated. Everyone took upon themselves to ensure that their neighbours were coping with the psychological pressure throughout the crisis. Authorities had an immediate understanding of what was required and provided it on a timely basis thanks to the close links between the Rural Support Trust of Federated Farmers –the farmers' association- and the Civil Defence. This could only be achieved because the communities affected knew and trusted each other as well as the local authorities. (Rural Support Trust, Federated Farmers, meeting held in March 2008)

Analysis reveals that this level of trust and understanding originates in the farmer support network that was built following the end of the state subsidies to agriculture (leading to a period of hardship for the farming industry in the 1990s) coupled with regular (annual) meetings between this network and the authorities. The network is based on 5 key people and a minimum of 20 volunteers and is set in such a manner that it can be activated quickly and does not require initial assistance from the authorities. (Rural Support Trust, Federated Farmers, meeting held in March 2008)

From the perspective of recovery, such relationships are also important as this means that a dialogue is established throughout the crisis and this will facilitate the transfer of information at recovery phase too. In addition, successfully managed crises generally minimise the amount of work necessary at recovery level.

The experience of Ashburton district in the winter of 2006 is now used as a model for the organisation of hazard management in New Zealand. It also shows the importance of a support network both to convey information between authorities and local farmers and to ensure coordinated and efficient action to protect the livestock. This positive experience reinforced the resilience of farmers in the area in that they now know that they can count on each other in times of crisis and take co-ordinated actions to minimise the impact of natural hazards on their lives.

Discussions with the Civil Defence and other hazard management authorities reveal that recovery is currently the weak link and very few regional councils and/or districts have to date managed to integrate the recovery process into the overall hazard management process in New Zealand. It is however their objective in the near future as well as ensuring that a feedback loop is established linking all the steps of hazard management from Reduction to Recovery and feeding back to Reduction any information that could improve the process in the future. It is important that any lessons learnt during a crisis or its recovery phase are integrated in the management of future crises.

New Zealand is the only country the author visited during the study where the Civil Defence and the Ministry of Agriculture have such a close relationship in respect of hazards management. Agricultural management and the protection of human lives where natural hazards strike are recognised to be different processes that are managed by different authorities i.e. the former is the responsibility of the Ministry of Agriculture and the latter that of the Civil Defence. However, both acknowledge that, in areas where agriculture is an important source of income, farmers will not follow instructions from the Civil Defence unless they know that their livestock is safe.

The importance of availability of information was also discussed during the meeting the author attended (with attendees from Ministry of Agriculture, MCDEM, Earthquake Commission, GNS and researchers from University of Canterbury and Massey University). It was agreed that the possibility of extending the planned creation of ash protocol for health purposes (i.e. document issued by scientists to health authorities during an eruption that gives the ash composition for evaluation of the human health hazard it might cause) to the agricultural sector should be investigated.

4.4. Field visit 4: Costa Rica

4.4.1. Costa Rica: Details of the field visit and geological settings

Dates of the visit: 4 to 12 October 2008
Locations visited: Volcanoes Póas, Arenal, Irazu and Turrialba

Geological setting:

At the time of the visit, volcán de Arenal was erupting. Turrialba, Póas and Irazu, although all in quiescent periods, were showing fumarolic activity. Turrialba is the only one of these fours volcanoes to be considered in this study.

Turrialba is situated in the Central part of Costa Rica, approximately 50 km South-East of the capital, San José. Even though it has not erupted since 1866, Turrialba has been undergoing a period of intense fumarolic (sometimes seismic) activity since 2001 (OVSICORI-UNA (Observatorio Vulcanológico y Sismológico de Costa Rica, Universidad Nacional) 2008).

Figure 4.22 (next page) shows the location of volcán de Turrialba in relation with San José (the capital city of Costa Rica) and the main other populated centres in the vicinity of the volcano, including Turrialba town, the nearest town.

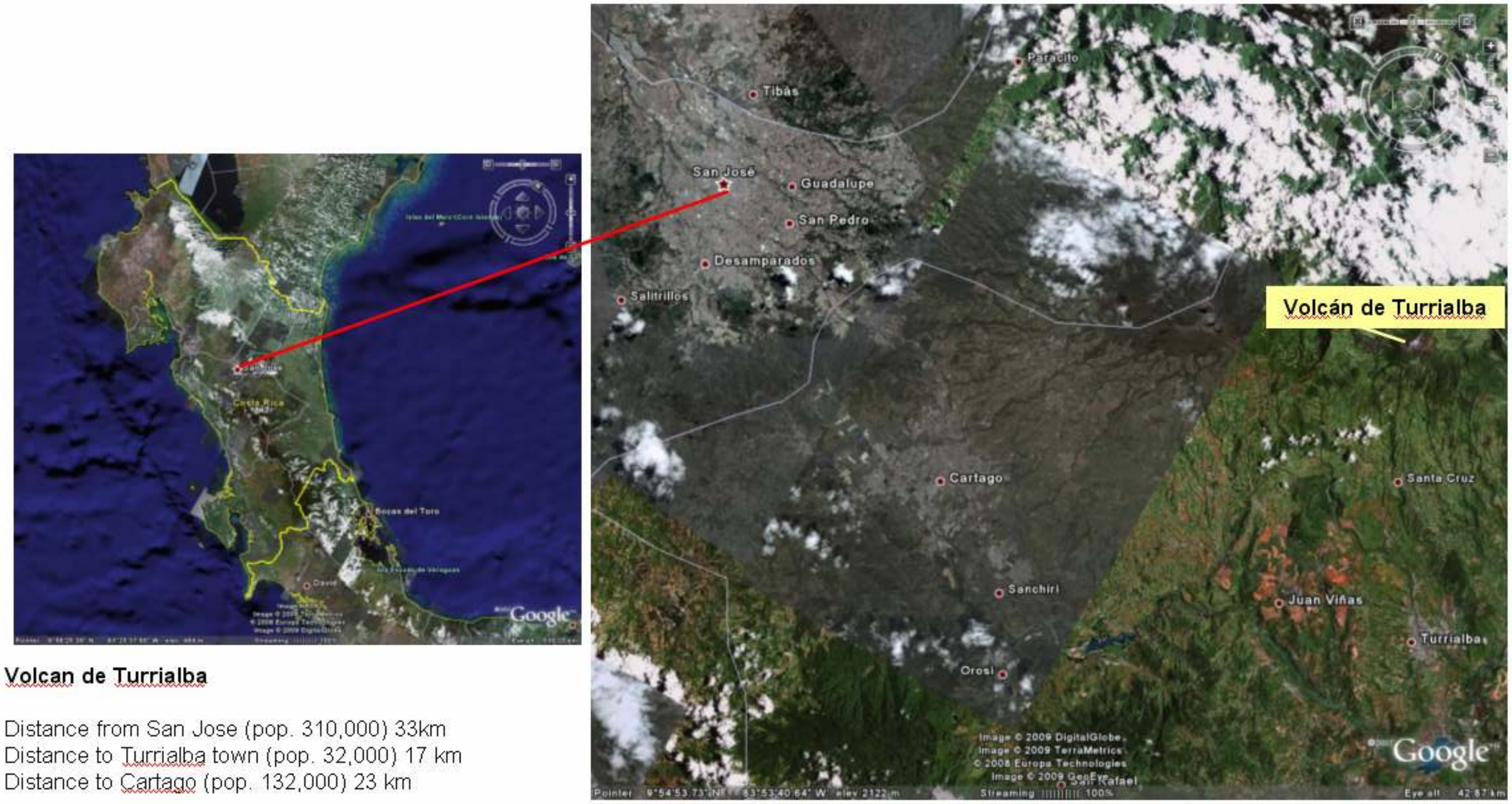
The area East and South-East of San José is used mainly for agricultural exploitation. However, this area shows a very large span of altitudes and climates. Turrialba town is situated at 646 m a.s.l. (above sea level) and has a hot climate, whilst the summit of the volcano is at 3340 m a.s.l. (Smithsonian 2008) and enjoys a temperate climate. As a result, tropical crops such as sugar cane and coffee are predominant on the lower part of the mountain range and land above 2000-2500 m a.s.l. is essentially occupied by temperate crops such as potatoes and grazing fields for dairy production (both sheep and cattle).

