Processes of Policy Mobility in the Governance of Volcanic Risk

Graeme Alexander William Sinclair
Lancaster Environment Centre
Lancaster University
Lancaster
LA1 4YQ
UK

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This thesis is submitted for the degree of Doctor of Philosophy.

Statement of Declaration

I hereby declare that the content of this PhD thesis is my own work except where otherwise specified by reference or acknowledgement, and has not been previously submitted for any other degree or qualification.

Graeme A.W. Sinclair

Abstract —National and regional governments are responsible for the development of public policy for volcanic risk reduction (VRR) within their territories. However, practices vary significantly between jurisdictions. A priority of the international volcanological community is the identification and promotion of improved VRR through collaborative knowledge exchange. This project investigates the role of knowledge exchange in the development of VRR. The theories and methods of *policy mobility studies* are used to identify and explore *how, why, where and with what effects* international exchanges of knowledge have shaped this area of public policy. Analyses have been performed through the construction of narrative histories. This project details the development of social apparatus for VRR worldwide, depicted as a *global policy field* on three levels - the global (macro) level; the national (meso) level; and at individual volcanoes (the micro level). The narratives track the transition from a historical absence of VRR policy through the global proliferation of a reactive 'emergency management' approach, to the emergence of an alternative based on long-term planning and community empowerment that has circulated at the macro level, but struggled to translate into practice. This is explored using five case volcanoes: Merapi, Indonesia; Nevado del Ruiz, Colombia; Mount Rainier, USA; Popocatépetl and Volcán de Colima, México. These cases demonstrate that policymakers at active volcanoes do not always deliberately access knowledge curated at the 'core' of the global policy field and use it to rationally develop 'best practice' VRR policies. More frequently, the transient *topologies* that carry knowledge between volcanoes, the *assemblages* of mobile knowledge with evolving local politics, culture and volcanic activity, and resulting *mutations* have produced unique and unpredictable results at each volcano. Mobile policies may encounter local resistance, ideas may go unused for decades and evolution over time does not automatically entail 'progression' towards an ideal. This work carries lessons for those seeking 'improved' VRR through knowledge exchange, including the development of the policy field across time and strata; current understanding of 'best practices' in VRR; challenges encountered when mobilising VRR policy into different volcanic settings; and examples of efforts to overcome those challenges.

Keywords — Volcanic Risk Governance, Policy Mobility Studies, Applied Volcanology, Critical Policy Studies, Disaster Risk Reduction, Volcán de Colima, Gunung Merapi, Nevado del Ruiz, Mount Rainier, Popocatépetl

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Chapter 1
Introduction

On 3rd September, 2018, at the opening plenary session of the International Association of Volcanology and Chemistry of the Earth's Interior's 'Cities on Volcanoes 10' conference, the Operational Director of Emergency Co-ordination for Italy's *Dipartamento della Protezione Civile* (Department for Civil Protection) outlined the operational plan designed to prevent disaster during future eruptions at Mount Vesuvius to the assembled delegates. This was a conference focussed on volcanic risk, attracting participants from around the world. Naples, Italy had been chosen as the setting due to the recognition of high volcanic risk posed to hundreds of thousands of inhabitants by two volcanoes - the large caldera, Campi Flegrei, and the stratovolcano, Vesuvius. Among the features of the plan described were the eruption scenario on which it was based (an explosive eruption of the same scale as a prior eruption in 1631); the parts of the community involved (a 'red zone' comprising 18 municipalities closest the volcano, to be completely evacuated, and a more distant 'yellow zone' and 'blue zone' with no pre-existing provision for evacuation); the four levels of public alert; the anticipated timescale of operation (72 hours, based on logistics rather than scientific prognoses of the timescale of an eruption) and the operational procedures (red zone residents to be brought to 'gathering areas' and sent by train, bus or ship to a region of Italy with which their municipality is 'twinned'). In the audience, I was able to note little to no change from when I had researched volcanic risk governance at Mount Vesuvius for my undergraduate dissertation at the University of Glasgow in 2011.

The subsequent speaker in the same plenary session, one of Italy's most senior volcanologists, Franco Barberi, voiced 'grave concerns' regarding many aspects of the *Protezione Civile* plan outlined by the previous speaker. He criticised the plan's basis in one eruptive scenario, noting that Vesuvius would be capable of a variety of eruptive styles, from a low-magnitude effusion of lava to an explosive eruption an order of magnitude larger than that of 1631. He stated that even once scientists had begun to detect changes in the activity of the volcano, it may be very difficult to identify which of these might ultimately manifest. As such, inflexibly planning for one scenario may be foolhardy. Barberi proceeded to criticise other aspects of the plan (e.g. the alert levels), at one point asking rhetorically whom in *Protezione Civile* would have the 'courage' to challenge these conventions.

I had become familiar with many of these criticisms of the Vesuvius plan through my undergraduate research project. The plan's inflexible basis in one eruption scenario; the use of municipal boundaries rather than the projected range of volcanic hazards to demarcate the evacuation zone; the logistical process of extricating hundreds of thousands from a densely populated urban area within a fixed 72-hour timeframe despite no guarantee that volcanic activity would align with this; and redistributing evacuees throughout Italy based on which local authority they live in - had all been criticised by Italian academics by the time that I was learning about the situation in 2011 (e.g. Dobran, 2006; Carlino et al. 2009).

At the time of the 2018 Cities on Volcanoes conference, I was in the latter stages of this PhD project - examining the complexities of turning knowledge in volcanic risk governance into policy and practice. I had seen much evidence that these processes were seldom clear-cut and straightforward. Despite this, a part of me could not help but be surprised that knowledge of the apparent inadequacies of this plan had reached my 21-year-old self in Glasgow a full seven years prior, and yet had seemingly not made a tangible impact on policy reform at its point of origin. This observation encapsulates a recurring theme throughout this thesis - that knowledge pertaining to 'improving' practices in the governance of volcanic risk can (and does) travel around the modern world virtually instantaneously, for reasons as random as a curious undergraduate student performing an internet search, and yet there is no guarantee that just because this information is available and 'mobile', that it automatically will 'go' where it is most needed and make the transition into practice.

This PhD project can be seen as a 'follow up' to a thesis completed at Lancaster University as part of my MSc Volcanology and Geological Hazards degree in 2013 (Sinclair, 2013). In seeking a research project related to volcanic risk reduction, I made a basic observation that there were some similarities between Volcán Nevado del Ruiz, Colombia and Mount Rainier, USA (i.e. both predominantly posed a risk to surrounding communities through volcanic mudflows generated by the impact of eruptions on summit glaciers). Contemporary disaster risk reduction is predominantly conducted through governance, or the development and implementation of *public policy* (UNISDR, 2015; Howes et al. 2013). Therefore, the project sought to examine and compare the policies for volcanic risk reduction at both volcanoes. Mackay and Shaxton (2007) define policy as "...a distinct path of action which is suitable for the pursuit of desired goals within a particular context, directing the decision making of an organisation or individual" embodied in written regulations and guidelines, enacted procedures and standards. The MSc project evolved through discussions of the potential practical applications of such a comparison, suggesting that exchange of information between the two volcanoes via some sort of 'twinning' initiative could perhaps improve policy at both.

At this stage, one of my MSc project supervisors, Professor Nigel Clark (now a supervisor of this PhD project) introduced me to critical geography studies of 'twin towns' (e.g. Clarke, 2009; 2011) which analysed social exchanges between 'twinned' communities in different countries. As the project unfolded, this provided a gateway to a broader body of social science literature regarding the international exchange of knowledge in policymaking. A key finding of the MSc thesis was that processes of knowledge exchange were a long-present, and arguably understudied feature of the development of volcanic risk governance and that there was a growing academic field with the lexicon to describe and explain how and why these processes had influenced social responses to volcanic risk and may do so in the future - policy mobility studies:

> *The field of policy mobilities studies how, why, where and with what effects policies are mobilized, circulated, learned reformulated and reassembled* (McCann and Ward, 2012).

After completion of my MSc, I undertook a voluntary volcanology work placement at Volcán de Colima, México (January-June 2014). Whilst there, I witnessed that ideas from 'elsewhere' had also played a fundamental role in shaping the governance of volcanic risk at that volcano, and yet the practical reality seemed far from the theoretical ideals of risk governance. The potential for employing the theories and methods of policy mobility studies in order to understand the parallels and differences between Volcán de Colima and the cases I had previously examined became increasingly apparent. Moreover, there appeared to be an opportunity to study mobility in volcanic risk governance as a global phenomenon.

This PhD project brings together the theories and methodologies of policy mobility studies and the branch of applied volcanology dedicated to the governance of volcanic risk in an interdisciplinary study. The aim is to understand how, why, where and with what effects policies and practices designed to reduce risk from volcanic activity are developed and mobilised globally and the extent to which these factors contribute to contemporary understandings of 'best practice' in volcanic risk governance. The investigation is therefore concerned with the movement of information across scales: around the globe (the 'macro' level); through different national polities (the 'meso' level); and into the surroundings of individual volcanoes (the 'micro' level) (Section 3.2.1). Furthermore, it seeks to understand the impacts and interactions of this mobile knowledge with the specific social and volcanic aspects of its destinations.

Firstly, a review of the existing literature (Chapter 2) and the methods employed in this investigation (Chapter 3) are presented. The following objectives reflect the structure of the main body of the thesis:

(1) Trace and map the development of volcanic risk reduction policy through space and time at the global (macro) level (Chapter 4).

(2) Identify case studies within different national (meso) level policy contexts which exemplify diverse policy approaches to volcanic risks then trace and map the development and effect of volcanic risk reduction policies for each (Chapter 5).

(3) Present a field-based, ethnographic narrative policy analysis for volcanic risk reduction policies and practices at Volcán de Colima, with insights at the institutional/interpersonal (micro) level (Chapter 6).

(4) Use cross-case comparisons to postulate processes of mobilising policies which may improve practices in volcanic risk reduction in the context of global disaster risk reduction (Chapter 7).

Finally, Chapter 8 presents the conclusions of this research and the potential for further work stemming from this project.

Chapter 2
An Assemblage of Literatures: Applied Volcanology, Disaster Risk Science and Policy Mobility Studies

This chapter presents a review of literature relevant to contemporary understanding of volcanic risk governance. Volcanic risk is a product of the interaction of natural and social phenomena. This chapter therefore must synthesise prior work in both the natural and social sciences. Firstly, a summary of contemporary understanding of volcanic activity is offered with specific focus on the range of volcanic phenomena and their potential impact on human communities and infrastructure, drawing on volcanological literature (Sections 2.1 and 2.2). Secondly, this chapter discusses the state of volcanic disaster risk governance in theory and practice, using the existing bodies of work in disaster risk science, political science and applied volcanology to highlight developments and policy problems (Section 2.3). Finally, the chapter introduces the literature on policy mobility studies as the new 'lens' through which this study seeks to view volcanic risk governance in the pursuit of fresh perspectives and lessons.

2.1. Volcanic Activity

Volcanism is the process by which magma, a mixture of partially molten rock (with liquid and, potentially, suspended crystals) and volatile components, (in the form of dissolved gases or gas bubbles) is transferred from the Earth's interior onto its surface through ruptures in the crust (volcanic vents). This may occur through volcanic eruptions (Sigurdsson, 1999). Volcanoes are typically located at the boundaries of Earth's tectonic plates, and sometimes in other settings (Francis and Oppenheimer, 2004).

At volcanoes, both during and between eruptions, the emission of gases (e.g. H_2O, CO_2, SO_2, HCl, HF, H_2S, S_2, H_2, CO, SiF_4 and Rn) to the atmosphere occurs. The release of high-temperature (>350ºC), generally acidic gases or the diffusion of low-temperature (<350ºC) gases through soil on the flanks of a volcano may take place (Oppenheimer et al., 1998; Sigurdsson, 1999; Hansell and Oppenheimer, 2004).

During effusive eruptions, magma is extruded from a vent as a coherent fluid (i.e. lava), forming a lava flow. The conditions under which effusive eruptions may occur include when most of the gas content of magma is released prior to its eruption, or in submarine conditions where the pressure exerted by the ocean is too great to permit significant exsolution of gas. Explosive eruptions occur when the rapid exsolution and expansion of gases from the liquid, or rapid quenching and granulation, tears the magma apart; the resulting fragments are called pyroclasts (Sigurdsson, 1999; Parfitt and Wilson, 2008). In general terms, the most important controls on eruption style are the physical properties of the magma, in turn derived from its chemical composition: hot, low-volatile content (mafic) magmas such as basalt (typically associated with divergent plate boundaries) tend to be less viscous and allow gases to separate from the melt more efficiently. Cooler more volatile-rich (silicic) magmas such as andesite, dacite and rhyolite (commonly associated with convergent plate boundaries) generally have a higher viscosity and are more prone to explosivity (Francis and Oppenheimer, 2004).

Volcanic eruptions range from being highly localised, to those with global consequences. Some eruptions deposit volcanic products over much of a continental landmass or perturb global climate through the injection of volcanic gases and fine-grained pyroclasts into the atmosphere (Sigurdsson, 1999). A widely used scale for the quantification of volcanic eruptions is the *Volcanic Explosivity Index*, or *VEI* (Figure 1.1). Although, influential, the VEI has limitations. In particular it has been argued that the classification of small explosive eruptions within the VEI '0' and '1' categories does not reflect the violence with which these events can occur. One example given to support this assertion is a May 2013 VEI 0 eruption at Mayon volcano in the Philippines that killed 5 climbers (Klemetti, 2013).

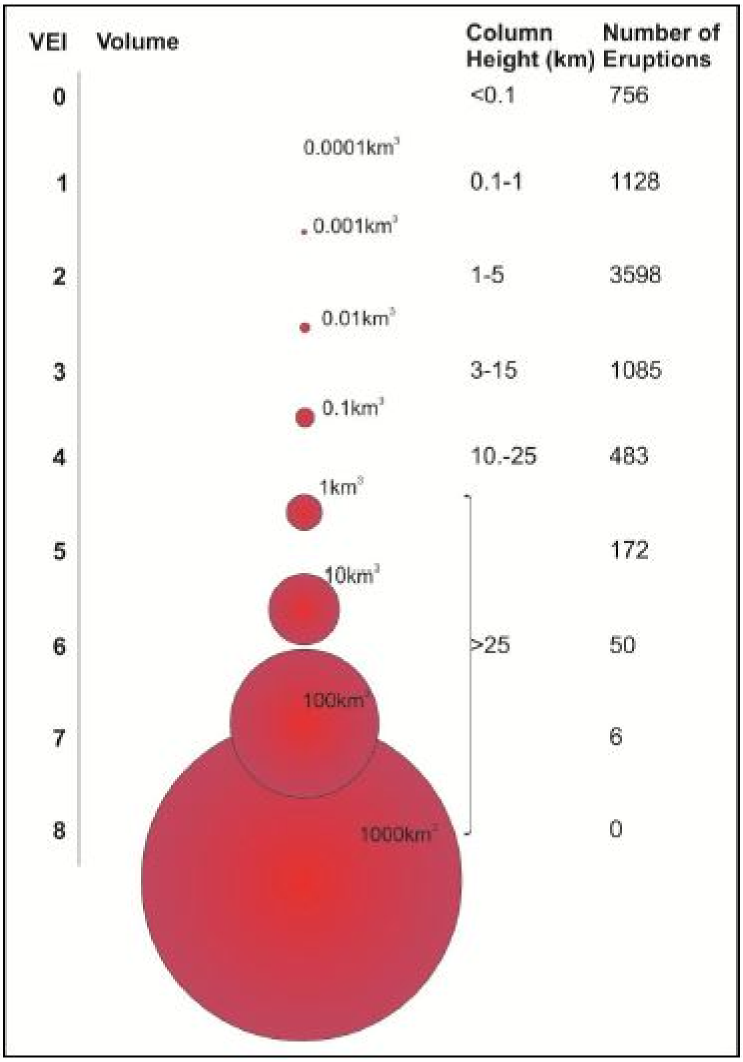


Figure 2.1. Graphic representation of the Volcanic Explosivity Index (GVM, 2014). This is a semi-quantitative logarithmic scale whereby the volume of erupted pyroclastic material, the height of the eruption column, or a combination of the two may be used to assign a 'VEI number' denoting a tenfold increase in magnitude and intensity from the previous VEI number (Newhall and Self,1982; GVM, 2014). Although the figure appears to indicate that the frequency of eruptive activity peaks at VEI 2, the frequency of volcanic activity is actually inversely proportional to both magnitude and intensity. Smaller eruptions are poorly represented because many leave little material to preserve their place in the geological record (Caricchi et al. 2014; Klemetti, 2013).

Volcanic activity has the capacity to impact significantly on the biosphere - as noted in Section 2.2.9, volcanic activity offers many long-term benefits to humans and other living things. However, eruptions frequently prove lethal to exposed organisms (Marti and Ernst, 2005). Volcanic activity thus represents a continual challenge to human communities due to its unpredictability and the range of potentially destructive phenomena generated (Bryant, 2005). Volcanoes can be understood as a 'hazard': "(a) potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social or economic disruption or environmental degradation" (Baas et al., 2008).

The historical record documents an approximate 278,880 human fatalities caused by volcanic activity to date. 58% of these fatalities (162,928) stem from only five eruptions: Tambora, Indonesia, 1815 (60,000); Krakatau, Indonesia, 1883 (36,417); Mont Pelée, Martinique, 1902 (28,800); Nevado del Ruiz, Colombia, 1985 (23,187); Mount Unzen, Japan, 1792 (14,524) (Auker et al., 2013; Chapter 4; Chapter 5). These figures demonstrate that individual volcanic events have the capacity to cause loss of life on a scale which meets the United Nations' definition of disaster:

> *A serious disruption of the functioning of a community or society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources. A disaster is a function of the risk process. It results from the combination of hazards, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk* (Baas et al., 2008).

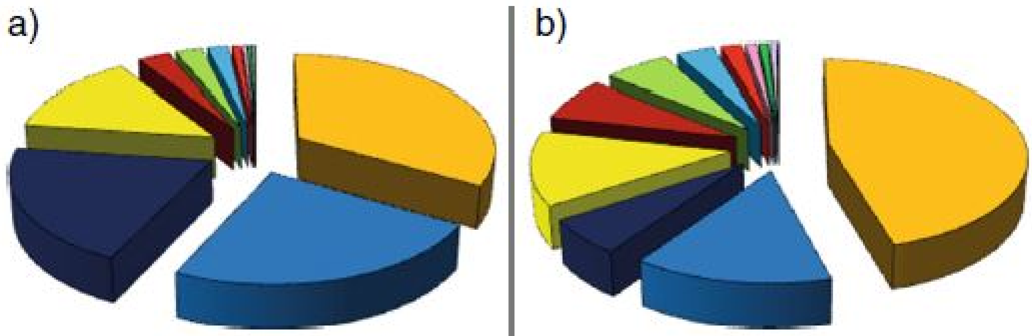
'Conditions of vulnerability' may be understood in two categories: 'physical vulnerability' is the exposure of humans, property and infrastructure to hazards, 'social vulnerability' is the capacity for exposed systems to respond to those events (Kunzler et al., 2012). Risk can thus be expressed through the following function:

Risk = Hazard x Vulnerability (e.g. Kumpulainen, 2006)

Herein, risk is understood to comprise the potential magnitude of hazardous natural events and the susceptibility of human systems (in terms of physical situation and coping capacity).

2.2. Volcanic Hazards and Risk: An Overview

Hansell et al. (2006) suggest that the range of eruptive scales and styles may make volcanoes the most diverse single source of disaster risk in the natural world. Papale (2015) and Bryant (2005) both suggest that volcanic activity is the natural phenomenon with the highest destructive potential, discounting a large bolide impact. The following presents a review of the range of volcanic hazards (Figure 2.2) and the general implications of these for 21st century human societies.



All Fatal Incidents			Largest 5 Disasters Removed	
Fatalities	%	Hazard	Fatalities	%
91,484	33	Pyroclastic Density Currents	50,994	46
65,024	24	Indirect	15,724	14
55,277	20	Waves (Tsunami)	6,813	6
37,451	14	Lahars (Primary)	14,054	13
8,126	3	Tephra	8,126	7
6,801	3	Lahars (Secondary)	6,801	6
5,230	2	Avalanches	3,953	3
2,151	0.78	Gas	2,151	2
1,163	0.42	Floods (Jökulhlaups)	1,163	1
887	0.32	Lava Flows	887	0.79
765	0.28	Seismicity	765	0.69
142	0.05	Lightning	142	0.13

Figure 2.2. Distribution across volcanic fatalities for all fatality causes on record (Auker et al. 2013). Column (a) comprises fatalities from all known eruptions, column (b) removes the five eruptions with the largest death tolls (Tambora, 1815; Krakatau, 1888; Mont Pelée, 1902; and Nevado del Ruiz, 1985).

2.2.1. Volcanic Gas Hazards

The emission of volcanic gases, both syn-eruptive and between eruptions, may have detrimental impacts upon human infrastructure and health (including direct mortality and increased morbidity). For example, the release of volcanic CO_2, including from volcanic lakes in events known as 'limnic eruptions', may cause substantial atmospheric concentrations (between 10 to 30%) to collect temporarily in low-lying areas around the source (Hansell and Oppenheimer, 2004; Halbwachs et al., 2004). The principal health hazard from large-scale CO_2 emissions is anoxic asphyxia, which can result from atmospheric concentrations of >5% if exposure is sufficiently prolonged; examples include the 1984 and 1986 limnic eruptions of Lake Monoun and Lake Nyos in Cameroon, which resulted in the fatal asphyxiation of 37 and ~1,700 people respectively (Hansell and Oppenheimer, 2004; Section 4.2).

The full range of gas species outlined in section 2.1 are released from vents in varying concentrations as a volcanic smog, sometimes known by the Hawaiian term 'vog' (Longo et al., 2010). The immediate effects of exposure may include headaches, eye and throat irritation, coughing, tightness of the chest and shortness of breath. In high concentrations certain species such as H_2S can cause loss of consciousness and death (Hansell and Oppenheimer, 2004). Gas emission may be localised to areas proximal to the vent (Longo et al. 2010). However, during larger eruptions, the impacts may be further-reaching. The 1783-84 Icelandic Laki fissure eruption distributed vog over much of continental Europe (Oppenheimer, 2011). Computer simulations of a hypothetical similar eruption in the modern day suggest that 100,000 deaths across Europe could be caused by the detrimental health impacts (Papale, 2015). The documented 2,151 fatalities from volcanic gas emissions account for 0.78% of the total volcanic fatalities record (Figure 2.2). However, Hansell and Oppenheimer (2004) suggest that any effort to quantify the human health impact of volcanic gas is likely to be an underestimate as inter-eruptive degassing may be overlooked, the extent of dispersion of volcanic gases may not yet be fully understood and the impacts on long-term morbidity may be difficult to constrain.

2.2.2. Lava Flow Hazards

Lava flows consist of molten rock which pours onto the Earth's surface during effusive eruptions or may be formed by the aggregation of partially molten pyroclasts during explosive eruptions. 'Lava flow' may refer to both the moving lava and to the resulting solidified deposits (USGS, 2015a; Parfitt and Wilson, 2008). The extreme heat of flowing lava, combined with its capacity to surround and bury most obstacles mean that any vegetation or human constructions in its path will be severely damaged or destroyed (Papale, 2015; GVM, 2014). Buildings brought into contact with an active lava flow may be subject to any combination of the following: wall collapse; burial; ignition; inundation; uplift and transport within the flow; foundational failure and damage from pyroclasts which detach from the main flow (Blong, 1984).

Lava flows generally move sufficiently slowly for humans and animals to evacuate before direct exposure. They account for only 0.32% (887) of the total recorded fatalities from volcanic activity (Figure 2.2), thus the greatest risk from lava flow hazards is economic loss from the destruction of businesses and property (GVM, 2014). Exceptions to this rule include the 1977 and 2002 eruptions of Mount Nyiragongo in the Democratic Republic of the Congo which produced lava flows of exceptionally high velocities (between 10-60 km/h) and reportedly killed 70 and 147 people respectively; the 2002 eruption also inundated and destroyed ~20% of the city of Goma, including the airport (Favalli et al., 2008; Allard et al., 2002). Many of the casualties from the 2002 eruption were caused by explosions when lava subsumed a petrol station causing fuel to ignite (Papale, 2015). More viscous, silicic composition (e.g. andesite, dacite and rhyolite) magma may form vertically-sustained structures called lava domes if they lose sufficient gas to prevent significant fragmentation prior to extrusion (Melnik and Sparks, 1999; Parfitt and Wilson, 2008).

2.2.3. Tephra Hazards

Pyroclasts expelled during explosive eruptions are collectively named tephra. Fragments >64 mm in diameter are known as blocks (if solid) or bombs (if partially molten), fragments 2-64 mm in diameter are known as lapilli, and ash is the collective name for pyroclasts <2 mm wide (Papale, 2015; Hansell et al. 2006). Blocks and bombs follow ballistic trajectories and may cause death or severe injuries through blunt trauma or burns (e.g. Bruce, 2002) but typically do not travel >5 km from the vent and thus do not feature significantly on the global fatalities record (Blong, 1984; Auker et al. 2013).

Ash and lapilli are expelled in a jet of gas at speeds of up to 400 m/s during explosive eruptions (Sigurdsson, 1999). Convection driven by heat permits explosive eruptions to form volcanic columns, clouds which may extend >40 km above the vent in large magnitude explosive eruptions (Oppenheimer, 2011; Bonnadonna and Costa, 2013). These columns are subsequently dispersed by wind to form volcanic plumes, allowing deposition of ash and lapilli ('airfall tephra') on the ground over a wide area. Typically, lapilli as well as large and dense ash particles are deposited close to the vent whereas the finest grade ash may remain suspended in the atmosphere sufficiently long to circle the globe (Oppenheimer et al. 2003; Papale, 2015). Deposit thickness generally decreases with distance from the vent although secondary maxima do occur due to aggregation of particles while in transit (Costa et al., 2010; Tajima et al., 2013).

Airfall tephra may be deposited in volumes significant enough to supplant existing topsoil on an order of centimetres to hundreds of metres (IVHHN, 2006). Tephra fall (or 'ashfall') may impact on: buildings (loading may lead to structural damage or roof collapse), critical infrastructure (structural damage to power, transport and communications networks, contamination of water), agriculture, forestry and fishing (rendering land inert, increasing mortality and morbidity in livestock), human health and psychology.

The aerial dispersal of volcanic ash also presents hazards to aviation; the ingestion of glassy ash particles by jet engines may cause damage and engine failure; fuselages and windscreens may be subject to abrasion such that visibility is reduced and critical instruments cease to function (Hansell et al., 2006; Papale, 2015). No losses of life are known from volcanic ash impacts on aviation to date. However, there have been multiple instances of engine failure and closure of airspace (Sigurdsson, 1999).

There is substantial evidence for airfall tephra impacting human health (e.g. causing asthma attacks and bronchitis, coughs, breathlessness, chest tightness and wheezing) which can be fatal to elderly people or those with pre-existing medical conditions. No conclusive evidence for ash causing long-term illness such as silicosis or chronic obstructive pulmonary disease is found, although this may be attributed to lack of study (Horwell and Baxter, 2006). 8,126 (3%) of the historical fatalities record is attributed to tephra (Figure 2.2).

2.2.4. Pyroclastic Density Current Hazards

Pyroclastic density currents (PDCs) are fast-moving (up to 700 km/h) gravity-driven avalanches of fragmented volcanic rock and gas (USGS, 1997; Burgisser and Bergantz, 2002). PDCs may originate through the collapse of an eruption column when insufficient air is entrained to support buoyant propagation; due to an explosion that takes pace on the flanks of a volcano (i.e. a lateral blast); or from the gravitational collapse of a lava dome (Branney and Kokelaar, 2002). There are two types of PDC: pyroclastic flows are concentrations of hot rock, and gas which are typically gravitationally confined to valley floors due to density; pyroclastic surges are dilute, turbulent clouds of gas and ash which may separate from a pyroclastic flow and spread rapidly, surmounting topographical barriers and even crossing water (GVM, 2014). PDCs may occur during explosive eruptions of all magnitudes, with volumes ranging from <1,000 m^3 to tens/hundreds of cubic kilometres (Papale, 2015).

PDCs have caused more human casualties than any other volcanic phenomenon - 33% of the historical fatalities record (91,484 deaths) (Figure 2.2). The speed and temperatures of PDCs combined with pyroclastic missiles within the flow enable them to kill or destroy any organism or structure in their path (Ongaro et al., 2002; Wright and Pierson, 1992). The 1902 eruption of Mont Pelée, Martinique (Section 4.1.4), demonstrated the fullest extent of PDC impact on a population centre to date, the near-total destruction of all structures in the city of St. Pierre and the deaths of all ~28,800 directly-exposed inhabitants (McKie, 2002; Auker et al., 2013; Hansell et al., 2006).

2.2.5. Lahar and Flood Hazards

Lahars are the result of volcanic material mixing with water to create debris flows that range in consistency from that of muddy water to wet cement depending on the ratio of sediment to water (USGS, 2015b). Lahars fall into two categories. Primary lahars originate syn-eruptively when freshly erupted hot material is brought into contact with sufficient water, either through groundwater, freshwater reserves (e.g. crater lakes) or glacial meltwater from a volcano's ice-cap. These lahars tend to have volumes of 10^7-

10^9 m^3 and travel at speeds exceeding 20 m/s to distances tens-to-hundreds of kilometres from their source (Papale, 2015). Secondary lahars occur when water mobilises existing pyroclastic debris, independent of volcanic activity. The water which feeds these lahars may come from precipitation ('rain lahars') or during 'breakouts' from freshwater reserves. The poor consolidation of pyroclastic deposits on many volcanoes permit this material to be easily eroded. Secondary lahars tend to have volumes of 10^4-10^6 m^3 and runoff distances of <10 km (Kunzler et al. 2012; Papale, 2015).

Lahar deposits may be metres to tens-of metres thick and subsume entire settlements (GVM, 2014). Primary lahars are responsible for 14% of recorded historical fatalities (37,451 deaths); secondary lahars for 3% (6,801) (Figure 2.2). The 1985 eruption of Nevado del Ruiz in Colombia (Section 5.2.3) generated primary lahars with a volume of 11-12 million m^3 (Thouret, 1990) leaving deposits on average 1.5 m thick (Pierson et al. 1990) and killing approximately 23,000 people (Voight, 1990; Parra and Cepeda, 1990).

Floods initiated by volcanic melting of glaciers may not necessarily entrain sufficient volcanic material to become lahars, such floods comprise 0.42% of the total fatalities record (1,163) (Figure 2.2).

2.2.6. Debris Avalanche Hazards

Debris avalanches are caused by the partial collapse of a volcanic edifice and may be syn-eruptive or non-eruptive (Siebert, 1984; Hoblitt et al., 1995). Debris avalanches may be triggered by the intrusion of new magma, phreatic (steam-driven) explosions, precipitation or earthquakes (Sigurdsson, 1999). Debris avalanches accompanied by magmatic activity may lead to lateral blasts and extensive PDCs, a prominent example being the 1980 VEI 5 eruption of Mount Saint Helens, USA (Section 4.2). The 1998 landslide on Volcán Casita, Nicaragua, triggered by heavy rainfall during Hurricane Mitch was a non-eruptive sector collapse that killed ~3,800 people (GVM, 2014; Macias and Aguirre, 2006).

The risks from 'hot' debris avalanches may therefore not be easily distinguished from those of large-volume PDCs, likewise with the impact of 'cold' debris avalanches and lahars. Avalanches constitute 2% (5,230) of the historical fatalities record (Figure 2.2). If debris avalanches enter the ocean or a lake then they may cause tsunami, a series of waves triggered by displacement (Hansell et al. 2006; Intergovernmental Oceanographic Commission, 2013). Volcanogenic tsunami are responsible for 20% of the historical fatalities record (55,277 deaths) (Figure 2.2).

2.2.7. Volcanoseismic Hazards

0.28% of the historical fatalities record (765 deaths) are documented as resulting specifically from volcanic seismicity (Figure 2.2). Seismic activity is a near-constant feature of active volcanism and may result from various processes including high-frequency 'A-type' events caused by the fragmentation of rock, low-frequency 'B-type' events generated by the pressurisation of fluid within a volcano and 'tremor', sustained low-frequency signals thought to be caused by unsteady fluid flow. Seismicity is also generated by other volcanic processes including explosions, lahars and rockfalls (Sigurdsson, 1999; McNutt, 1992).

Volcanic seismicity is generally of low magnitude (2-3 on the Modified Mercalli scale) relative to tectonic seismicity; although larger earthquakes (magnitude >7) have occasionally been known to accompany volcanic eruptions (Zobin, 2001). Deaths and injuries from seismicity are predominantly caused by blunt trauma triggered by the collapse of buildings, or by fire (Centres for Disease Control and Prevention, 2011; Scrawthorn, 1997).

2.2.8. Volcanic Lightning Hazards

0.05% of historical fatalities (142 deaths) are documented as resulting from volcanic lightning (Figure 2.2). Volcanic lightning is described as "fairly common yet relatively understudied" by McNutt and Williams (2010). The study of electrical discharge due to volcanism has mostly focussed on the fragmentation of silicic viscous magma, where it is suggested that fractoemission (the release of electrons and ions from fresh fractures) is the key mechanism of particle electrification (Gilbert et al. 1991; James et al. 2008; Cimarelli et al. 2013). The occurrence and distribution of volcanic lightning is difficult to predict and does not feature heavily in volcanic hazard assessments.

The remainder of the Auker et al. (2013) record (Figure 2.2) is composed of indirect fatalities from disease, drought and starvation after volcanic eruptions, comprising 24% (65,024) of deaths.

2.2.9. Globalised Volcanic Risk

Approximately 800 million people live in close proximity to active volcanoes (Papale, 2015). Traditionally, volcanic regions have been inhabited because soils derived from volcanic ejecta may (with careful management) become highly fertile and agriculturally productive (Sparks, 2004; GVM, 2014). The Campania region in Southern Italy is an example whereby agriculturally productive land formed by activity at the volcanic centres Vesuvius and Campi Flegrei, has fed one of the longest continually inhabited areas in Europe (Dobran, 2006).

Modernity has brought other benefits to living near volcanoes: the heat they generate can be harnessed and turned into geothermal electricity; a ‘clean’, renewable fuel source (World Bank, 2011). The income volcanoes can generate as tourist attractions is another advantage. This is the case in many volcanic regions, with an expanding geotourism sector bringing visitors to places as diverse as Indonesia and Iceland; ongoing volcanic activity can be a significant draw for tourists and active volcanoes such as Etna and Stromboli in Italy attract large numbers of visitors every year. The early effusive stage of the 2010 Eyjafjallajökull eruption was known as the 'tourist eruption' (Jenkins, 2010; Erfurt-Cooper and Cooper, 2010). As such, the likelihood of tourists and tourist infrastructure being brought into contact with volcanic hazards may be increasing.

Volcanic eruptions, both effusive and explosive are hazardous. The risk is greater in the present day than at any point in the past because of the current extent of human society. Due to significant population growth, more of the Earth's surface (and atmosphere) than ever before is occupied by human settlements and infrastructure (UN, 2019). This expansion of humanity across the planet has been accompanied by increasing interdependence between social systems, part of the phenomenon known in the social sciences as 'globalisation'. This concept emerged in studies of late 20th Century socioeconomic processes, specifically the worldwide spread of neoliberalism, the political paradigm characterised by an unregulated market economy with minimal state intervention (Kotz, 2002). "The concept of globalization refers to the growing interdependence of countries, resulting from the increasing integration of trade, finance, investments, labour markets and ideas in one global marketplace" (Frunza et al. 2009). During the most recent four decades, human societies across the surface of the earth have come to rely upon one another to an unprecedented extent, with neoliberalism providing the framework for these exchanges.