In Costa Rica (population approx. 4.2 million people), 62% of economy is service-related (occupying 64% of population), and 8.6% linked to agriculture (occupying 14% of population) (CIA 2008d).

Main contacts and interviewees during the visit:
Park rangers at Turrialba National Park, employed by MINAE (Ministerio de Ambiente y Energia)
Local dairy farmers
Local residents

Note: Despite several contact attempts with respect to the situation in and around Turrialba, no response was received from scientists of OVSICORI-UNA, organisation in charge of volcanic monitoring in Costa Rica

Figure 4.22: (next page) Volcán de Turrialba, Costa Rica. Location map and main urban centres. (Source: Instituto Nacional de Estadísticas y Censos and Google Earth)



Above picture represents an area 50km wide

Volcan de Turrialba

Distance from San Jose (pop. 310,000) 33km
Distance to Turrialba town (pop. 32,000) 17 km
Distance to Cartago (pop. 132,000) 23 km

Note: population figures include only population of the cities. The province of San Jose counts 1,345,000 inhabitants, the province of Cartago 432,000 people and the canton of Turrialba (part of Cartago province) 68,000 people.

Population figures from Instituto Nacional de Estadisticas y Censos (INEC) Costa Rica - Aerial pictures from Google Earth

4.4.2. COSTA RICA: VOLCANIC ACTIVITY AT VOLCÁN DE TURRIALBA AND IMPACTS ON AGRICULTURE

The visit for this study was triggered by Costa Rican scientists reported an impeding risk to populations and agriculture on the slope of Turrialba volcano at an international conference during the summer of 2008 (Duarte et al., 2008). The aim of this short visit was to obtain first-hand view of the damage degassing can cause to vegetation and collect the views of the residents (farmers and others) on the event.

This author could not find any peer-reviewed articles in respect of this degassing episode of the volcano.

In recent years, Turrialba has been degassing continuously, showing phases of stronger degassing during 2001-2005 and then again from August 2007 until 2008 (Smithsonian 2008).

a:

Figure 4.23: Volcán de Turrialba, Costa Rica. 2008.

a: The summital area of Turrialba. The picture shows both the vegetation kill area at the summit of the volcano and the agricultural activity below.

b: (next page) Close view of the crater and the degassing area.

c: (next page) The Western flank of the volcano. The picture shows how the various areas have been affected by the volcanic gases. Vegetation nearest to the summit has died as a result of the exposure to the gases. Going down the slope, dead vegetation gets less frequent and trees present green foliage. The foreground shows a recently harvested potato field; according to local farmers, the crop was not affected negatively by the high level of degassing.

All pictures were taken in October 2008.

b:

c:

Discussions between the author and local farmers indicate that there is no perceived threat from the volcano at this stage. In fact, they report an increase in yield of their crops and a better quality of grass for the grazing of dairy cattle and sheep. As a result, the increased degassing of Turrialba is perceived as a positive event instead of the threat described by scientists.

At the time of the visit, the area of visible vegetation kill was limited to the summital area and did affect neither crops nor pastures (Figs 4.23 and 4.24).

Interviews of farmers on site revealed that the reports of potential hazards and damage from a volcanic event in the region published in the press tend to anger residents as it has the effect of frightening tourists away. Tourism is the second biggest source of income in the area after farming and reports of high hazardous levels in the area in the press could lead to a dwindling of the trade in the region.

During discussions with the park rangers (employed by MINAE, the Costa Rican Ministry of Environment and Energy), the volcano was referred to as a very high threat to the environment. However, no explanations of why this would be the case were provided and the view of farmers that no damage to crops and pastures had been observed was dismissed as irrelevant.

This present study found no reports of research on the long term effects of the permanent fumigation by volcanic gases of the areas used for agricultural purposes. Similarly, it does not appear that any assessment of the potential contamination of soil, crops and dairy products through the exposure to high levels of sulphur, chlorine or fluorine has been carried out. Only SO_2 fluxes are reported at this stage on the OVSICORI-UNA website.

Overall there seem to be very limited communication between local residents and scientists/authorities regarding the degassing event and it is uncertain how efficient communication between these parties would be during a crisis, considering the antagonism with which official views are perceived by residents at this stage.

As the visit was short, it is not possible to comment on the presence of a support network that might help local communities facing an increased level of hazards with more resilience. However, the communication breakdown described above that even if information is available during a crisis, its transfer to the relevant users might be hampered by the absence of trust between the parties involved.

a:

b:

Figure 4.24: Turrialba, Costa Rica, 2008.

a: Chemical damage to vegetation on the slopes of Mt. Turrialba. The plant is located at approximately 200m from the degassing crater.

b: Summital area of Mt. Turrialba. The picture shows that the vegetation even on the outside flank of the crater has died for distances up to dozens of metres from the summit.

Pictures taken in October 2008.

4.5. Documentary review: main lessons

This section gives a brief summary of information gathered in respect of agricultural areas affected by volcanic activity which were not visited during the study. The facts and analysis below are therefore based on documentary reviews only.

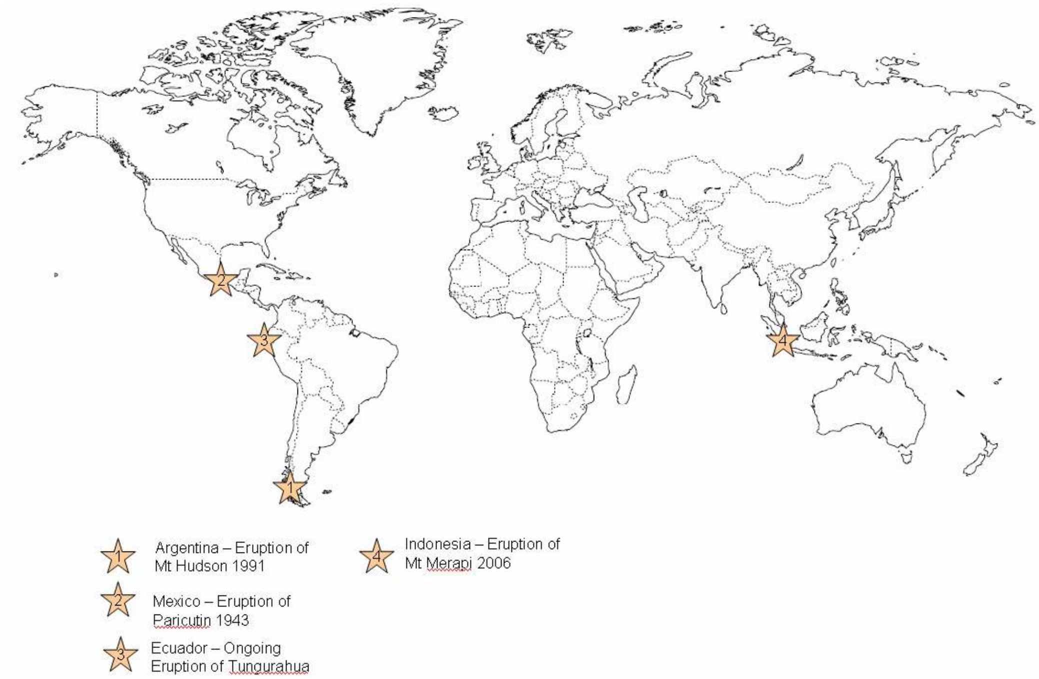


Figure 4.25: Map showing the location of the events studied through documentary review

A review of documents discussing the aftermath of eruptions in various parts of the world reveal a number of interesting facts to support this study.