However, some scholars have suggested that to conceive of globalisation as, at its core, an economic phenomenon that only emerged during the last three decades of the 20th century is to ignore the technological, biological, cultural and historical aspects of a millennia-long, complex, multi-faceted process (Bordo et al. 2003). Northrup (2005) argues:

> *Forces for convergence had long operated in parts of the ancient world: regional empires consolidated disparate peoples and overlaid their traditions with a common culture, world religions spread universalistic beliefs, and long-distance traders spread ideas and technologies as well as goods. Irregularly at first and then with increasing force and speed after 1000 ce., historical forces drew people closer and closer economically, culturally, and politically. This "Great Convergence," as I shall call it, provides a useful framework for understanding the past thousand years of world history and the phenomena that in recent years have come to be called globalisation.*

It may thus be understood that the value of vulnerability in the risk equation has been increasing gradually for at least the last millennium as humans and the activities required to support their communities have spread across the Earth, including into volcanic areas. However, the exponential acceleration of both population growth and globalisation in recent decades has seen this exposure to volcanic hazards reach levels far greater than at any previous time in history, and there are currently no signs of this process slowing (Chapter 4).

2.3. Volcanic Risk Governance

The above text reflects current understanding of hazardous volcanic phenomena and the risk incurred by human occupation of volcanic areas. Volcanic risk is certain to affect human society for the foreseeable future. Attention is now turned to the current understanding of processes for reducing volcanic disaster risk.

2.3.1. Disaster Risk Reduction and Public Policy

Work towards the reduction of environmental risks is necessary because humans continue to live in areas where they are exposed to the vicissitudes of natural events (Tobin and Montz, 1997). Disaster risk reduction has become a growing priority as population growth, environmental degradation and the advent of anthropogenic climate change have seen the frequency and severity of disasters increase (UNISDR-STAG, 2015).

As noted in Chapter 1, contemporary disaster risk reduction is mainly conducted through the development and implementation of public policy. Mackay and Shaxton (2007) classify written policies, subject to consultation and review, as *formal* policy. Ad hoc, unwritten, but generally accepted practices may be recognised as *informal* policy. These authors define *public* policy as "...a decision made by government to either act, or not to act in order to resolve a problem." Governments are those who have a legitimate mandate to instate normative guidelines according to the law of the jurisdiction in question.

'Policymaking' is the process by which paths of action are decided and implemented. Mackay and Shaxton (2007) argue that all policies share three elements: a problem definition, goals to be achieved and the 'policy instrumentation' to fulfil those goals, including economic tools (e.g. taxes, financial incentives) or regulations (e.g. laws incentivising or prohibiting certain practices) (Cairney, 2013).

'Policy cycles' have been an influential heuristic for portraying policymaking as a logical process comprised of discrete stages (Hallsworth et al. 2011). There are multiple models in use, however the oldest and most influential is the 'classic' 5-step model (Figure 2.3).

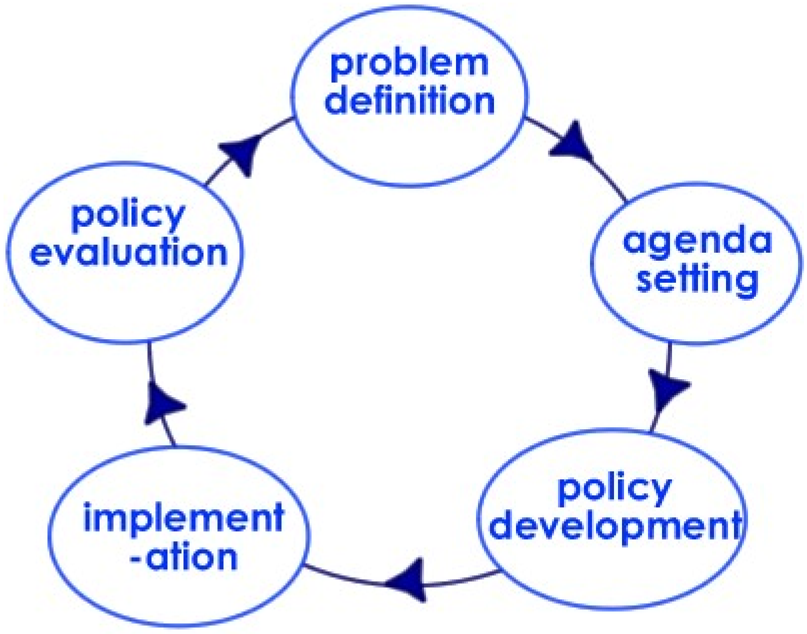


Figure 2.3. The 'classic' 5-step policy cycle model (Soer, 2013), adapted from Harold Lasswell's 1951 work *The Problem Orientation*, arguably the foundation of modern political science (Turnbull, 2008; Freeman, 2013). This model portrays policy development as a stepwise, iterative process conducted by a single policymaking body, beginning with the articulation of a 'problem' to be 'solved' through subsequent phases. Finally, the performance of the policy is evaluated and any unresolved issues feed into the start of the next cycle (Mackay and Shaxton, 2007; Howes et al. 2013).

Critics of the policy cycle "...argue that policymaking is not as logical or clear cut and point out that even proponents of this model have admitted that it is more of an ideal than a definitive explanation of practice" (Howes et al. 2013). Hallsworth et al. (2011) provide four reasons for this:

(1) Policy making does not take place in distinct phases: "The 'stages' of policy making do not just often overlap, they are often inseparable. In the real world, policy problems and policy solutions frequently emerge together, rather than one after another."

(2) Policies need to be designed, not just conceived: "Current processes greatly underestimate the value of *policy design*. A greater emphasis on policy design helps to ensure that the planned actions represent a realistic and viable means of achieving the policy goals."

(3) Policymaking is often determined by events: "Policy making does not take place in a vacuum, where the government is in total control of its agenda. The result can be sharp discontinuities and apparently illogical decisions, as the government's coherent position can get overwhelmed by events."

(4) The effects of policies are often indirect, diffuse and take time to appear: "Current guidance presents policies as discrete interventions to tackle specific problems, whose effects can then be reliably measured and evaluated. But there is plenty of evidence that the effects of these interventions may be complex, wide-ranging and unintended."

Howes et al. (2013) believe that the stepwise-cyclical approach has also been dominant in disaster risk policymaking, embodied in the *disaster management cycle* (Warfield, 2004). Coetzee and Van Niekerk, (2012) argue that, similar to other policy cycle models, the disaster management cycle has undergone multiple interpretations: "...on perusal of the various permutations of this cycle it becomes apparent that a bewildering array of variations has emerged over time, leading to much confusion among scholars and practitioners alike." According to Coetzee and Van Niekerk, these variations mainly concern the number of phases, with some models possessing eight (pre-disaster, warning, threat, impact, inventory, rescue, remedy, recovery) and some incorporating just two (pre and post-disaster). The review states that until 1968, phase-based models of disaster were predominantly scientific exercises. However, in the 1970s, the first disaster management cycles intended as guidelines for policymaking emerged (Figure 2.4).

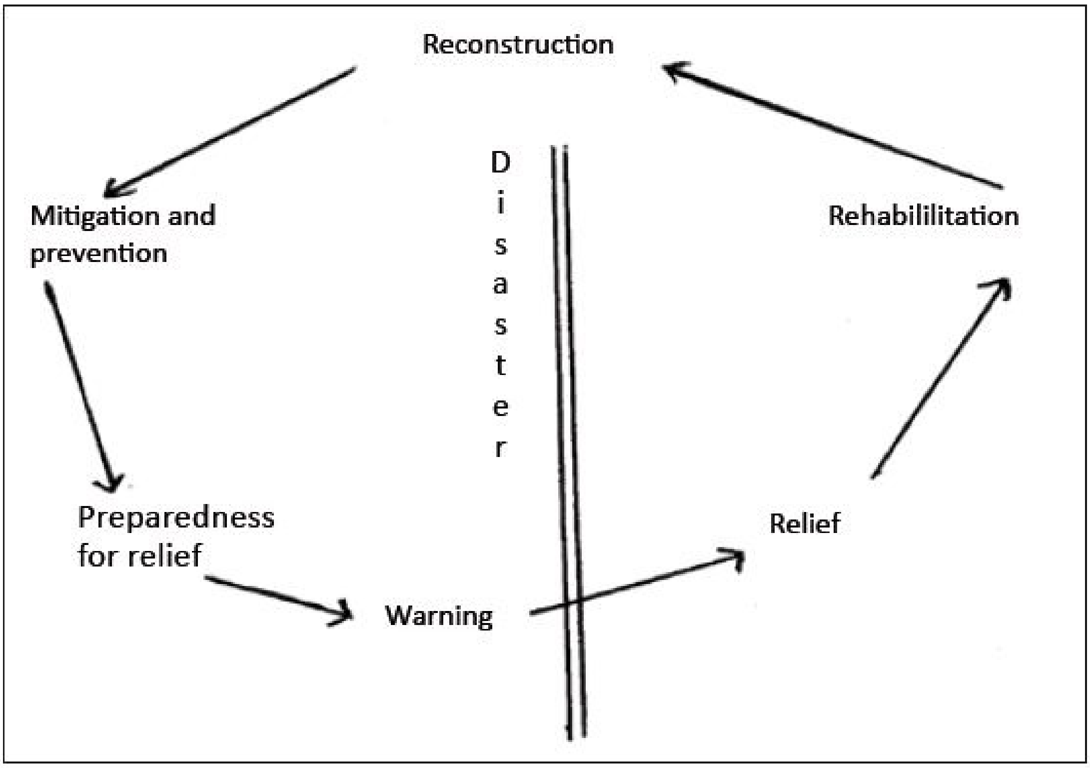


Figure 2.4. The disaster management cycle (Baird et al. 1975).

Crondstedt (2002) suggests that the disaster management cycle emerged in 1978 as the US State Governors' Association's 'Comprehensive Emergency Management' strategy. This version incorporated four phases: Mitigation, Preparedness, Response and Recovery. Mitigation was subsequently incorporated into a broader 'Prevention' category and the subsequent Prevention, Preparedness, Response and Recovery (PPRR) paradigm has become highly influential, having been adopted from its original US context to various other countries (Crondstedt, 2002; Warfield, 2004). The different phases of the PPRR model aim to reflect the unfolding stages of an emergency, providing policymakers with actions to implement at each juncture (Warfield, 2004).

Much as the policy cycle has been subject to criticism, the PPRR approach has also been challenged. Crondstedt (2002) reviews PPRR-cycle-based policymaking and implementation in Australia. Crondstedt argues that while PPRR continues to influence contemporary disaster risk governance, "the 'fit' is not neat and has inherent problems." Crondstedt identifies the following four criticisms:

(1) This approach creates artificial partitions between the four stages; the challenge of identifying where these partitions should be made often requires time and effort, categorising actions instead of carrying them out.

(2) Each 'stage' is seen as a unit of equal weight to the others. This approach does not acknowledge that certain strategies may skip a stage, or have uneven emphasis on certain actions.

(3) PPRR assumes that the same steps must always be implemented in the same order, rather than deciding the most appropriate action based on the circumstances.

(4) It is assumed that adopting an affirmative course of action according to PPRR is always the correct thing to do and will always produce the 'appropriate' solution. This is a *reactive* approach to disaster risk. It does not account for, nor attempt to change the underlying factors that frequently permit natural events to become disasters. Crondstedt argues that many factors related to vulnerability do not fall into the discrete categories of PPRR.

It can thus be understood that, despite its unique challenges, disaster risk governance has parallels with general policymaking. 'Problems' are identified and incorporated into the agenda of a policymaking body. The pursuit of 'solutions' is a policymaking process, distinguished by its chronological-stepwise approach. Despite the conclusions of academic studies that efforts to divide the process into equal, sequential stages are unrepresentative of the real world and render policymaking less effective, old models die hard. Cairney (2013) suggests that the policy cycle has fallen out of favour in academia; however, in practice, this approach continues to be influential. Likewise, thirteen years after Crondstedt's (2002) critique of the PPRR model in Australia, Queensland state government's disaster management plan was still explicitly based on PPRR (Queensland Disaster Management Committee, 2015).

Christie et al. (2015) argue that while the social science related to disaster risk has evolved rapidly, 'policy communities' have responded slowly. The disconnection between these two discourses is emphasised by the continued dominance of the disaster management cycle for policymakers, despite the opinions of academics. In order to understand how disaster risk policymaking works currently, and may evolve in the future, it is therefore essential to understand, not just the policymaking process, but the relationships between the individuals, communities and institutions involved. Mackay and Shaxton (2007) outline a range of organisations, institutions, roles and responsibilities involved in policymaking:

> *Government does have the ultimate decision making and funding power, but there are many other actors that contribute to public policy, often in a network on which government relies for the delivery of complex policy goals.*
>
> - ***Government**: social control of behaviour, power of coercion*
> - ***Cabinet**: monopoly over supply of legislation, locus of power - few people make decisions*
> - ***Public Servants**: technical knowledge and policy advice, service providers*
> - ***Political Parties**: develop relationships in exchange for political support*
> - ***Media**: report information to the public, generate interest, shape public opinion*
> - ***Interest Groups**: seek to advance interests of members, can have a major influence - can force policy network to react*
> - ***Legal system**: interpret laws, acts independently*
> - ***Public**: elects government, forms opinions, joins interest groups and coalitions, relies on the media for information*

Policymaking may thus be understood, not just as a linear series of steps taken by a single-minded government, but as a complex process, comprised of interactions and relations between a myriad of institutions and individuals. Mackay and Shaxton (2007) choose to describe these individuals and institutions as *actors* and the relationships that bind them as a *network*. This terminology evokes Actor-Network Theory (ANT), defined by Law (2008) as:

> *...a disparate family of material-semiotic tools, sensibilities and methods of analysis that treat everything in the social and natural worlds as a continuously generated effect of the webs of relations within which they are located. It assumes that nothing has reality or form outside the enactment of those relations. Its studies explore and characterise the webs and practices that carry them.*

According to Law, ANT is not a singular social theory, but a way of conceiving of reality that lends itself to multiple disciplines and methodologies. The crux of this framework is that the connections between individual components that comprise a network are the determinants of that component's existence; nothing exists in isolation, everything is connected, and those connections provide meaning and agency. According to Latour (1996), actor-networks are collections of related, yet separable, heterogeneous elements (e.g. humans, microscopic organisms or subatomic particles), wherein each element possesses agency (i.e. human and non-human 'actants' are viewed as capable of shaping outcomes and relations). This avoids compartmentalising networks into 'social', 'technological' or 'natural' brackets. ANT places emphasis on the *arrangements* in which actants are embedded, rather than the intrinsic qualities of those actants; networks are transient, and may drastically alter or cease to exist through time as the connections go through multiple mutations and reconfigurations (Clegg and Haugaard, 2009; Angeluci and Cacavallo, 2016).

Polk (2015) outlines several strands of argument that have emerged to contest ANT: there are those who believe that assigning equal agency to all actants ignores human *intentionality*, a factor that distinguishes humans from objects that lack self-awareness. It is also argued that an approach which assigns equal importance to all actors within the network does not accurately explain the influence of pre-existing power relations.

Irrespective of the validity of ANT as a model of reality, Hannigan (2012) argues global disaster risk governance cannot be accurately described as a network, since there are not always organisational links between different activities (e.g. post-disaster relief and aid may have little-to-no interaction with pre-disaster preparedness and mitigation policymaking processes). Nor can it be portrayed as a system since it lacks structural interdependence (wherein a change in one unit will unequivocally have repercussions for all other connected units). Instead, Hannigan elects to depict the political structures related to disasters and risk as a *global policy field*, where disasters constitute the 'central issue' around which multiple competing 'field constituents' contest and shape actions and behaviours at an organisational scale. Hannigan identifies nine main categories of field constituent that form the 'architecture' of the global policy field of disaster risk:

(1) National states and local governments
(2) Regional organisations (e.g. the Centre for National Disaster Prevention in Central America)
(3) International finance institutions (IFIs) (e.g. the World Bank, the International Monetary Fund)
(4) United Nations disaster agencies and other international governmental organisations (IGOs) (e.g. UNDRO, UNISDR, UNICEF)
(5) Non-governmental organisations (NGOs) (e.g. OXFAM, IFRC)
(6) Multi-actor initiatives and partnerships (e.g. the World Bank's GFDRR)
(7) Scientific, technical and academic communities
(8) Private actors
(9) The mass media

It is observed that relationships between field constituents are characterised by 'soft law'. Hannigan (2012) shows that, although the global disaster policy field is extensive, *national sovereignty* has always been paramount, with the ultimate responsibility for formal policymaking falling to national governments and their local subdivisions. This is still the case under the UN's Sendai Framework for Action, which reiterates support for national sovereignty as a priority (UNISDR, 2015). Although the dominant neoliberal socioeconomic paradigm stresses the benefits of minimal state intervention, it has been argued that in disaster risk governance the national public sector remains dominant, even in very neoliberal economies such as the USA (Collier, 2014).

Hannigan (2012) argues that the emphasis on national sovereignty has often made nation-states look inwards, at the expense of international collaboration. Whilst international field constituents associated with relief and recovery have thrived, Hannigan believes that support for international policymaking coalitions, and particularly UN institutions has been 'anaemic' at best. Although this has resulted in diverse frameworks for disaster risk governance emerging in different national contexts. there are some general trends. Smith and Petley (2009) identify three approaches to disaster risk policy:

(1) The earliest policy approach to disaster risk is the *Behavioural paradigm*: the dominant theory in disaster risk governance throughout the 20th Century. Behavioural thought emphasises disasters as 'extremes' that unpredictably encroach upon the 'normal', and prioritises physical science, modelling, structural engineering and prediction, with limited reference to human behaviour and perception (Prowse, 2003; Van Niekerk, 2012). The 'emergency management' approach to disaster risk, exemplified in the PPRR model, is a standard Behavioural policy response to disaster risk. Calhoun (2004) argues that the term 'emergency' suggests that a well-oiled, functional system is disrupted by a disaster and that 'management' must be employed to restore the pre-existing equilibrium.

Smith and Petley (2009) state that this paradigm is still favoured by many governments. However, they argue that emergency management policies provide only short-term solutions due to an managerialist and technical approach which views the populations at risk as passive participants to whom disasters 'happen' rather than active participants in the construction of risk.

(2) In response to the ineffectiveness of Behavioural approaches in less economically developed countries, social scientists (e.g. Wisner et al., 2004) advanced the *Development paradigm*, also known as the 'structural paradigm' (Hannigan, 2012; Van Niekerk, 2012):

> *In summary, the development view is based on the theory that disasters spring from under-development arising from political dependency and unequal trading arrangements between rich and poor nations... Specifically, rural overpopulation, landlessness and migration to unplanned, hazard-prone cities are the inevitable outcome of capitalism,*

> *which is the root cause of environmental disaster.* (Smith and Petley, 2009).

The Development paradigm has been influential academically, establishing vulnerability and marginalisation as factors which may equal or outweigh hazards in determining the severity of a disaster. However, it has had a comparatively limited impact on policymaking. It has introduced considerations of vulnerability as a standard in the disaster risk process, leading to the proliferation of 'disaster risk management' (a form of the Behavioural paradigm with additional efforts at pre-event mitigation and post-event adaptation) (Smith and Petley, 2009; Van Niekerk, 2012; UNISDR, 2015). The UNISDR (2015) Global Assessment Report (GAR) concludes that 'disaster risk management' has become the dominant approach to disaster risk worldwide.

(3) The most recent scientific paradigm to emerge has been *Complexity*, an approach which views disasters as a result of the mutual interaction of natural and social systems (Smith and Petley, 2009). Smith and Petley identify the 2003 earthquake in Bam, Iran as an example of how complex interplay between hazardous physical processes and human circumstances may create a 'disaster'. Scientists argue from the perspective of Complexity, that public policy, business, agriculture, anthropology and sociology should be considered in the development of long-term integrated strategies for *disaster risk reduction* (Dynes, 1999; Macias and Aguirre, 2006).

The sciences, both physical and social, have been a continual catalyst for the development of disaster risk governance as governments have recognised the importance of informed decision-making (UNISDR-STAG, 2015). It is argued in the 2015 GAR that the transition from disaster risk management to a holistic framework for reducing risks remains the greatest challenge in disaster risk policymaking (UNISDR, 2015). Hannigan (2012) believes that developments in disaster risk have not followed Kuhn's (1962) model of scientific and political change, in which an emergent paradigm will successfully replace the established order after a period of contestation:

> *In an ideal world, a new policy discourse would be widely and immediately recognised as sensible and worthwhile, and would be instantly embraced. The real world, of course, operates differently and new ways of thinking and acting are normally contested, or even ignored. The discourse of disaster risk reduction is no different. Since it emerged in the 1980s, DRR has moved onto centre stage in the global field of disaster management, but it is not universally accepted.* Hannigan (2012).

Epistemic communities have not bound policymakers to approach disaster risk in new ways through international treaties as has been the case in other environmental policy arenas (e.g. climate change) and as such, these three paradigms remain coexistent and in ongoing competition.

2.3.2. Volcanic Risk Reduction Policy and Practice

Volcanic risk governance represents a unique set of challenges to human societies. Volcanology has been the scientific discipline at the heart of the effort to understand and lessen the impact from volcanic activity. Volcanologists, like most other natural scientists, investigate processes to advance understanding of natural phenomena. However, volcanology is "...a science which differs from most others in one crucial respect: crises may arise from time to time which require volcanologists to make immediate recommendations that affect public safety" (Aspinall et al. 2003). The traditional remit of volcanologists has been academic research into volcanic processes and operational short-term volcano monitoring, whereby various phenomena including seismicity, gas emissions, ground deformation or the composition of spring-water at volcanic sites may be used to prognosticate the near-future activity of a volcano. This information is subsequently presented to decision-makers (Sigurdsson, 1999; Papale, 2015). However, volcanologists have frequently found themselves at a confluence between the science/technology and governance/decision making elements of the process. Donovan et al. (2011) argue that in volcanic crises a volcanologist's responsibilities may surpass risk assessment and become risk management. This area of the discipline is known as 'applied volcanology': "...a key realm of volcanology that occupies the front line between academic research and governmental organizations that are responsible for decision-making and policy processes that reduce the impact of volcanic hazards on society" (Calder et al. 2015).

In addition to volcano monitoring, applied volcanology has also encompassed long-term academic and operational initiatives. The 'Decade Volcano' project (Chapters 4-6) was the International Association of Volcanology and Chemistry of the Earth's Interior's contribution to the UN International Decade of Natural Disaster Reduction. IAVCEI have subsequently established multiple applied volcanology initiatives including the Subcommittee for Crisis Protocols, the Tephra Working Group and the Commission on Volcanic Hazards and Risk (Newhall, 1999; Calder et al. 2015).

Other prominent projects in applied volcanology have included the Smithsonian Institution's Global Volcanism Program (GVP) (Smithsonian Institution, 2013) creation of the Volcano Population Index (VPI) (Ewert and Harpel, 2004) which quantifies the number of people within a certain radius of an active vent - subsequently applied to all known Holocene active volcanoes (Siebert et al., 2010). Aspinall et al. (2011) created the Population Exposure Index, which builds upon the VPI by weighting the likelihood of fatalities within 10 and 30 km radii. The emergent international collaborations; Global Volcano Model, VHub, the Asociacion Latinoamericana de Vulcanología, and the Volcanic Unrest in Europe and Latin America (VUELCO) project, demonstrate that applied volcanology is continually expanding (Palma et al. 2014; Papale, 2015). The *Journal of Applied Volcanology* was established in 2012 to provide a forum for multi-disciplinary research regarding volcanic risk (Johnston, 2012). It has since carried articles on topics including: operational volcano forecasting (Selva et al., 2012); volcano alert levels (Winson et al., 2014; Potter et al., 2014); community-based disaster risk reduction (Stone et al., 2014); the statistical analysis of the volcanic fatalities record (Auker et al., 2013) and indigenous knowledge (Hicks et al. 2014). Barclay et al. (2008) argue that there is an "urgent need" for interdisciplinary studies contextualising volcanic risk within the global movement for disaster risk reduction, providing examples of 'best practice' in various contexts.

In 2015, the UNISDR GAR included information about volcanic risk for the first time (UNISDR, 2015; GVM, 2014). However, it has been argued that policy paradigms are comparatively understudied within applied volcanology:

> *This absence is particularly noticeable in the literature on volcanic disasters and disaster risks, where the focus has traditionally been on the individual and collective actions of stakeholders living in close proximity to the hazard and less on the prevailing governance regimes* (Wilkinson, 2015).

Work Package 4 of the Strengthening Resilience in Volcanic Areas programme (STREVA) is an applied volcanology project dedicated to assessing and analysing institutional capacity for volcanic risk reduction using a multiple-loop learning framework based on political economy studies on four 'forensic' volcanoes (Wilkinson, 2015).

Some critical literature on volcanic risk reduction policy exists. The publication of *Volcanic Emergency Management* by the United Nations Disaster Relief Organisation (UNDRO, 1985) saw this manual become a widely-used blueprint for volcanic risk reduction policies (Macias and Aguirre, 2006). However, given their global distribution, volcanoes impact on societies with varying degrees of socioeconomic development. Therefore, even within these guidelines protocols vary widely in terms of structure and available resources (Sigurdsson, 1999; Dunkley, 1999).

Macias and Aguirre (2006) use a case-study approach to review UNDRO-based volcanic risk reduction at Popocatépetl and Volcán de Colima, México, and at Tungurahua, Ecuador. They conclude that the UNDRO system possesses attributes typical of the Behavioural paradigm. Poor communication of risks/alert levels/emergency plans and failed evacuation attempts were common to all case studies. In Ecuador, a rapid, military-led evacuation led to insurgency, kidnappings, injuries and deaths. Undermining the trust between these citizens and the infrastructure intended to protect them demonstrates that failure to implement long-term disaster risk reduction renders reactive 'emergency management' inadequate. This has also been apparent at multiple volcanoes under UNDRO-based governance post publication of Macias and Aguirre's 2006 paper (e.g. Colombia Reports, 2007; Colombia Reports, 2012). It can be appreciated that the broader issues with transitioning to a long term disaster risk reduction strategy are relevant within applied volcanology.

Macias and Aguirre (2006) cite San Cristobal, Nicaragua as a volcano where the UNDRO (1985) system was not adopted in favour of combining scientific input with local participation, developing plans and an alert system congruent with the perceived needs of local people. The 'MIA-VITA Handbook for Volcanic Risk Management' (Bignami et al. 2012) is a 'best practice guide', similar in intent and purpose to the UNDRO manual, published by the European Commission and informed by more recent risk reduction science and applied volcanology than its UN predecessor.

The range of volcanic risk reduction systems reflects the diversity of the problem, both in terms of hazard and coping capacity. Nonetheless, the pursuit of 'best practices' is a long-established priority of those working in applied volcanology (Sigurdsson, 1999; Barclay et al., 2008). To that end, there has been an increasing emphasis on 'knowledge transfer' in the field, reflected in the recent establishment of numerous international interdisciplinary projects. Multiple applied volcanology studies have postulated 'knowledge transfer' as a tool for volcanic risk reduction (e.g. Aspinall et al. 2011; GVM, 2014). However, transfer of knowledge does not inherently yield solutions. The problems associated with the UNDRO (1985) volcanic emergency management system are described by Macias and Aguirre (2006) as an example of the difficulties associated with international policy transfer, whereby a policy system designed within a particular context is mobilised through international networks and brought into another.

It is in the interest of those working in applied volcanology to ensure that future knowledge transfers live up to their expectations. There exists a growing body of academic work analysing the processes of mobility in public policy which has scarcely begun to turn its attention to disaster risk; it may be that by incorporating the knowledge generated in this arena of social science, the capacity of applied volcanology to fulfil its purpose can be greatly enhanced.

2.4. Policy Mobilities

Although learning from one another's experience has doubtless been an integral component of human life for millennia, the academic study of *how* governments learn from one another in terms of policymaking originates in the early 1990s when literature on 'lesson-drawing' emerged (Rose, 1991; Wolman and Page, 2003; Clarke, 2009). By the mid-1990s this had developed into the study of 'policy transfer', a field of political science wherein the key question was: "Who learns what from whom?" (Dolowitz and Marsh, 1996). Policy transfer research came to encompass multiple concepts, including policy convergence (the process whereby structures and functions are homogenised across multiple jurisdictions through the enacting of a universal socioeconomic paradigm, e.g neoliberalism) and policy diffusion (the process whereby policy development in one context influences changes in others) (Evans and Davies, 1999; Holzinger and Knill, 2005; Braun et al., 2007). Policy transfer studies recognise three broad techniques: emulation (adoption of a whole policy system), hybridisation (combining elements from multiple policies), and inspiration (experience elsewhere acting as a spur for new ideas) (Rose, 2005).

However, 'importing' a policy model does not always produce the desired or intended effect. Swainson and de Loe (2011) identify three possible causes of 'failure' in the movement of policy systems: uninformed transfer occurs when the receiving jurisdiction has insufficient information about the original policy; incomplete transfer occurs when key operational elements are neglected and inappropriate transfer occurs when variations in context between locations are not sufficiently considered.

McCann (2011) critiques the policy transfer literature, suggesting that its tendency to employ typologies when categorising policy actors and processes (such as the mobility techniques and failure mechanisms outlined above), its focus on interaction between national (rather than local or regional) governments and its general assumption that policies move as complete packages and remain unaltered throughout the process of moving, limit the utility of this approach. Prince (2015) states: "Sometimes policy travels in unpredictable and capricious ways, such as because of an idea from a half-remembered conversation, or an experience on an overseas trip." McCann (2011) suggests that instead of conceiving of 'complete' policies being exchanged between nation-states (from a perspective concerned with 'success' or 'failure'), that tracing the path of a policy and exploring the spheres of influence it interacts with as it moves is the appropriate approach for understanding the obscure and irrational social processes which shape mobile policy.

Policy mobility studies may be understood as a branch of critical policy studies, a post-positivist discipline, concerned with interpreting the complex processes which cause certain policy ideas to be adopted in certain ways, in certain settings, rather than quantifying these as 'successes' or 'failures' (Peck and Theodore, 2012). Although the study of policy mobilities is concerned with notions of 'best practice', these are not reified but observed from a critical perspective which acknowledges that 'best practice' is subjective (Temenos and McCann, 2013).

Policy mobility studies 'follow' mobile policy by tracing its movement through space and time, a technique designed to answer *how,* policy projects work, and not whether, but *how,* success is or is not achieved, and for whom (Peck and Theodore, 2012). Kennedy (2015) contests that the ethnographic methods used to 'follow' policies have tended to focus on the movement of policy actors, models and documents as objects, explaining how policies move inasmuch as those within the international technocracy (see below), who are already convinced of their worth, guide them from place to place. However, Kennedy believes that a researcher's understanding of these processes may only be completed by understanding the way in which local actors are 'convinced' of the worth of these policy models through argumentative discourse. In Kennedy's view, arguments are constructed from 'stories'. Kennedy believes that even greater emphasis should be placed upon discursive analysis of these mobile arguments and the stories that comprise them, which accompany policy ideas into new settings, basing his examples on historical policy mobility studies which he calls "an under-researched area".

Policy mobility studies support the notion that policies are more than just isolated documents, but are formed through the continual coming-together of strategies, practices, institutions, individuals, social backdrops, resources, and crucially, knowledge (both local and mobile) (see also Section 2.3.1). Thus, policies themselves are understood by policy mobilities researchers as *assemblages* (e.g. McCann and Ward, 2012; Prince 2015; Kennedy, 2015; Savage, 2019). Assemblages are transient-but-tangible 'arrangements' of heterogeneous components, each bounded, but frequently fluctuating, overlapping, and interconnected among other assemblages (Savage, 2019). Donovan (2017) applies assemblage theory to disaster risk reduction, noting that disasters themselves (and even volcanoes) can be viewed as assemblages. Prince, (2015) draws on the 'policy worlds' theory from anthropology to explore the idea that a policy is always more than a document, but there is a specific sphere of influence which certain policies occupy, encompassing individuals, institutions and sections of societies, not always bounded by geographical location, further contributing to the construction of a unique *topology*. Assemblage theory is closely linked to this concept of topology, the idea that connections between certain components can bring them 'closer' to one another than they are to topographically proximal objects:

> *To understand how policy mobility is implicated in the assemblage of territories, we need to, in a sense, look backwards from the moment of transfer to consider how different policy territories were produced as spaces between which policy could be mobilised. It is the topological ordering of space that makes policy mobility possible, not through the attachment of the policy to a topographically moving object, but through the production of separate territories with parallel but provincialised responsibilities* (Prince, 2016).

Prince (2015) outlines the importance of *technocracies* in the development of mobile policy, the practices of a relatively small group of 'experts' are frequently responsible for shaping the infrastructure through which policy travels, and creating unique topologies. The distinct disaster risk sector referred to in UNISDR (2015) may be construed as an example of such a technocracy, the international 'expert community' of volcanology is arguably another, although their political 'clout' may be more limited. The concept of *mutation* reflects the fact that policies frequently change 'in transit' and may continue to evolve upon 'arrival' in their new setting depending on the way in which they interact with the other parts of the local policy assemblage over time. Thus, a policy which served one purpose in its original setting may come to function completely differently elsewhere due to its interactions with other parts of the assemblage (Peck and Theodore, 2010).

The movement of ideas has been intrinsic in the development of volcanic and disaster risk governance. UNDRO (1985) is just one example of a policy model created in a particular set of circumstances which has moved and mutated in new settings. Policy mobility studies have now encompassed social welfare, crime, education, environmental issues and urban studies (Benson and Jordan, 2011; Temenos and McCann, 2013). However, literature examining policy mobilities in disaster risk is scarce: Webber (2015) uses the perspective and methods of policy mobility studies to critically assess the World Bank's financing of climate change resilience projects in Kiribati and the Solomon Islands. It is found that policies portrayed as 'best practices' to be mobilised from the Kiribati Adaptation Project did not achieve the intended outcomes in their initial implementation, but when work began on a resilience program for the Solomon Islands, prior experience in Kiribati became the reference point and internal perception of the Project changed. Sharma and Paudel (2015) provide a short review of the manner in which the arrival of humanitarian aid and international disaster risk experts after the 2015 Nepal earthquake impacted the fragile political climate and saw disaster response practices from other jurisdictions enacted very rapidly and chaotically without the rational deliberation believed to accompany traditional policy transfer.

Applying the theories and techniques of policy mobility studies to applied volcanology may therefore yield valuable insights into the diverse state of volcanic disaster risk reduction policy and the reasons for this. Given the urgency with which applied volcanology pursues the ideal of 'best practices', a critical investigation, based around deconstructing that concept may contribute a unique understanding which may lead to improved standards of volcanic disaster risk reduction.

Chapter 3
Mobile Methodologies in the Study of Volcanic Risk Governance

3.1. Policy Mobility Studies: Analytical Framework and Methods

Policy mobility studies (PMS) is a part of the wider interdisciplinary field of critical policy studies (Peck and Theodore, 2012). Arguably, all forms of policy analysis fall into one of two categories: analysis *for* policy refers to research conducted for the purposes of policy development, generally commissioned by policymakers (functional framework); analysis *of* policy is more typically an academic exercise, seeking independent understanding of policy problems and processes without a policy goal (critical framework) (Bell and Stevenson, 2006; Taskoh, 2014).

McCann and Ward (2012) clarify that PMS has generally endeavoured to critically observe, record and analyse the movement of policy knowledge. They outline the following 'mobile methodologies' tailored to tracing the creation, circulation and impact of mobile policy: "content analysis, analysis of citation reports, discourse analysis, oral histories, mapping knowledge domains and networks, ethnography, interviews, direct and participant observation, questionnaires (and) field notes." McCann and Ward (2014) further justify the application of these approaches (both in their own field of urban studies and more broadly):

> *We contend that qualitative empirical investigations of case studies are a necessary element in any conceptualization of mobile policy. In doing so, we pay close attention to: 1) how urban policies are set "in motion" globally and how geographically-extensive circuits of policy knowledge and the transfer of policy models influence the governance of specific cities; 2) how the "making up" of policy [Ward 2006] is a fundamentally territorialized and political process, contingent on specific historical-geographical circumstances, and 3) how this case study says something about instances of sameness and of difference in a world in which instances of serial policy reproduction seem all too common, but that nevertheless should not be assumed.*

Drawing on McCann and Ward's 'mobile methodologies', Sharma and Paudel (2015) propose the following methods for researching mobilities in disaster response policy at local, national and international level: case studies, cross-case comparisons and policy narrative/discourse analysis. Kennedy (2015) also argues that future PMS research should place greater focus on the importance of 'stories' in the movement of policies.

This is an academic investigation, therefore the critical framework of PMS is employed. However, because this is an interdisciplinary project incorporating the disciplines of applied volcanology and disaster risk science, we also aim to suggest how these critical reflections may 'improve' future volcanic risk reduction (VRR) policy. These factors provide this project with several considerations for applying PMS research methods to the development of volcanic risk governance:

(1) The project must consider the importance of temporal and geospatial factors in the development and movement of VRR ideas from one site to another. Employing a hybrid of historical and geographical methods to investigate these 'specific historical-geographical circumstances' is intrinsic to this approach.

(2) Networks of knowledge exchange or 'technocracies' (Prince, 2015) are a prolific means of facilitating the movement of policy models between sites. These arguably form the framework that holds together the global policy field across scales. Therefore, this project should assess how 'expert' networks have shaped the movement of volcanic risk policies and practices over time.

(3) Multiple case studies should be compared in order to evaluate and contextualise policies at particular volcanoes (the sites at which VRR policy manifests) with respect to others. Case studies are a standard unit of investigation throughout the policy mobilities literature (e.g. Clarke, 2009, 2011; Peck and Theodore, 2010, 2012; McCann, 2011; McCann and Ward, 2012, 2014, Kennedy, 2015).

3.2. Narrative Case Study Methodologies

Yin (2003) argues that case study methodologies are appropriate under the following conditions:

1. The type of research questions: typically to answer questions like 'how' and 'why'?

2. Extent of control over behavioural events: when researcher has little/no possibility to control the events.

3. General circumstances of the phenomenon to be studied: contemporary phenomenon in a real-life context.

This investigation is concerned with 'how' and 'why' knowledge about volcanic risk circulates around the world in the effort to derive 'best practice' volcanic risk reduction. The degree of control this project has had over these processes is minimal. These are real-life phenomena which cannot be effectively reproduced under artificial circumstances.

McCann and Ward's (2014) contention that PMS case studies should "say something about instances of sameness and of difference" suggests that the project should compare cases. We therefore employ multiple case studies to demonstrate the role of mobile policy on the development of volcanic risk governance at geographically diverse volcanoes and in the construction of the global policy field that links them.

3.2.1. Narrative Analysis Methods

The first part of the process is to outline the development and makeup of the global policy field. Chapter 4 constructs a history of volcanic risk governance to date with a focus on the role of the exchange of information across space and time in shaping policy and practice. This is presented in the form of a chronological narrative in order to capture the 'specific historical-geographical circumstances' of mobile policy in VRR.

Historical enquiry "...inevitably uses the process of narrative linkage if history is understood as portraying past events with the coherence, logical consistency and significance demanded by the concept of history since the 18th Century" (Fulda, 2014). Narratives are arguably fundamental to how humans experience existence, as a sequence of events, through causes and effects (Jones and McBeth, 2010). Narrative policy analyses view the construction of public policy as a composite of sequences of events and perspectives which can be compiled, compared and contrasted in order to derive a representative 'meta-narrative' from a range of available sources, or 'small stories' (Baynham and Georgakopolou, 2006). Jones and McBeth (2010) note that narrative policy analyses can focus on multiple levels, which they name the macro (global), meso (institutional), or micro (personal). Given this project's focus on the impact of globe-spanning processes of knowledge exchange, documenting their impact at specific geographic sites (volcanoes), our narrative analyses aim to encompass these three levels. The term 'macro' is used to describe processes and assemblages on the global policy field which span or link more than one national jurisdiction, 'meso' to describe the distinct national-level context where decision-making power tends to lie, and 'micro' for the local-level policy fields that manifest around distinct volcanoes, and their constituent assemblages.

Meta-narratives are central to the post-positivist school of critical policy studies, which contends that reality can never be depicted completely accurately by one observer due to each observer's own prejudices and circumstances, ergo the 'truth' must be aggregated by drawing together (sometimes conflicting) accounts (Jones and McBeth, 2010; Hampton, 2011; Sharma and Paudel, 2015). No narrative can seek to provide a literal transcription of everything that has occurred during the time span it covers. In the construction of any meta-narrative, certain events and periods elicit greater focus than others. As such, this study's meta-narratives are 'kairotic', or 'event-driven' (Czarniawska, 2010). We first create a chronological timeline of events pertaining to volcanic risk governance to provide the 'bones' for the meta-narrative. Hollis (2014) provides an example of how this may be achieved in the context of general disaster risk governance (Table 3.1).

Table 3.1 Key moments in the history of disaster risk governance according to Hollis (2014). It is worth noting that, as mentioned above, sequential qualitative studies are generally not all-encompassing/holistic and Hollis' timeline does not include every significant historical development in the history of DRR; omitting, for example, the mid-20th Century role of the 'Chicago School' (e.g. Gilbert F. White and Robert Kates) in the development of a post-positivist understanding of disaster risk that acknowledged the role of subjective social factors in governing the behaviour of communities exposed to disaster risk - contrary to prior work which had sought the 'solution' to disasters through purely engineering-based or economic means (Tobin and Montz, 1997).

Year	Event	Related Policy Field
1755	Expression of external relief aid to Lisbon earthquake	Humanitarianism
1863	International Committee of the Red Cross (ICRC)	Humanitarianism
1877	St John Ambulance Association	Humanitarianism
1882	*Samariterverein*	Humanitarianism
1891	Royal Life Saving Society	Humanitarianism
1927	International Relief Union	Humanitarianism
1948	UN Human Rights Charter	Humanitarianism
1949	Truman's 4-point plan	Development
1972	UN Office of the Disaster Relief Coordinator	Disaster Risk Reduction
1972	Stockholm Conference	Development
1987	Brundtland report	Development
1990–99	International Decade for Natural Disaster Reduction	Disaster Risk Reduction
1992	International Earth Summit – Agenda 21	Development
1994	Yokohama Strategy and Plan of Action for a Safer World	Disaster Risk Reduction
	IFRC Code of Conduct	Humanitarianism/Disaster Risk Reduction
1997	The Sphere Project	Humanitarianism
2000	Millennium Deceleration	Humanitarianism/Development/Disaster Risk Reduction
2000	UN International Strategy for Disaster Reduction (UNISDR)	Disaster Risk Reduction
2002	World Summit on Sustainable Development	Development
2002	Millennium Development Goals	Humanitarianism/Development
2005	Hyogo Framework Programme for Action (HFA)	Disaster Risk Reduction
2005	Global Forum for Disaster Risk Reduction	Disaster Risk Reduction

Siebert et al. (2010) provide the most extensive chronology of Holocene volcanism to date. This is a database covering thousands of eruptions from 1,448 volcanoes. In creating our timeline, we identify relevant entries from this list along with those from Hollis (2014) and other documentary sources such as Witham's (2005) database of volcanic disasters and incidents in the 20th Century, Auker's et al. (2013) analysis of the historical volcanic fatalities record and both editions of the *Encyclopaedia of Volcanoes* (Sigurdsson, 1999; 2015). Such a chronological list becomes a narrative once imbued with meaning through linguistic description of the causal relations between entries (Feldman et al. 2004). In order to derive the meaning of each entry, we identify sources of data or 'small stories' regarding each event in the timeline and 'stitch' these together. The data for this process have been derived from primary and secondary documentary sources, including policy documents and government reports, peer-reviewed articles, media articles textbooks, reports from conferences or documentation relating to projects/organisations within volcanology and disaster risk governance.

Narrative analysis methods may focus on content, structure or context (Roe, 1994; Stone, 2002; Frost and Oullette, 2011). Feldman et al. (2004) contend that: "The use of any analytical tool must be related to the question being asked of the data. The ways scholars use this analysis will vary by the content of their research questions and the kinds of data they have." As we seek to analyse the substance of VRR policies rather than prioritising the stories' semantics or the circumstances of their narration, 'content analysis' is prioritised. Exemplary 'themes of analysis' for the meta-narrative stem from McCann and Ward's (2012) 'follow the policy' questions, which include:

> *How are policies made mobile? What calculative technologies and political contexts facilitate mobile policy? What situations, transit points and 'sites of persuasion' do policies travel through? How do policies mutate as they travel? What are the consequences for the places through which the policies are moved? How do mobile policies impact the character and politics of places?*

In satisfying the geospatial element of McCann and Ward's (2012) 'follow the policy' process, we seek to understand VRR policy assemblages, their components and the topologies of knowledge exchange that have contributed to their construction. These may include organisations and policy apparatus (legally constituted and informal) at the macro, meso, and micro levels - projects which belong to/link these organisations - and individual actors. In satisfying the temporal element, we seek to 'follow' the evolution of these assemblages (and their consequences) over the course of the event-driven narrative, wherever possible starting at the historical inception of risk governance at a particular volcano. Frequent analytical commentary pertaining to these themes of investigation is woven throughout the narratives and key 'findings' are highlighted and summarised.

The global-level narrative in Chapter 4 compiles 'small stories' from volcanoes around the world to illustrate the changing state of volcanic risk governance throughout human history and the role of the global policy field in its evolution. Seawright and Gerring (2008) state that case-based studies frequently derive knowledge from 'background cases', examples which are not examined to the same extent as the 'main' case studies but nonetheless play a key role in informing the investigation overall. Chapter 4 is a rich tapestry of 'background cases', providing a contextual backdrop for the subsequent (Chapters 5 and 6), more in-depth case studies.

3.2.2 Selection of Case Studies

From the global-level history presented in Chapter 4, we identify five case study volcanoes with volcanic or policy characteristics that exemplify interesting parallels and differences in volcanic risk governance. These volcanoes have been, in turn, subjected to the narrative analysis methods detailed above, extending the investigation to the meso (Chapter 5) and micro (Chapter 6) levels.

Volcán de Colima, México is the central case study (Chapter 6) for this investigation. This volcano was one of the examples which most prominently displayed the flaws of the Behavioural model of emergency management, mobilised through the UNDRO (1985) manual (Macías and Aguirre, 2006). Volcanic risk governance at Volcán de Colima has not undergone significant subsequent reform at the time of writing, despite frequent potentially hazardous activity at the volcano. In 1990, Volcán de Colima was designated a 'Decade Volcano' of special scientific interest by IAVCEI because it satisfied the following criteria: it is representative of one or more hazards, it is active, it is in a populated area and there are local organisations dedicated to its study (Barberi et al. 1990). These aspects and many more exposed in Chapter 6 have made this volcano an ideal example of the role of policy mobilities, mutations and assemblages in the idiosyncratic development of volcanic risk governance. An ethnographic field study has been undertaken at this volcano, which forms the core 'micro level' component of this research.

A suite of four case study volcanoes have been juxtaposed with Volcán de Colima. A major reason that the field of policy mobilities emerged and distinguished itself from the earlier policy transfer research was due to an acknowledgement that the movement of policies is seldom rational (Peck and Theodore, 2010). As such, rather than establishing a set of rigid criteria to identify case studies, we have instead identified volcanoes with differing (volcanological and socio-political) characteristics which suggest that comparison with Colima may be interesting from a PMS perspective. These volcanoes are briefly described below:

Gunung Merapi, Indonesia (Section 5.1) is a highly active 'Decade Volcano' which was part of a 'twin volcanoes' exchange programme with Volcán de Colima due to perceived similarities, although this was later abandoned due to lack of funds (IAVCEI, 1999; Gavilanes, pers. comm. 2016; Newhall, pers. comm. 2017). Merapi provides an excellent example of a long-existing, slowly evolving volcanic risk governance framework in a less economically developed context that has been confronted with multiple small-to-medium scale disaster events and subject to very different processes of knowledge exchange through time.

Volcán Nevado del Ruiz, Colombia (Section 5.2), is a glaciated stratovolcano, and the site of the second-highest volcanic death toll of the 20th century. Resultantly Colombia developed a national disaster risk reduction sector which provided the blueprint for global reform during the IDNDR (Bruce, 2002; UNISDR, 2015). Like Volcán de Colima, Nevado del Ruiz straddles two semi-autonomous authority areas. An exchange program between Nevado del Ruiz and Mount Rainier based on similar volcanic hazards was initiated in 2012 (Ciudad Region, 2012).

Mount Rainier, United States of America (Section 5.3), a glaciated stratovolcano and part of the 'Decade Volcano' project which, unlike Volcán de Colima and Merapi, has not erupted significantly in modern human history. Nonetheless, at this volcano, a volcanic risk reduction system designed via consultation with local communities, businesses, scientists and politicians has resulted in a strategy which arguably more closely resembles the 'disaster risk reduction' paradigm (PCDEM, 2008). This example allows for comparison with a volcano in a more economically developed setting and without the immediate political pressure of impending volcanic activity.

Popocatépetl, México (Section 5.4) is a highly active stratovolcano located within the same national context as Volcán de Colima. Despite this fact, and although some of the components mobilised from 'elsewhere' and used in the development of VRR policy at both volcanoes are the same (e.g. the UNDRO [1985] *Volcanic Emergency Management* manual), there are significant differences at each with respect to the timelines for policy development, the topological connections formed with sites and actors 'elsewhere' on the global policy field of VRR, and the resulting VRR policy frameworks. Popocatépetl is an ideal example for illustrating the unpredictability and complexity of mobile policy due to these parallels and divergences with the central case study.

The narrative policy analysis of each of these volcanoes repeats the methods used for Chapter 4, constructing event-based chronologies and tracing the development of policy assemblages through these.

3.2.3. Ethnographic Field Research

Field research at Volcán de Colima has utilised the full range of 'mobile methodologies' outlined by McCann and Ward (2012) (Section 3.1). During two field seasons between 5th February 2017 until 2nd July 2018 and 24th January 2018 until 9th May 2019, I conducted an ethnographic study based at the *Universidad de Colima*, the institution currently responsible for the bulk of official monitoring at Volcán de Colima. With kind permission and co-operation of Dr Nick Varley, I was able to work in the offices of the *Colima Intercambio e Investigación en Vulcanología* (Colima Exchange and Research in Volcanology, or CIIV), an exchange programme of the Faculty of Sciences that offers foreign students voluntary internships to assist in volcano monitoring. The core findings are presented in Chapter 6.

Ethnography is an umbrella term for detailed qualitative assessment of every day life and practice in a particular setting; encompassing interviews/questionnaires and observations (Hoey, 2014; Fetterman, 2010). When combined with the narrative case study approach (Section 3.2.1 and 3.2.2.), the full suite of available methods intersects well with Yin's (1994) six sources of data in the case study protocol: documentation, archival records, interviews, direct observation, participant observation, and physical artefacts. Marrero et al. (2015) consider research at the personal level necessary in order to understand the internal workings of disaster risk reduction systems. Peck and Theodore (2010) state that ethnographic methods are "...in many ways well-suited to the challenges of studying embodied policy knowledges and mutating technologies of government", but argue that these methods intrinsically pay less attention to macroinstitutional frameworks. By combining this micro-level research (Chapter 6) with the meso (Chapter 5) and macro-level (Chapter 4) research, this project has sought to create as comprehensive an understanding of the mobilities within volcanic risk reduction as possible with the time and resources available. The blend of ethnography, historical enquiry, human geography and applied volcanology used in this study of policy mobility can be regarded as a form of methodological *bricolage* (Lévi-Strauss, 1966) - a 'multimethodological approach to qualitative enquiry' which allows the researcher a dual role of engaging directly with the situational specifics of the data encountered at their field site(s) whilst retaining a connection with the broader scholastic/theoretical implications of those data (O'Regan, 2015). This study's unique *bricolage* has drawn upon Lorimer's (2009) notion of 'making-do' - bringing together information derived via archival and field-based research that evolves through the doing of the investigation rather than adhering rigidly to one pre-existing, purist methodological framework:

> *Amidst any cross-disciplinary traffic of ideas and techniques concerning the fragmentary past, the specifics of method can still be hard to pre-plan. More likely, they are fallen upon ,or opportunistically designed. To do so requires that faith be kept in immediate surroundings and our human abilities to perceive them. With exploratory mapwork, educated guesswork and direct observation, things from the past issue forth, and begin to connect up. In places, they abound: to saturation point, or standing proud. In others, they remain concealed, squirreled away, needing to be chiseled out... What yet can be grubbed up and snuffled out? With whom can conversations be struck? What living memories remain? What kinds of return can be made?...*
>
> *Making-do might usefully be thought of as collagist and chthonic, in character and, being of earthly making, considered portable to all manner of other places… As such, making-do can be understood as an adaptive mode of inquiry.* (Lorimer, 2009)

During my time at CIIV, I kept a diary of observations based on my experiences working every day in the institution monitoring Volcán de Colima, and identified individuals from across the local (and national) VRR policy field whose stories and perspectives would be used to construct a detailed historical narrative of the development of volcanic risk governance. I conducted 26 formal interviews with 22 individuals, including university volcanologists, state and national civil protection authorities - as well as many informal conversations during my time at CIIV and attendance of three international volcanology conferences (CoV 9, Puerto Varas, Chile, November 2016; IAVCEI Scientific Assembly, Portland, Oregon, USA, August 2017; and CoV 10, Naples, Italy, September 2018).

Formal interviews were conducted in English and Spanish, recorded using the "voice recorder" application on my HTC One mobile phone (password protected according to Lancaster University ethics standards). These data were subsequently transferred to my password-protected Hewlitt-Packard Pavilion 15 notebook PC. All formal interviewees received Participant Information Sheets and completed Consent Forms in accordance with ethics standards. I fully transcribed all formal interviews in English (translating those conducted in Spanish). Because I was interested in using the interview data to construct a chronological meta-narrative, I obtained narratives from my interviewees by asking the open question "tell me the story of your involvement in risk governance at Volcán de Colima" (or variants thereof) and encouraging interviewees to recount their experiences from the beginning to the present (or the end, if they were no longer involved). These narratives were complimented by unstructured questions, generally dictated by the content of the preceding information.

Interview data have been incorporated into the chronology for the Volcán de Colima case study (and additionally the Popocatépetl case study), arranged thematically and according to the timeline. Where permission has been given, interviewees are identified by name (except in situations where the information or opinions given is judged as potentially harmful to relationships on the policy field and may ultimately do more damage than help to 'improve' volcanic risk governance if the identity of the interviewee is revealed, in which case the interviewee is referred to by the number of the interview). Otherwise, interviewees are referred to by the number of the interview. Complementing the secondary-research led narrative analysis with these ethnographic data provides the meta-narrative for the Volcán de Colima case study with a broader range of sources and permits analysis at a depth which would not be achievable otherwise.

3.2.4 Cross-Case Analyses

Analysis according to the theoretical framework of PMS is conducted throughout the construction of the case histories and woven through the narratives. This includes comparison between 'background' cases in Chapter 4, and between the 'main' cases in Chapters 5-6. In Chapter 7, a discursive analysis of the findings from Chapters 4-6 is presented. Khan and VanWynsberghe (2008) consider cross-case analysis an ideal methodology for exploring the mobilisation of knowledge between cases:

> *"Cross-case analysis enables case study researchers to delineate the combination of factors that may have contributed to the outcomes of the case, seek or construct an explanation as to why one case is different or the same as others, make sense of puzzling or unique findings, or further articulate the concepts, hypotheses, or theories discovered or constructed from the original case. Cross-case analysis enhances researchers' capacities to understand how relationships may exist among discrete cases, accumulate knowledge from the original case, refine and develop concepts (RAGIN, 1997), and build or test theory (ECKSTEIN, 2002). Furthermore, cross-case analysis allows the researcher to compare cases from one or more settings, communities, or groups."*

Khan and VanWynsberghe (2008) outline various methodologies for conducting cross-case analysis. This project takes inspiration from two of these - the 'multi-case' method and the 'process tracing' method - throughout Chapters 4-7. In the 'multi-case' method, a common problem (in this case an active volcano with an exposed population) is identified across a suite of case studies which also contain unique issues, and a series of research questions (in this case how, why, where and with what effects have processes of mobile policy influenced the development of volcanic risk governance) is applied across cases. In the 'process tracing' method, the course of a common process (in this case the development of a volcanic risk governance system) shared by multiple case studies, is charted, and the similarities and differences are highlighted. Process-tracing usually takes the form of a detailed narrative.

In Chapter 7, the general findings from the case narratives of Chapters 4-6 are summarised and thematic analyses are conducted, based on the following three concepts: the *aspirations* of those on the global policy field seeking to identify, promote and share 'best practices' in volcanic risk governance; the *complications* encountered in the process of circulating ideas pertaining to volcanic risk governance in particular volcanic settings; and the *considerations* suggested by the findings of this research in terms of overcoming those complications and reducing volcanic risk to a minimum at the maximum number of volcanoes.

Chapter 4
Volcanic Risk Governance Through Space and Time

This chapter presents an historical account of the development of volcanic risk governance with focus on the global mobility of knowledge and policy. Volcanic eruptions have impacted human societies since the origins of our species, but the historical record of volcanic eruptions is far from complete (Oppenheimer, 2011). Siebert et al. (2010) provide the most extensive chronology of Holocene volcanism to date, a database covering thousands of eruptions from 1,448 volcanoes. This chapter does not seek to exhaustively catalogue all policy responses to these, but to select examples to depict and explain the development of the global policy field of VRR and the mobilities therein.

4.1. Pre-Civil Defence Volcanic Risk Governance
4.1.1. Volcanic Risk Governance in Ancient Rome
The VEI 5 Plinian eruption of Mount Etna in 122 BCE was a rare event for a volcano that typically produces "quasipersistent Strombolian activity and frequent lava flows" (Coltelli et al. 1998). After this eruption the Sicilian city of Catania was exempted from paying 10 years' taxes to Rome following damages sustained through fire and roof collapse (Coltelli et al. 1998). The decision to grant the city a tax exemption illustrates that the impact of the eruption was sufficiently severe that the Roman Republic was willing to give up ten years' revenue from the most prosperous city in contemporary Sicily (Zappala, 2016) in order to aid its recovery.

Coltelli et al. (1998) identify another significant Etnaean eruption in 44 BCE. In a study of contemporary literature, Stothers and Rampino (1983) present no evidence of related policy decisions from Rome. Because the eruption occurred concurrently with the assassination of Julius Caesar, the ensuing vacuum of power may have precluded any attention being paid to a crisis in a relatively distant province and nullified the political capacity to respond, especially since the atmospheric impacts of the eruption were attributed to divine retribution for Caesar's assassination.

The 79 AD eruption of Mount Vesuvius was another VEI 5 eruption (and the origin of the nomenclature 'Plinian') in the area known at the time as *Italia*, the heartland of

Roman territory. The cities of Pompeii and Herculaneum were destroyed by a combination of airfall tephra, PDCs and lahars. By 79 AD, the Roman Republic had become the Roman Empire, governed by an autocratic Emperor. Rome's response to the eruption of Vesuvius was thus at the discretion of the incumbent premier, Titus. Titus made several policy responses. He authorised post-disaster relief from Imperial funds; Dobran (2006) states that Titus was: "instrumental in providing aid to the survivors". He appointed two ex-consuls to supervise restoration work and to deal with legalities. He also visited Sorrento, a relatively unscathed community south of the Bay of Naples where he dedicated a sundial to the disaster and minted commemorative coinage (Scandone et al. 1993; Oppenheimer, 2011).

This suggests that Titus treated his responsibility as seriously, if not more so than the Senate of the Republic had done nearly 200 years' prior. However, there is no evidence that 'lessons' from the former crisis had any bearing on the latter; the decisions and the political apparatus for taking them varied substantially. Oppenheimer (2011) states that after Titus' death (two years after the eruption):

> *...the devastation sent barely a ripple through the Roman world... there is virtually no further reference to the disaster in the extant literature of the day. The Campanian region lost its prestige as Rome's favourite playground but there was very little dent in its exports of agricultural products. Before long the fate of Pompeii and Herculaneum was just a vague memory in folklore.*

Both Dobran (2006) and Oppenheimer (2011) conclude that the area was uninhabitable for between two and three centuries; however, the eruption was largely forgotten afterwards, achieving its modern fame after excavations in the 1700s (Scandone et al. 1993).

These examples illustrate that governance decisions regarding volcanic eruptions are not a new phenomenon. They show that policy responses to volcanic crises may vary depending on eruptive and socio-political circumstances; sometimes personalities of decision-makers have a strong influence. They also suggest that it is possible for a volcanic crisis to have a significant societal impact at the time, to be recorded and archived, and for that information to have little to no application in the governance of future crises. Arguably, the majority of volcanic crises throughout human history have been of this 'discrete' variety, where VRR policy, formal or informal, is enacted without significant retention of knowledge. Although this has understandably been the case between geographically disparate volcanoes and societies, the above examples illustrate that this is also entirely possible at the same volcano, or within the same political jurisdiction. Indeed, although part of Campania was rendered uninhabitable following the 79 AD eruption of Vesuvius, it was populated again by the time of Vesuvius' VEI 4 eruption in 472 and again, by the time of the VEI 4 event in 1631, which was preceded by ~500 years of inactivity and which claimed ~6000 lives (Rolandi et al. 1993; Mastrolorenzo et al. 2002). If the 79 AD eruption did not re-enter the public consciousness until a century after the latter of these eruptions, it can be reasonably concluded that its 'lessons' did not prevent loss of life in either instance.

4.1.2. The Origin of International Disaster Relief

In Hollis' (2014) historical review of DRR policy, humanitarian aid is identified as the oldest form of governance response to disaster. Hollis states that:

> *Humanitarian aid has a long and well-documented history that, in terms of disaster relief, can be traced back to at least 1755 when King George II of England* [sic] *and the city of Hamburg sent relief aid to Lisbon in the aftermath of a great earthquake and a tsunami that destroyed most of the city. Reflecting emerging sentiments two years after the Lisbon earthquake, Emmer de Vattel wrote:* “all governments with an abundance of provisions should come to the assistance of those countries which have been smitten by disaster."

The instances from ancient Rome in examined Section 4.1.1 provide examples that post-disaster relief as a policy response is far older than 1755: "As long as there have been disasters, individuals and communities have tried to do something about them" (Haddow et al. 2007). However, the co-operation between sovereign states (i.e. macro-scale mobility) renders this event significant. Hollis argues that although this was an important precedent, the emerging 'humanitarian sensibility' did not become institutionalised until more than a century later (Section 4.1.3). This has parallels with

Northrup's (2005) assessment of the processes of early globalisation, or the 'great convergence' which saw global socio-political processes manifest 'irregularly at first and then with increasing force and speed...". Of the nine categories that form the modern global policy field of DRR according to Hannigan (2012), only 'national/local governments' and (arguably) 'the mass media' existed at this stage. This situation is seen to continue into the following (19th) century, wherein the rate of political change and interconnectedness would gradually begin to increase. Ferreira et al. (2016) argue that processes of early globalisation at the start of the 19th Century, associated with increased trade in food and raw materials, created the conditions by which powers in western Europe (particularly the United Kingdom of Great Britain and Ireland) were able to undertake the transition from a predominantly subsistance-based agrarian economy to a manufacturing-based industrial economy - through the *agricultural* and *industrial revolutions*. Industrialisation would have a transformative impact on governance generally, including the governance of disaster risk:

> *The terms* pre-industrial *and* industrial *were introduced by Gilbert White (1974, pp. 5) to describe characteristics* [sic] *ways in which human responses are related to level of economic development. In pre-industrial societies the emphasis is focused on responses that are,* inter alia*: predominantly locally- based, involving a wide range of actions; which are flexible and emphasise harmonisation with nature, action being taken by individuals and/or local groups. In contrast, industrial responses involve: the State to a much greater degree; emphasise technological control over nature and adopt more uniform responses* (Chester et al. 2015)

4.1.3. Volcanic Risk Governance in the 19th Century

In 1812, the House of Commons of the United Kingdom received a petition from the colonial government of the Caribbean island of Saint Vincent detailing the impacts of an eruption at the island's Soufrière volcano on 30th April that year. The eruption was a VEI 4 Sub-Plinian event (GVP, 2013). The affected territory was marked by 20 plantations all of which were "completely covered with stones, sand and scoria, and other volcanic substances, 10 inches deep, over a surface of more than 6,000 acres" (House of Commons, 1812).

The report contains four letters from estate proprietors and administrators, an account of the eruption and two loss estimations, one calculated by estate owners, (£110,000) and the other by a committee authorised to investigate the losses (£79,045 and 5 shillings). Most of the 80 fatalities occurred among the island's black slave population, whose 'huts' collapsed more readily than colonial homesteads (Clifford, 2017). One of the extracts states, "If we do not get relief, I fear we must abandon our estates, and our poor Negroes must be divided into lots, and sold for the benefit of our creditors, and their families torn from one another" (House of Commons, 1812). The impact of power structures on social vulnerability is starkly evident, perhaps to be expected of a governance model where racial subjugation was an explicit feature.

The report emphasises the eruption as an unprecedented event within the context of British colonialism. Thus, as empire-building expanded the British polity. new challenges, including volcanic risk, were encountered. At this stage, scientific understanding of volcanoes was such that volcanic landforms discovered before the eruption did not lead the settlers to realise the risks of their new home. Clifford (2017) notes that British media did show "some interest" in the eruption, but the government was more concerned with the forthcoming war with the USA. A House of Commons publication from 1814 states that £25,000 was eventually donated to the survivors of Saint Vincent by the British government (House of Commons, 1814).

From this case, several prominent features can be identified: limited scientific understanding inhibiting *ex ante* action to avert volcanic disaster; predominantly reactive, relief-centred policy solutions; and prioritisation of social elites at the expense of others exposed to volcanic hazards. Despite other inconsistencies, these three themes recur throughout the 19th Century. Another of Hannigan's (2012) 'field constituents' can also be seen to emerge in this example: the private sector, as loss to businesses forms a key part of the petition.

The April 1815 eruption of Mount Tambora (Sumbawa, Indonesia) was a VEI 7 ultra-Plinian event with the highest known death toll from a single eruption - an estimated minimum of 60,000 fatalities (GVP, 2013; Auker et al. 2013). At the time, Sumbawa was governed as part of the Dutch East Indies, briefly subject to a British takeover (1811-1816) under Governor Thomas Stamford Raffles (Gallop, 2014).

Sumbawa was divided into six sultanates: Sumbawa, Bima, Dompo, Sanggar, Pekat and Tambora. It was notionally under the supervision of a colonial Resident. However, the sultanates, presided over by royals called *rajas*, remained largely self-governing (Oppenheimer 2011; Aritonang and Steenbrink, 2008). Oppenheimer notes a substantial precursory explosion, sending a plume to 33 km above sea level on the evening of 5th April. Several sultanates were sufficiently alarmed that they requested aid from the Resident's office who responded by sending an official named Israel to investigate. D'arcy Wood (2014) states that by 10th April, Israel had arrived on the slopes of Tambora when the climactic phase of the eruption began, becoming one of the first casualties.

In Yogyakarta, the British administration believed the noise to be cannon fire and despatched a military unit. Independently of this, two relief ships were sent to sea from other port towns, with the expectation that ships were under attack (Oppenheimer, 2011).

The raja of Sanggar survived with some of his family and community. D'arcy Wood (2014) speculates that he may have used royal prerogative to secure the fastest horses and left early enough to avoid the worst of the eruption, although his daughter later died, drinking ash-contaminated water. The raja sought an audience with Lt. Owen Phillips of the British Royal Navy. D'arcy Wood states that the raja's account moved Phillips to grant him several tons of rice and quote him in writings to Governor Raffles.

Most of these governance responses had very little impact in reducing human losses (i.e. sending troops and boats to tackle a non-existent military threat due to a misinterpretation of volcanic signals; or sending Israel to his death). The escape of the raja, his family and his court was a decision taken by a governing figure in response to the eruption and is an example of a successful evacuation (albeit one that prioritised social elites). Lt. Phillips' decision to donate rice may have been an act that alleviated human suffering in the wake of the eruption, but this was a personal decision, not rooted in a policy framework (in any sense other than Phillips' colonial position of power). Phillips' donation was also significantly smaller than need created by the crisis. Oppenheimer (2011) notes that the eruption and the famine afterwards claimed between 60,000 and 120,000 lives, with victims recorded on islands, distant from Sumbawa (e.g. Bali). On Sumbawa, the famine apparently led to thousands selling their children into slavery to be able to afford a small quantity of rice, an extreme example of an informal policy decision taken by a community under duress. The eruption caused a mean global temperature drop of 3ºC, killing crops in Europe and North America (UCAR, 2012). With the possible exception of despatching Israel, the actions taken were reactive responses to events already in motion (and even Israel's mission was in reaction to a precursory explosion).

It can be reasonably concluded that few of the actions of the incumbent regimes had a significant impact in reducing losses. It is also worth noting that neither the foreign aid precedent established in 1755 (section 4.1.2) nor the aid supplied to Saint Vincent appear to have influenced the governance responses to Tambora. In 1822, after the Dutch re-established control, a VEI 5 eruption of Gunung Galunggung on the island of Java killed 4,011 people.

In 1822, in Abuta village, Hokkaido, Japan, an earthquake swarm at 02:00 on 10th March concerned Shigematsu Ban-uemon, a local samurai official. An elder resident suggested, based on past experience, that this could mean the nearby volcano, Usu was going to erupt. Ban-uemon suggested locals prepare to evacuate. 60 hours later, when the first explosions started, he ordered locals to flee to two more distant villages. After 10 days, during which ash had fallen up to 15 cm thick 22 km from the volcano, heavy rain drove some of the evacuees back to Abuta against the evacuation order. The following day, a PDC destroyed Abuta, killing 80, although a rescue did save some survivors. After this, the roads to the affected area of the volcano were closed. When ashfall contaminated water at the shelters, Ban-uemon arranged for evacuees to relocate further from the volcano. The eruption lasted four months (Tsukui, 2013).

Several aspects of the Usu crisis provide interesting counterpoints to other Section 4.1.2 examples. Firstly, although not based on quantitative volcano monitoring, correctly identified precursors allowed for *ex ante* action and an (initially) successful evacuation. Secondly, the use of the elder's knowledge illustrated that lessons learned during prior eruptions *could* influence governance. Thirdly, although rooted in hierarchical Japanese feudalism, the officials appear to have acted to benefit all those exposed and been adaptable, learning from the deaths in Abuta by closing the road and realising the current shelters were no longer suitable when the water became contaminated. The 1822 Usu volcanic crisis was, however, in many respects another example of a 'discrete' or 'bounded' micro/meso level event, in terms of mobility of knowledge in space and time. No evidence has been found that lessons from this eruption had any influence during subsequent eruptions in Hokkaido in 1853 and 1856.

During the 1835 VEI 5 eruption of Cosiguina volcano in Nicaragua, the decision taken by the authorities to combat the darkness from ashfall was somewhat different:

> *The garrison of the town at the same time kept up incessant discharges of cannon and musketry, which was done by the order of the government, by the mind of some intelligent chemists, who thought by such means, by letting off rockets, lighting fires, and causing all the church bells to be rung, the atmosphere might be cleared.* (Galindo, 1835).