4.5.1. TUNGURAHUA (ECUADOR) ERUPTION ONGOING AND MERAPI (INDONESIA) 2006 ERUPTION

In the early stage of the current eruption of Tungurahua (Ecuador), which started in 1999 (Smithsonian 2008), it was reported that farming communities had to face not only the fact that their crops were destroyed by ashfalls but also that the chemistry of the soils was affected by the ash composition. Farmers had to shift their production to more ash resistant crops such as potatoes and onions. This did however have disastrous consequences as the large influx of such products on the market led to a drop in prices and hence very low revenues for farmers. (Linda Rutherford, University of Florida, pers. comm., 2006)

Similar shifts in crop types were observed after the eruption of Merapi (Indonesia) in 2006 (Wilson et al. 2007) but the effects were less dramatic as the volcanic crisis has been of a much shorter duration (just over one year). In neither cases was assistance provided in order to determine whether other more profitable crops would grow in similar conditions.

Figure 4.26: Damage to crops during the 2006 eruption of Merapi, Indonesia, 2006. The left picture shows damage from acid aerosols to chilli-peppers; the rights shows acid damage to tomato plants. (Source: Wilson and Kayes, 2007)

In these two cases, no external assistance was expected by local population beyond that of evacuation facilities and possible emergency food assistance. As a result, they were left with no other option than to work on the basis of the resources and information that was available to them. The main lesson from this case is that population in these areas show a higher level of resilience than where assistance from the authorities is expected, in a way very similar to the situation described below in respect of the recovery from Typhoon Nargis (see section 4.7 below).

4.5.2. PARICUTÍN (MEXICO) 1943 ERUPTION

Rees (1979) carried out extensive reviews of the effects of the Paricutín (Mexico) eruption of 1943-45 on agricultural activities in surrounding areas.

Impacts on maize crops were widespread; this was very important because maize represent a significant contribution to local diet. He reports that experiments carried out in the 1950s show that three years fertilisation of the soil without any cultivation would be necessary to bring it back to productive stage. This was an impractical solution for local farmers that could not stay for three years without income and did not have the resources to fund the purchase of fertiliser.

As a result, Rees (1979) reports that farmers then went on to develop their own soil rehabilitation technique of furrow ploughing by trial and error. The furrows (or trenches) allow the mixing of soil, ash, weed and old crop stubbles to be mixed providing thereby the soil with nitrogenous enrichment and the mixing between different size particles. In the longer term (20 years), productivity of the soils covered by the ash of the Paricutín of 1943-45 increased to become nearly three times as high as before the eruption.

The case of Paricutín shows that when armed with the right information and a better understanding of the impacts of the products that have been deposited on agricultural land, farmers can develop techniques that will enable them to re-establish production or even yield potential additional benefits that these can bring to the land.

4.5.3. MT. HUDSON (CHILE) 1991 ERUPTION

The eruption of Mt. Hudson (Chile) in 1991 had significant impacts on agricultural activities in Argentina (situated downwind from the volcano). The ash plume behaved in a very similar way to the ash plume of the current eruption of Chaitén (Fig. 2.4).

Bitschene (1995) reports that 5 to 6 million sheep died as a result of the eruption. According to Rubin et al. (1994), the deaths are to be attributed to the physical properties of the ash, together with the fact that the livestock was already weak due to having to live on overgrazed pastures.

The limited vegetation together with the strong wind blowing in the area during certain part of the years had for consequence the remobilisation of ash for a number of years after the eruption, leading to the need of instigating new agricultural techniques such as the use of greenhouses (Thomas Wilson, University of Canterbury, pers. comm. March 2008).

Also, a study carried out 17 years after the eruption by a team of scientists from New Zealand shows that the location where people were linked together by a strong community spirit, acting as a support network recovered better than others (Wilson, University of Canterbury, pers. comm. March 2008).

4.6. Lessons learnt from the Hekla experience (Iceland)

This section has for purpose to summarise some of the lessons learnt from the experience of Iceland during and after the eruptions of Hekla. The author was based at the University of Iceland in Reykjavík throughout the study, and as a result had access to number of sources of information on how such crises were handled in the past. However, the very specific nature of Icelandic climate, with long winters, and agriculture mean that only some aspects of the Icelandic experience are relevant in a wider context.

In Iceland, sheep, the main livestock, are left to roam freely through the Highlands (wild, unfenced area) during the summer months; during the fall, they are gathered and 'non-reproduction' stock slaughtered. Minimum numbers of sheep are held at the farms during the winter months. Open field crops only form a small part of agricultural activities as horticultural crops are grown in greenhouses.

Hekla is one of the most active volcanoes in Iceland. It has experienced five eruptions in the last 60 years, the strongest and longest of which was that of 1947-48 (VEI: 4) (Thorarinsson 1979, Frogner et al. 2006). Earlier eruptions have not be been considered for the purpose of this study. Reviews of these eruptions and their impact can be found in Thorarinsson 1965.

Figure 4.27: Hekla and surrounding fields, Iceland, 2008.

Due to the high latitude setting of the volcano, eruptions of Hekla mostly impact on agricultural activities when they arise in the summer time. During other seasons, livestock is maintained indoors. If a snow cover is present, a large part of the ash will be washed away rapidly at snow melt, limiting the potential physical and chemical impacts of the ash on soils and plants. As a result, only the eruptions of 1947-48 (March until April the next year) and of 1970 (May to July) had any noticeable impact on agricultural activities.

Farm abandonment following these eruptions has been fairly low (only two farms were abandoned following the 1947-48 eruption) and has been reported to result from the ageing of the farmers rather than being a direct impacts of the eruptions (Haraldsson, farmer at Hekla, pers. comm. 2008). The damage caused by the eruptions only acted as a catalyst for abandonment to take place at an earlier time than would have occurred naturally.

Figure 4.28: Cleaning of tephra from land in Southern Iceland in 1947. (Photo: V. Sigurgeirsson reproduced in Kjartansson 1967).

The main hazard to livestock brought by these eruptions was that of fluorosis as experienced in 1970 (Óskarsson 1980).

State financial help for damage after eruptions was not available to Icelandic farmers until fairly recently (the current support fund is not agriculture specific, assistance is provided from a fund against calamities available for anyone affected). As a result, recovery from these events in the past has been led from within the local communities. A strong level of support can be found within farming communities, and also from other parts of the society, such as friends and family (Fig. 4.28). Farmers form a fairly close-knit community as they are used to collaborate. Every year they work together during the sheep gathering period, as sheep are herded to the lowlands and then split between owners.