Galindo also notes that 350 miles away in Belize, British authorities thought the noise of the eruption was cannon fire and launched a cannon offensive. Inconsistency remained a key feature of the embryonic policy field of volcanic risk.

In 1841, following two petitions from the Academy of Sciences in Naples in 1806 and 1829, King Ferdinand II of Bourbon approved the establishment of the *Osservatorio Vesuviano*. This was the world's first dedicated volcano observatory and a significant precedent for volcanology (INGV, 2012).

Hollis (2014) argues that the 'humanitarian sensibility' began to be formally institutionalised in 1863 when the Geneva Society of Public Welfare convened a conference at which 16 national governments and four philanthropic organisations were represented, establishing the International Relief Committee for Injured

Combatants, which by 1875 had become the International Committee of the Red Cross, with individual committees in each country (ICRC, 1988). This was a significant macro-level development on the policy field of DRR. Hollis (2014) cites the St John Ambulance Association (1877), the *Samariterverein* (1882) and the Royal Life Saving Society (1891) as further examples of international humanitarian institutions coming into being around this time.

In August 1883, the midst of this period, a VEI 6 eruption occurred in the Dutch East Indies, on the island of Krakatau, in the Sunda Strait between Java and Sumatra. In 1883 Krakatau was uninhabited. Scarth (2001) summarises its social significance thus: "the Soenda Straits formed one of the most concentrated international shipping lanes in the world, funnelling trading vessels between Europe and the Far East. However, apart from the helmsmen, nobody needed to take much notice of Krakatau." Krakatau therefore formed an incidental backdrop to a key contemporary global site of mobility in goods, people, knowledge and policy.

The eruption of Krakatau began on 20th May, with related seismicity felt in the colonial capital, Batavia (now Jakarta) 155 km away, including by the director of the city observatory (Simkin and Fiske, 1983; Scarth, 2001). Early on 21st May, explosions prompted telegrams to be sent from Batavia to Willem Beijerinck, a local colonial administrator, requesting that he investigate. Beijerinck had dismissed reports from local fishermen that part of Krakatau was on fire, but following the messages from the capital, he sailed to the island to discover an ash cloud covering passing ships (Hamblyn, 2010).

The presence of a telegraph network allowed the Dutch administration in Batavia a demonstrably greater capacity for involvement in this volcanic crisis than the British authorities in Yogyakarta had during the eruption of Tambora. Indeed, it was interest from the capital that overrode scepticism from the local colonial authority. Telegraphy, combined with the constant sea traffic through the strait, meant that up-to-date reports could be regularly provided and the chances of the volcano's activity being misidentified were significantly reduced. However, Hamblyn (2010) indicates that none seemed to anticipate the possibility of a major disaster: "...once they had recovered from their initial disquiet, the European residents of Bantam and Batavia were delighted to have a newly active volcano within a week's reach of the capital." A week after the first explosions, the Netherlands-Indies Steamship Company took 86 day-trippers from Batavia to witness the activity. The excursion was chartered by J.A. Schuurman, on behalf of government geologist Rogier Verbeek. Verbeek had been involved in volcanological investigations in the Dutch East Indies, including crater measurements following the VEI 4 eruption of Merapi in 1872 (Voight et al, 2000; Section 5.1). Schuurman spent the trip taking notes and led a small party to the rim of the active crater (Scarth, 2001).

Activity continued through June and July (Scarth, 2001). The local division of the Dutch Topographic Survey sent the Chief of the Surveying Brigade in Bantam, Captain Ferzenaar, to the island on the 11th of August to determine the feasibility of conducting a full survey. In what became the last human landing on the island, Ferzenaar concluded that in its current state of activity, it was 'inadvisable' to attempt to realise a full survey (Hamblyn, 2010; Ormeling, 2013). Beijerinck, Schuurman and Ferzenaar's official excursions illustrate that there was interest in understanding more about the activity on Krakatau from the colonial authorities. However, the only way to learn was to send observers directly to high-risk areas, as had been the case with Israel in 1815. Although Ferzenaar made his assessment while activity persisted, there is no indication that anyone anticipated the possibility of the most intense phase of the eruption or the risk it represented. Colonial society continued to function as 'normal' with no further government reaction: "... in a district where earthquakes and volcanic outbursts are so frequent, this eruption of Krakatoa during the summer months of 1883 seems to have been regarded as nothing more than a nine-days' wonder, and soon ceased to attract any particular attention" (Symons, 1888).

On 26th August, the Plinian phase of the eruption began, marked by frequent explosions, significantly more powerful than those of the preceding months. Explosions and tsunami continued at intervals of approximately 10 minutes throughout the night and although many feared the collapse of their houses, the majority remained indoors (Thornton, 1997; Rinard Hinga, 2015). Willem Beijerinck did ask his wife, Johanna, and family to leave the coastal village of Katimbang. However, they waited to eat first, suggesting that they underestimated the immediate nature of the threat. The first major tsunami that evening inundated the community, partly destroying the Beijerincks' house. Willem survived by clinging to a tree. The family made their way to another house they owned inland, accompanied by around 3000 survivors. 16 acquaintances of the Beijerincks, were able to enter the house, most remained on the ground outside (Rinard Hinga, 2013). On the morning of the 27th, four explosions between 05:30 and 10:52 constituted the climactic phase of the eruption, during which >60% of Krakatau was destroyed and 18 km^3 of tephra was ejected, leaving a caldera approximately 7 km in diameter. The resulting ocean-traversing pyroclastic surges and tsunami officially killed 36,417 inhabitants of the coastal communities around the Sunda Strait (Simkin and Fiske, 1983; Auker et al. 2013). Although Morgan (2013) implies that the true death toll may have been higher, accounts suggest far smaller uncertainty regarding the total casualties from this eruption than from the Tambora event.

After the strongest explosion at 10:02, PDCs reached the Beijerinck house, killing a third of the survivors from Katimbang, including the youngest Beijerinck child. (Rinard Hinga, 2013). Although seriously injured, the remaining Beijerinck family survived a further four days. Johanna Beijerinck sent an old native man to the beach to signal for help to any passing vessels and one Captain Hoen eventually landed and found the family. He ordered locals to construct litters. They refused, saying they were without food and would starve. Hoen agreed to give them rice and salt and the family were carried to Hoen's ship and borne to hospital in Batavia where all made a full recovery (Grade 7 Advanced Science, 2016).

The number of fatalities illustrates that despite significant activity, including small-to-moderate tsunami preceding the strongest phase of the eruption, there was little understanding of the full extent of the hazard or vulnerability among the affected population (indigenous or colonial), thus little to no potential to form a policy response that reduced its impacts. Although the evacuation of Katimbang adhered to the power structures of colonial governance in the sense that Willem Beijerinck 'led' it, it was an impulsive reaction to the tsunami with no basis in Dutch colonial law and under no direction from the administration in Batavia. In this sense, it can be viewed as a micro-level informal policy that may have saved 2000 lives (notwithstanding the loss of a third of the total participants) but did not prevent the losses of tens of thousands elsewhere around the Sunda Strait.

At the meso level, the administration in Batavia assumed responsibility for post-eruption relief: "The first efforts of the Dutch Indian Government were, of course, directed to taking measures for the safety and relief of the survivors of this terrible catastrophe" (Symons, 1888). A man-of-war was despatched to clear a way through the pumice rafts in the Sunda Strait, and a survey ship investigated the changes in morphology of the channel.

> *In the aftermath of the Krakatau eruption, the Dutch government did a reasonably good job of providing disaster assistance, though critics charged that it was more concerned with providing succour to the tragedy's white survivors than with assisting afflicted Indonesian natives. Money was raised for disaster relief measures, food and blankets were distributed, roads were cleared and temporary shelters were reopened.* (Reilly, 2009)

There is abundant evidence that governance favoured colonial Europeans: the narratives are dominated by European voices. In the 1880s, Europeans constituted 0.5% of the population of the Dutch East Indies, but accounted for 60% of the taxable income; 97% of the population were indigenous Indonesians, collectively accounting for 20% of the taxable income (Beck, 2008). Although the volcano killed and destroyed property without prejudice, parts of Johanna Beijerinck's account, such as the rescue, illustrate the privileges of the colonial elite. Of the entire death toll, 37 were European (Symons, 1888). It can thus be understood that, although the post-disaster response in terms of supporting survivors was considerably more advanced than in any prior example in this chapter, it was selectively deployed. There was considerable anger among the indigenous population regarding this, although it did not manifest into collective political action at the time (Reilly, 2009).

Institutional racism aside, humanitarian aid was the keystone of the official response to the eruption; the centrally-authorised allocation of funds and distribution of resources shows a marked difference from the British regime's response to Tambora. There is no mention in any of the accounts examined of involvement from the international humanitarian institutions mentioned above; this seems to have originated with the Dutch colonial administration. However, as a global policy field began to manifest with 'humanitarian sensibility' at its core, the Dutch Indian relief policy can be viewed as part of the general 'direction of travel'.

At the macro level, it can be argued that Krakatau represents an event horizon. The telegraphic circulation of reports of the eruption "create(d) an entirely new category of disaster: the universal news event, a story followed, in the case of Krakatau, by more than half the world's population" (Hamblyn, 2010). As noted above, Tambora had profound global effects in 1815, but these were only attributed by later scientific investigations. In 1883, the accumulation and circulation of information accompanied the phenomena, virtually in real time (Simkin and Fiske [1983] note that communications travelled faster than some of the atmospheric effects, allowing their occurrence to be anticipated before being observed) making this a significant event in terms of both the international exchange of knowledge and the development of volcanology. By October 1883 the Dutch government established a commission to make a full scientific investigation; Rogier Verbeek was put in charge and the reports were published in Dutch and French (Morgan, 2013). It has been argued that Verbeek's quantitative approach represents the foundation for modern volcanology (Thornton, 1997). In the United Kingdom, the Royal Society established the multi-disciplinary "Krakatoa Committee" which augmented Verbeek's work with substantial data of their own, collating accounts and observations from many sources worldwide (Symons, 1888).

Consistent with Northrup's (2005) observations of the piecemeal nature of early globalisation, international knowledge mobility and the burgeoning science of volcanology did not have a consistent impact on every volcanic crisis following Krakatau, however, it indicated the trends to come. Despite interesting attributes, such as a several-day rescue effort at New Zealand's Mount Tarawera (Christchurch City Libraries, 2015) and the successful evacuation of six villages on the basis of precursory earthquakes at Tonga's Niuafo'ou (Seach, 2011), in 1886, these smaller eruptions did not become international news phenomena nor prompt extensive scientific investigation as in the case of Krakatau. The earliest encounter between international humanitarian aid and volcanic risk occurred during the 1888 eruption of Mount Bandai, Japan, with the first disaster response by the Japanese Red Cross

(Gorman, 2017). This eruption also saw two Japanese volcanologists publish a detailed study in English: (Sekiya and Kikuchi; 1890). This paper emerged in the wake of the Krakatau studies, illustrating a growing trend of international knowledge exchange regarding volcanoes.

At the close of the 19th century, the global policy field of volcanic risk governance now comprised five distinct (if still embryonic) constituent categories: national and local governments, NGOs, scientific and technical communities, private industry and a (far better connected) mass media. These would drive further developments in the century to come.

4.1.4. Volcanic Risk Governance in the Early 20th Century

1902 saw three significant volcanic disasters: 7th May eruption of Soufrière, Saint Vincent; 8th May eruption of Mont Pelée, Martinique and 24th October eruption of Santa María, Guatemala. These eruptions caused death tolls of 1,500, 28,800 and 8,700 respectively (Auker et al. 2013).

Saint Vincent remained under British governance. An 1897 commission concluded that investment from Westminster was required to prevent the bankruptcy of the region. The commission's recommendation was reluctantly accepted, and a series of grants were approved by Parliament (Besson and Momsen, 2007). Although slavery was abolished in 1834, the distribution of wealth and power remained skewed along racial lines and suffrage was not extended to those of non-European descent until 1951 (BBC, 2011). This was the backdrop against which the eruption of 1902 occurred.

From February through April 1902, earthquakes put the residents of northern Saint Vincent on alert. Two indigenous Carib communities petitioned the authorities to move away from the volcano. Officials were sent to reassure them that this was unnecessary. Anderson and Flett (1903) speculate that: "It may be that traditions linger among them regarding former disastrous eruptions...". Anderson and Flett meanwhile note that: "The white inhabitants regarded them with indifference or curiosity... There were some, however, who, aware of the suddenness with which the eruption of 1812 had broken out, could not help suspecting they foreboded another outburst." In this instance, the communities relying on oral tradition appear to have taken the risk seriously and tried to pro-actively reduce their vulnerability, more so than the elites who actively discouraged the Caribs. Anderson and Flett's account states that, following three strong earthquakes on April 29th the Carib community, "fully anticipating an outburst, were preparing to evacuate their houses and flee to Chateaubelair and other places of safety."

The eruption began on 6th May and the Carib community of Morne Ronde on the western side of the island immediately began evacuating. At 14:40, a loud explosion was heard and a plume became visible. Telecommunications allowed the authorities to transmit news of the eruption across the island (Anderson and Flett, 1903). By 17:00, Morne Ronde was deserted and what Anderson and Flett describe as a "general stampede" was occurring from other western settlements towards Chateaubelair. Constant telephone communication was maintained between Chateaubelair and the capital, Kingstown; the Chief Constable, the district Medical Officer and the capital's Medical Officer were despatched, arriving at midnight. Governor Llewelyn sent a telegram from Kingstown to London, alerting the Colonial Office, however the message was delayed in transit until the following day (Great Britain Colonial Office, 1902).

On the eastern side of the island, the crater could not be seen:

> *Telephonic messages had been sent from Kingstown to police headquarters at Georgetown that the people at Chateaubelair had seen steam arising from the crater. But a dense trade-wind cloud covered the mountain, the rumbling sounds were mistaken for thunder, and in the West Indies there is always so much untrustworthy news in circulation that it is not difficult to understand that this unexpected information was received with scepticism.* (Anderson and Flett, 1903).

Despite the presence of a more advanced telecommunications network than during previous volcanic crises, this event was not exempt from issues of misinterpretation and miscommunication.

The following day, the communities to the north became aware of the activity and evacuated. On the eastern side of the island, scepticism persisted, even after a group of fish sellers hiking over the volcano reached the crater at around 09:00, turned back and tried to report what they saw: "They were scoffed at as fools and cowards" (Anderson and Flett, 1903). A message arrived at ~11:00, stating that most western communities had evacuated. At this point, the estate managers decided that a party of white men should hike to the crater rim. En route, they encountered the fish sellers and, as they heard their story, ashfall began. The party returned to report the eruption. Some of the estates stopped work, evacuating to Georgetown, the largest settlement nearby. However, others continued working until lapilli began to fall and people retreated to their dwellings or the main buildings of their estates (Anderson and Flett, 1903).

At 14:00 on 7th May, the climactic phase of the eruption occurred and PDCs descended on all sides of the volcano, causing most of the ~1,500 deaths in the unevacuated eastern communities (Auker et al. 2013). Anderson and Flett conclude that: "had the leeward side of the hill not been free of mist, so that a view of the crater was obtained by those dwelling there, the loss of life would certainly have been greater..." The PDCs were visible from Chateaubelair. Most people evacuated by boat, but around 400 were left on the beach to evacuate by foot.

After the eruption, most of the easterly survivors made their way to Georgetown. Officials, clergy and volunteers formed a group to rescue as many of the "helpless injured" as possible and bring them to Georgetown hospital. Most survivors were re-housed there or in Kingstown. Anderson and Flett state that:

> *From Trinidad, from Jamaica, Barbados, St. Lucia, in fact from all the British islands of the Caribbean Sea, help was sent. The American Government, without delay, despatched the 'Dixie' with stores and medical comforts. Lists of subscriptions were opened in England and elsewhere, and money poured in with great rapidity. Nothing was omitted that could be done to save life or mitigate suffering.*

Thus, a substantial humanitarian response, coordinated over significant global distance, on the part of multiple jurisdictions, territories and sovereign states was a noteworthy feature of the governance of this volcanic crisis. A further explosion on 18th May prompted ad-hoc evacuations of both Chateaubelair and Georgetown.

The telegraphic communications presented in the papers of the Great Britain Colonial Office (1902) represent the primary method by which this intercontinental response was orchestrated, both internally, among imperial administrations (including non-Caribbean territories such as Mauritius, Australia and New Zealand), as well as with the governments of the USA, Canada and France. The eruption of Mont Pelée in the French Caribbean territory of Martinique (see below) on 8th May 1902, by virtue of spatial and temporal proximity, became inextricably incorporated into this policy assemblage. The actions taken were not based on 'hard law'. The discourse suggests all offers of assistance to be voluntary and based on the capacity of the donor (with amounts varying from £200 - >£25,000). Correspondences ran between 6th and 13th May. By the latter, the extent of both crises was apparent. Financial aid and ships with supplies, press and medics were despatched to both islands on 10th and 11th. By 17th May, Governor Llewelyn reported "all immediate wants" satisfied and monies were being raised for the financial support of the 2,200 survivors over the subsequent 6 months. The Royal Society scientific commission that produced the Anderson and Flett (1903) report into both eruptions was also arranged through these correspondences. Thus, the precedent of post-crisis scientific investigation established at Krakatau continued, furthering the science of volcanology and signalling the desire of authorities to learn from volcanic disasters with the aim of reducing their impacts in the future.

At the micro level, the community-based decision-making that led to the evacuation of Morne Ronde, which has the distinction of being a rare *ex ante* VRR strategy in this era, juxtaposed with more typical reactive self-evacuations seen during the eruption. The former appears to have been the most successful undertaking on the island in terms of reducing casualties.

At the meso level, the actions of the island administrators, after failing to respond to the precursors, involved sending officials into high-risk areas. This strategy had tragic consequences in some previous cases (e.g. Tambora), although in this crisis it arguably expedited the evacuation of Chateaubelair. Telecoms proved more effective in this crisis than in any previous case. A significant amount of the post-disaster relief was administered at the meso level. Despite the inequality which pervaded the society, all evacuees and survivors in need were fed and housed at the expense of the state for at least six months.

At the macro level, a cross-continental, international policy response provided the resources and political will for post-disaster relief, recovery and study, not just at this volcano, but at another which was part of a separate colonial administration. Although the topologies and assemblages were transient, they allude to a greater global interconnectedness than in any prior case. As the processes of convergence accelerated, the themes of institutionalised humanitarianism and science, identified by Hollis (2014), are observed to grow alongside sovereignty as prominent features of the global policy field of volcanic risk.

Prior to 1902, Mont Pelée, located in the north of Martinique in the Windward Islands, had only erupted once in recorded history, a small expulsion of ash in 1851. According to Anderson and Flett (1903): "The earlier stages of the eruption of this year, were of a precisely similar character, and this was one of the causes which lulled the suspicions of the inhabitants of St. Pierre and inspired in them a false sense of security." The Carib community of Martinique had named Mont Pelée 'fire mountain', suggesting awareness of its nature. However, the Caribs of Martinique were exterminated by settlers in 1635 (Scarth, 2002).

Anderson and Flett (1903) state that emissions began more than two weeks prior to the 8th May eruption. Although, initially it was "so gentle that it awakened only curiosities", activity incremented. Governor Louis Mouttet set up a commission to investigate, they climbed to the crater on 27th April, reporting a growing ash cone in the crater lake (Reed, 2002).

The political sphere on Martinique was, however, more concerned with impending elections on 11th May. The incumbent conservative party on the island, and mainland France, were concerned at the prospect of a black socialist gaining the vote of the majority black and mixed-race population. Most of the conservative voters lived in Saint Pierre, the capital, and authorities in Paris ordered Mouttet to keep them there (Reed, 2002). On 5th May, a section of the crater wall collapsed, creating a lahar which killed 23 people; however, the commission reported that "the safety of St. Pierre is assured" (Camp, 2004; Siebert et al. 2010). Mouttet convinced a conservative daily newspaper to state there was no risk from the volcano and many people from surrounding villages flocked to Saint Pierre, inflating the population to >28,000 (Camp, 2004). Camp notes that when some tried to leave, Mouttet ordered troops to turn them back.

On the morning of 8th May at 08:00, a PDC completely razed Saint Pierre. Of the 28,800 residents, there were three survivors (Camp, 2004). Governor Mouttet died in the PDC. Governance fell to one M. L'huerre, who corresponded with Governor Hodgson of Barbados, accepting the offer of aid (Great Britain Colonial Office, 1902). The only survivor in the city, a prisoner trapped underground, was rescued after three days, suggesting that despite the survival rate, rescue efforts were thorough (Reed, 2002). Originally medical officers were sent from UK territories and the USA, however with so few injured, it became apparent that the main problem would be extricating and feeding isolated communities north of Saint Pierre. On 20th May, a second PDC killed 2,000 working in the ruins of St. Pierre and on 30th August, another PDC destroyed Morne Rouge village, killing ~1,500 (Bresson, 2012; Rosen, 2015).

Much has been mentioned in this chapter regarding 'lessons of past eruptions' and the mobilisation of knowledge in a beneficial sense. However, this example illustrates that, although effective VRR is frequently derived from past lessons, past lessons are not endemically inured to create effective VRR. Indeed, there is little doubt that the governance of this crisis maximised the losses. The historical record in Martinique did not present the worst case scenario, and focus on the election limited the political will to objectively evaluate the risk. The rapid manifestation and poor understanding of the PDC hazards put reaction beyond the technical capacity of the society, such that, on three separate occasions in a four month period, >1,000 people died, illustrating that 'lessons' do not automatically emerge, mobilise, and result in affirmative action, even over distances of a few kilometres or a timescale of months.

The post-disaster relief operations were one significant macro-level result of this crisis. Another was the continued evolution of the international community coalescing around volcanology. Tanguy (1994) argues that contemporary volcanology exhibited an over-reliance on data from the only existing observatory at Vesuvius, which had not witnessed PDCs. Following this eruption, Albert Lacroix, a French volcanologist named them 'nuées ardentes' (glowing clouds) (Rosen, 2015). Lacroix was one of a number of scientists who converged on Mont Pelée, furthering the trend of post-eruption investigation and publication. Others included Anderson and Flett, Professor Jaggar of Harvard University, Professors Hill and Russell of the US National Geographic Society and Frank Perret, who operated a makeshift volcano observatory before Lacroix officially established the world's second observatory on the island (Anderson and Flett, 1903; Reed, 2002; Rosen, 2015). Auker et al. (2013) state that the aftermath of this eruption is most frequently cited as the true foundation of modern volcanology.

The 24th October eruption of Santa María, in Quetzaltenango, Guatemala, was the largest of the 1902 events, a VEI 6 ultra-Plinian eruption with a sector collapse (GVP, 2013). Strong earthquakes at the volcano had occurred throughout 1902 but, with no historical record, the eruption was unexpected (Williams and Self, 1983). The area affected was largely rural, and dominated by coffee plantations, but these were more crowded than normal as labourers had gathered for the harvest. An estimated 8,700 were killed (Anderson, 1908; Auker et al. 2013). Guatemala was under the dictatorship of Manuel Estrada Cabrera who wished to revive worship of the Roman goddess Minerva among his people and had organised a festival to this end on 27th and 28th October. The eruption threatened to spoil the festivities, so Cabrera's administration denied its occurrence. When this was no longer tenable, they published a claim that the eruption was occurring in México and that Guatemala was largely unaffected. Finally on the 3rd of November, the government recognised that the eruption had happened, but claimed: "The volcano expelled a faint rain of ash to a distance of 14 leagues [~80km], causing only the loss of some small coffee estates" (Pinto and Escobar, 1989).

Pinto and Escobar state that the victims were left without aid, to death, disease and economic hardship; it took years for the region to recover. In this crisis, the sovereign government entirely neglected humanitarianism, both internally and at the macro level which was so prominent in the crises of La Soufrière and Mont Pelée. However, the scientific community once again succeeded in mobilising information regarding the crisis to the global level, as scientists from Germany, Sweden and the USA visited the volcano soon after the eruption, publishing their observations (Ball, 2011a). Furthermore, Tempest Anderson (of Anderson and Flett) visited Santa María in full co-operation with the Cabrera regime to research his 1908 publication *Volcanoes of Guatemala*.

In 1912, Anderson's colleague from investigations in Latin America and the Caribbean, Thomas A. Jaggar, who had become head of Geology at Massachusetts Institute of Technology, founded the Hawai'i Volcano Observatory (HVO) with support from local businessmen. Reed (2002) states that Jaggar's effort to establish a permanent observatory in the US was inspired by the work on St. Vincent and Martinique in 1902. Watson (1997) argues that HVO pioneered putting 'modern' volcano monitoring techniques into practice simultaneously and continuously, including geological, seismological, geophysical and geochemical monitoring, a model adopted and "...presently employed by other observatories monitoring active volcanoes elsewhere, principally in Indonesia, Italy, Japan, Latin America, New Zealand, Lesser Antilles (Caribbean), Philippines, and Kamchatka." HVO was incorporated by the USA Federal Government in 1919 and placed under the permanent control of the US Geological Survey (USGS) in 1948 (Watson, 1997).

In 1918, the government of the Dutch East Indies established a commission to study volcanoes in western Sumatra (Van Padang, 1960). On 19th May 1919, the VEI 4 eruption of Gunung Kelud in East Java generated lahars which caused 5,235 deaths, destruction of 130 villages and a three-year economic downturn in the region of Blitar (GVP, 2013; Nihayatul et al. 2017). A dam had been constructed in 1905 to protect Blitar from lahars, but this was 'easily' overcome by the lahars of 1919 (Van Padang, 1960).

Nihayatul et al. (2017) detail the response to the crisis from the Council of Blitar. In the immediate aftermath, hospitals were overwhelmed and six emergency medical facilities were established. Resources and personnel were brought in from neighbouring regencies, paying for medicine, provisions and funerals, providing compensation (given to village administrators for each community), revitalising the agricultural sector as rapidly as possible and replacing utilities. The costs were significant and government spending was supplemented by community fundraising. "Kelud disaster awareness committees" were spontaneously formed in regencies such as Yogyakarta and Surabaya, and fundraising fairs attracted donations from local businesses.

Following the Kelud eruption, the volcanological commission was augmented to a "Volcanological Watching Service" and Dr. Kemmerling, the scientist in charge, was despatched to Kelud to continue the now-established practice of post-crisis investigation (Van Padang, 1960; Nihayatul et al, 2017). A week after the 1919 eruption, lectures were held in Batavia at which Dutch volcanologist Berend George Escher suggested that eruptive interaction with the crater lake was the cause of the lahars, and that it be drained. By 1926, the crater was drained via seven tunnels. In the subsequent eruption of 1951, no lahars were generated, although the eruption damaged the tunnels and lahars occurred once more during the next eruption in 1966 (Van Padang, 1960; GVP, 2013).

According to Smith and Petley (2009), before civil defence became commonplace on the global policy field, *ex ante* policy approaches to disaster risk tended to be based on scientific forecasting and structural engineering solutions. This study has found *ex post* aid to be the dominant governance response to volcanic risk during this period of history. Following embryonic examples at Vesuvius and Mont Pelée, a more holistic form of scientific forecasting of volcanic risk was being pioneered in Hawai'i and was on the cusp of becoming formal policy in the USA. It would be some time before this model would achieve global prevalence. However, the Dutch Indian government provides an example of institutionalised volcanology at the meso scale. Structural engineering solutions directed at volcanic hazards have historically been relatively rare. The Kelud tunnels are an uncommon but nonetheless significant example - this decision in 1919 arguably prevented deaths more than 30 years later. However, as the global policy field of DRR stood unknowingly on the cusp of a paradigm shift, these processes were a long way from consistently generating a meaningful reduction in losses from volcanic crises.

4.2. Volcanic Risk Governance in the era of Civil Defence and Emergency Management

The 20th Century saw transformations in the global policy field of DRR. These evolved over decades, however, one of the most significant drivers manifested very rapidly. A new category of field constituent emerged - the international governmental organisation (IGO). This was a shift, not just for DRR, but for global governance. Kennedy (1987) describes the end of the First World War as a break with the preceding narrative of 'international life'; and the inception of institutionalised practices which have perpetuated ever since. Claude (1971) names the 19th Century the era of *preparation for* international organisation, while the *establishment of* international organisation is "...a phenomenon of the 20th Century."

The League of Nations (LN) was a product of the 1919 Paris Peace Conference. The Covenant of the LN came into effect at the same time as the Treaty of Versailles on 10th January 1920 (Scott, 1973). The LN was composed of a secretariat, an assembly, a council and a range of commissions (Wilson, 2011). There were 42 member states at the foundation of the LN, and 58 at its greatest extent in 1934-35. Although US President, Woodrow Wilson was an 'architect' of the LN, the US never joined (Blucacz-Louisfert, 2002).

In 1927, the LN convened a conference, resulting in the *Convention Establishing an International Relief Union*, formalised in December 1932 (Macalister-Smith, 1981). The International Relief Union (IRU) was designed as a global 'mutual insurance' scheme whereby LN members would contribute to a 'pot' from which funds could be withdrawn at any time by any member in need. The IRU was consistently underfunded due to member states' general unwillingness to 'pay forward' for disasters which may or may not occur and largely ignored in favour of the Red Cross (Hannigan, 2012). Despite this, the Red Cross had played a significant role in the establishment of the IRU, having originally suggested a subdivision for disaster response to the LN in 1921 (Macalister-Smith, 1981).

Hannigan (2012) argues that preference of the Red Cross over the IRU illustrates the fundamental schism in the global policy field of DRR; the divide between 'apolitical' humanitarianism and 'human rights'. In this era, when communism was perceived as a threat, a human rights approach was considered too left-wing by influential member states. Soft law and NGO-based humanitarianism won out, maintaining the role of sovereignty and restricting hard law pertaining to disaster risk to the meso and micro levels. The *Convention Establishing an International Relief Union* remains the only article of hard international law in disaster risk governance to the present day.

> *...if the International Relief Union, in unexpurgated form, had somehow managed to beat the odds, we would have a framework for dealing with disasters that differs markedly from what we have today. There would be no need for the media-driven charity appeals that follow major catastrophes... Nor would there be any space for the thousands of NGOs and charities that currently descend on disaster-stricken regions... people around the world who are innocent victims of nature's wrath would have an unchallenged legal right to receive international assistance* (Hannigan, 2012).

In the 1930s, when Japan, Italy and Germany began breaching treaties, the LN was unable to agree a coherent policy response (Wilson, 2011). When the Second World War began as a result, the LN headquarters in Geneva were abandoned for the six years of conflict (Scott, 1973). These events saw the demise of both the LN and the IRU (Hollis, 2014).

The 'institutional turn' impacted the volcanological expert community as well. In August 1919, the constitutive assembly of the International Research Council (now the International Council for Science) in Brussels, Belgium created one of the first NGOs not focussed on humanitarian relief (ICSU, 2017). During this assembly, the International Union of Geodesy and Geophysics (IUGG), with a volcanology 'section', was also founded (Ismael-Zadeh, 2012). An associated journal, the *Bulletin Volcanologique* entered circulation in 1922 (IAVCEI, 2008). Thus, this period saw volcanology become progressively institutionalised at all three (macro, meso and micro) scales. The 'increasing force and speed' with which Northrup (2005) argues the forces of globalisation act after a slow and irregular start is evident in these developments. However, these processes were neither linear, nor universal. After the establishment of the observatory on Martinique, Mont Pelée entered a period of inactivity and it was decommissioned in 1925. The volcano began to erupt again in 1929 and the observatory had to be re-established (Reed, 2002). The 1929 eruption of Mont Pelée saw the authorities successfully evacuate communities in the north of Martinique. However, in the same year, a collapse of the Santiaguito dome on Santa María killed a further 3,080 (Ball, 2011b; Auker et al. 2013).

In 1930, the individual sections of the IUGG became semi-autonomous 'International Associations'. One of these was the 'International Association of Volcanology' (Ismael-Zadeh, 2012). By 1932, the 'Volcanological Watching Service' of the Dutch East Indies had become a 'Volcanological Survey', comprised of four European 'experts' and 18 other 'assistants' and 'observers' (predominantly native Indonesians). The survey aimed to permanently monitor seven volcanoes. The research was published in Dutch and English (Van Padang, 1960).

Although the 1930s saw six eruptions of VEI 4 or larger, the majority of these did not cause disasters (GVP, 2013). The June 1937 eruptions in Rabaul caldera, Territory of New Guinea, were a notable exception. The Territory was at the time under Australian administration, established via mandate from the LN, and Rabaul town was the seat of authority (Young, 2016). On 29th May, 1937 explosions from one of the cones in the caldera, produced ashfall over Rabaul and at the telegraphed request of the government, police in Vunapope, a community further down the coast and the local Catholic chaplaincy arranged evacuations by boat. Vunapope became "a great army camp" with more than 5000 native refugees, along with 240 Chinese and 70 Europeans. Government officials provided accommodation. After a week of free rations, evacuees were required to work - those who did not received nothing (Arculus and Johnson, 1981).

According to Blong (2013), 375 of the 441 fatalities were caused by suffocation due to tephra fall. By 9th June, the government were already ordering people back to Rabaul for restoration work (Arculus and Johnson, 1981). Governor McNicoll was criticised for focussing more on the restoration of the capital than aiding the worst affected villages, but received full support from the Australian government (Johnson and Threlfall, 1985).

The post-eruption investigation was conducted by Charles Stehn, head of the Netherlands Volcanological Survey, W.G. Woolnough, geological advisor to the Commonwealth and Norman Fisher, government geologist of New Guinea. Stehn and Fisher advocated the establishment of a fully instrumented observatory, whilst Woolnough believed that the territory was too dangerous and should be completely abandoned. A growing number of observatories had been established worldwide, now including Vesuvius, Etna, Kilauea, Pelée, and Aso and Asama in Japan. Fisher received volcanological training from Stehn in the Dutch East Indies in 1939 and obtained funds to found an observatory at Rabaul in 1940 (Johnson, 2013).

On 24th October, 1945, the United Nations (UN) came into being as the formal successor to the LN. The UN has since remained the most prolific and powerful IGO on the planet (Evers, 2012). Several organisations were transferred from the LN, including the International Labour Organisation, the International Court of Justice and the World Health Organisation (UN, 2010). A raft of new organisations also formed, and following the devastation of the war in Europe and beyond, several of these were focussed on the administration of humanitarian aid: the UN International Children's Emergency Fund, the International Refugee Organisation, the Food and Agriculture Organisation and the World Health Organisation become the "new vanguard of relief", with greater political clout than their predecessors (Hannigan, 2012). Hannigan notes that the IRU re-emerged in 1945 but was ignored by its member states and turned to promoting scientific research into disaster prevention until it was liquidated in 1968.

The establishment of the UN determined the trajectory of macro-level policy pertaining to disaster. As IGOs emerged alongside the pre-existing NGOs, a continued focus on *ex post* humanitarianism rooted in soft law was assured. However, post-war culture profoundly altered meso and micro level DRR policy as well. A notable feature of virtually every example featured in this narrative thus far is the informal and reactive nature of policy decision-making, due to a dearth of pre-written policy frameworks for addressing volcanic risks. However, through subsequent decades, disaster risk became a public policy issue.

The concept of civil defence emerged in the UK in the aftermath of the First World War, institutionalised in 1935 as the Civil Defence Service. During the Second World War in 1941, the United States followed suit (UNISDR, 2015). Governments assumed responsibility for defending citizens against military threats through emergency protocols. However, civil defence organisations also began to develop plans for environmental and social disasters, and over time this became their primary function (Alexander, 2002). Alexander uses the term 'civil protection' to distinguish the de-militarised version of the practice. Smith and Petley (2009) name 1950 as the beginning of the era of 'emergency management' and the dominance of the Behavioural approach (Section 2.3.1).

There were comparatively few volcanic crises during the early post-war period. Notable examples include the 1951 eruption of Mount Lamington in Australian-governed Papua New Guinea and the 1963 eruption of Gunung Agung on Bali, in recently-independent Indonesia. There was no documented history of volcanic activity at Mount Lamington, neither among the Australian governing class, nor in native folklore (Taylor, 1958). On 15th January, 1951, landslides and degassing began. This escalated over the subsequent five days and residents of some villages self-evacuated (USGS, 2008). From the closest large town, Higaturu, the District Commissioner informed the acting Administrator, F.B. Phillips in the capital, Port Moresby, requesting the opinion of a volcanologist. The following day, Phillips flew to Mount Lamington (without state volcanologist Tony Taylor), declared there was "no immediate danger to human life at Higuratu" and flew back to Port Moresby. The decision not to evacuate was disseminated by the local police (Johnson, 2013). At 10:40 on 21st January, Lamington produced a VEI 4 explosion. The resulting PDCs destroyed Higuratu and killed approximately 3,000 people (Taylor, 1958; NOAA, 2008).

During the eruption a small group of European men tried to administer the chaos on the roads whilst others attempted to make radio contact with Port Moresby. The extent of the disaster was not anticipated. Although thousands had died, there were thousands of survivors. Two camps were established with medical centres, schools and inoculation services. Eventually, after consultation with the displaced communities on social, economic and agricultural issues, they were resettled in a manner that suited both them and the Administration. Resettlement was not permitted in the devastated area (Johnson 2013). Taylor produced a 215-page report, regarded as a 'classic' of the volcanological literature (USGS, 2008).

The 1963-64 VEI 4 eruption of Gunung Agung was the largest volcanic eruption in 20th Century Indonesia. On 18th February 1963, two days of seismicity preceded minor explosions and a lava flow. This activity persisted until 17th March, when larger explosions began and, on 20th, PDCs reached villages, causing the first casualties. The death toll accumulated in a piecemeal fashion. Peaks in March and May were attributable to PDCs whilst a large number in November were due to rain-driven lahars. (Witham, 2005; Self and Rampino, 2012).

The Volcanological Survey of Indonesia succeeded the Netherlands Volcanological Survey following independence, but they had no observational infrastructure in Bali. Teams were sent to establish temporary observatories, however, pressure was put on them to conduct DRR decision-making over and above this:

> *The first aim of the Volcanological team was to consider what measures are to be taken, because the island of Bali is rather densely populated. Having no previous record concerning the character of her activity, the first volcanological team was put in a difficult situation in making predictions. Knowing that Mt. Agung has always an open crater, the formation of nuees ardentes to such an extend[sic] was the last expected thing* (Zen and Hadikusumo, 1964).

Van Padang (1960) notes that hazard mapping was a Survey technique employed during the 1930 eruption of Merapi (Chapter 5.1). This practice was also used at Agung. A 10 km radius from the summit was declared the 'closed zone' and beyond this, river valleys were named 'danger areas'. In periods of heightened activity, the volcanologists took it upon themselves to evacuate the areas around the temporary observatories. They submitted a request to the Balinese government on 13th March, before the first casualties, advising a complete evacuation but this was ignored. Zen and Hadikusumo (1964) believe that the eruption occurring in the middle of a season of Hindu festivals based in temples high on Agung, combined with a lack of experience of prior eruptions contributed to the lack of political will. Further volcanic crises in 1960s Indonesia included the April 1966 eruption of Kelud where lahars killed ~200 and the August 1966 eruption of Awu, which killed ~90 (Witham, 2005; Rehnberg, 2015a).

The narratives of these crises show little proof of dramatic policy transformation in the first volcanic crises of the post-war era. Ad-hoc policy decisions that did not consider the worst case scenario were evident in both cases. In Papua, the administrator made a decision based on no volcanological evidence and Balinese authorities wilfully chose to disregard the recommendations of the state volcanologists. Despite the emergence 'elsewhere' of new schools of thought, policy models and globe-spanning technocratic structures, it could be argued that the relative infrequency of volcanic disasters and their occurrence in sites that were (at the time) topographically and topologically distant from the 'core' of these developing international assemblages (wealthy 'western' nations) delayed the mobilisation and application of new ideas, practices and policy structures in sites subject to volcanic risk.

The most prominent recurring role of volcanologists to this point in the account has been to perform post-mortem investigations on crises and publish investigations. Despite being rooted temporally and spatially in the surroundings of each volcano these activities were significant in terms of curating an incrementally expanding body of knowledge and establishing topological connections through which that knowledge could circulate to an increasing number of volcanic sites. The growing global expert community of volcanologists continued to accumulate and mobilise lessons as part of a broader community of Earth scientists throughout the wealthier nations at the 'core' of the international community (predominantly in western Europe and North America) that was undergoing a 'revolution' through the exchange of knowledge related to the emergence of influential theories such as continental drift (Hallam, 2014). Over two meetings in 1960 and 1967 the International Association of

Volcanology assumed its current form, IAVCEI, and adopted the following core statutes;

(1) To study scientific problems related to volcanoes and volcanic processes, past and present, and to the chemistry of the Earth's interior.

(2) To encourage, initiate and coordinate research, and promote international cooperation in these studies.

(3) To encourage volcanologists to alert appropriate authorities about the importance of adequate surveillance of active and potentially active volcanoes, and of volcanic risk assessment.

(4) To arrange for the discussion and publication of the results of scientific research on volcanology and on the chemistry of the Earth's interior (Schmincke, 1989).

Thus, the volcanological community consolidated its place on the global policy field. It was engaged in sharing insights into volcanic disasters at the macro level and interacting directly with them at the meso and micro levels. However, on the evidence presented, it is perhaps safe to describe the volcanologists of this time as 'policy outsiders' on all scales, although by no means apolitical, certainly limited in political influence.

Civil defence organisations were established in 1965 in Papua and 1966 in Indonesia (Papua New Guinea Association of Australia, 1993; IFRC, 2005). There is no evidence of any specific link between the two territories' adoption of the model. Civil defence policies became increasingly widespread throughout the late 1960s and 1970s (Alexander, 2002). However, as is generally the case with mobile policy, this should not be viewed as the intentional handing-out of a ready-made policy solution from its architects in the UK and US to a collective of grateful, disaster-prone former colonies. Vale (1987) notes that the role of civil defence organisations varied significantly between nations, but that there were also still a large number of countries where it was not practiced. In 1970, as the Behavioural paradigm had become more prevalent in practice than ever before, academic thought had already begun to progress to the vulnerability-based Development paradigm (Smith and Petley, 2009).

In 1971, following a series of high profile disasters in the southern hemisphere, the UN established the United Nations Disaster Relief Office (UNDRO) (Hannigan, 2012). UNDRO notionally had three aims: to organise emergency relief and donations after a disaster, to promote pre-disaster planning and preparedness, and to promote preventative methods for disasters (UIA, 2017). Hannigan (2012) argues that from its inception, UNDRO was underfunded and had no clarity of purpose, as sovereignty was still seen as paramount, limiting UNDRO's remit. Hannigan and several other authors (e.g. Cuny, 1983; Kent, 1987) conclude that UNDRO did not reduce disaster losses due to a fundamental failure to understand the links between disasters and development. Hannigan states that the most prolific organ of the whole Office was the Preparation and Planning division who disseminated advice to governments. In policy mobility terms, therefore, UNDRO was a macro-level technocratic body with a specific remit for defining and mobilising 'best practices'. Thus, even as disaster risk science was becoming convinced that 'emergency planning' was an inadequate approach to disasters in developing societies, through UNDRO, this model was being increasingly promoted in those societies.

The 1970s saw relatively few volcanic disasters. The highest death toll came from a VEI 1 eruption of Nyiragongo in the Democratic Republic of the Congo when lava flows inundated the city of Goma and killed between 60 and 500 people (Allard et al. 2002; Witham, 2005; Papale, 2015). However, this was also the beginning of a ten year period in which the volcanological community was brought increasingly into the political realm. The UN held three regional seminars on operational volcano monitoring between 1974 and 1976. Following a motion at the first IAVCEI general assembly in Durham, England, 1977, a meeting was convened in 1978 at UNESCO headquarters in Paris, France, to discuss producing a handbook for volcanic risk governance (UNDRO, 1985).

The 1975-77 episode of unrest at La Soufrière on Basse-Terre Guadeloupe, a French Caribbean territory, saw volcanology politicised at the meso and micro levels. A volcano observatory had operated on the island since 1950, under the authority of the French government's *Institut de Physique du Globe de Paris* (IPGP, 2016).

Heightened seismicity was identified in June 1975, but the first eruptions did not manifest until July 1976 and a period characterised by volcanic tremor and phreatic eruptions every few days lasted until 10th November, when a quiet period of 56 days ensued. On 5th January 1977, further eruptions began, accompanied by minor lahars and landslides. This lasted until 1st March, after which seismicity diminished until the crisis was declared over in June (Feuillard et al. 1983).

Despite the relatively minor nature of the activity, the communities on Basse-Terre were seriously concerned. The destruction of Saint Pierre was well remembered (UNDRO, 1985). In 1973, the IPGP ratified the creation of a national volcanological service and appointed Haroun Tazieff at its head. After the first seismicity was detected, the director of IPGP contacted France's Civil Defence, recommending they develop an 'eruption plan'. This was presented to authorities on Guadeloupe and approved in March 1976. The plan was presented to the population in April. After the first explosions, many on Basse-Terre self-evacuated. However, following an evaluation of the activity, Tazieff's team concluded that the risk was minimal and people should return to their homes. Tazieff left on a field excursion to Ecuador and John Tomblin and Robert Brousse assumed his responsibilities. When activity escalated in August, calls for evacuations were made by the government, with the approval of the new head of the IPGP, Claude Allègre (Beauducel, 2015). 76,031 people were evacuated from Basse-Terre, officially for three months, but for many it was closer to six (Chenet et al. 2014).

Tazieff returned on 29th August, made a public declaration that the evacuation had been excessive and called for people to return to their homes. In response, Allègre announced his intention to dissolve the volcanological service and assume Tazieff's responsibilities. A Paris newspaper ran with the headline "*Tazieff against Brousse: the little war of volcanologists makes as much noise as the volcano*" (Beauducel, 2015). The evacuation, initially welcomed, eventually became deeply unpopular as economic vulnerability and disrupted school schedules took their toll. It has left a bitter legacy among islanders (Chenet et al. 2014). The French government created an ad-hoc *Comité Scientifique International sur La Soufrière* of six non-French volcanologists to resolve the dispute. The Committee conducted a 3-day investigation into the crisis and concluded that close monitoring should continue but there was no immediate danger. Within hours, the evacuation was brought to an end (Fiske, 1984).

In this case, the French meso-level part of the global assemblage of volcanology became directly involved in the governance of the crisis firstly by encouraging civil defence policymakers to develop emergency plans for the volcano, then effectively making the decision to execute those plans, before having a protracted public debate about whether this had been appropriate. Despite being a disagreement between two members of a small sub-section of the community, the repercussions of this event for volcanology and the perception of 'best practices' in volcanic risk have been profound and long lasting. It has influenced policy documents (UNDRO, 1985), the IAVCEI code of conduct (Newhall et al. 1999) and numerous investigations into volcanic risk reduction (e.g. Fiske, 1984; Barclay et al. 2008; Chenet et al. 2014; Hincks et al. 2014). In a perfect illustration of the capricious nature of mobile policy, an ad-hoc decision incorporating a global cross-section of the expert community ultimately brought the political crisis to a close.

In May 1980, Mount Saint Helens in Washington State, USA produced a VEI 5 Plinian eruption (Lipman and Mullineaux, 1981; Newhall and Self, 1982). Signs of volcanic activity became apparent on 20th March, when a magnitude 4.0 earthquake caused fracturing on the summit glacier. This was followed a week later by a small eruption (Lipman and Mullineaux, 1981).

On 25th March, an emergency co-ordination centre was set up and US Forest Service (USFS) officials began collaborative meetings with USGS scientists. On 1st April, a volcanic hazards map was released and on 9th, the USFS issued a *Mount Saint Helens Contingency Plan* (Tilling et al. 1990). It was recommended that the areas around the volcano be evacuated, establishing 'red' (no public access) and 'blue' (limited public access) zones in late April (Ray, 1980). Some citizens felt forcibly evicted and economically disadvantaged: "...many people broke down the roadblock barriers or drove around them. Finally, local officials called in the National Guard to operate the roadblocks." (Ganeri, 2008).

1974 legislation gave the USGS the legal responsibility to provide authorities with data on all active volcanoes in the USA (Tilling et al. 1990). At the time, HVO was still the only American volcano observatory and there were no emergency funds available, there having been no major volcanic crises in USA history. In order to afford the staff and equipment required at Mount Saint Helens, the USGS would need to go through a time-consuming review process to acquire additional federal funds. The volcanologist in charge of the investigation resorted to illegally using an account intended for office supplies, accumulating a bill of >$1,000,000. The growth of the bulge reassured the volcanologists that this would be vindicated (Tilling, 2017 pers. comm).

On the 18th of May at 08:32, the north face of the mountain collapsed and a lateral blast "...devastated an area nearly 30 km from west to east and more than 20 km northwards from the former summit of the volcano. In an inner zone extending nearly 10 km from the summit, much of which had been densely forested, virtually no trees remained. The devastated area of 600 km^2 was blanketed by a deposit of hot debris carried by the blast" (Lipman and Mullineaux, 1981). 57 people were killed, mostly outwith the exclusion zone. Economic losses of $1.1 billion USD were sustained (Tilling et al. 1990; Ganeri, 2008). Congress voted for $951 million USD of relief funds to the Small Businesses Administration, the US Army Corps of Engineers and the Federal Emergency Management Agency (FEMA) (Tilling et al. 1990).

The pre-eruption phase seems to largely have been governed through a quickly-established assemblage of the federal USGS volcanological team and the USFS. Executive power lay with the USFS and the State Governor, but the volcanologists contributed strongly to the evolution of policy. Interestingly, due to their role as owners of the land, the USFS appears to have fulfilled the traditional role of civil defence. Post-disaster relief was administered by the federal government. FEMA was directly descended from the Office of Civil Defense, which distanced itself from its military predecessor to deal predominantly with environmental disasters (US National Archives, 2016). This can be viewed as an example of the mutation of a mobile policy, which saw the function of the original UK-USA civil defence model evolve into a 'demiltarised' practice which Alexander (2002) distinguishes as *civil protection*.

This eruption transformed volcanology, locally and worldwide. The Cascades Volcano Observatory (CVO), established on 18th May 1982, mobilsed the HVO model into yet another setting (Tilling et al. 1990). The volcano became the subject of intense study from domestic and overseas scientists (USGS, 2016). Mount Saint Helens is mentioned in 1,168 individual articles in the Journal of Volcanology and Geothermal Research alone (Science Direct, 2019). USGS volcanologist Don Swanson states: "Mount St Helens' eruption was important because it was so well observed. It provided a kind of model for jump-starting volcano monitoring around the world. Existing observatories got increased funding and people learned how to respond" (Seeker, 2010).

The following year, the World Organisation of Volcano Observatories (WOVO) was established as a sub-committee of IAVCEI at a meeting in Guadeloupe and Martinique. Its goals were as follows:

(1) To create or improve ties between observatories and institutions directly involved in volcano monitoring.

(2) To facilitate exchanges of views and experiences by convening periodical, perhaps annual, meetings.

(3) To maintain an up-to-date inventory of instrumentation and manpower that could be made available to any member institution when a situation arises that requires scientific reinforcement.

(4) To promote funding from international organisations to help defray travel and related expenses of scientific reinforcement teams (Sigvaldsson, 1981).

WOVO entered collaboration with UNESCO. It co-ordinated international scientific responses to volcanic crises throughout the 1980s and established a Directory of Volcano Observatories supported by a UN grant (Schmincke, 1989).

Within the first six years of the 1980s there were several eruptions with significant impacts on the global policy field of volcanic risk. Mount Saint Helens was the first of these. However, consistent with the trends observed by scientists who were beginning to question the Behavioural paradigm of DRR, volcanic disasters were generally more frequent and severe in less economically developed countries (Smith and Petley, 2009). In 1981, Semeru in Indonesia and Mayon in the Philippines killed 372 and 47 people respectively, Indonesia's Galunggung killed 37 in 1982 and a further 37 were killed during a 1984 limnic eruption of Lake Monoun in Cameroon (Witham, 2005). During the Galunggung eruption, 60,000 people were successfully evacuated, under the care of the Indonesian Red Cross and repopulation of the highest risk zone was prohibited. The Galunggung eruption also highlighted the impacts of volcanic ash on aviation when two commercial jets experienced engine failure after flying into the eruption cloud (UNDRO, 1985). The casualties sustained in these eruptions were of similar (or greater) magnitude to those from Mount Saint Helens. However, a basic Google search provides significantly fewer results for all of these events (9,930 for Semeru eruption, 1981; 75,700 for Mayon eruption, 1981; 27,500 for Galunggung eruption, 1982; 101,000 for El Chichón eruption, 1982; and 22,700 for Lake Monoun eruption, 1984) compared to 560,000 results for Mount Saint Helens eruption, 1980 suggesting that their global media profile was comparatively far lower. The VEI 5 magnitude and previously unstudied physical peculiarities of the Saint Helens event likely go some way towards explaining its significant impression upon the international discourse of VRR. However, it is equally likely that the wealth, power and status of the USA played a role. In the aftermath, the budget of the USGS' volcanic hazards programme grew from >$1 million to $12.6 million USD making it probably the best-funded VRR institution in the world (Fang, 2010). The influence of the USGS was further illustrated by the appointment of Robert I. Tilling, the senior volcanologist who had overseen the Mount Saint Helens eruption, as the first president of WOVO (Sigvaldsson, 1981).

The other 'significant' volcanic events of the 1980s were the 1982 VEI 5 eruption of El Chichón, México, the 1985 VEI 3 eruption of Nevado del Ruiz, Colombia and the 1986 limnic eruption of Lake Nyos, Cameroon. Substantial loss of human life was incurred by each; ~2,000 in México, ~23,000 in Colombia and 1,746 in Cameroon (Witham, 2005). WOVO President Robert Tilling has stated that Nevado del Ruiz "was seen as a total failure on our part" and that if Mount Saint Helens was a watershed for physical volcanology, Nevado del Ruiz was its equivalent for applied volcanology (Tilling, pers. comm. 2017). The Lake Nyos event can be considered a rare example of volcanic crisis in the post-civil defence era that took place in a 'policy vacuum'. It occurred with no perceived warning in a rural area of Cameroon, and the world beyond the affected communities did not become aware until four days later when Swiss missionary helicopters flew over. By this point the survivors had buried their dead and conducted their own recovery operations (Kling et al. 1987). The policy field became involved at the meso and macro levels in the *ex post* response to the crisis, when the victims were taken to hospital in the capital Yaoundé and financial and logistical aid arrived from the USA, France, the UK, Israel and other European countries. Scientists from the USGS and France also arrived to investigate (BBC, 1986; Kling et al. 1987).

During this period, interaction increased between volcanology and policy-making processes across multiple scales. During volcanic crises, volcanologists were incorporated into the world of ad-hoc fast policy, on the borderline between research and decision-making, but also with further-reaching and faster access to the global research community to bring knowledge from 'elsewhere' to localised volcanic crises. 'Hard science' is a prominent feature of the Behavioural/emergency management approach to disasters, so the increased influence of volcanology was perhaps an indication of the growing prevalence of this model worldwide. The now-frequent involvement of civil defence/protection in volcanic risk governance is also evidence that, even as the Behavioural paradigm began to be challenged in academic circles, 'emergency management' was becoming increasingly common in practice. On the macro level, following the IAVCEI general assembly of 1977, a trend towards more frequent meetings was established and the organisational structures of this technical community became progressively more specialised, calibrated not just to research, but also to policy problems, e.g. the creation of WOVO and the IAVCEI Commission on Mitigation of Volcanic Disasters (Schmincke, 1989). This period saw connections established between volcanology and the IGOs which dominate the global policy field, such as the link between IAVCEI, WOVO and UNESCO.

These trajectories converged two weeks after the eruption of Nevado del Ruiz, when UNDRO's Preparation and Planning division published *Volcanic Emergency Management* (UNDRO, 1985). A Spanish-language version was published in 1987

(UNDRO, 1987). As the two largest volcanic disasters of the decade had occurred in Spanish-speaking countries, the two-year translation delay perhaps illustrates the dominance of Anglophonic countries within the technocratic communities involved. The document was developed by senior personnel from IAVCEI and the UN over seven years. It tailors the 'emergency management' model to the specificities of volcanic risk. Chapters include:

(1) The nature of volcanic hazards
(2) Some examples of volcanic emergencies
(3) Hazard assessment and prediction
(4) Protective measures
(5) The development of volcanic emergency plans
(6) Perception and acceptability of risk
(7) Communication between scientists, civil authorities, news media and the public
(8) Some examples of organisation for volcanic emergency management

Experience from 'elsewhere' forms a key component of the handbook. The second chapter cites Heimaey (Iceland) 1973, La Soufrière de Guadeloupe 1975-77, Mount Saint Helens 1980 and Galunggung 1982 as volcanically and socially diverse examples of volcanic emergencies. The eighth chapter outlines the extant policy frameworks for volcanic risk in Iceland, Japan, Papua New Guinea, the Philippines and the USA.

The particularities of the global politics of DRR give this document an unconventional status compared to many examples of mobile policy. The limited influence of UNDRO (indeed, the UN in general) and the respect afforded to national sovereignty mean that it was not conceived as a formal policy document:

> *It is not the purpose of this handbook to discuss the details of the planning and organization needed to deal with volcanic emergencies, since these will of necessity vary from country to country according to political, social, legal and economic conditions and to the level of technological development. What has been attempted, is to distil from*

> *past experience in various parts of the world some general principles of organization and practice which, it is hoped, may prove to be of universal validity* (UNDRO, 1985).

Despite this, Chapter 5 of the UNDRO manual contains a general blueprint for the structure of volcanic emergency plans, a basis for policy development. This document is not a policy model rooted in a specific geopolitical context, set 'in motion' through subsequent social discourse. It is instead an assemblage of scientific and policy knowledge, compiled from a geographically widespread range of sources with the intention of being remobilised internationally. This thesis Chapter has outlined the numerous ways in which mobile policy has shaped the development of VRR, however, the UNDRO (1985) manual is arguably the most direct example in the entire chronology and served to further the geographical distribution of 'emergency management' policy approaches to volcanic risk, cementing the dominance of the Behavioural model in volcanic risk governance.

4.3.Volcanic Risk Governance in the era of Disaster Risk Reduction

Processes of globalisation have provided one of the two undercurrents (along with volcanics) that have kept this narrative in motion. As was the case with the preceding two 'eras', there is no cut-off point applicable to all processes and therefore some degree of overlap; late-stage globalisation was underway prior to 1985, which has been used in this study due to the significance of that year to the development of VRR. Processes of global exchange and mobility in governance are now substantially more numerous, accelerated, complex and nuanced than in previous sections. Attempting to constrain all of these simultaneously at the macro level would prove extremely difficult, if not impossible. This section outlines significant macro-level developments and events since 1985.

Appalled by the Nevado del Ruiz disaster, USGS volcanologists entered into collaboration with the US Office of Foreign Disaster Assistance (OFDA) to establish an initiative called the Volcano Disaster Assistance Program (VDAP). VDAP comprises a team of USGS volcano scientists that can provide scientific and technical support to local volcanologists and governments. VDAP also conducts ongoing training and capacity-building activities with VRR organisations in their respective countries. VDAP has responded to >70 crises at 50 volcanoes worldwide and performed longer-term capacity strengthening in 12 countries. (USGS, 2011; Tilling, pers. comm, 2017).

VDAP cemented the USGS as one of the most influential bodies on the global policy field of VRR. Over the course of more than 70 events it has interacted with the governance of volcanic crises around the world, mobilising many practices into diverse volcanic and socio-political settings, which will have further mutated in a myriad of unique ways, forming many assemblages and topologies with different lifespans. Macias and Aguirre (2006) believe that VDAP was so fundamental to initially mobilising the UNDRO (1985) system of volcanic emergency management that they refer to it several times as the UNDRO-USGS system. Pallister (2017) highlights that VDAP has now collated >30 years of experiences. It should therefore be thought of as a dynamic agent of change, a growing assemblage of knowledge and a consistent (although not ubiquitous) influence on the definition, promotion and distribution of 'best practice' VRR.

The disasters of the 1980s convinced many on the global policy field of DRR that further work was required as the established Behavioural paradigm was failing to avert disaster losses. The initiative to name the 1990s the International Decade of Natural Hazard Reduction (IDNDR) originated at an earthquake engineering conference in 1984 and the natural science community (of which volcanology was a constituent) championed investment in hazard research, monitoring and engineering solutions, whilst social scientists continued to advocate reducing social vulnerability (Hannigan, 2012). The UN Special High Level Council responsible for the IDNDR ultimately settled for the 'disaster risk management' approach which augmented the established behavioural paradigm with limited considerations of social vulnerability (Section 2.3.1). By 2015, disaster risk management based on the Colombian system of civil protection post-Nevado del Ruiz was the most commonly practiced model of disaster risk governance (UNISDR, 2015).

The broader community of volcanology continued to pursue 'best practice' VRR through WOVO and the IAVCEI Commission on the Mitigation of Volcanic Disasters, which by 1989 was the organisation's largest commission (Schmincke, 1989). Throughout the 1990s, IAVCEI held increasingly frequent assemblies, settling into a four-year pattern in the 2000s (Ismael-Zadeh, 2012). The 'Decade Volcano' project, the volcanological community's contribution to the IDNDR was also administrated by IAVCEI (Schmincke, 1989; Section 2.3.2). Barberi et al. (1990) outlined an ambitious programme of exchange. Despite the ultimately limited nature of the project due to struggles to secure funding, it was initially named by the UN as one of the 'spearhead projects' of the Decade (Verstappen, 1993). Although the project has never formally ended, it is in many ways functionally redundant and mainly endures in the connections established during its active years (Rehnberg, 2015b). During the 1990s, the Decade Volcano project was paralleled by the European Union/European Science Foundation's 'European Laboratory Volcanoes' project, which selected volcanoes in European-governed territories for collaborative research, including: Mount Etna (Italy); Furnas (São Miguel, Azores, Portugal); Piton da la Fournaise (Réunion, Indian Ocean, France); Teide (Tenerife, Spain), Santorini (Greece) and Krafla (Iceland) (Barberi et al. 1994; Chester et al. 2017).

In 1987, driven by the Galunggung eruption of 1982 (and the Redoubt eruption of 1989 which caused $80 million USD in damages to a passenger jet) the UN-based International Civil Aviation Organisation (ICAO) created the International Airways Volcano Watch, charged with monitoring airborne ash and distributing warnings to air traffic. By 1997, it had established nine Volcanic Ash Advisory Centres (VAACs) which between them were notionally responsible for all global airspace (Papale, 2015). The policy community pertaining to volcanic ash and aviation is a unique assemblage on the global policy field of VRR in the sense that the absolute rule of national sovereignty is reduced and the entire planet falls under one formal policy framework.

Against this backdrop, the first major volcanic crisis of the post-Ruiz era occurred - the VEI 6 eruption of Mount Pinatubo, Luzon, Philippines (USGS, 2015d). Following precursory seismicity in March 1991 and phreatic explosions in early April, the Philippine Institute of Volcanology and Seismology (PHIVOLCS) recommended that civil protection evacuate approximately 5,000 people. These were predominantly indigenous Aeta tribespeople, living within 10 km of the volcano. PHIVOLCS contacted the USGS and were joined in late April by VDAP. The USA government had a vested interest in preventing disaster at Pinatubo, because it had two military installations (Subic Bay Naval Base and Clark Air Base) close to the volcano. The latter became the site of the Pinatubo Volcano Observatory (PVO). The PVO team established monitoring systems and conducted surveys to create a hazard map. En route to the Philippines, the VDAP team flew over Katmai-Novarupta in Alaska, the site of the largest eruption of the 20th Century. During the first flyover of Pinatubo, USGS volcanologist John Ewert observed that the landforms were similar, stating: "Wow, that looks like Katmai, this is bad!" (NOVA, 1993; Newhall and Punongbayan, 1996).

In early June a lava dome emerged on the crater floor. The volcanologists collaborated with authorities to design a policy response appropriate to the increasingly apparent risks:

> *The PVO team used the hazard map and analysis of the volcano's unrest to acquaint civil-defense officials and military commanders with the potential eruptive hazards: extensive voluminous pyroclastic flows, tephra falls, and lahars that could extend far beyond the reach of the pyroclastic flows. A preliminary version of a videotape illustrating volcano hazards, produced by filmmaker-volcanologist Maurice Krafft, enormously helped the team explain hazards foreign to people in an area lacking historic eruptions" (Newhall and Punongbayan, 1996). The videotape had been created as part of an IAVCEI Commission on Mitigation of Volcanic Disasters initiative* (Schmincke, 1989).

By 10th June, increasing ash emission, shallow earthquakes and harmonic tremor led PHIVOLCS to declare the highest alert and double the exclusion zone around the summit evacuating a further 25,000 people, including all but a 1,500-strong military skeleton crew, plus the volcanologists who remained on Clark Air Base. They subsequently evacuated during the climactic phase of the eruption on 15th June when ashfall had reduced visibility to near zero (Newhall and Punongbayan, 1996). Despite the evacuations, between 600-1,200 were killed, predominantly by roof collapse due to ashfall (Witham, 2005; Rosenberg, 2017). In the aftermath, the Philippine government established the *Mount Pinatubo Commission*, a body for coordinating relief and recovery activities among both governmental and non-governmental organisations as well as engineering solutions to the enduring lahar hazards (Newhall and Punongbayan, 1996). Newhall and Punongbyan (1996) note the role of global processes of knowledge exchange in the governance of the Pinatubo crisis:

> *International collaboration was notable at Mount Pinatubo--first, between Philippine and U.S. scientists, and later, spontaneously, involving scientists from at least 10 countries. An event of this magnitude would challenge any single country, and, because volcanological communities are typically small, it makes good sense for volcanologists to help each other in times of major crisis.*

The response to Pinatubo provides further evidence that after Nevado del Ruiz, the volcanological community had become the most pro-active and organised component of the global policy field of VRR, consistently working to derive and promote 'best practice' volcanic risk governance and creating topological links. This was conducted at the macro level, through IAVCEI, VDAP and numerous less formal arrangements, and percolated into the meso and micro levels in unique ways through the interactions between volcanologists and the social and Earth processes at individual volcanoes. Although ostensibly conducted under the umbrella of the IDNDR, the lack of tangible support from the UN saw the volcanological community somewhat politically isolated. Despite the loss of hundreds, (possibly thousands) of lives, the successful evacuation of ~25,000 people from the worst affected areas means that Pinatubo has long been cited as a 'success' story and a counterpoint to Nevado del Ruiz in volcanologists' narratives of VRR (e.g. Newhall and Punongbayan, 1996; Pallister, 2017). Pinatubo is, to date, the last volcanic crisis in which >500 lives were confirmed lost. It is also the last time a >VEI 5 eruption occurred in a densely populated area. Subsequent developments and innovations in the global policy field of VRR have not been tested under these circumstances.

1994 saw the United Nations' World Conference on Natural Disaster Reduction, the first UN congress on disaster risk. Participants signed the *Yokohama Strategy and Plan of Action for a Safer World,* a 10-item article encouraging signatories to adopt strategies for disaster risk management, incorporating: prevention and preparedness, mitigation, early warning, participation at all levels of government, international collaboration, environmental protection and the responsibility of each country for managing disaster risk in its own territory (United Nations, 1994). It is likely that this event played a significant role in the proliferation of disaster risk management. However, Hannigan (2012) notes that, as has continued to be the case, signatories were under no obligation to fulfil the commitment. As such, each signatory is free to act upon the document as they see fit, with the outcome being, from the perspective of PMS, that the policy model will spawn distinct mutations (and distinct outcomes) according to the interpretation of each nation.

In 1995, IAVCEI convened a conference in Rome, Italy, entitled 'Volcanoes in Towns'. This was the antecedent to the now bi-annual Cities on Volcanoes conferences, scientific gatherings specifically focussed on the development of 'best practices' in applied volcanology. To date there have been ten - in Italy (in the cities of Rome/Naples corresponding to risk from the volcanoes Vesuvius and Campi Flegrei), New Zealand (Auckland; Auckland Volcanic Field), the USA (Hilo; Mauna Loa, Mauna Kea and Kilauaea), Ecuador (Quito; Guagua Pichincha) Japan (Shimabara; Mount Unzen), Spain (Santa Cruz de Tenerife; Pico del Teide), México (Colima; Volcán de Colima), Indonesia (Yogyakarta; Gunung Merapi) and Chile (Puerto Varas; Volcán Calbuco and Volcán Osorno) (IAVCEI, 2016).

Although Pinatubo was, at the time of writing, the last major Plinian eruptive crisis, there have since been various smaller eruptive crises. A prominent example is the 1995-2013 eruption of the Soufrière Hills volcano on the British Caribbean territory of Montserrat. A sequence of five eruptive episodes produced numerous lava domes, PDCs and Vulcanian explosions which cumulatively rendered the southern part of the island uninhabitable, destroyed the capital (Plymouth), killed 19 residents and reduced the island's population by two thirds (Wadge et al. 2014). From 1995 until 1997, the crisis was overseen by several ad-hoc assemblages of volcanologists before the UK's Foreign and Commonwealth Office established the Montserrat Risk Assessment, which was renamed the Scientific Advisory Committee in 2003. Initially, the scientists attempted to use the UNDRO (1985) manual but felt that it "proved inadequate to guide all mitigation efforts as the eruption slowly evolved" (Druitt and Kokelaar, 2002; Wadge et al. 2014). The British Secretary for International

Development encouraged evacuation (against the will of the Montserratian administration) and offered £10,000,000 as an aid package. As this amounted to <£2,500 per adult to pay for all the costs of emigration and starting a new life, it was met with widespread protest that forced the resignation of the Chief Minister who negotiated it (BBC, 1997). This example illustrates that although the orientation of the global policy field of DRR had begun to acknowledge the role of social vulnerability, even in 'developed' polities, marginalised communities (such as those in post-colonial territories) could still suffer disproportionately and that the lessons from previous volcanic crises in the British-governed Caribbean had not been effectively retained.

The IDNDR ended in 1999, replaced by the UN International Strategy for Disaster Reduction (UNISDR) (Hannigan, 2012). IAVCEI was, however, continuing to promote and develop the Decade Volcano Project within its limited means (IAVCEI, 1999). This constituted part of a growing suite of applied volcanology initiatives under the IAVCEI umbrella. Its Subcommittee on Crisis Protocols published a document entitled 'Professional conduct of scientists during volcanic crises' outlining suggested 'best practices' for crisis situations (Newhall et al. 1999). In 2003, an IAVCEI commission, the International Volcano Health Hazard Network (IVHHN) was established to investigate the impacts of volcanic activity on public health, incorporating epidemiology, toxicology and medicine, among other disciplines (IVHHN, 2017).

In 2005, the Yokohama strategy of 1994 was succeeded by the *Hyogo Framework for Action*. The previous convention's 10-item agreement was replaced by the following 'priorities for action':

> ***(1)*** *Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation.*
>
> ***(2)*** *Identify, assess and monitor disaster risks and enhance early warning.*
>
> ***(3)*** *Use knowledge, innovation and education to build a culture of safety and resilience at all levels.*

(4) Reduce the underlying risk factors.