The fairly harsh climate and exposure to other natural hazards such as earthquakes and volcanic eruptions has for consequence that Icelanders, in general, show a relatively high level of resilience.

The fact that communication is generally informal in Iceland seems to have also contributed to assisting farming communities. Local communities affected by the volcanic eruptions were in a position to get information from scientists as and when needed without having to go through any specific communication channel (Haraldsson, farmer, pers. comm. 2008).

4.7. Lessons learnt from non-volcanic events used for supporting evidence

The response of local populations when struck by natural hazards can differ widely. For the purpose of this study, we also reviewed the accounts of recovery from three more short-lived non-volcanic events in order to assess what additional factors could influence recovery time.

1- Magnitude 9.1 earthquake off the West coast of Sumatra on 26 December 2004 and subsequent tsunami:

An earthquake of magnitude 9.1 shook the region off the West coast of Sumatra (Indonesia) on 26 December 2004 triggering a large tsunami affecting fourteen countries of South Asia and East Africa. The tsunami affected around 1.7 million people and 227,898 people were killed or reported missing. (USGS, 2008c)

The event drew the attention of the world and substantial amounts of money were pledged in order to help the populations affected both from governmental (through international aid and international organisations) and from private sources (through NGOs (Non Governmental Organisations)).

The publicity around the potential influx of funds means that, in the months after the catastrophe, local population were expecting government-led and externally-funded action to take place (Freysteinn Sigmundsson, geophysicist, pers. comm. 2009).

Furthermore, the international press report unrest is some of the regions affected (e.g. Andaman) up to two years after the events as local population were rioting in protest against the inadequacy ('wrong type of housing') of the support provided (BBC, 2008a).

These events seem to show apathy of local populations to recover from natural hazards where there is an expectation that solutions and recovery actions will be brought to them and implemented for them. The expectation of external assistance seems to erode the resilience of local populations as they expect others to take action.

2- Magnitude 8.0 earthquake near the coast of Central Peru on 15 August 2007:

A magnitude 8.0 earthquake struck near the coast of Central Peru on 15 August 2007, leading to the death of at least 514 people and injuring over 1000 (USGS, 2008d). The slow response of the Peruvian government led to a sparkling of protests immediately after the crisis, and again one year later (BBC, 2008b).

In this case too, people affected by the event seemed to be unwilling to take any recovery action and waited for government hand-outs, leading to frustration when those happened to come slower than anticipated.

3- Cyclone Nargis passing over Burma in early May 2008:

Category 4 cyclone Nargis hit the coast of Burma in early May 2008 (NASA, 2008), leading to the death of an estimated 130000 people and affecting more than 2.5 million people (BBC, 2008c).

Due to constraints set by the local political regime, international aid has been slow to trickle in and fairly restricted, which means that the Burmese population had to take action instead of relying on external assistance. Yet, the international press relates that within two months, 75% of the survivors had rebuilt a home and, six months after the disaster, all rice fields have been replanted (BBC, 2008c). Even if part of the population is still relying partly on emergency food aid from the World Food Programme, the recovery process is well and truly on its way despite the limited assistance that was provided.

This case shows that, where local populations do not expect assistance from their government, they can prove to be very resilient and take upon themselves to initiate and implement recovery.

Chapter 5:

Analysis

The case-studies described in chapter 4 show a number of ways in which cases of emergencies and recovery from natural hazards have been handled over the last few decades.

This review shows that information known by scientists has contributed or could have contributed to a better management of the crisis and recovery in areas where agriculture is important. Providing relevant information to local population that can assist them in making decisions that minimise the impact of an eruption on their agricultural activities on a timely manner helps empowering them and hence building resistance to stress and resilience.

For agricultural purposes, the nature of the information required will also be very dependent on circumstances. Socio-economic conditions of the local population, type of crops being grown as well as climatic conditions prevalent at the time of and subsequently to an eruption are all influencing factors.

What information can be of use to local populations in the context of agriculture?

The case studies demonstrate the importance of the following type of information:

- Dispersion of ash:

Models predicting the dispersion of ash are of use for the management of a volcanic crisis. They help anticipate required protective actions for cattle and sheep such as transfer to other areas, or keeping them inside, in order to minimise exposure to ash. They can also help defining areas where harvesting should be initiated earlier so as to avoid damage. Anticipated dispersion patterns will also be relevant for recovery as ash depth will determine the remedial action that can be undertaken, the time that would be required for recovery of the area and the type of crops/trees that can be expected to grow in the future etc. In terms of dispersion, both the thickness deposited and the particle size will be of relevance for agricultural activities.

- Composition of the ash and anticipated chemical reactions:

The ash composition and anticipated chemical reactions can prove to be key to predict any changes in soil properties due to leaching of material from the ashes. These have significant implications for the ability of certain types of crops or plants to grow in the areas affected in the future. The potential impacts depend strongly on climatic conditions at the time of and after the eruptions and will influence how elements can be released from the volcanic particle to which they are attached.
The combination of information relating to particle size and composition would be particularly important in cases where toxic elements are found due to the relatively higher content of potentially toxic elements that smaller particles may carry.

- Possible remobilisations of material:

It is important to assess and predict whether the material deposited is likely to the subject of remobilisation in the months or years subsequent to the eruption. Remobilisation can be wet (e.g. Mayon case), taking the form of lahars, or dry, with ash being blown around due to limited consolidation in the soil and strong winds (e.g. Hudson case). A potential remobilisation will impact strongly on the decision whether or not to use the area for agricultural purposes while the risk of ash movement is present and also on the type of use that can be made of the area. Where impacts of remobilisations are expected to be significant, the best solution might be to limit agricultural activities to the seasons where it is unlikely that remobilisation occurs, by focusing on seasonal crops for examples, or to switch temporarily to species that would not be affected.

- Gas composition and dispersion:

Volcanic gases can have certain destructive effects on specific types of vegetation. Knowledge about the composition of a gas plume and its expected pattern of dispersion is therefore quite important for agricultural management purposes. In case of prolonged degassing, this type of information can lead the decision to switch to more resistant crops so as to preserve a certain level of productivity to the area.

The creation of pre-agreed protocols for agricultural purposes would appear to be a potential way of transferring the information collected by scientists to the relevant authorities. The existence of a pre-agreed format would ensure that information is understandable to all parties and comprehensive for the needs of the user. Protocols could also be defined based on the socio-economic context of the area as understanding of the requirements of the end-users is key to the success of such document. Such protocols already exist to issue warnings to airlines regarding the dissemination of ash on flight paths; these are called ASHTAMs and are issued by VAACs (Volcanic Ash Advisory Centres) (more detailed information on ASHTAMS is available from: http://www.smn.gov.ar/?mod=vaac&id=22)

A project was initiated in New Zealand that would involving volcanologists issuing information to authorities about the properties and dispersion of ash during a crisis in order to manage the potential impacts of a volcanic crisis on human health. Although an initial protocol defining the information required by the health authorities was drafted at the time, it has not yet been formally agreed between the parties involved. The idea of developing a similar scheme for information for agricultural purposes was discussed during the visit in New Zealand.

How can information be disseminated efficiently?