(5) Strengthen disaster preparedness for effective response at all levels (UNISDR, 2015).

DRR had become the focus of the UNISDR as social vulnerability continued to generate disaster losses. However, national sovereignty remained paramount and participation was entirely voluntary (Hannigan, 2012; Hollis, 2014). Volcanic risk was again overlooked.

The 2010 eruption of Eyjafjallajökull in southern Iceland has thus far been the most globally high-profile volcanic event of the 21st Century (Klemetti, 2011). The eruption was characterised by four stages: an effusive phase from a flank fissure which began on 20th March, lasting 23 days; a brief quiescence; an explosive phase from the summit vent from 13th April until 17th May and low-level unrest as the volcano gradually ceased activity (Jenkins, 2010). This was the first Icelandic eruption to distribute ash extensively over western Europe in the era of aviation and led to major airspace closures, the cancellation of 108,000 flights, 10.7 million passengers stranded and losses of $1.7 billion USD (Budd et al. 2011).

As soon as they were made aware of the effusive phase by scientists, the Icelandic Department of Civil Protection and Emergency Management implemented the existing Eyjafjallajökull emergency plan, successfully evacuating 500 civilians over two hours. Other emergency measures included the delay of international flights to and from Reykjavík, as well as cancelling all internal flights. Around 4000 passengers experienced disruption. The following day, the residents of all but the 14 farms closest the volcano were permitted to return (Iceland Review, 2010). Subsequently, the effusive phase became a tourist attraction (Jenkins, 2010).

The swift enactment of emergency initiatives on 20th March was repeated on 14th April, when the explosive phase became apparent, with around 800 people evacuated in anticipation of primary lahars (Gunnarsson, 2010). Ultimately, glacier-burst lahars caused some damage to farmland but much structural damage was avoided by diverting the flows through artificial levees (Karlsdóttir et al. 2012). Livestock were kept in winter housing as they could not graze in the ash, with estimated losses of 5% of animals (Jenkins, 2010).

During the explosive phase, tephra was erupted directly into the jet stream, causing widespread dispersal across western Europe (Karlsdottir et al. 2012). Many countries chose to close airspace completely (House of Commons Science and Technology Committee, 2010). This decision was also taken by the central EU authority (Walt, 2010). The cancellations did not just affect the countries covered by the ash cloud. The closure of global air-travel hubs meant that many in other continents could not catch connecting flights, extending the volcano's impacts beyond its physical sphere of influence (Walsh, 2010). Freight aircraft were also affected (Sammonds et al. 2010).

There was significant backlash from airlines and the public: "the closing of European airspace (and the ensuing travel disruption) was quickly articulated as a failure of government leadership or bureaucratic decision-making" (Budd, 2011). Following a test flight of a jet aircraft, British Airways' Chief Executive declared the closures unnecessary (House of Commons Science and Technology Committee, 2010). However, when ash distribution resumed during the next explosive episode, EU authorities continued to err on the side of caution and close airspace again (Walsh, 2010). Pressure from external bodies forced the UK Civil Aviation Authority to change its definitions of 'safe flying zones' by the end of the eruption (Sammonds et al. 2010).

Eyjafjallajökull was a crisis like no other to date, born of the increased mobility that has come to underpin a globalised society. Its geographical scale and the number of affected people were unprecedented. It was a truly macro-level event, drawing attention from social scientists studying mobility as a social process (Birtchnell and Buscher, 2011). This situation demonstrates that as human infrastructure continues to evolve in spaces subject to volcanic phenomena, vulnerability may continue to evolve unexpectedly. This crisis illustrates that the policy infrastructure regarding volcanic ash hazards and aviation forms a unique part of the global policy field where conventional tropes such as national sovereignty are less applicable.

After the Eyjafjallajökull eruption, the volcanological community seems to have capitalised on political will to drive forward the agenda of VRR at the macro level. Several international projects designed to research and promote 'best practices' in various aspects of VRR were established, funded by a combination of national governments, IGOs, international financial institutions and other partnerships. These included the MIA-VITA project which sought to create a successor handbook to UNDRO (1985); the Volcanic Unrest in Europe and Latin America (VUELCO) project; the Global Volcano Model (GVM); and the Strengthening Resilience in Volcanic Areas (STREVA) project (VUELCO, 2011; GVM, 2012; Bignami et al. 2012; STREVA, 2012). These initiatives were operationally autonomous, but linked through IAVCEI and direct collaborative agreements (STREVA, 2012). They have collectively engaged with public, private and academic institutions in over 18 countries. Collaboration between the GVM and the UNISDR saw volcanic risk incorporated into the 2015 Global Assessment Report at the launch of the Sendai framework for action (GVM, 2014; UNISDR, 2015). Significant volcanic crises during the writing of this thesis have included the 2017-2019 activity at Gunung Agung, Indonesia, which prompted the evacuation of approximately 70,000 people; the June 2018 eruption of Volcán de Fuego, Guatemala where PDCs killed at least 190 people; and the December 2018 eruption and tsunami at Krakatau with 437 fatalities and 31,943 injured (GVP, 2013; Echeverria, 2018).

4.4. Synthesis

This chapter shows that volcanoes have prompted formal and informal policy responses from political regimes for more than 2000 years. Before institutionalised civil defence (theoretically) gave citizens an equal right to protection, before consistent records and prior to the rapid circulation of knowledge facilitated by modern globalisation, such responses were likely to be poorly documented, inconsistent, arbitrary, discriminatory, ad-hoc and nearly always reactive. In this sense, there is comparatively little advancement between ancient Rome and the early 20th Century. The lack of institutional frameworks for reducing disaster risks, the primitive-to-non-existent nature of volcanology, compounded by limited continuity in social memory reduced the capacity for lessons to mobilise between crises, frequently rendering intermittent eruptions a novel challenge for each society confronted by them. There are several examples where local knowledge curated over generations played a crucial role in saving lives. However, this was not a ubiquitous feature of the policy field and seldom incorporated into 'formal' policy. In the late 19th and early 20th Centuries, we see the gradual manifestation of the social apparatus that would eventually spawn modern volcanic risk governance.

Although the lexicon of PMS has emerged to describe mobile policy in a connected, globalised 21st-Century world, rather than the decisions of emperors, slave-owners, samurai, dictators, Carib communities, colonial scientists etc., the processes of seeking 'better' solutions to policy problems through learning from the world around us are a defining feature of the history of governance (and humanity). Before the mid-20th Century these processes are seen to be slow, disjointed and non-linear, but nonetheless significant in the lives of thousands worldwide. As globalisation gathers momentum, the integral role of mobilities on the governance of volcanic crises becomes increasingly evident. The evolution of technocracies can be argued to have a significant impact; on both the humanitarian relief that became a prevalent 'best practice' after volcanic crises, and the 'expert community' of volcanologists that began curating lessons and sharing them globally (albeit among a small number of likeminded scientists). Even at this early stage, mutations and transient assemblages can be identified (for example, Thomas Jaggar taking his Caribbean experiences and developing the HVO, and the international relief effort in 1902 that temporarily brought together the Caribbean colonial administrations and the governments of the UK, France and the USA in a co-ordinated policy response).

During the 20th Century, the civil defence model emerged and mobilised to the extent that, by the mid-1980s, most volcanic crises were being governed through 'emergency management' practices, replacing the prior vacuum of *ex ante* VRR policy. Nonetheless, emphasis was placed on reactive strategies - volcanic emergencies were to be managed when they arose. Processes of mobilising policy/knowledge became far more rapid and better connected. The emergence of IGOs and the evolution of the volcanological community were key features of this era. Althought initially disparate, volcanology and governance gradually became increasingly linked. Despite these developments, the early-mid 1980s were marked by severe volcanic disasters, and it was the failure of the now-dominant Behavioural model to prevent these (among other environmental disasters) that provoked the subsequent transition into the era of DRR.

Throughout recent decades, the constituent parts of the technical community of volcanology have multiplied and diversified, engaging with a wider range of formal and informal policy actors on the global policy fields of VRR and DRR than ever before. Collaborative links and funding from the UN, the EU, the World Bank, various national governments and private actors have somewhat reduced volcanologists' status as 'policy outsiders'. The potential number of resulting assemblages and policy mutations can only be guessed at. However, a populous, fast-moving, interconnected, complex, loosely-bound collection of systems, organisations and individuals has come to replace the once sparse, slow-moving and poorly-interconnected landscape of the global policy field of VRR.

In spite of there being more work done to mobilise VRR knowledge and practices than ever before, there is little evidence for homogenisation in VRR policy (as would be the case under a policy convergence model). Nor is there indication that macro-level changes spread through the policy field in any predictably coherent way (as a policy diffusion model would suggest). Despite this being named 'the era of disaster risk reduction'; by the UNISDR's (2015) own admission, it has thus far failed to establish a functional DRR policy framework. DRR remains an influential goal to pursue, however the long-term lessening of social vulnerability through reduction of poverty and inequality required for 'true' DRR challenges some assumptions of the neoliberal model that has remained ascendant. The backlash during the Eyjafjallajökull eruption perhaps provides a snapshot of the political pressure that may be expected when policy decisions regarding the safety of citizens challenge 'business as usual'.

Every volcanic crisis described in this chapter has arguably been a unique assemblage of Earth processes and human actions. It has been demonstrated that 'best practices' from 'elsewhere' have, in various instances, proven the difference between life and death for tens of thousands of people. However, the history of mobility in VRR policy also suggests that there is no one 'direction of travel' applicable to policy development at all potentially dangerous volcanoes and illustrates what can happen when governance of a volcanic crisis fails. It is impossible to quantify to what extent the likelihood of future volcanic disasters has been reduced by the mobility of VRR policy, but under the assumption that mobile policy manifests differently at each volcano where it 'arrives', in some instances proving effective and in others less so, there are undoubtedly still volcanoes around the world where a disaster on the scale of Mont Pelée or Nevado del Ruiz is a very real possibility. The uneven geography of VRR will be further explored in Chapters 5 and 6.

Chapter 5
Case Histories of Volcanic Risk Governance

This chapter presents historical accounts of policy mobilities in volcanic risk reduction at four volcanoes in different national (meso level) governance frameworks. Through these, this chapter aims to elucidate the complex interactions of mobile knowledge with the distinct volcanological and socio-political attributes of each volcanic setting; affecting the conception and implementation of the perceived 'best practices' that have shaped VRR policy.

5.1 Gunung Merapi, Java, Indonesia

Gunung Merapi (7.54°S 110.446°E; 2910 m; Figure 5.1) is a stratovolcano on Java, Indonesia, approximately 30 km north of Yogyakarta (Figure 5.2). Historically Indonesia's most active volcano, eruptions occurred on average every 4-6 years throughout the 20th Century. Frequent larger eruptions have been identified from the 7th-19th Centuries (Surono et al. 2012; Jenkins et al. 2016). In Witham's (2005) table of the most 'calamitous' volcanoes of the 20th Century, Merapi ranks eighth in terms of deaths caused (1590), sixth for injuries (932) and third for people rendered homeless (32,275) (Voight et al, 2000; Witham, 2005; Surono et al. 2012). Approximately 1.4 million people live in areas exposed to hazards from Merapi (Bakkour et al. 2015). This confluence of hazard and vulnerability arguably makes Merapi one of Earth's most consistently high-risk volcanoes.

Figure 5.1. Aerial photograph of Gunung Merapi from the southwest (GVP, 2013).

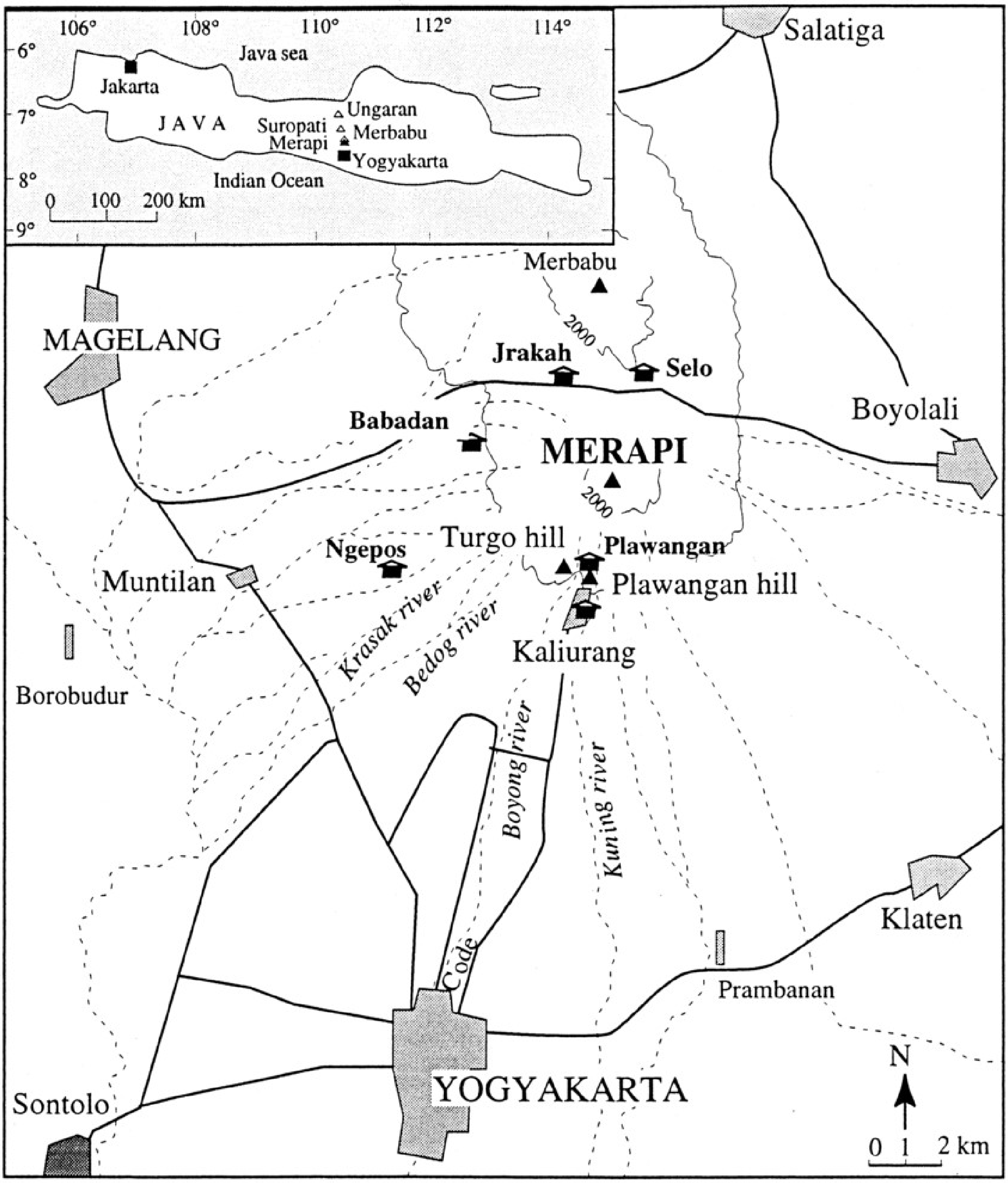


Figure 5.2. Map of the Merapi area (Voight et al. 2000a). Grey patches represent major towns and villages. Hut symbols represent volcanological observation posts. Solid lines are main roads, dashed lines are major drainage channels. Black triangles indicate the Merapi summit, Turgo and Plawangan hills.

Merapi's frequent activity has attracted much scientific scrutiny (Surono et al. 2012). Publications have also documented developments in VRR policy at Merapi since the

19th Century (e.g. Van Padang, 1960; Voight et al. 2000a; Donovan, 2010a; Mei and Lavigne, 2012).

5.1.1. Early Volcanic Risk Governance at Merapi

Newhall et al. (2000) suggest that Merapi has impacted Java socially for millennia. A system of hollow drums emplaced on Merapi may count as one of the earliest examples of a volcanic alert system (Casadevall, 2000). Newhall et al. (2000) note six moderately large explosive eruptions since the colonial era began, although many smaller events have presented significant hazards.

In October 1865, residents of the highest villages on the volcano self-evacuated, returning when activity diminished to find their crops destroyed. Spontaneous evacuations were also documented in May 1869, prompted by PDCs and ashfall (Voight et al. 2000a). A five-day VEI 4 eruption starting 15th April 1872 killed 130 people (Siebert et al. 2010). Rogier Verbeek, later to be in charge of the Krakatoa commission, surveyed the crater of Merapi after the 1872 eruption (Section 4.1.3), a sign that the volcanic nature of the territory had drawn the attention of Dutch colonial scientists.

By 1885, a colonial engineer was observing the crater monthly, and recommending houses in the highest villages be constructed to withstand tephra fall. In 1888, PDCs caused partial evacuation of two villages. One European resident stated that the evacuation lasted only a night, adding: "The people had received the notice to move but did not want to" (Voight et al. 2000a). Much of the local understanding of risk at Merapi has long been based on a blend of Islam and Javanese belief in spirit creatures from the volcano. Decisions to evacuate have traditionally been based on a combination of perceived activity at the volcano and spiritual interpretations that vary between individuals and communities (Donovan, 2010a). Dove (2008) refers to this acceptance of the dangers of Merapi as a 'culture of hazard'.

By 1888, risk from Merapi was familiar to local people and colonial administrators and both had actively engaged in practices to reduce it. Indigenous responses appear to have been typical of historical VRR as described in Chapter 4, with spontaneous decisions to evacuate based on visual observation of the volcano and religious understandings of volcanic phenomena. Colonial efforts were based on basic quantitative observation and authoritarian evacuations, this is notable given that institutionalised civil defence would not proliferate globally for decades to come. Frequent activity appears to have prompted the materialisation of an embryonic VRR policy field consisting of the colonial authorities, researchers and the indigenous Javanese communities. At this early stage, a contrast may be observed between the decision-making of authorities and the local communities - this is a recurring theme at Merapi.

Early policy did not avoid casualties. In 1904 and 1920, PDCs caused 16 and 35 deaths respectively (Siebert et al. 2010). In 1910, following an eruption at Semeru, another Javanese volcano, a government commission established a fund for victims of disasters (Van Padang, 1983). Shortly before the 1920 eruption, the Dutch Indian "Volcanological Watching Service" had been established (Section 4.1.4). At the time, this was the only government-funded volcanological organisation on Earth. In addition to volcano monitoring, two of its stated aims were to develop a system to warn/evacuate communities and to reduce the effects of eruptions (Van Padang, 1983).

Chief scientist, Georges Kemmerling, observed the 1920 eruption directly, although without visual precursors victims were unable to be alerted. Kemmerling made comparisons between the dome collapse PDC and the descriptions of explosively driven PDCs at Mont Pelée in 1902, concluding that they were different processes (Voight et al. 2000a). Thus, by 1920, experiences elsewhere in volcanology had begun to impact on Merapi and experiences at Merapi had begun to feed back into the budding volcanological community. This process continued in February 1924, when a seismometer purchased in Japan expanded monitoring at Merapi (Voight et al. 2000a).

Following five years of quiescence, seismicity began building in January 1930, until November when effusion of lava began. Notice to evacuate was immediately given to the closest residents. Van Padang (1983) notes that this was effective and casualties were low in the highest altitude communities. However, the size of the PDCs exceeded all expectations and 1,369 people were killed at distances of 8-10 km from the crater. The government provided 3,000 evacuees with accommodation, clothes, food and amenities (Van Padang, 1983; Voight et al. 2000a). In the post-disaster stage, the government and the army blocked road access to the volcano, established the limits of the affected zones and assisted the volcanological service in monitoring lahars (Van Padang, 1960). In 1933, the first hazard maps for Merapi were produced. These were the first such maps in the Dutch East Indies and the earliest at any volcano examined in this study. In 1934, seismic monitoring allowed populations to be alerted and evacuated within 40 minutes such that there were no casualties when PDCs reached populated areas (Van Padang, 1983).

In 1941, new regulations were implemented establishing concentric danger zones, including the 'forbidden zone' where it was recommended all communities be permanently abandoned (although this goal has never been achieved). This survived the forthcoming regime changes that came with the Japanese occupation and the subsequent emergence of an independent Indonesian state in 1945 (Suryo, 1985; Voight et al. 2000a). The zones were revised in 1960, 1978, 2002 and 2011 (Donovan, 2010a; Lavigne et al. 2017).

The history of institutionalised VRR at Merapi is far longer than at any other volcano examined. It is likely that Merapi's frequent high-risk activity (and that of other volcanoes in Indonesia) as well as its location in a territory governed by an industrialised power were strong contributing factors. This can be seen in the contrast between the scientific/technical response of the Dutch Indian government and the ad-hoc responses of the native communities, as well as the dominance of European scientists including Rogier Verbeek, Georges Kemmerling, Charles Stehn and George Escher. These scientists participated in the formation of the global scientific community of volcanology; Escher becoming president of the International Association of Volcanology (Van Padang, 1983). Features of VRR at Merapi included instrumented monitoring, an alarm system, hazard maps and attempts at land use planning with the establishment of the 'forbidden zone' as well as government-funded post-disaster aid. Many features of the Behavioural approach to disaster risk (Section 2.3) including the scientific investigation of hazards, plans triggered by the occurrence of 'emergency' situations and post-disaster relief had emerged in the Dutch East Indies long before they were prevalent worldwide.

5.1.2. Volcanic Risk Governance at Merapi after the establishment of the Indonesian Republic

Some actions under the pre-1945 framework, such as the evacuation of 1934, succeeded in reducing casualties. However the recurrence of deaths injuries and homelessness during fifteen subsequent eruptions of Merapi illustrate their limited scope, especially when expected to function against a backdrop of severe underdevelopment. Following Japanese occupation and independence in 1945, the Indonesian economy entered a 'catastrophic' state (Dick, 2002). The large number of ethnic and cultural groups that had united under the banner of Indonesian liberation began to split, spawning multiple armed conflicts while the Dutch continued to fight to reclaim the territory (Ricklefs, 1993). According to Ricklefs, the result was a country typified by poverty, low educational/skills levels and authoritarian traditions. Most European volcanologists left Indonesia, although at least two (W.A. Petroeschevsky and H.F. Klompé) remained (Van Padang, 1983).

In 1950, a democratic constitution was established and Sukarno, the leader of the independence movement who had served as President since 1945, was elected to the position (Ricklefs, 1993). In 1954 an eruption at Merapi killed 64 and destroyed three villages (Voight et al. 2000a). After a turbulent period of parliamentary democracy, Sukarno grew disillusioned and, between 1957 and 1959, instituted an authoritarian system called 'guided democracy', intended to appease three dominant factions, the military, Islamic groups and the communist party (PKI) (Ricklefs, 1993). During this period, Indonesia became increasingly aligned with the USSR, worsening relations with the West. While Indonesia did not become a fully communist state in the Soviet mould, this did shape the conduits for its international exchanges (Efimova, 2011).

The 'Volcano Service' was the replacement for the Netherlands Indies Volcanological Survey, known internationally as the Volcanological Survey of Indonesia (VSI) (CVGHM, 2016). In 1959-1960, a period of low activity at Merapi, a new seismograph was installed and I. Suryo, director of the VSI proposed an expansion of the 'forbidden zone' (Voight et al. 2000a). Thus, despite the challenges faced by Indonesia, the VSI continued its predecessor's monitoring, research and VRR activities.

The next eruption began in April 1961. Although communities had been evacuated in advance, some evacuees chose to return intermittently to tend farmland, 12 were killed and six seriously injured (Voight et al. 2000a). The continuing conflict of interest between the authorities and volcanologists seeking to maintain the 'forbidden zone', and the zone's inhabitants seeking to access their land is evident. Indeed, following this eruption, the Indonesian government incorporated 1,905 zone residents into its 'transmigration' programme. This process would recur after every subsequent significant eruption (Dove, 2008). The transmigration program was an initiative established by the Dutch and formally discontinued in 2015. It aimed to move people from the 'overcrowded' islands of Bali, Lombok, Madura and Java to less populous islands. The project later gained support from the World Bank. Transmigration has proven controversial domestically and internationally, as indigenous cultures have been threatened or subsumed by incomers, and their resources put under strain (Fearnside, 1997; NZ Radio, 2015).

In 1965, Sukarno's 'guided democracy' regime was shattered by conflict between conservative military leaders and the PKI. Military Commander, General Suharto won, eventually using his influence to supplant Sukarno as President:

> *Indonesia moved from being a leader of the radical left in world affairs to being a bastion of anti-communism. Suharto supervised Indonesia's economic recovery from the neglect of the Sukarno era to unprecedented levels of prosperity, albeit with unprecedented levels of corruption. He also presided over the killing of around half a million members and associates of the PKI...* (Cribb, 2015).

Over the subsequent three decades Suharto's subsequent military dictatorship, known as the 'New Order' presided over significant economic growth and a reduction in absolute poverty, improvement in infrastructure and public services through collaboration with foreign economies. Despite this, the regime was corrupt and brutally repressive (Aspinall and Fealy, 2010). The regime change led to a restructuring of institutions; a civil defence organisation was established. However, a separate National Disaster Management Advisory Board, assumed many DRR responsibilities (Mei and Lavigne, 2012; BNPB, 2017). The establishment of a specific body may be attributed to the frequency of disasters in Indonesia. The VSI was placed under the Directorate of Geology; it would alternate between departments of Geology and Mining in 1976, 1978 and 1992 (CVGHM, 2016).

During the 1960s, Indonesia experienced several volcanic crises, including the eruption of Gunung Agung (Section 4.2). In 1968, Japanese scientists brought state-of-the-art seismographs and event classification to Merapi. This collaboration was likely born of the New Order's courting of international investment. Enhanced seismological capacity aided the evacuation of several villages destroyed by PDCs in December 1968. Subsequent lahars destroyed 23 villages and caused three deaths (Voight et al. 2000a; Aspinall and Fealy, 2010). As a response, in 1969, the Indonesian government established 'Volcanic Disaster Prevention Projects'. These predominantly comprised of engineering solutions designed to limit lahars:

> *Projects were established within the Directorate General of Water-Resource Development (Ministry of Public Works). Co-operation with other Government Departments, e.g. the Volcanological Survey, with other countries via the Colombo Plan (Japan and New Zealand), and with local Universities, was also established and consultants engaged.* (Suryo and Clarke, 1985).

Through these projects, the policy field of VRR in Indonesia, and at Merapi, came (for a time) to host an assemblage of domestic and international organisations. Indonesia's engagement with the Colombo Plan, an IGO for trans-national development of policy and infrastructure was only possible due to the pro-Western leanings of the New Order (Colombo Plan, 2011). The 'Sabo' dams used were based on experience of controlling lahars and debris flows at Japanese volcanoes (Suryo and Clarke, 1985). Lahars have subsequently rarely exceeded 10 km from the crater. After project completion in 1987, no lahar-based fatalities have been reported (De Bélizal et al. 2013). In this instance, knowledge from 'elsewhere' and the conduits by which it was circulated played a key role in reducing one aspect of volcanic risk at Merapi, demonstrating that mobile policies sometimes do meet their proponents' aspirations and that engineering solutions can reduce casualties in the short-to-medium term.

Merapi was largely quiet through the early 1970s. In 1976 it re-entered a cycle of activity that lasted until 1979 (Voight et al. 2000a). On 25th-26th November 1976, lahars killed 28 and destroyed 358 houses. The Sabo dam project was still far from completion (Sumaronyo and Hildasan, 2010). In the late 1970s, Haroun Tazieff and a team of French volcanologists (Section 4.2) introduced geochemical investigations of fumaroles to Merapi and in 1982 the USGS installed a state-of-the-art seismograph network (Voight et al. 2000a). In 1985, Suryo, in collaboration with the British Geological Survey published a paper detailing the works of the Indonesian government towards reducing volcanic risk:

> *The prevention of serious loss of life and damage to property in areas menaced by volcanic activity is in part the work of the Volcanological Survey of Indonesia whose personnel observe and monitor activity, map and interpret records of previous eruptions and delineate volcanic hazard zones... Indonesia is at present benefiting from lessons learnt as a result of the eruption of Mt St. Helens in that the USGS are supplying volcanological expertise in the form of men and equipment in order to set up a model Volcanological Observatory for Merapi. Expert assistance is also received from Japan where high technological methods of monitoring are routine.* (Suryo and Clarke, 1985).

Both before and during the 'explosion' of volcanology in the 1980s, Merapi was assuming its place as a prominent site for the circulation, application and production of volcanological knowledge, eventually encompassing collaborations with (among others) the USA, France, Germany, Japan and Italy, with tangible impacts on VRR practices (Wirakusumah, 2000). At this point, institutionalised VRR that conformed to the Behavioural paradigm had existed at Merapi for around half a century, and the mobile knowledge that shaped policy and 'best practices' after 1945 arguably reinforced this, augmenting the technical capacities of a hazard-focussed approach. However, the communities around Merapi remained vulnerable.

From 1984 through 1993 there was minimal hazardous activity (Voight et al. 2000a). Voight et al. note that by 1994, a new dome lobe emerged, descending an established channel to the southwest, and rockfall deposits started to provide a ramp out of the channel onto the south flank. They argue that the implications of this development were not fully appreciated because the south flank had remained unaffected by hazards for a long time. Suryo and Clarke (1985) wrote that Merapi had a 'pattern' of activity, suggesting that the VSI had grown comfortable with Merapi behaving in a certain way. Van Padang (1960) called Turgo and Kaliurang villages on the south flank (Figure 5.2) "quite safe". Nonetheless on 22nd November 1994, the dome collapsed over seven hours. PDCs affected the southwest and southern flanks, killing 64 people. There were no identifiable precursors (Voight et al. 2000a).

At 07:30 the Kailurang observation post alerted the Merapi Volcano Observatory (MVO) in Yogyakarta. However, by the time the message had been relayed through the layers of government (district, sub-district and municipality) to begin organising the evacuation at 10:00, victims had been dead for two hours (Mei and Lavigne, 2012). Mei and Lavigne suggest that institutional and community unpreparedness was responsible for the severity of the disaster. No education had been provided by the Indonesian government or NGOs, and because Turgo had not been affected by the volcano in communal memory, local authorities were overwhelmed. Shelters and transport were poorly organised and provisioned, thousands self-evacuated, but were not provided with resources by the government to maintain livelihoods. Many returned on a daily basis to feed livestock.

Authorities decided that 2,700 villagers in Turgo should be relocated. They were given the option to be part of the transmigration programme or to relocate to a purpose-built replacement village called Sudimoro, around 10 km from Turgo. Fewer than 1% of Turgo residents expressed interest in transmigration, one commenting that she would rather be killed by Merapi than give up her land to the state (Dove, 2008). Turgo was erased from official maps, and villagers were no longer recognised by the authorities. Despite this, and the high quality construction of houses in Sudimoro, 60% of displaced residents chose to return to Turgo (Mei and Lavigne, 2012).

In 1996, Suharto's regime came under increasing pressure from the Indonesian Democratic Party (PDI). Previously a puppet of the New Order regime, the PDI began to take on a life of its own under the leadership of Sukarno's daughter, Megawati Sukarnoputri. Suharto acted with the military to depose Megawati (Coghlan, 2010).

This sparked a wave of protest that escalated over the subsequent years, compounded by financial crisis in 1997. Suharto was forced to resign on 21st May 1998 (Mydans, 1998). Indonesia's parliamentarians set about instituting a series of gradual, extensive reforms that, after a period of violence and uncertainty, brought about the 'full democratisation' of Indonesia. This became known as the period of *Reformasi* (reform) (Horowitz, 2013; Hays, 2015).

5.1.3. Volcanic Risk Governance at Merapi in the era of Reformasi

Several crises occurred at Merapi during the turn of the *Reformasi* period. An eruption on 31st October 1996 rendered 300 people homeless, a further eruption on 17th January 1997 killed six and affected 3,000-8,000. In July 1998, 312 were injured (Witham, 2005). During the 1990s, (the IDNDR) Merapi was named by IAVCEI as one of the Decade Volcanoes (Section 4.3). Two workshops were held on Merapi in 1995 and 1997, with support from UNESCO (Voight et al. 2000b):

> *The workshops included discussions on such topics as dome collapse mechanisms, hazard evaluation, public education concerning Merapi Volcano and lahar mitigation. These discussions were very important for scientists in Indonesia, as the knowledge gained could be applied to our nearly 130 active volcanoes. The international colleagues of VSI are also able to use their experiences at Merapi to contribute to both local science and hazard reduction, as well as to solve similar problems elsewhere in the world* (Wirakusumah, 2000).

One product of these was a special issue of the *Journal of Volcanology and Geothermal Research* (JVGR) dedicated to Merapi, encompassing scientific and governmental contributions from (among others) France, the USA, Japan, the Netherlands, New Zealand and Australia. This issue comprised studies of volcanic history; magmatic processes; monitoring; PDCs; lahars and hazard evaluation (Voight et al. 2000b). Also at the workshops, Merapi and Volcán de Colima in Mexico (another Decade Volcano) were named 'Twin Volcanoes', due to perceived similarities between the two (Newhall, pers. comm. 2017). Exchange visits were conducted between scientists of the VSI and the Universidad de Colima, although the project never achieved funding to continue beyond these (Section 6.4). In July 2000, the IAVCEI general assembly was held in Bali (Ismail-Zadeh, 2012).

Several authors in the special edition refer to Merapi as a 'laboratory volcano' for the global community of volcanology due to its consistent activity (Casadevall, 2000; Wirakusumah, 2000; Voight et al. 2000b). The exchanges of the 1990s represent expansion and acceleration of the global mobility of VRR knowledge to an unprecedented scale. Merapi can perhaps be conceived of as the focal point of a vortex of information drawn from all the participants' 'home volcanoes'; colliding and being reshaped in the Merapi context before feeding back to other volcanoes in Indonesia and worldwide. In this sense, Merapi had arguably come to constitute a classic site of policy mobility, reminiscent of the 'global cities' cited in the PMS literature (e.g. Clarke, 2009; McCann, 2011). However, it is once again worth noting that the focus of these exchanges was still predominantly hazard-based and thus concerned with enhancing technical capacities within the context of the Behavioural approach to disasters. Although theories of complexity and disaster risk reduction had begun to emerge elsewhere on the global disaster policy field, their percolation onto the field of VRR at this stage appears limited.

Work continued at Merapi in terms of research, monitoring and defining the areas at risk. In 2001, the VSI became integrated with organisations for studying other geological hazards and became the Centre for Volcanology and Geological Hazard Mitigation (CVGHM, 2016). The Merapi hazard map was revised in 2002, although Donovan (2010) notes that it remained 'remarkably similar' to its predecessor from 1978 and was still based exclusively on 20th Century activity. It was noted in the special edition of the *JVGR* that activity during the 20th Century was unusually small-scale for Merapi and that more attention should be given to larger (VEI 4 or greater) scenarios (Newhall et al. 2000; Voight et al. 2000). It is worth emphasising that simply because knowledge arrives in a particular setting does not mean that it will always be rationally re-purposed as policy.

On 26th December 2004, an earthquake occurred off northern Sumatra, triggering a series of tsunami that killed large numbers around the Indian Ocean. One of the worst affected areas was Aceh in Indonesia, where 170,000 were killed and 500,000 were left homeless (Lubowski et al. 2009). Following this, the Indonesian government entered a rigorous reconfiguration of its disaster policy, enthusiastically adopting the *Hyogo Framework for Action*: "Involvement from multiple stakeholders produced legislation that re-evaluated the importance of preparedness, mitigation, and risk reduction; enabled contributions from civil society and international partners; and required disaster risk reduction (DRR) be built into development projects" (Brown et al. 2016). Brown et al. note that while significant progress has been made towards establishing a DRR-focussed approach since 2005, this was not achieved instantaneously but through a continuous process.