The process of information dissemination is critical if one wants it to be received on a timely basis and relied upon by users.

A number of factors seem to have contributed to success in the case studies described in chapter 4.

- Support network:

The existence of a support network, prior to the crisis is important. Such network can be of different type but require a good knowledge of the needs of specific to the area and of the people living in it. This will ensure that they are in a position to assess whether the information that is been passed on to them is relevant and sufficient to handle the crisis and recovery.

The pre-existence of a network, like in the examples of Pinatubo (Philippines) Ashburton (New Zealand), will ensure good knowledge of the people in need of assistance, and also a relationship of trust will already have been established prior to a crisis meaning that the information provided will be more easily accepted.

- Involvement of recovery in response:

It is important that the people managing the recovery phase be involved early on in the crisis either actively or passively. This will enable them to anticipate actions that might be required at the recovery stage already during the crisis and wherever possible start preparing for these. Also an in-depth knowledge of the emergency phase will give them a better idea of where issues might arise during recovery.

In order to improve recovery processes, it is also critical to integrate all phases of hazard management into one single process, in a way similar to that designed by MDEM (Ministry of Defence and Emergency Management) in New Zealand, as the work to be carried out a recovery level is partly dependent on how the crisis phase has been handled. Further research needs to be carried out in order to develop an integrated approach to volcano hazard management, from monitoring to recovery.

- Feedback loop:

Once stability has once again been established after an event, it is important that the lessons learnt from the crisis be taken into account in the handling of future events. It is not only important from the perspective of efficient management of crisis but also to ensure that trust existing within the network is maintained since the repetition of mistakes can become the source of distensions.

How would this help the recovery process?

It is expected that the ideas above can contribute to successful recovery through leveraging resilience of local population to a maximum. A number of examples of recovery management show that people affected by natural hazards tend to more and more expect that their government will be arranging 'Japanese-like' solutions where everything, or nearly everything, is implemented for them. This is not imaginable for most countries due to lack of resources, but furthermore the socio-cultural context would probably lead to the failure of such strategies. An example of this occurred at Mt. Pinatubo where this was attempted through the building of resettlement towns that were progressively abandoned. There are very few cultures within which everyone would accept to have decisions regarding their future made for them. In some cases, centrally-led action is also the result of promises made by politicians in order to gain more public support and not necessarily part of an overall plan for recovery.

This limited reactivity has been observed recently both after the tsunami in Asia in 2004 and after the earthquake in Peru in 2007. When governmental response did not meet the expectations of the local populations, massive protests took place instead of the population taking their fate into their own hands. As a result, parts of the affected populations have still not yet 'bounced back' two years (or even four years in the case of the Andaman Islands) after the event.

On the other hand, recovery from typhoon Nargis in Burma in May 2008 appear to have been rather prompt (around six months) even though means and resources were limited. These limitations, essentially a consequence of governmental restrictions, meant that the population took their fate in their own hands, with the complement of assistance (such as emergency food) whenever available. The population drove the process and as a result are in control of their own lives instead of expecting someone else to make decisions for them.

Therefore, a switch in approach, delegating the initiative to the local population with support of the authorities, is required so as to maximise the use of people's resilience capacity. It appears preferable that government intervention is that of supporting a movement led by the people directly affected instead of instigating the movement. This can only be achieved if the majority of people feels that they have the means in their hands to surmount the crisis. In such a process, the availability of relevant and timely information is extremely important.

Quite a number of decisions taken at the preparation and mitigation phases of a volcanic crisis can have a significant impact on recovery. Involving local population throughout the process would help ensure required information is collected and delivered on a timely basis and as a result the impact of the hazard on local populations would be minimised. Such mechanisms could be operated through the creation of a support network mentioned above.

Chapter 6:

Conclusions and perspectives

This study shows that efficient recovery can be improved if a number of measures are taken that will open the path to empower local populations to initiate rehabilitation work, in which availability and diffusion of geological information hold a very important role.

Three mains factors seem to be required for the process to be efficient:

1- Resilience: In recent years, the work of hazard preparedness and mitigation teams has in many cases focused on the building of resilience of local populations in order to soften the impact of catastrophes on humans. The necessity for such preparative work is in itself surprising as humans could be expected to be resilient by nature. However, modern society appears to have to some extent eroded this capability to respond to adversity.

The expectation that governments will take things in hand leads local populations to wait for centralised and state-funded action.

In the case of a volcanic eruption, this becomes even more critical because the crisis might not be short-lived. Tsunamis, earthquakes and typhoons strike at one point in time and recovery will start shortly thereafter. Volcanic eruptions can last for days, weeks, months or even years and their evolution is relatively unpredictable in the medium to long term. So, adaptability of those impacted is extremely important. It appears critical for success that people are empowered and enabled to make their own decisions instead of waiting for the government or local authorities to drive the process. Empowerment also requires people to be in possession of the clear and relevant information to make informed decisions.

2- **Information:** Due to the wide variety of impacts that can be caused by volcanic products on agricultural activities, it is particularly important that farmers be supplied with timely and relevant information that will enable them to decide on actions to be taken.

In areas focusing on traditional methods of production, it is important to ensure that the information provided to farmers includes wherever possible an assessment of whether the chemical changes in the soil will require an adaptation of type of crops or any remedial work before they will be in a position to resume normal productive activities. These traditional methods of production are more flexible and as a result more adaptable to change. The lack of technical expertise and high dependence on their subsistence crops could however mean that technical support would be required as well as potentially food support until there can be a return to normal production levels.

Where production is achieved through modern methods, people will have a higher access to technical support networks and possibly also more extensive knowledge due to higher levels of education. However, in those cases, availability of infrastructure tends to be critical, and, as a result, it is important to know when it will be available in order to make suitable decision in respect of production and access to markets, etc.

In both cases, the access to information is critical and can only be achieved if suitable channels of communication have been put in place.

3- **Support network:** Efficient transmission of information requires the presence of suitable communication network. This would need to be established before an event in order to ensure that local populations are supplied with relevant information. Also it is important that people affected by the crisis trust the person delivering the message. Relationships should ideally be established before the onset of the crisis. In addition, specificities of circumstances, types of crops and type of individuals requiring the information will determine the information required for efficient recovery. The role of the network is not only to ensure that effective communication is taking place but also that whatever is communicated is relevant and in an appropriate format for the audience. It is important that what is transmitted to the populations affected is information and not data. This, in general, will only be achieved where the network pre-exists the crisis as this will give its members the opportunity to understand the needs of the users as well as to establish the necessary relationship of trust with them.

This research demonstrates that the presence of the three elements above will contribute towards efficient recovery. These elements are inter-dependent and, to achieve efficiency, all three are required. Improved resilience levels are hard to achieve in absence of the required information or of some form of support.

However, an important fact this study has highlighted is that even though a significant number of individual studies have been carried out post-eruption, this study found no evidence of any centralised information point relating to previous cases of damage caused by volcanic eruptions that scientists can draw from. This means that, when faced with a crisis, it will often be easier and less time-consuming to start from scratch than look for assistance in the existing literature. A library or references database based on more systematic gathering and referencing of case studies could become a critical resource for emergency and recovery managers in the future.

Simultaneously, it is important that additional studies be carried out to widen the information available in order to optimise recovery processes. Even though quite a number of studies have been published to date on recovery of natural vegetation from volcanic eruptions, those focusing on impacts on agricultural activities are not as numerous and their scope is generally relatively limited. If adequate and prompt support is to be provided to rural communities, further research needs to be carried out in order to get a better understanding of mechanical and chemical processes taking place that will affect crops and livestock in order to determine actions required.