In March 2006, a new dome began to grow and by April, an 8 km radius around Merapi's summit was declared an exclusion zone. The activity incremented through May, evacuations began on 3rd. By 16th, 22,000 had been evacuated (Donovan, 2010a). It is notable that many self-evacuated (Wilson et al. 2007). The Red Cross reported that, 20,080 evacuees were sheltered between four districts (Mei and Lavigne, 2012). Activity continued without large PDCs. The government and scientists did not inform evacuees that a long-onset eruption was a possibility and by 28th May, up to 1,800 evacuees had returned home to tend their livestock (Mei and Lavigne, 2012).

On 27th May, a magnitude 5.9 earthquake struck Yogyakarta, killing over 5,800 (Wilson et al. 2007). According to Wilson et al., the earthquake 'eclipsed and overwhelmed' the ongoing Merapi operation, with camps beginning to experience sanitation and supply issues. The activity continued into June and on 4th-5th, a remnant of the 1931 dome called the Geger Boyo which had provided a barrier to PDCs on the southeast flank, collapsed, creating the potential for a repeat of 1994 where previously 'safe' communities became exposed. Despite this, the alert level was lowered and villagers transported home, with instructions to remain on alert. On 14th, at 12:00 a small PDC travelled down the gap left by the Geger Boyo, entering the Gendol river valley. MVO issued an immediate alert and the nearby community of Kaliadem evacuated before a much larger PDC buried part of the village. Two volunteers who had assisted with the evacuation were killed. This was the 'peak' of the crisis, after which the activity and alert levels decreased and evacuees gradually began to return home (Wilson et al. 2007; Donovan, 2010a). Wilson et al. (2007) is a report from scientists sent by the government of New Zealand to learn from this crisis in order to reshape domestic volcanic risk governance.

Shortly before the 2006 eruption, a number of DRR programmes were established around Merapi (Mei and Lavigne, 2012). This was likely part of the increased interest in DRR on the part of the Indonesian government. Mei and Lavigne argue that these were different to previous efforts which had lacked community participation. They state that the communities and the government were generally well prepared and that training and simulation exercises were conducted in April 2006, before the height of the eruption.

> *...on 26 May 2006, a cooperative network named Forum Merapi was initiated; it gathered local authorities from Sleman, Klaten, Magelang and Boyolali, the MVO, several local and international NGOs, academic institutions, and representatives of local communities. The forum's goal was to create a more comprehensive and participative disaster risk reduction programme on the Merapi Volcano. Since 2006, several programmes on volcano-related disaster management were conducted under the forum's umbrella* (Mei and Lavigne, 2012).

The efforts of the Indonesian government and the assemblage that formed Forum Merapi therefore represented a transition from the hazard-based focus of the preceding decades to a DRR-based approach. However, much media attention was placed on those whose refusal to become involved with efforts to evacuate was still based on traditional beliefs. The unwitting figurehead of this movement was Mbah Marijan, an elder of the village of Pelemsari who had been appointed the hereditary 'gatekeeper' of Merapi by the Sultan of Yogyakarta. In Pelemsari, Mbah Marijan was a respected elder, responsible for ceremonies celebrating the spirits of Merapi. However, the residents of many other communities afforded him a greater spiritual significance, including believing that he could control the volcano. When Marijan decided to remain during the 2006 eruption, despite his encouragement of fellow villagers to evacuate, it became a highly publicised story that influenced some evacuees' decisions to return to their homes (Donovan, 2010a). Donovan (2010b) argues that while traditional beliefs did have some influence on those who chose to remain, their role was exaggerated by the media - economic motivations were also a determining factor. Donovan wrote "Although the villages in the south were spared in 2006, the next large eruption will most likely devastate this region."

The Indonesian Disaster Management law of 2007 represented the formal incorporation of the post-2004 DRR activity into a national legal framework, set out to define the role of government and stakeholders through all phases of the PPRR model. To this end, the current National Disaster Management Agency (*Badan Nasional Penanggulangan Bencana*, BNPB) was established with counterpart organisations at every level of government. The current institutional framework for emergency response at Merapi is depicted in Figure 5.3.

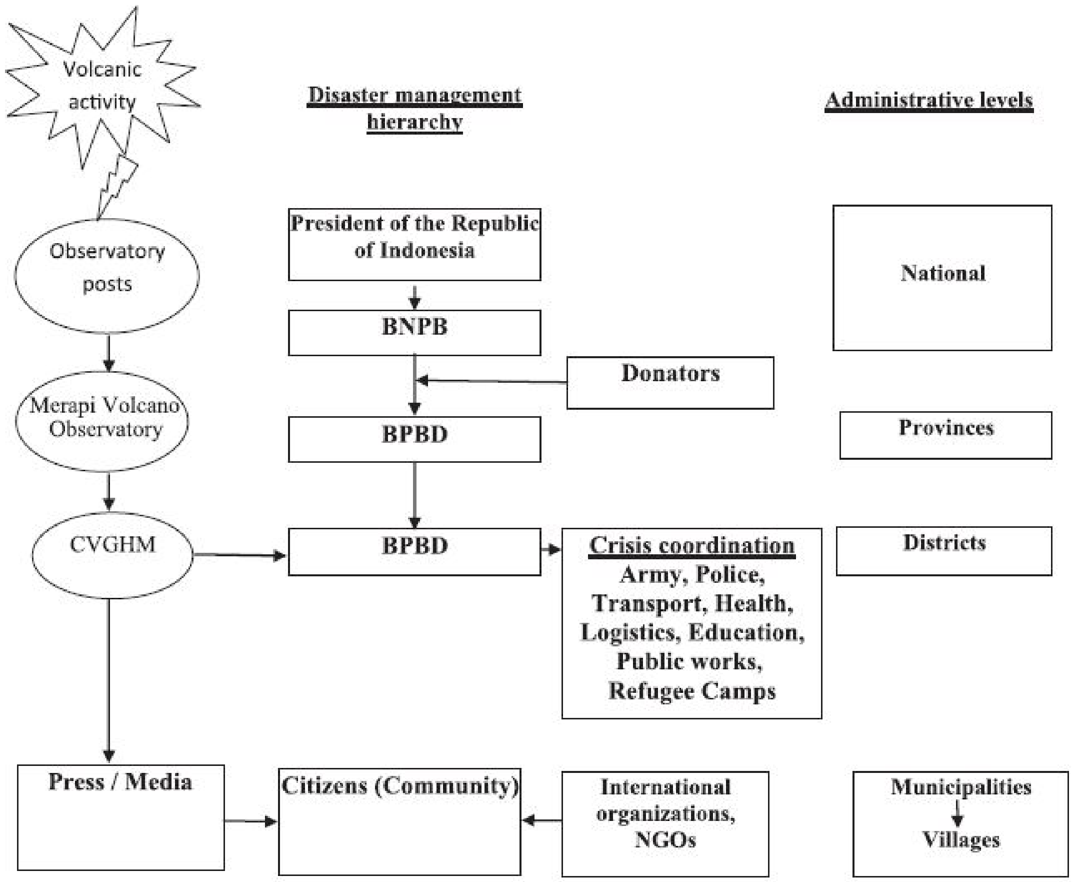


Figure 5.3. The institutional framework for disaster risk at Merapi (Bakkour et al. 2015). BPBD is the acronym for the local counterparts to the BNPB, these are the organisations that execute plans in the case of an emergency in co-ordination with a number of other public ministries.

In addition to disaster risk management, in co-ordination with the National Development Planning Agency, a National Action Plan for Disaster Risk Reduction was established extending through all layers of government (Cribben et al., 2011). Cribben et al. (2011) is a report of a project to promote community-based DRR as part of the Hyogo Framework, noting that while significant progress had been achieved, several disasters, including the 2010 eruption of Merapi, "highlighted persistent vulnerabilities in Indonesia and underscored how disaster and poverty are intertwined."

The VEI 4 October-November 2010 eruption of Merapi, was the largest since the 19th Century (Mei and Lavigne, 2012; Surono et al., 2012). Early indicators caused CVGHM to raise the alert level from I ('normal activity') to II ('increased activity') on 20th September. Subsequently, the precursors intimated to the volcanologists that a larger volume of magma than they had experienced was accumulating. On 21st October, the alert level was raised to III ('high unrest, likely eruption') and on 25th, it was raised to level IV, calling for the evacuation of communities within a 10 km radius of the summit (Gertisser et al. 2011; Surono et al., 2012). As was the case in 2006, the majority evacuated, however some remained, including Mbah Marijan and some members of his community who were among the 34 casualties of the first PDCs (Mei and Lavigne, 2012). The Gendol valley, unblocked in 2006, became the main outlet and, as Donovan (2010b) predicted, the villages on the south flank were destroyed.

Jenkins et al. (2016) suggest that had the eruption been the same size as the largest of the 20th Century, the 2002 map and the existing evacuation plans would have been 'appropriate'. However, as activity escalated over a period of 11 days to scales unseen at Merapi for more than a century, the existing VRR infrastructure "had to be abandoned... Evacuation zones toward the south had to be rapidly expanded, and displaced people in existing shelters had to relocate multiple times as shelters were consumed within the new, larger evacuation zones" (Jenkins et al. 2016). Authorities expanded the zones by 5 km three times from 3rd of November to 5th, as the eruption continuously incremented (Mei and Lavigne, 2012).

Official figures state that 396 were killed; the largest proportion (~170) were residents of the Gendol valley 10-15 km from the crater who failed to respond to the expansion of the evacuation zones in sufficient time, or did not believe that the eruption could reach them (Jenkins et al. 2016; Lavigne et al. 2017). More than 323,000 people were evacuated until 3rd December, by which point the activity had diminished. However, as had been the case during past eruptions, many evacuees (50-70%) returned to their land frequently to tend livestock and ensure that looting had not occurred (Mei and Lavigne, 2012; Pierson et al. 2014).

A long-term spatial planning initiative spanning five government ministries was introduced to redesign land use in the affected areas (Hidayati et al. 2011). CVGHM produced the most recent hazard map, with zonation adjusted for the impacts of the 2010 PDCs (Lavigne et al. 2017). A significant number of applied volcanology studies on Merapi emerged after 2010, building on the work of Dove (2008) and Donovan (2010a; 2010b) (e.g. Mei and Lavigne, 2012; Bakkour et al., 2015; Jumadi et al., 2015; Handayani et al. 2017). A further edition of the *JVGR* dedicated to the 2010 (and 2006) eruptions of Merapi was published in 2013 (Jousset et al., 2013). CVGHM collaborated with the EU-funded MIA-VITA project, producing a risk map based on hazard, vulnerability, exposure and coping capacity. The process for producing this map was presented in the *MIA-VITA Handbook for Volcanic Risk Management* (Bignami et al. 2012). Some local authorities discouraged the residents of the most exposed villages from returning to their homes, attempting to incentivise new settlements outside the evacuated zones. However, as with Turgo in 1994, most residents chose to return (Hidayati et al. 2011). Hidayati et al. also note that more than a year after the eruption, there were still 2,000 living in temporary shelters. 14 Sabo dams were destroyed and De Bélizal et al (2013) state that the volume of material erupted once more raises the probability of hazardous lahars. Lavigne et al. (2017) note that the Sabo dams actually assisted the separation of mobile dilute surges from pyroclastic flows.

Post-2010, Merapi has seen a VEI 2 explosion in November 2013, a VEI 3 explosion in April 2014, phreatic explosions which caused flight cancellations in May 2018 and dome growth from August 2018 until the time of writing (GVP, 2013). Brown et al. (2016) state: "With Indonesia’s focus on disaster management prevention and mitigation, strategies were put in place that paid off when Mount Merapi became active again in 2013. Residents gathered quickly at designated assembly points and were evacuated successful [sic], waiting to return home until the threat had passed." However, they also note that maintaining this culture of preparedness may prove a challenge.

Dynamic processes of policy mobility have shaped VRR at Merapi since the end of the 19th Century. Uncommonly frequent hazardous activity made Merapi a policy problem for Dutch colonists. As a result of their bringing a European industrial governance framework to the archipelago, an institutional response comprising many features of 'emergency management' was established at Merapi decades before it was a worldwide trend. The colonial VRR framework evolved over time, influenced by crises at the volcano and colonial scientists. However, inexperience and lack of focus on vulnerability saw eruptions frequently become disasters.

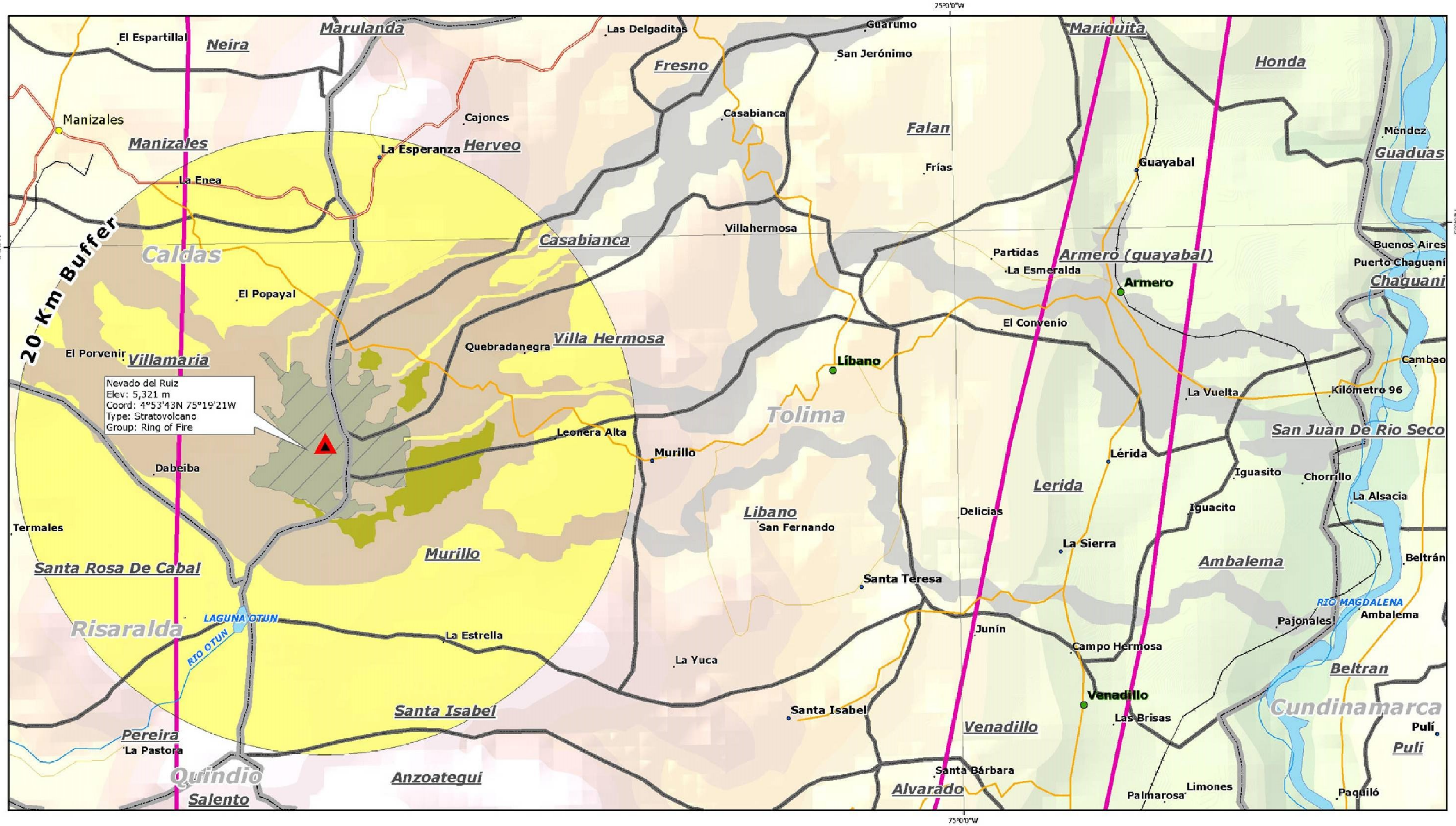
The framework survived independence and continued to evolve. As European scientists were distanced from the core assemblages, for a time, it mutated in relative isolation, influenced by the limited resources and international relations of the Sukarno era, as well as the ongoing activity. Following the rise of the New Order, Merapi was open to international collaboration and these many exchanges profoundly shaped VRR therein. Merapi became a recipient of, and a conduit for the redistribution of 'best practices' in volcanic risk governance according to the most advanced understanding of the time. Nonetheless, disasters continued to happen as the vulnerable communities surrounding the volcano were confronted by a regime and a policy framework that did not incorporate their understanding of Merapi, nor their way of life. In addition to these social challenges, Merapi proved to be a volatile source of hazard, capable of lulling both laypeople and volcanologists into a false sense of security before devastating areas previously thought 'safe'.

Institutional continuity was a key tenet of the *Reformasi* period. As such, the Behavioural paradigm continued to dominate into the early 2000s. However, evidence suggests that the Indian Ocean tsunami of 2004 provided a 'focussing event' that inspired the *Hyogo Framework for Action* of 2005 and then fed back into the Indonesian context. Indonesia's commitment to institutionalising the 'best practice' policy strategy promoted by the UN is evident in the response to the Merapi crises of 2006, 2010 and 2013. It could be argued that the frequent recurrence of hazardous events with disaster potential has kept political momentum behind the DRR agenda. The resistance to evacuations in 2006 and 2010, and the death toll of the latter eruption are indicators that even once a DRR-based approach has been adopted and institutionalised, its implementation is a gradual progression and will be affected by social, cultural, economic and volcanic processes. Indeed, the outcome of the next crisis remains uncertain, even if the incumbent policy framework is striving toward the 'best practices' of the international technocracies of VRR and DRR. However, the post-2007 policy framework has likely significantly reduced loss of life and potentially initiated a culture shift around the volcano, such that, that although in terms of lives lost, Merapi is currently the most 'calamitous' volcano of the 21st Century, it need not continue to claim that title.

5.2. Nevado del Ruiz, Colombia

Nevado del Ruiz (4.892°N 75.324°W; 5279 m; Figure 5.4) is a stratovolcano in the Cordillera Central of the Colombian Andes. Historically, it has been Colombia's second most active volcano, after Galeras. Forming the border between the departments of Tolima and Caldas, Nevado del Ruiz spans 250 km^2 (Figure 5.5). It is heavily glaciated; estimates suggest 1200-1500 million m^3 of ice on the summit (Thouret et al., 1990; Orozco-Alzate, 2006; GVP, 2013). In Witham's (2005) database of the most 'calamitous' volcanoes of the 20th Century, Ruiz ranks second in terms of deaths caused (23,080) and first in terms of injuries (4,470). Both of these figures stem from the 13th November 1985 eruption.

Figure 5.4. Aerial photograph of Nevado del Ruiz taken from the north (GVP, 2013).



Colombia, Nevado del Ruiz Volcano, Hazard Zones

Map prepared by Emergency Preparedness Branch (ODEP) 31.05.2011

The Nevado del Ruiz, aka La Mesa de Herveo is a volcano located on the border of the departments of Caldas and Tolima, about 129 kilometers (80 mi) west of the capital city Bogotá. It is a stratovolcano, composed of many layers of lava alternating with hardened volcanic ash and other pyroclastic rocks. The volcano usually generates Plinian eruptions, which produce swift-moving currents of hot gas and rock called pyroclastic flows. These eruptions often cause massive lahars (mud and debris flows), which pose a threat to human life and the environment. The volcano continues to pose a threat to the nearby towns and villages, and it is estimated that up to 500,000 people could be at risk from lahars from future eruptions. (Source: Wikipedia)

Hazard
- High lava-flow hazard
- High mudflow hazard
- High pyroclastic-flow hazard
- Moderate Hazard
- Moderate pyroclastic-flow hazard

Boundaries
- Regional
- District
- Fault

Water Bodies
- River
- Lake

Settlements
- Large City
- City
- Town
- Village

Transportation
- Primary Road
- Secondary Road
- Tertiary Road
- Railway

0 4 8 16 Km

Boundaries and names on this map do not imply official acceptance or recognition by World Food Programme or United Nations. The World Food Programme makes no warranty on representation as to the reliability or accuracy of the data contained herein. Figures on this map are accurate and up to date to the best of our knowledge.
Data Sources: GD, NGA, GAUL, ADC, Nasa, Wikipedia, Vmap, INGEOMINAS

Figure 5.5. Map of Nevado del Ruiz showing estimated hazard distribution, physical and political boundaries, settlements and transport infrastructure (UN World Food Program, 2011).

5.2.1. Early Recorded Eruptions at Ruiz

Nevado del Ruiz has produced 20 confirmed eruptions since 6660 BCE (GVP, 2013). Historical observations begin in 1570, since then there have been 13 confirmed eruptions. Nine of these have been small (<VEI 2), with three VEI 3 events (1845, 1985 and 2012-2013) and one VEI 4 eruption (1595). The 2012-2013 event was an extended period of low-intensity activity (GVP, 2013). Therefore, there have been three significant explosive episodes at Nevado del Ruiz in recorded history, each of which has been "a catastrophe in human terms" (Parra and Cepeda, 1990).

The 1595 eruption occurred when the territory that is now Colombia was part of the Spanish-controlled New Kingdom of Granada, governed from the city of Santa Fé de Bogotá. The land was also populated by indigenous peoples, over whom the conquistadores had assumed rule (Avellaneda, 1995). Reports of the eruption, describing four loud pulses and fall of ash and pumice, were collated by a priest However, the most significant outcome was that two rivers (which originated in the volcano's snow cap) "ran so full of ash that it looked more like a thick soup of cinders than like water. Both overflowed their channels leaving the land over which they flowed so devastated that for many years afterward it produced nothing but small weeds" (Voight, 1990). 636 were declared dead, predominantly indigenous residents of the Guali river valley (Parra and Cepeda, 1990).

In 1819, following a period of conflict with the Spanish, the independent Republic of Gran Colombia was declared (Gobierno de Colombia, 2010; Eissa-Barroso, 2016). In 1846, Joaquin Acosta, a Colombian explorer and scientist, attended the Academy of Sciences in Paris, presenting observations of a flow of mud that following 'a great subterranean noise' had descended the Rio Lagunillas 'from its sources in the Nevado del Ruiz'; approximately 1,000 people died. Acosta concluded that 'the causes of the catastrophe are unknown' (Parra and Cepeda, 1990; Voight, 1990). Acosta wrote: "It is astonishing that none of the inhabitants of these villages, built on the solidified mud of old mass movements, has even suspected the origin of this vast terrain...".

The social infrastructure (indigenous and colonial) of the territory around Ruiz in 1595 and 1845 had no apparent *ex ante* planning for the risk from the volcano (although the fact that death tolls were recorded, as well as allusions to rescue attempts by Acosta, suggest limited *ex post* action). It is also apparent that information regarding these events was collated, archived and even shared in an international academic forum. However, no evidence suggests the long-term retention of 'lessons', such that very similar volcanic processes killed significant numbers in the same way twice within 300 years. This is arguably to be expected of a volcano that had only produced eruptions of social consequence with a recurrence interval greater than a single human lifetime in the pre-civil defence era.

5.2.2. The Development of the Polity of Colombia

After 1845, two political parties emerged and have subsequently dominated Colombian politics: the *Partido Conservador*; and the *Partido Liberal*. Initially a Liberal-run federation, in 1886, Conservatives established a unitary republic and many state (now 'department') level powers returned to the central government. A faction of the Liberal party violently opposed this, culminating in the 'War of a Thousand Days' (1899-1902), which killed 100,000 (Watkins, 2004). In 1948 the assassination of a prominent Liberal, led to a series of riots. The resultant conflict (*La Violencia*) lasted 18 years and caused more than 200,000 deaths (Watkins, 2004; Coatsworth, 2003).

The Colombian Red Cross (CRC) was founded in 1915 by medics who had fought in the War of a Thousand Days. Presidential decree established the CRC as "...a special non-profit institution of common utility with its own independent assets, organised through a Federal system, constituted in accordance with the laws of the Republic of Colombia." It was formally recognised by the International Red Cross in 1922 (Cruz Roja Colombiana, 2014). In 1948, this assemblage of personnel was formally constituted in law as the *Socorro Nacional* (National Relief). The *Socorro Nacional* was given authority for providing relief after 'calamities' with the acknowledgement that the Government would provide resources and personnel, whilst legally maintaining the Red Cross's commitment to neutrality. The *Socorro Nacional* became a central pillar of the CRC (Cruz Roja Colombiana, 2009).

In 1958, as a response to the ongoing *Violencia*, the *Frente Nacional* (National Front); an arrangement whereby both parties would alternate in govenment for four-year fixed terms was established. The power to choose the President was taken out of the hands of the electorate. This proved contentious and, in 1964, politicised guerrilla organisations emerged (Watkins, 2004). As a response an internal security organisation, *La Defensa Nacional* was established; a division of which (*Defensa Civil*) was dedicated to unarmed action "to avoid, annul or diminish the effects that the actions of the enemy or nature may provoke against lives or social wellbeing" (Gobierno de Colombia, 1965).

The CRC/*Socorro Nacional*, and *Defensa Civil Colombiana* have subsequently operated collaboratively. The Red Cross model was first implemented in Colombia as a response to Colombian social issues, seven years prior to the involvement of the International Red Cross. Thus, institutionalised disaster relief 'arrived' in Colombia, not through the machinations of an international NGO, but through a group of private individuals, having been inspired by that NGO from afar. Through the CRC, a form of institutionalised disaster relief came to exist in Colombia decades before the era of Civil Defence, in harmony with the state, but not explicitly *of* the state. This remained the case even after the establishment of the *Socorro Nacional*. Similarly, the civil defence model seems to have manifested organically in Colombia, as a response to Colombian issues, with no clearly evident process having brought it from 'elsewhere'. Thus, by the mid-point of the 'era of civil defence', Colombia possessed established infrastructure for disaster response, and therefore had arguably instituted the Behavioural paradigm of DRR. However, there was no policymaking directed at volcanic risk. Colombian volcanology was nonexistent, and no significant volcanic hazards had presented themselves in living memory to draw the attention of policymakers.

The *Frente Nacional* lasted until 1974 (Watkins, 2004). The complicity of both parties had weakened their support bases, meaning that the transition back to democracy was completed peacefully. A Liberal President, Alfonso López Michelsen became the first directly elected leader since the 1950s. However, circumstances remained turbulent - the Liberals lost the presidency in 1982 and the incoming

Conservative, Belisario Betancur, took charge of a recession, a fiscal deficit, international debt and internal warfare from guerrillas and narcotics cartels (Hanratty and Meditz, 1988). Colombia in the early 1980s was simultaneously attempting to govern multiple crises and severely lacking resources. It was against this backdrop that Nevado del Ruiz began to show signs of unrest.

5.2.3. The Eruption of November 1985

In December 1984, the staff of a refuge on Nevado del Ruiz felt earthquakes and heard unusual noises. Ruiz had been subject to geological mapping and petrological analysis by two US doctoral projects, but was largely unstudied and unmonitored. The first institution to show interest was the *Centro Hidro-Electrica de Caldas* (CHEC), a private electricity provider from Manizales, capital of Caldas department (Figure 5.5), which had, in collaboration with Italian scientists, been investigating Ruiz for possible development of geothermal infrastructure since 1983 (Hall, 1990). On 6th January 1985, CHEC scientists visited the crater and produced a report stating "the authorities must implement a geophysical and geochemical program for monitoring a probable eruption" (Voight, 1990). In late January, 'interested individuals' from businesses (including CHEC) and NGOs organised a committee with Manizales' mayor intending to monitor Ruiz and create a 'work plan' (Hall, 1990). Thus, it can be argued that existing institutions in Caldas (notably predominantly non-governmental institutions) assembled on an emerging micro-level policy field of VRR without external bodies or processes of policy circulation. However, the realisation of these plans quickly necessitated the involvement of people and organisations outwith Manizales and Caldas.

In early February 1985, the search for experts began with Colombian universities and INGEOMINAS (The Colombian Bureau of Geology and Mines). INGEOMINAS were contacted by *Defensa Civil* authorities after a meeting between the Caldas and national-level organisations. It was quickly discovered that there were no volcanologists in Colombia (Bruce, 2002). Nonetheless, scientists from CHEC visited the crater in mid-February followed by an INGEOMINAS team. The CHEC team produced a report recommending that Caldas and neighbouring departments "undertake a survey of the volcanic and seismic risk of Nevado del Ruiz...". The full report was published in national newspaper *La Patria* (Hall, 1990).

A request from INGEOMINAS and *Defensa Civil* to a team of UNDRO scientists (who happened to be in Colombia) connected Ruiz to the global policy field. The UNDRO team visited the crater and published conclusions that daily data-gathering, expanded instrumentation, training of Colombian scientists, the creation of a volcano monitoring and hazard evaluation programme by INGEOMINAS and the provision of logistical support, alert systems and evacuation plans by *Defensa Civil* were all necessary (Voight, 1990). A seminar on volcanic risk was held in the National University at Manizales and, at the end of March UNESCO, disappointed at inaction from INGEOMINAS/*Defensa Civil*, alerted the recently-established WOVO, bringing a further constituent of the global policy field of VRR into the frame. WOVO assembled a team in early April 1985, led by Minard Hall. *Defensa Civil* in Caldas produced an emergency plan for volcanic eruptions (Hall, 1990; Voight, 1990).

Hall's visit included meetings with many constituents of the policy field growing around the volcano, predominantly in Caldas: CHEC scientists, *Defensa Civil* Caldas, the *Universidad Nacional* at Manizales, the Mayor of Manizales, the Governor of Caldas, the National Director of *Defensa Civil* and scientists from INGEOMINAS. Hall's meeting at INGEOMINAS raised the issue of funding. The WOVO report concluded that the activity at Ruiz was potentially hazardous and a full monitoring network should be established (Hall, 1990). The report also stated the Caldas emergency plan was "excellent and completely adequate", with the correct focus on lahar hazards, although it stressed the necessity for producing a hazard map (Voight, 1990). After it became apparent that INGEOMINAS and the *Universidad Nacional* in Bogotá did not have sufficient funding, INGEOMINAS asked the USGS for seismometers. The USGS acquiesced, but did not provide personnel. Colombia's ambassador to UNESCO informed Bogotá that the UN was willing to provide technical support and funds, but the message 'went missing' for more than two months (Hall, 1990).

The committee in Caldas was formalised in early July and given $1.5 million Col (£720,120) for monitoring and risk assessment. CHEC petitioned Italian scientists for assistance, while the state government and UNESCO requested assistance from Switzerland. The USGS' seismographs were installed by INGEOMINAS, however the instruments did not work until the Swiss scientist Bruno Martinelli arrived and established three seismometers of his own in collaboration with CHEC, while also helping to make the USGS/INGEOMINAS seismographs functional. Around mid-August, CHEC and INGEOMINAS formed separate seismology groups and did not share data (Hall, 1990; Voight, 1990).

In early September regular volcanic tremor was registered. This concerned Martinelli, particularly because the seismograms were sent to Bogotá unprocessed. On 11th September, Nevado del Ruiz produced a continuous seven-hour phreatic explosion causing ashfall over Manizales and a lahar 20 km down the Rio Azufrado. Residents of the upper river valley were alerted, but not evacuated. Following an emergency meeting, the Caldas committee, *Defensa Civil* Caldas and the Governor recommended evacuations. Nonetheless, *La Patria* ran a front page headline claiming"Ruiz activity is not dangerous" in an attempt to restore calm (Voight, 1990).

Following the 11th September eruption, activity on the VRR policy field surrounding Ruiz accelerated. The Caldas Committee met almost daily, the Governor of Caldas attempted to organise a work group with the governors of neighbouring departments (it was decided that each department would work autonomously). Multiple meetings were held in Bogotá, involving bodies as diverse as the Coffee Growers' Association of Caldas, the Ministry of Mines and the Nuclear Institute. At the national level, five 'working groups' were formed: Budget, Public Health, Agriculture, Water and Scientific. Nevertheless, a two-day debate on 24th and 25th September in Congress was initiated when Caldas accused the government of a lack of support. The Minister of Mines and Energy insisted that support had been given not just to Caldas, but to the other departments (Tolima, Quindío and Risaralda) identified as potentially being affected. An educational programme about volcanic hazards began in Caldas schools (Hall, 1990).

Until September 1985, Caldas had almost exclusively been the focal point for VRR policy development and mobility. From the start, Caldas developed its own micro-level policy field with assemblages of private and civic institutions. Throughout 1985, this had become connected to the global policy field of VRR and shaped by a coming-together of international technocratic bodies and existing local infrastructure.

However, it became apparent that communities in Tolima, on the eastern side of the volcano were perhaps at greater risk than any in Caldas.

In mid-late September, the Mayor of the town of Armero (Figure 5.5) and the Director of the Red Cross in Tolima, drew attention to the potential for lahars to cause overspill on a dam on the Rio Lagunillas, creating a flood which would cause serious damage in the town. The Mayor's office suggested a drainage plan, but construction never began. At the end of September, a meeting was held between the scientists monitoring the volcano and the Secretary for the government of Tolima, at which a census of communities along the Tolima river valleys, and the placement of individuals with radios was discussed. On 1st-2nd October, a two-day seminar was held in Ibagué, capital of Tolima to instruct officials on volcanic emergency response. An emergency committee similar to that in Caldas was formed in Tolima (Hall, 1990; Voight, 1990).

Tolima's institutions found themselves with a need to develop policy for a rapidly evolving situation, with substantial intrinsic uncertainty, despite no prior involvement in VRR developments around the volcano. Martinelli noted in a personal communication to Voight (1990):

> *During the whole period of my stay there were no mutual contacts or cooperation between the region Caldas, where I was, and Tolima. Only on September 13th, i.e. after the eruption of September 11th, was a meeting held at the* Defensa Civil *in Bogotá, organized by General De La Cruz, with representatives of the authorities of Caldas and Tolima, of the Red Cross, and the* Defensa Civil. *As far as I could see, even after this meeting cooperation between the two regions was insufficient.*

Voight argues: "the focus on Manizales may have retarded local emergency management in neighbouring Tolima province, where much greater risk existed."

On 18th September, an article in *La Patria* claimed that the volcanic risk was overstated and the in-development hazard map would 'devalue' property in a form of 'volcanic terrorism'. This was supported by statements from the USGS and other foreign scientists whose opinions conflicted with Martinelli's, arguing that an eruption would likely only affect a 10 km radius around the vent. INGEOMINAS presented the first version of the map on the 7th October. Only ten copies were distributed, but it was stated at the meeting that, according to the map's projections, Armero would have two hours to evacuate after the generation of any lahar (Hall, 1990). Hall notes that the conflicting messages between groups of scientists and prominent local figures confused the population. The Mayor of Armero stated on 8th October that the community "...did not have the necessary information or financial resources to do anything in the event of a catastrophe. For this reason, the people have lost confidence in the veracity of the information and have commended their fate to God".

In mid-October, UNDRO and UNESCO published reports, concluding that a hazardous eruption could occur at any time, and monitoring at the volcano was 'almost non-existent' due to issues with the seismometers (Hall, 1990). Meanwhile, the Caldas risk committee and INGEOMINAS were still not sharing data; Martinelli wrote to Voight (1990):

> *during the whole time of my visit I noted a pronounced rivalry between the emergency committee and INGEOM1NAS. I was never able to figure out the reason for this conflict nor to clarify what responsibilities each institution actually had. In any case, this rivalry had a strong influence on the whole phase of emergency preparation.*

On 6th November, many of the external scientists based in Manizales returned to their parent organisations (Hall, 1990). Guerrillas laid siege to the Colombian supreme court and President Betancur ordered an armed response in which 100 died (Hanratty and Meditz, 1988). The resulting political crisis forced the presentation of the completed hazard maps to be delayed from 12th November until 15th. The updated maps indicated that residents of Armero would need to travel over 1 km to escape inundation. Three days of continuous tremor starting on 10th November raised concerns but no action was taken (Voight, 1990).