References

Araya (2003) "Fluorosis en Ganado como consecuencia de erupción volcánica" (In Spanish) [Online] http://comunidad.veterinaria.org/articulos/articulo.cfm?articulo=34029&pag=1&area=1&buscar=&donde=1 [Last accessed 16 December 2008]

Araya O., Wittwer F. and Villa A. (1993) "Evolution of fluoride concentrations in cattle and grass following a volcanic eruption", Vet. Hum Taxicol. Vol. 35, Issue 5, pp. 437-440.

Barnard Sc., Cole J. and Johnston D. (2007) "Potential impacts of volcanic ash on waterwater systems and telecommunications infrastructure in New Zealand", Cities on Volcanoes 5 conference Shimabara, Japan, November 19-23, 2007, Abstract Volume, Oral Presentation.

Bazon Bautista C. (1996) "The Mount Pinatubo disaster and the people of Central Luzon", In: Newhall C. and Punongbayan R. Fire and Mud. Eruptions and lahars of Mount Pinatubo, Philippines, University of Washington Press, Seattle, pp. 151-161.

BBC (2008a), "Andaman tsunami victims protest" http://news.bbc.co.uk/2/hi/south_asia/6157728.stm [last accessed 11 December 2008]

BBC (2008b), "Thousands join Peru quake protest" http://news.bbc.co.uk/2/hi/americas/7564703.stm [last accessed 07 December 2008]

BCC (2008c), "Hope dawns in post-Nargis Burma" http://news.bbc.co.uk/2/hi/asia-pacific/7699615.stm [last accessed 04 December 2008]

Bebbington M., Cronin Sh., Chapman I. and Turner M. (2008) "Quantifying volcanic ash hazard to electricity infrastructure", J. Volcanol. Geotherm. Res, Article in press.

Besoain, Ruiz and Hepp (1995) "The Hudson eruption and its effects on agriculture in the XI region" [in Spanish], Agricultura Técnica (Chile), Vol. 55, Issue 1-2, pp. 204-219.

Bitschene P. (1995) "Environmental impact and hazard assessment of the August 1991 eruption of Mt. Hudson (Patagonian Andes)", In: Bitschene P. and Mendia J. (Eds) The August 1991 eruption of the Hudson volcano (Patagonian Andes): a thousand days after, Comodoro Rivadavia, Argentina, pp. 2-15.

Bitschene P., Fernandez M., Arias N., Arizmendi A., Grizinik M. and Nillni A. (1994) "Volcanology and environmental impact of the August 1991 eruption of the Hudson volcano (Patagonian Andes, Chile)", Zentralbaltt für Geologie und Palaeontologie, Teil 1/2: 165-177

Blong (1982) "The time of darkness: local legend and volcanic reality in Papua New Guinea", University of Washington Press, 1982.

Brady N. and Weil R. (2004) "Elements of the nature and properties of soils", Pearson Education, New Jersey, 606p.

CIA (2008a) "The world factbook – Philippines" [Online] https://www.cia.gov/library/publications/the-world-factbook/geos/rp.html [Last accessed 3 January 2009]

CIA (2008b) “The world factbook – Japan” [Online] https://www.cia.gov/library/publications/the-world-factbook/geos/ ja.html [last accessed 4 January 2009]

CIA (2008c) “The world factbook – New Zealand” [Online] https://www.cia.gov/library/publications/the-world-factbook/geos/nz.html [last accessed 10 December 2008]

CIA (2008d) “The world factbook – Costa Rica” [Online] https://www.cia.gov/library/publications/the-world-factbook/geos/cs.html [last accessed 5 January 2009]

Cook R., Barron J., Papendick R., Williams G. III (1981) “Impact on agriculture of the Mount St. Helens eruptions”, Science, Vol. 211, 2 January 1981.

Corpuz E (2005) “Volcanic disaster risk mitigation in the Philippines”, Presentation made at Expert Group Meeting (EGM) on Technical Options for Disaster Management Systems: Tsunami and Others, 22-24 June 2005, Bangkok, Thailand.

Cronin Sh., Hedley M., Neall V. and Smith R. (1998) “Agronomic impact of tephra fallout from the 1995 and 1996 Ruapehu Volcano eruptions, New Zealand”, Environ. Geol. Vol. 34, Issue 1, pp. 21-30.

Cronin Sh., Manoharan V., Hedley M. and Laganthan P. (2000) “Fluoride: a review of its fate, bioavailability and risks of fluorosis in grazed-pasture system in New Zealand”, New Zealand J. Agric. Res., Vol. 43, pp. 295-321.

Dale V. Delgado-Acevedo J. and MacMahon J. (2005) “Effects of modern volcanic eruptions on vegetation”, In: Marti J. and Ernst G. (Eds) Volcanoes and the environment, Cambridge University Press, Cambridge, pp. 225-249.

Delmelle P., Gerin P. and Oskarson N. (2000) “Surface and bulk studies of leached and unleached volcanic ashes”, EOS, Trans. Am. Geophys. Union, Vol. 81, F1311.

Delmelle P. and Stix J (2000) “Volcanic gases”, In: Sigurdsson, Houghton, McNutt, Rymer and Stix (Eds.) Encyclopia of volcanoes. Academic Press, San Diego, pp. 803-815.

Delmelle P., Stix J., Baxter P. And Garcia-Alvarez J. (2002) “Atmospheric dispersion, environmental effects and potential health hazard associated with the low-altitude gas plume of Masaya volcano, Nicaragua”, Bull. Volcanol., Vol. 64, pp. 423-434.

Delmelle P., Lambert M., Dufrene Y. Gerin P. And Oskarsson N. (2007) “Gas/aerosols-ash interaction in volcanic plumes: new insights from surface analyses of fine ash particles”, Earth Planet. Sci. Lett., Vol. 259, pp. 259-170.

Department of Internal Affairs (2008) “National Civil Defence emergency management strategy” Wellington, New Zealand, p 20. (Available from: http://www.civildefence.govt.nz/memwebsite.NSF/Files/National_CDEM_Strategy/$file/National-CDEM-strategy-2008.pdf)

Duarte E., Fernandez E., Martinez M. and Saenz W. (2008) “Severe Environmental Impact due to Enhanced Magmatic Degassing: Turrialba Volcano, Costa Rica.”, IAVCEI General Assembly 2008, Oral presentation.

Fano J. (2007) "Optimised counter-measures for debris flow and landslide mitigation in Mayon Volcano, Philippines", Cities on Volcanoes 5 conference Shimabara, Japan, November 19-23, 2007, Abstract Volume, Oral Presentation

FAO (2001) "Lecture notes on the major soils of the world" Eds Driessen, Deckers and Spaargaren, [Online] http://www.fao.org/docrep/003/y1899e/y1899e00.HTM [Last accessed 28 November 2006]

FAO (2004) "FAO Statistics Yearbook – Country profiles: Philippines", [Online], Available from: http://www.fao.org/es/ess/yearbook/vol_1_2/index.asp [Accessed: 4 February 2008]

Flaathen Th. and Gislason S. (2007) "The effect of volcanic eruptions on the chemistry of surface waters: The 1991 amd 2000 eruptions of Mt. Hekla, Iceland", J. Volcanol. Geotherm. Res., Vol. 164, pp. 293-316.

Frogner P., Kockuma, Herbert R. and Gislason S. (2006) "A diverse ecosystem response to volcanic aerosols" Chemical Geology Vol. 231, p57-66.

Garcia S., Vega R., Aguillar E., Dayo H., Wagan A-M and Montesur J. (1993) "Rebuilding lives through the save-farm approach: the case of barangay Moraza", In: Central Luzon State University, Central Luzon Agriculture Resources Research and Development Consortium, Proceedings of symposium on agricultural research information for Mt. Pinatubo affected areas (June 16, 1993), pp. 148-158.

Gerlach T., Doukas M., McGee K. and Kessler R. (2001) "Soil efflux and total emission rates of magmatic CO_2 at the Horseshoe Lake tree kill, Mammoth Mountain, California 1995-1999", Chem. Geol., Vol. 177, pp.101-116.

Georgsson G. and Pétursson G. (1972) "Fluorosis of sheep caused by the Hekla eruption in 1970", Paper presented at the Fourth Annual Conference of I.S.F.E., The Hague, 10/24-27/1971.

Gisladóttir G., Erlendsson E. and Lal R. (2008) "Terrestrial vulnerability to volcanic hazards in Reykjanes, southwest Iceland.", European Geosciences Union General Assembly, Geophysical Research Abstracts, Vol. 10, EGU2008-A-08381, 2008, Oral presentation

GNS 2008, "New Zealands volcanoes: Mt Egmont" http://gns.cri.nz/what/earthact/volcanoes/nzvolcanoes/egmontprint.htm [last accessed 10 December 2008]

Grattan J., Durand M. and Taylor S. (2003) "Illness and elevated human mortality in Europe coincident with the Laki fissure eruption" In: Oppenheimer C., Pyle D.M and Barclay J. (Eds) Volcanic degassing. Geological Society, London, Special publications 213, pp. 401-414.

Haraldsson Sverrir, farmer, Selsund (Hekla), Hella, Iceland, conversation held in August 2008.

Hata K. Director, Unzen Restoration Project office, Kyushu Regional Development Bureau, Ministry of Land, Infrastructure and Transport, conversation held on 23 November 2007

Inbar, Ostera, Parica, Remesal and Salani (1995) "Environmental assessment of 1991 Hudson volcano eruption ashfall effects on southern Patagonia, Argentina", Environ. Geol., Vol. 25, pp. 119-125.

Instituto Nacional de Estadísticas y Censos (INEC) Costa Rica Website. [Online] Available from : http://www.inec.go.cr/ [Last accessed : 31 December 2008]

IVHHN (2008) "Gas and aerosols guidelines" [online] http://www.ivhhn.org/ [Last accessed 16 December 2008].

Jones M. and Gíslason S. (2008) "Rapid releases of metal salts and nutrients following the deposition of volcanic ash into aqueous environments", Geochim. Cosmochim. Acta, Vol. 72, pp. 3661-3680.

Kjartansson G (1967) "Some secondary effects of the Hekla eruption. Exhalation of carbon dioxide, contamination of ground-water and lowering of water-table" In: Vísindafélag Íslendinga, The eruption of Hekla 1947-1948 III, Reykjavík, H.F. Leifur, pp. 1-42.

Larsen G and Eiríksson J. (2008) "Holocene tephra archives and tephrachronology in Iceland – a brief overview", Jökull, Vol 58, pp.229-250.

Le Guern F., Bernard A.and Chevrier R. M. (1980) "Soufrière of guadeloupe 1976–1977 eruption — mass and energy transfer and volcanic health hazards", Bull. Volc., Vol. 43, Issue 3, pp. 577-593.

Lebon S. (2006) "Potential hazards caused by carbon dioxide degassing and possible means of preventing and mitigating hazards to human health", Dissertation for the degree of Bachelor of Sciences (Honours) in Geosciences, Open University, Milton Keynes.

Maeda T., Takenaka H. and Warkentin B. (1977) "Physical properties of allophane soils", Adv. Agron., Vol. 29, pp. 229-264.

Masujima H. and Mori T. (1962) Res. Bull Hokkaido Natl Agric Exp Stn 79 1-35, Quoted in Maeda T., Takenaka H. and Warkentin B. (1977) "Physical properties of allophane soils", Adv. Agron., Vol. 29, p253.

Mercado R., Bertram J., Lacsamana T. and Pineda G. (1996) " Socioeconomic impacts of the Mount Pinatubo eruption", In: Newhall C. and Punongbayan R. Fire and Mud. Eruptions and lahars of Mount Pinatubo, Philippines, University of Washington Press, Seattle, pp. 1063-1070.

Miller T. and Casadevall T. (2000) "Volcanic ash hazards to aviation" In: Sigurdsson, Houghton, McNutt, Rymer and Stix (Eds.) Encyclopia of volcanoes. Academic Press, San Diego, pp. 915-930.

Mirabueno Maria Hannah, Researcher, Philvolcs, Philippines and University of Kagoshima, Japan, conversations held in June 2007 and in November 2007.

Nagasaki Prefectoral Government (2007a) "Restoration of farmland", briefing document for open poster presentation, traduction by Laura Hart, International Relations, Nagasaki Prefectoral Government.

Nagasaki Prefectoral Government (2007b) "Recovery projects after the eruption of Mt. Unzen", COV5 Open Poster Presentation Abstract Volume, Cities on Volcanoes 5.

Nakada S. (2008) "Preface: special issue, scientific drilling at Mount Unzen", J. Volcanol. Geotherm. Res., Vol. 175, pp. v-vi.

Nanzyo M. (2002) "Unique properties of volcanic ash soils", *Global Environ. Res.*, Vol. 6, Issue 2, pp. 99-112.

NASA (2008) “Cyclone Nargis” [Online] http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=19860 [Last accessed 8 December 2008]

National Statistics Office Philippines Website [Online], Available from: http://www.census.gov.ph/ [Last accessed 31 December 2008]

Neall (2008) “Volcanic soils” edited by Verheye, in Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford ,UK, [http://www.eolss.net]

Nelson Gloria Luz, Professor of Sociology, University of the Philippines, Los Baños, Philippines, conversations held in June 2007.

Neumann (1996) “Rabaul – Yu swit moa yet – Surviving the 1994 volcanic eruption”, Oxford University Press, 1996.

Newhall C., Daag A., Delfin F. Jr., Hoblitt R., McGeehin J., Pallister J., Regalado M., Rubin M., Tubianosa B., Tamayo, R. Jr. and Umbal J. (1996) “Eruptive history of Mount Pinatubo”, In: Newhall C. and Punongbayan R. Fire and Mud. Eruptions and lahars of Mount Pinatubo, Philippines, University of Washington Press, Seattle, pp. 165-195.

Oppenheimer C. (2003) “Volcanic degassing”, In: Ed Rudnick R., The Crust, Elsevier-Pergamon, Oxford.

Óskarsson N. (1980) “The interaction between volcanic gases and tephra: Fluorine adhering to tephra of the 1970 Hekla eruption”, J. Volcanol. Geotherm. Res., Vol. 8, Issue 2-4, pp. 251-266

OVSICORI-UNA (2008) “Volcán Turrialba” [Online] Available from: http://www.ovsicori.una.ac.cr/vulcanologia/volcanes/turrialba.htm [Last accessed on 7 January 2009]

Paulsen Desiree, Emergency Management Officer, Taranaki Regional Council, Stratford, New Zealand, conversation held in April 2007.

Ping C-L (2000) “Volcanic soils”, In: Sigurdsson, Houghton, McNutt, Rymer and Stix (Eds.) Encyclopia of volcanoes. Academic Press, San Diego, pp. 1259-1270.

Punongbayan R., Newhall C., Bautista M., Garcia D., Harlow D., Hoblitt R., Sabit J. and Solidum R. (1996) “Eruption hazard assessments and warnings”, In: Newhall C. and Punongbayan R. Fire and Mud. Eruptions and lahars of Mount Pinatubo, Philippines, University of Washington Press, Seattle, pp. 67-85.

Rees J. (1979) “Effects of the eruption of Paricutín Volcano on landforms, vegetation and human occupancy”, In: Payson P.D. and Grayson D.K. (Eds.), Volcanic activity and human ecology. Academic Press, New York NY, pp. 249-292.

Rymer H. and Harris N. (2002) “Forging the land bridge”, Produced by Martin Kemp.BCC (for the Open University) [Video:VHS].

Rubin C., Noji E. Seligman P., Holtz J., Grande J. and Vittani F. (1994) “Evaluating a fluorosis hazard after a volcanic eruption”, Arch. Environ. Health, Vol 49, Issue 5, pp. 395-401.

Rutherford Linda, Sociologist, University of Florida, conversations held in January 2006.

Self S., Zhao J-X., Holaseck R., Torres R. and King A. (1996) "The atmospheric impact of the 1991 Mount Pinatubo eruption", In: Newhall C. and Punongbayan R. Fire and Mud. Eruptions and lahars of Mount Pinatubo, Philippines, University of Washington Press, Seattle, pp. 1089-1115.

Self S., Thordason T. and Widdowson M. (2005) "Gas fluxes from flood basalt eruptions", Elements, Vol. 1, pp. 283-287.

Shimizu H., Matsushima T., Nakada S, Fujii T., Takarada Sh., Miyabuchi Y., Ui T., MiyakeY., Sugimoto T. and Nagai D. (2007) "Intra-meeting excursion – Unzen eruption – Disaster and recovery – Fieldtrip guide", Cities and volcanoes 5 conference, Shimabara 2007.

Shoji S. and Takahashi T. (2002) "Environmental and agricultural significance of volcanic ash soils", *Global Environ. Res.*, Vol. 6, Issue 2, pp. 113-135..

Smithsonian (2008) "Global volcano program – Volcanoes of the world" http://www.volcano.si.edu/world/ [last accessed 09 December 2008]

Sigmundsson F., geophysicist, Nordic Volcanological Centre, University of Iceland, Iceland, conversations in January 2009.

Takahashi T. and Shoji S. (2002) "Distribution and classification of volcanic ash soils", *Global Environ. Res.*, Vol. 6, Issue 2, pp. 83-97.

Thorarisson S. (1944) "Tefrokronologiska studier pa island", Geografiska Annaler, Vol 26, pp. 1-217.

Thorarinsson S. (1949) "The eruption of Hekla 1947-1948" Vísindafélag Íslendinga, 1949-1967

Thorarinsson S. (1979) "On the damage caused by volcanic eruptions with special reference to tephra and gases". In: Payson P.D. and Grayson D.K. (Eds.), Volcanic activity and human ecology. Academic Press, New York NY, pp. 125-159.

Thordarson, T., and S. Self (2003), Atmospheric and environmental effects of the 1783–1784 Laki eruption: A review and reassessment, *J. Geophys. Res.*, 108(D1), 4011, doi:10.1029/2001JD002042.

Thornton (2000) "The ecology of volcanoes: recovery and reassembly of living communities" In: Sigurdsson, Houghton, McNutt, Rymer and Stix (Eds.) Encyclopia of volcanoes. Academic Press, San Diego, pp. 1057-1081.

Tsukui M., Kawanabe Y., Kazahaya K., Yamasato H. and Niihori K. (2007) "Active volcanoes on the Izu Arc: Izu-Oshima and Miyakejima" Fieltrip Guidebook, Cities on volcanoes 5 conference, Shimabara, Japan November 19-23, 2007.

Ugolini and Zasoski (1979) "Soils derived from tephra" In: Payson P.D. and Grayson D.K. (Eds.), Volcanic activity and human ecology. Academic Press, New York NY, pp. 83-124

Ugolini F. and Dahlgren R. (2002) "Soil development in volcanic ash", *Global Environ. Res.*, Vol. 6, Issue 2, pp. 69-81.

Unzen Restoration Project Office (2007) “Unzen, Project outline”.

USGS (2008a) “Fact sheet, Volcanic air pollution – A hazard in Hawai’i, Fact sheet 169-97” [Online] Available from: http://pubs.usgs.gov/fs/fs169-97/ [Last accessed: 4 January 2009].

USGS (2008b) “Major volcanoes of Japan” [Online] Available from: http://vulcan.wr.usgs.gov/Volcanoes/Japan/Maps/map_japan_volcanoes.html [Last accessed: 4 January 2009].

USGS (2008c) “Magnitude 9.1 – Off the west coast of northern Sumatra” [Online] http://earthquake.usgs.gov/eqcenter/eqinthenews/2004/usslav/#summary [Last accessed 8 December 2008]

USGS (2008d) “Magnitue 8.0 – Near the coast of central Peru” [Online] http://earthquake.usgs.gov/eqcenter/eqinthenews/2007/us2007gbcv/#summary [Last accessed 8 December 2008]

Volcano Hazard Website (2008) “Volcanic ash … what it can do and how to prevent damage” [Online] Available from : http://volcanoes.usgs.gov/ash/index.html [Accessed 15 December 2008]

Williams-Jones Gl. And Rymer H. (2000) “Hazards of volcanic gases”, In: Sigurdsson, Houghton, McNutt, Rymer and Stix (Eds.) Encyclopia of volcanoes. Academic Press, San Diego, pp. 997-1004.

Wilson Th. (2006) “Exposure of the dairy industry to volcanic hazards in New Zealand. Objective 1: Overview of study and summary of the likely effects of a volcanic eruption on dairy farms”, Natural Hazard Centre, University of Canterbury, New Zealand.

Wilson Th. and Kayes G. (2007) “Agricultural fragility estimates for volcanic ash fall hazards”, GNS Science Report 2007/37, 51p.

Wilson Th., Kaye G., Stewart C. and Cole J. (2007) “Impacts of the 2006 eruption of Merapi volcano, Indonesia, on agriculture and infrastructure”, GNS Science Report 2007/07, 69p.

Wilson Thomas, Natural Hazard Research Centre, University of Canterbury, Christchurch, New Zealand, conversations held in March 2008.

Wikipedia (2008) “Mt. Taranaki”, [Online] Available from: http://commons.wikimedia.org/wiki/File:Mt_Taranaki.JPG [Last accessed: 5 January 2009]

Wollf J. and Sumner J. (2000) “Lava fountains and their products”, In: Sigurdsson, Houghton, McNutt, Rymer and Stix (Eds.) Encyclopia of volcanoes. Academic Press, San Diego, pp.321-329.

WRI (2008) “World employment statistics” [Online] http://www.wri.org/ [Last accessed 16 December 2008].