On 13th November, Nevado del Ruiz erupted again. Phreatic explosions began at 15:06. However, the summit of the volcano was obscured by cloud, and the seismic signals were confused for high winds by CHEC scientists. At 16:00, ash began to mix with rainfall in Tolima. National *Defensa Civil* and CRC were alerted by the co-ordinator of *Defensa Civil* Tolima before 17:00, at which point he convened a regular meeting of the regional committee in Ibagué. The first action was to contact police stations and municipal CRC organisations to inform them to prepare for evacuation 'if necessary'. The meeting then turned to 'routine' matters such as developing emergency plans. At 19:30, when it was reported that ashfall had ceased, authorities in Armero encouraged citizens to remain indoors (Hall, 1990; Voight, 1990; Bruce; 2002).

At 21:08, magmatic emission began. Explosions illuminated the clouds. CHEC scientists who witnessed this alerted the Caldas committee. They informed the Governor who issued an evacuation order for Caldas. The eruption peaked between 21:30 and 22:00, generating glacier-burst lahars. In Caldas, the village of Chinchiná was the first hit, at 22:30. Although a partial evacuation had occurred, approximately 1,100 died. In Tolima, authorities in Ibagué became aware of the eruption's climax between 21:45 and 22:00 and attempted to order the evacuation of Armero. However, the ash-laden rainstorm caused power outages and the message was not received. Most residents remained in their homes when the lahar surges arrived. The town was overwhelmed and approximately 23,000 were killed (Voight,1990). Total economic losses were later estimated at $218,000,000 USD (Mileti et al. 1991).

One week later, survivors and victims were still being pulled from the mud in a relief effort co-ordinated by the CRC and *Defensa Civil.* A Presidential task force named *Resurgir* ('Rise Again') was created to co-ordinate all related private and public-sector activities, including emergency preparedness, housing, redevelopment, food distribution and identification of survivors. Subcommittees were created for each of these, each incorporating two or three survivors (Mileti et al. 1991).

As the extent of the crisis became apparent through international broadcasting, large organisations on the global policy field of DRR began to contribute. Foreign aid donations totalled $50 million USD and the World Bank and the Inter-American Development Bank provided loans of $1.2 billion USD for reconstruction (Serrill, 2005).

> *In the frantic and mournful days that followed, the ranks of the Volcanic Risk Comité swelled with volunteer scientists from many nations... To aid the Comité, the USGS immediately dispatched (with OFDA support) about ten veteran volcanologists and mudflow specialists armed with sophisticated instrumentation... In addition, the U.S. Department of Defense sent two C-130 aircraft and 12 helicopters from the U.S. Army Southern Command to assist in medical evacuation, rescue and hazard missions...* (Voight, 1990).

The Caldas risk committee appealed to the USA to fund a seven-station lahar monitoring network, however OFDA rejected the proposal due to cost, and two stations were ultimately installed by Japan (Voight, 1990). Of Armero's 5,000 survivors, 1,000-2,000 who were unable to find shelter with family were accommodated in refugee camps. A decision was taken not to resettle the land and replacement housing was constructed 13 km away (Mileti et al. 1991).

The institutional response to the 1984/85 eruptive crisis of Nevado del Ruiz is laden with policy mobilities, assemblages and mutations. Prior to 1984, Colombia possessed no VRR policy infrastructure. The Ruiz crises of 1595 and 1845 had not resonated through the country's turbulent political history and Colombian DRR institutions had neither awareness nor incentive to perform *ex ante* planning during the volcano's inactivity. Although, by this point, much VRR experience existed 'elsewhere', and the international 'explosion' of volcanology that had followed the 1980 eruption of Mount Saint Helens was underway, connections to the global policy field of VRR at the start of the crisis were virtually nonexistent. Over the subsequent 11 months a policy field emerged, a confluence of existing Colombian meso and micro-level organisations and a variety of international actors. The result was not a cohesive policy system characterised by protocol and straightforward flow of information, but an uneven, chaotic and fragmented collection of emergent assemblages that saw profound differences in the rate and nature of policy development.

In Caldas, a local, ad-hoc institutional response was established relatively rapidly. The Caldas committee sought expertise from 'elsewhere'. Although this was arguably a rational decision, the end product was more typical of mobile policy; a patchwork of ideas and practices derived from the involvement of INGEOMINAS, *Defensa Civil*, UNDRO, UNESCO, WOVO and more besides, underpinned by Colombia's fractious internal politics and lack of resources. Two key examples of this are the divide between the Caldas committee and INGEOMINAS; and the complete lack of policy development in Tolima until after the 11th September eruption. Tolima appears to have attempted to emulate the model established in Caldas without any active collaboration with Caldas, nor the international connections and additional scientific input the Caldas committee received. It is unsurprising, given that this crisis occurred during the period identified in Chapter 4 as the peak of the Behavioural paradigm (not to mention the involvement of UNDRO) that the overall shape of the policy strategy employed by authorities in Caldas and Tolima conformed to the 'emergency management' approach, with all focus placed on responding to an eruption and little-to-no focus on the reduction of vulnerability. The resulting policy framework failed to achieve its goal and contributed to the second largest volcanic disaster of the 20th Century.

5.2.4 Volcanic Risk Governance at Nevado del Ruiz since 1985

The November 1985 eruption of Nevado del Ruiz had a transformative impact. Significant policy developments stem from the Armero tragedy at the local, national and global levels. In Tolima, much effort was expended to understand the extent of the hazard, to communicate to the public and to develop policy to mitigate the risk (Mileti et al., 1990). The Caldas risk committee was transformed into a Colombian Volcanological Observatory under INGEOMINAS (ironically, given the prior disharmony between these two organisations). The Observatory was established by February 1986 with technical support from the USGS and financial support from OFDA (Voight, 1990). This USGS/OFDA approach would go on to become VDAP (Section 4.3) another product of the Ruiz eruption.

The Observatory was part of a new national-level policy strategy for volcanic risk based on the UNDRO (1985) *Volcanic Emergency Management* manual, published weeks after the eruption. The technical aspects of the UNDRO system were ingrained in the approach (Mileti et al. 1991). The colour-coded alert system that the Observatory derived from the UNDRO manual has four levels: green (IV) 'stable';

yellow (III) 'in flux'; range (II) an eruption is expected in the timescale of days to weeks; and red (I) an eruption is in progress (El Colombiano, 2015).

Despite its origins in the Caldas committee, the Observatory was established as an instrument of the national government. It was required to report any eruption to the President's office, who would convene the National Emergency Committee (*Comité Operativo de Emergencia - COE*) established after the 1985 eruption. The COE was based in Bogotá and comprised the President's office, INGEOMINAS, CRC, *Defensa Civil*, *Resurgir* central command, the Governor of Tolima and local emergency services. In an emergency, the COE would inform *Defensa Civil* at national level, who would alert the Governor's office, who would alert local media and town mayors, who would alert the local police stations, who would alert a network of 'siren keepers' who would finally alert the public. An education campaign was also conducted, including school workshops, the distribution of flyers and hazard maps. The maps attracted criticism from those afraid they would cause a recession (Mileti et al. 1991).

By February 1986, the new system had been employed twice: the first was a drill conducted without warning; the second was an actual evacuation decision by the COE, triggered by an eruption on 4th January, 1986 (although no hazardous lahars were generated). In both instances, it took more than three hours from the decision to the sirens, due to the complexity of the command chain. Few participated, despite the recentness of the Armero tragedy. An investigative team from the USA government visited Nevado del Ruiz in February 1986 to produce a report on the anatomy of the disaster. The second evacuation effort occurred during their visit and the apparent lack of success prompted them to write a report for Colombian policymakers recommending changes to the system: principally, increased instrumentation of the volcano; simplifying the command chain; and replacement or accompaniment of sirens with verbal warnings (Mileti et al. 1991).

Low-moderate activity persisted at Nevado del Ruiz until July 1991. During this time, several increments in activity resulted in the COE calling evacuations. Six weeks of harmonic tremor and ash emission in June 1986 resulted in an order to permanently evacuate the zone within 10 km of the summit (with a population of 1,700) and a recommended evacuation of the 10-20 km zone as well. However, this did not occur.

In March 1988 the 10 km zone was once more ordered to evacuate. Several hundred complied, however more than 1,000 chose to remain. At 02:15 on 1st September 1989, a phreatomagmatic explosion occurred and a lahar travelled 7 km, destroying a bridge. Sirens were sounded at 04:50 (again suggesting several hours between the identification of the eruption and the alert). This was the last crisis of 1984-91 (GVP, 2013). Williams (1990) argues that the Observatory in Manizales had become 'world class', collaborating with volcanologists across the globe. The result was a special issue of the JVGR, notable for containing a 'policy section' (Hall [1990], Parra and Cepeda [1990] and Voight [1990]) wherein volcanologists reflected on the governance of the crisis.

Between 1986 and 1990, the policy infrastructure that developed in response to the Nevado del Ruiz eruption was expanded into the *Sistema Nacional de Prevención y Atención de Desastres* (National System of Prevention and Attention to Disasters) or SNPAD (Gobierno de Colombia, 2014). This new system integrated across all levels of government placed Colombia at the vanguard of disaster risk policymaking and along with the start of the IDNDR, was one of the major global-level policy developments that kick-started the era of DRR at the macro level (UNISDR, 2015; Sections 2.3.1. and 4.3).

After the 1984-91 eruptive period, Nevado del Ruiz showed no further activity and the attentions of the Colombian policy field of VRR were drawn to Volcán Galeras in the southern department of Nariño, selected as a 'Decade Volcano'. During a Decade Volcano workshop in January 1993, a field excursion to Galeras' crater coincided with an explosion that killed six volcanologists and three tourists (Baxter and Gresham, 1997; Bruce, 2002). Although not caused directly by volcanism, in 1994, a magnitude 6.4 earthquake triggered lahars from Nevado del Huila volcano resulting in 271 confirmed deaths, 1,700 missing and more than 32,000 evacuees (GVP, 2013).

The Nevado del Huila lahar was the last volcanic crisis of the 20th Century in Colombia. However, SNPAD had become occupied an increasing number of disasters. Between the start of the IDNDR and 2011, nearly 17,000 disasters were registered, predominantly caused by hydrometeorological hazards, earthquakes and slope failure. The *Plan Nacional para la Prevención y Atención de Desastres*

(National Plan for Disaster Prevention and Response) or PNPAD was created in 1998. The PNPAD endeavoured to change the focus of the DRR system to the long-term reduction of risk through development. However, implementation was partial and subject to varying interpretations. Disasters continued to increment - 9,270 were registered between 2000 and 2009. The fatalities from disasters dropped from 3,957 in the 1990s to 2,180 in the 2000s, however, the total number of people affected grew from 9,204,412 in the 1990s to 9,284,073 in the 2000s, predominantly through property damage due to population expansion in vulnerable areas (Campos et al. 2011).

Campos et al. (2011) argue that a holistic evaluation of potential volcanic risk in the country had not been performed. Only 12 out of 20 potentially active volcanoes were monitored by the three INGEOMINAS observatories (laterally the *Servicio Geologico Colombiano* - SGC) in Manizales, Popayán and Pasto. There was no database of communities and assets at risk. Nevado del Huila became active, producing lahars in April 2007 and November 2008 (CNN, 2007; BBC, 2008). Several evacuations were ordered. It was argued by the Pan-American Health Organisation (2007) after the first of these that memory of the 1994 event had contributed to a high rate of participation. However, in the following eruption (which did not produce lahars) the evacuation order was ignored by many (Colombia Reports, 2007). The November 2008 eruption produced the largest lahars, evacuations of 10,000 predominantly indigenous people were ordered <2 hours before the lahars reached settlements. These were largely successful, however, 10 were killed (BBC, 2008; Campos et al. 2011).

After the 2010-11 La Niña that caused 510 deaths and $ 8.6 billion Col in damages, the Colombian government requested that the World Bank's Global Facility for Disaster Reduction and Recovery, a multi-actor partnership on the global policy field, conduct an external examination and recommend policy changes (Campos et al. 2011). The report concluded that increasing disaster risk was predominantly attributable to DRR having not been incorporated into land management, leading to higher vulnerability. This was compounded by 'gaps' in the policy infrastructure, whereby municipal and department-level actors, private citizens and businesses frequently did not understand their roles in the system, nor the ongoing process of risk reduction. The GFDRR recommendations were incorporated into a new successor entity. The SNGRD (*Sistema Nacional de Gestión del Riesgo de Desastres*) coordinated by the UNGRD (*Unidad Nacional para la Gestión del Riesgo de Desastres*) created in 2012. Three national committees were established for distinct functions: study of risk; reduction of risk and management of disasters. Councils for risk reduction were also established at every level of government (department, district and municipality) (Gobierno de Colombia, 2012).

In the period 1991-2012, the observatory in Manizales had predominantly registered low seismicity and fumarolic activity at Nevado del Ruiz. A minor explosion in 1994 resulted in the alert level being raised to Yellow and the emergency committee of Caldas temporarily declaring the summit closed to climbers. A significant earthquake swarm in May 2002 caused the alert level to be raised to Orange, although no eruption ensued. Heightened seismicity in September 2010 again caused the alert level to be briefly raised to Yellow (GVP, 2013).

In January 2012, SO_2 flux increased significantly and explosive degassing signatures began to appear on the seismic record. On 29th March a hundredfold increase in seismicity led to an Orange alert being issued. The National Park that encompasses the volcano closed in April 2012 over fears that the rainy season would generate secondary lahars. On 3rd May, the alert level was dropped to Yellow. However, on 29th May, an increase in seismicity resulted in the alert being restored to Orange before explosions dispersed ash over 20 communities northwest of the volcano and caused the closure of three airports on advice from the Washington VAAC (GVP, 2013). The municipal division of the SNPAD in Manizales ordered an evacuation of 24 families deemed to be at highest risk. In a press release on 7th June, the director of the Municipal Office for Prevention and Attention to Disasters admitted that some had not evacuated and while the organisation was willing to offer evacuees a $150,000 Col lease subsidy, there was no legal mechanism to force them to comply (El Espectador, 2012).

Widespread ashfall continued throughout June, before a significant increase in activity at the end of the month:

> *On 30 June 2012, seismicity increased and large plumes of ash vented from the summit... At 1700 that day, authorities raised the alert to Level I (Red). Local news media reported the preventative evacuation notice provided by the Emergency Committee of Caldas... An estimated 300 families were ordered to evacuate from the rural zones of districts Chinchiná (30 km WNW), Villamaría (28 km NW), Palestina (40 km WNW), and Manizales (30 km NW) due to both escalated explosions and also the potential for flooding along the rivers Chinchiná and Río Claro. In the Department of Tolima, located S of Caldas there was a recommendation to evacuate 1,500 families in risk zones in eight municipalities* (GVP, 2013).

Approximately 4,000 people were ordered to evacuate. However, only 43% complied, prompting Colombian President Juan Manuel Santos to express his frustration on Twitter: "They have not evacuated all who should have been evacuated. How many were supposed to be evacuated? 4,000 people were supposed to be evacuated and 1,710 were evacuated. What does this say about us? That we lack education, collaboration and social discipline. Here we have to improve" (Colombia Reports, 2012). This failure to engage the at-risk population is arguably comparable to other examples of UNDRO-based VRR systems that failed to achieve their policy goals. There is little evidence in the volcanic crises in Colombia since 1985 of a straightforward progression towards increasingly efficient evacuation procedures.

President Santos' first challenge as head of government had been the La Niña crisis of 2010-2011 and it was his administration that consulted the World Bank and ultimately brought about the transition from the SNPAD to the SNGRD. As the Nevado del Ruiz crisis of 2012 unfolded, the director of the UNGRD published objectives for the creation of a *Contingency Plan for Eruption of Nevado del Ruiz*:

- Identify the panorama of risks in the zones influenced by Nevado del Ruiz.
- Establish the functions and responsibilities of the different national and territorial entities.
- Establish organisation and planning mechanisms for actions to attend and control emergency situations in an opportune manner.

- Determine the inventory of physical, human and logistical resources for attending emergencies.
- Formulate a plan of action to face the impacts that could be generated by a possible eruption of Nevado del Ruiz.
- Develop recommendations to help regional and municipal organisations to take the necessary precautions (Márquez, 2012).

At this stage, it can be argued that the focus was still orientated towards responding to an emergency, as opposed to the long-term DRR goals espoused by the SNGRD project. However, this was the first step in reviewing the VRR system at Nevado del Ruiz since its reactivation and it is possible that longer-term policy goals were incorporated later. After the evacuations of June-July 2012, activity diminished. The alert was lowered to Orange on 2nd July and to Yellow in September 2012. Yellow alert has been maintained ever since (GVP, 2013).

Since 2012, this study has not encountered official publications from the Colombian government regarding the development of policy pertaining specifically to Nevado del Ruiz. However, there have been other developments with the potential to influence VRR policy and practice at Ruiz. In 2015, the UNGRD produced the National Plan for Disaster Risk Management, the co-ordinating strategy of the SNGRD. Its goals are:

- Reduce national mortality caused by disasters by 2025 and reduce the national mortality rate caused by disasters per 100,000 people in the decade 2015-2025, compared to the period 2005-2015.
- Reduce the number of people affected in the country by 2025 and reduce the rate of people affected by disasters per 100,000 people in the decade 2015-2025, compared to the 2005-2015 period.
- Reduce the number of homes destroyed and directly affected by recurrent phenomena in the decade 2015-2025 with respect to the 2005-2015 period (UNGRD, 2015).

This policy strategy aims to reduce physical and social vulnerability around Nevado del Ruiz (and throughout Colombia). The National Plan includes several goals pertaining to volcanic risk. Under 'Study of Risk', it encourages further investigation of seven active volcanoes and reinforcement of monitoring networks. Under 'Preparation for Response in Regional Risk Scenarios', there are aims for the "elaboration and realisation of national protocols for response to volcanic phenomena" such that 100% of departments located in areas affected by volcanic phenomena have protocols in place by 2025 (UNGRD, 2015). If these policy goals are to be realised then a co-ordinated VRR policy approach to risk at Nevado del Ruiz involving all stakeholders and levels of government should be under development. However, details have not been published to date.

The practices of volcanologists have been more visible. Since 2015, the Manizales volcano observatory has published monthly reports of outreach activities, including internet publications, regular presentations and meetings in communities and with authorities (SGC, 2018). Moreover, in 2012, the SGC entered into collaboration with VDAP, resulting in a 'Bi-National Exchange' project between the USA and Colombia specifically aimed at improving VRR at Nevado del Ruiz and Mount Rainier (USGS, 2015c; Section 5.3). Finally, Nevado del Ruiz has been one of the 'forensic volcanoes' of the Strengthening Resilience in Volcanic Areas (STREVA) project (Sections 2.3.2; 4.3). STREVA involvement at Nevado del Ruiz included a workshop entitled "Learning from past eruptions at Nevado del Ruiz to build a more resilient future" (6th-11th of October 2014). This was arranged collaboratively by STREVA team members, SGC and UNGRD. One of the goals of the workshop was to start a long-term programme of research and collaboration pertaining to volcanic risk and to contribute to the ongoing process of risk reduction in Colombia (Sword-Daniels et al. 2014). A further result of STREVA involvement at Nevado del Ruiz has been the publication of an extensive investigation of multiple aspects of vulnerability (e.g. access to resources and public services, education, quality of life, quality of housing, livelihood) in three municipalities in Tolima and Caldas. This study suggests that, although awareness among residents that they live in an area of high volcanic risk is generally strong, knowledge of the hazards and the plans and actions to reduce vulnerability is still limited. Alhough all households examined were in a high risk area, only 43% of respondents were aware of this in Villa María, Caldas, and 45% were aware in Armero-Guayabal, Tolima. In Villa María, 80% and in Armero-Guayabal, 62% of residents had not seen the risk maps produced by the SGC for the volcano. There was a high margin of confidence among residents that they knew what to do in case of an eruption, however only around half of households had a personal emergency plan, as recommended by authorities. (Armijos and Few, 2017). This suggests that, in the development of the latest iteration of the Nevado del Ruiz VRR policy, there is still much work to be done with regard to community engagement.

The aftermath of the 1985 eruption of Nevado del Ruiz saw a policy model shaped through an influx of mobile knowledge. The UNDRO (1985) manual formed the basis for this - likely its first application. Typically of mobile policy, it 'mutated' in its new setting, influenced by the Colombian context and inputs from 'elsewhere'. The resulting policy framework became the foundation for a nationwide DRR system. Volcanology became well established in Colombia and extensive international collaboration meant that mutual exchange of information drove advances in the science and encouraged focus on applied volcanology. Among other field constituents, VDAP and all of its subsequent impacts on the global policy field originate in the aftermath of the 1985 Ruiz eruption.

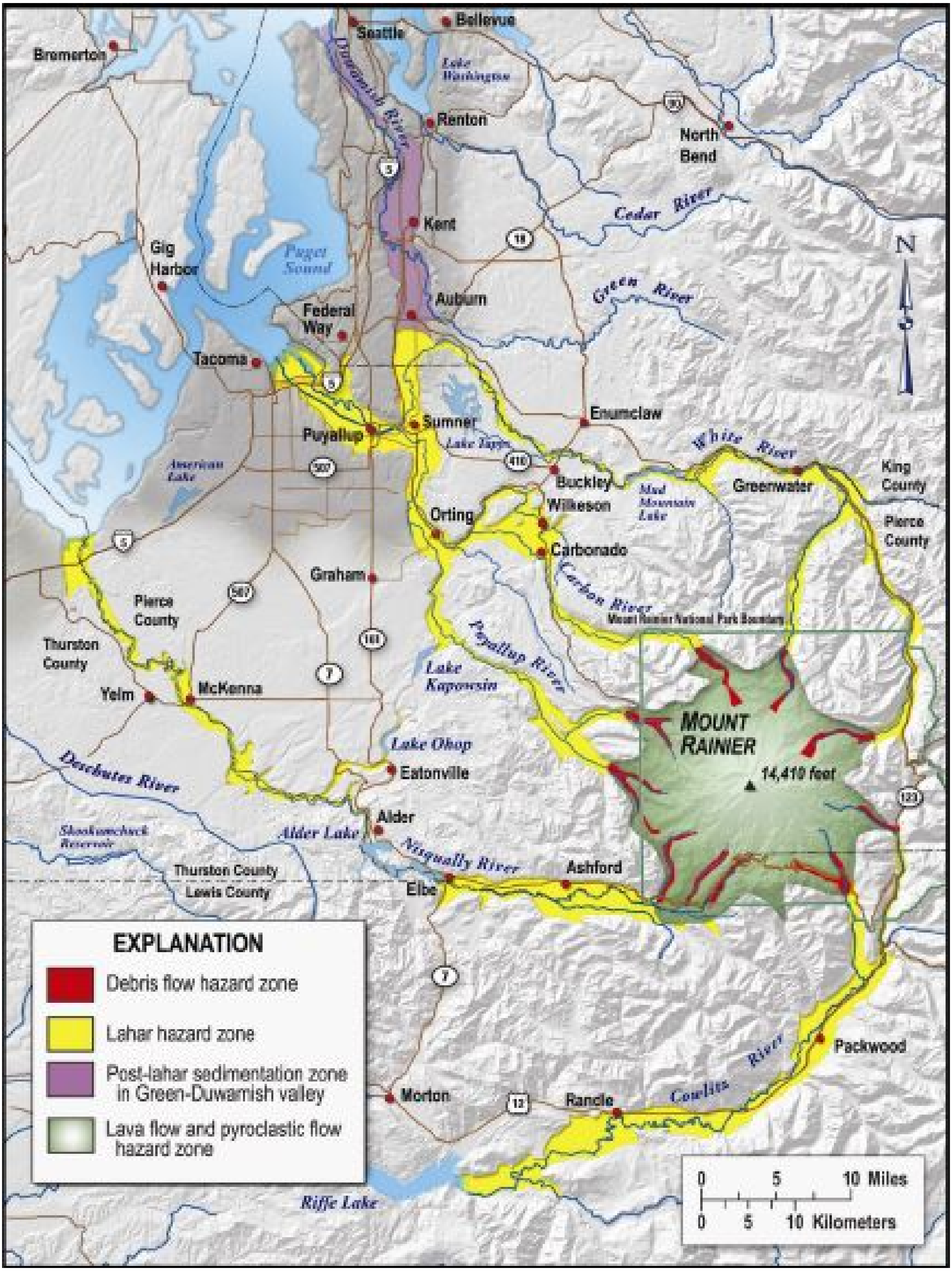
The Colombian system itself went on to become a globally mobile policy model that fed into the IDNDR and UNISDR, becoming a crucial component in kick-starting the transition from 'emergency management' to 'disaster risk management' at the global level, recognising the importance of *ex ante* policymaking (even if the transition to full DRR is incomplete). These macro-level entities on the global policy field have subsequently fed back into the Colombian context through the Hyogo and Sendai Frameworks and the Colombian government's consultation of the World Bank in 2011. Due to the 1991-2012 quiescence, it is arguable that these developments somewhat bypassed Nevado del Ruiz and thus, when the volcano awoke, (coincidentally, as Colombia was on the cusp of a further leap towards DRR) the unchanged UNDRO-based policy model proved inadequate for much the same reasons as at various other volcanoes. Had the 2012 eruption been larger, a second major disaster was entirely feasible.

There are signs of work to develop an integrated DRR policy framework that presumably incorporates Nevado del Ruiz. However, in an ideal DRR framework, the details would arguably be public knowledge and every stakeholder, including the general public, would be aware of their roles. As such, the true nature of the form that governance of future crises at Nevado del Ruiz will take is currently uncertain, although there is evidence that the international volcanological community is maintaining the flow of knowledge from 'elsewhere' in the pursuit of 'best practices'. There is potential for further mobilities, mutations and assemblages to have a profound and unpredictable effect on volcanic risk governance at Ruiz.

5.3 Mount Rainier, United States of America

Mount Rainier (46.853°N 121.760°W; 4,392 m; Figure 5.6) is a glaciated stratovolcano in Washington State, USA. 1980s studies estimated ice cover at 90 km^2 and volume at 4.2 km^3 (Dreidger and Kennard, 1986). In light of worldwide glacial retreat, a recent study has estimated the perennial snow and ice cover on Mount Rainier at 80.82 km^2. However, an adjusted volume estimate has not yet been made (Beason, 2017). Magma-water interaction and sector collapses have produced lahars and debris avalanches that have reached Puget Sound, 48 km from the summit (PCDEM, 2008; Figure 5.7). The last confirmed eruption of Mount Rainier was in 1450 (± 100 years) (GVP, 2013). Mount Rainier is, therefore, unlike the previous two case studies in that it has not produced significant hazardous activity in modern history. However, by 2009, the deposits around this volcano had come to be inhabited by approximately 78,000 people and USGS scientists have suggested that this makes Rainier potentially the most dangerous volcano in the USA (Driedger and Scott, 2008; Wood and Soulard, 2009).

Figure 5.6. Photograph of Mount Rainier from the northwest (GVP, 2013).



Seattle
Bellevue
Bremerton
Lake Washington
Duwamish River
Renton
North Bend
Kent
Cedar River
Gig Harbor
Puget Sound
Auburn
Green River
Federal Way
Tacoma
Enumclaw
Sumner
Puyallup
Lake Tapps
White River
American Lake
Buckley
Greenwater
King County
Wilkeson
Mud Mountain Lake
Orting
Pierce County
Carbonado
Graham
Carbon River
Pierce County
Mount Rainier National Park Boundary
Thurston County
Puyallup River
Lake Kapowsin
Yelm
McKenna
MOUNT RAINIER
14,410 feet
Lake Ohop
Deschutes River
Eatonville
Alder
Alder Lake
Shookumchuck Reservoir
Nisqually River
Ashford
Thurston County
Lewis County
Elbe
EXPLANATION
Debris flow hazard zone
Lahar hazard zone
Post-lahar sedimentation zone in Green-Duwamish valley
Lava flow and pyroclastic flow hazard zone
Packwood
Cowlitz River
Morton
Randle
Riffe Lake
0 5 10 Miles
0 5 10 Kilometers
N

Figure 5.7. United States Geological Survey hazard map of Mount Rainier (PCDEM, 2008) showing at-risk areas, topography, waterways, county boundaries, roads and settlements.

5.3.1. The Roots of Volcanic Risk Governance at Mount Rainier

The limited nature of VRR in the Cascades until the 1980s is detailed in Section 4.2. The foundation of the Cascades Volcano Observatory (CVO) in 1982 was a local policy consequence of the Mount Saint Helens eruption that came to encompass the other volcanoes in the range. The risk of lahars from glaciated stratovolcanoes had become apparent after the Mount Saint Helens and Nevado del Ruiz eruptions. By 1991, scientists at CVO had identified the potential threat from Mount Rainier. A successful nomination bid for Mount Rainier was submitted to the IAVCEI committee responsible for organising the Decade Volcano project (Section 4.3) with the condition that the USA government provided finances, as the (unsuccessful) request for UN funding was to be dedicated to the 7+ volcanoes from 'developing' countries (Swanson et al. 1992).

The Decade Volcano Demonstration Project for Mount Rainier began in September 1992 with a workshop at the University of Washington involving 75 Earth scientists, disaster risk scientists and representatives of government agencies (US Geodynamics Committee, 1994). It was recognised that Rainier was poorly studied outwith 1960s geological surveys which were insufficient to constrain past activity. The 1994 US Geodynamics Committee report outlines a course of action including long-term studies in geology/petrology, geochemistry and seismology, the establishment of a monitoring programme encompassing seismicity, ground deformation, hydrothermal activity, visual observation and debris flows/lahars. Furthermore, it contains a section dedicated to 'mitigation' outlining recommendations for communication between stakeholders and a long-term strategy:

> *Planning and implementation of risk-mitigation measures should involve scientists, government, business, and citizens and should be coordinated and, where appropriate, integrated with other planning activities in the region. Several measures, including the following, should be considered for implementation in order to significantly reduce risk from volcanic hazards to people and property:*

• *analyses to identify regions and populations at risk;*

• *land use planning and economic incentives to discourage inappropriate use of high-risk areas; and*

• *engineering solutions to mitigate risks where possible, from specific volcanic hazards* (US Geodynamics Committee, 1994).

The report outlines the legal framework for implementation (the Washington State Growth Act of 1990 and its subsidiary legislation in Pierce County [Figure 5.7], the most vulnerable jurisdiction). An elected committee of resident representatives developed a series of recommendations and working guidelines for VRR policymaking in Pierce County, based on the best available information regarding the volcanic risk. The US Geodynamics Committee report noted: "Careful tracking of how that information is (or is not) translated into actual mitigative measures is needed to transfer successful ideas to other jurisdictions, or to spot jurisdictions for which more information, more aggressive application, or alternative measures are needed." This demonstrates some awareness the complexities of policy mobility at an early stage in the process.

It is notable that the volcanologists at CVO initiated the entire policy development process at Rainier by engaging with the Decade Volcano project. They used a macro-level initiative, driven by the global volcanological 'expert community' (a component of the larger IDNDR programme) to frame Mount Rainier as a policy problem and assemble a collective of meso-and-micro level actors with the goal of establishing a VRR governance framework. The involvement of citizens' groups is also noteworthy, as this is a policy goal of the then-new 'disaster risk reduction' paradigm not seen at other case study volcanoes at this stage.

5.3.2. The Mount Rainier Volcanic Hazards Response Plan

Preliminary discussions between USGS volcanologists and the Pierce County Department of Emergency Management (PCDEM) concluded that the policymaking process would require involvement from federal, state and local government and the other stakeholders listed above. A 'work group' comprising all of these was convened, co-chaired by the director of PCDEM and the Chief Ranger of Mount Rainier National Park, and regular quarterly meetings ensued. Initially, the idea was to create an 'operational response plan' for emergencies (the 1985 UNDRO manual was cited in the first published version) however, it became apparent that participants' understanding of the risks and available courses of action was limited. It was therefore recommended that a public education programme be implemented in parallel. The authors argue that the work group has since: "…created an outstanding network of individuals, educated to, familiar with and most importantly concerned about what Mount Rainier may do… strengthened our community and fostered relationships that will encompass more than just issues surrounding the mountain" (PCDEM, 2008).

As the policy developed and the group became more informed, it was decided that a long-term mitigation strategy would potentially reduce the scale of a short-term emergency response. A post-disaster phase was also incorporated. The first version of the *Mount Rainier Volcanic Hazards Response Plan* (*MRVHRP*) was published by the Washington Emergency Management Division in 1999 (WEMD, 1999). A second, expanded edition was published by PCDEM in October 2008. Despite no significant activity at the volcano, the work group have conducted continual 'plan maintenance', aiming for revisions every two years, incorporating new scientific information, changes in command structure, technology etc., although the 2008 document remains the most recent published edition (PCDEM, 2008). Both versions are available to download from their respective publishers.

The *MRVHRP* encompasses multi-jurisdiction, multi-agency and multi-disciplinary concerns, from local (e.g. town fire departments) to national (Incident Command System) organisations. It has a detailed breakdown of operations in a crisis. Its "Command" chapter is dedicated to outlining the operational hierarchy (PCDEM, 2008). It designates one body; the Washington Emergency Management Division (WEMD) as 'area command'; the lead agency responsible for coordinating operations throughout all affected jurisdictions (Figure 5.8):

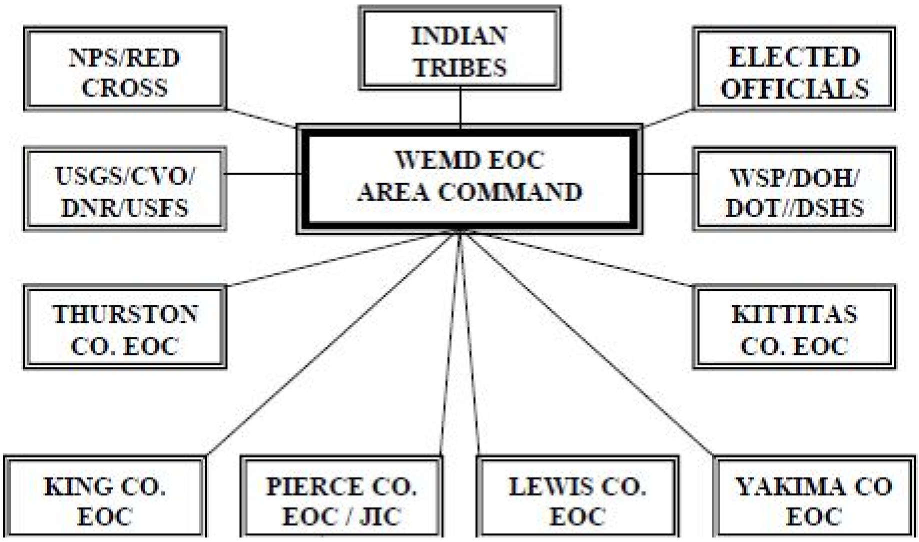


Figure 5.8. The command structure of the *MRVHRP* (PCDEM, 2008); Washington Emergency Management Division Emergency Operations Centre (EOC) provides a hub for the numerous agencies and organisations, coordinating flow of information and directing operations for actors as diverse as county EOCs, police and environmental health agencies, volcanologists at the Cascades Volcano Observatory (CVO) and, notably, indigenous communities. This system is known as a unified command structure and is advocated by the Federal Emergency Management Agency (FEMA) for all multi-jurisdiction emergency management scenarios in the USA, aiming for less conflict, less duplication of efforts and more effective utilisation of resources (FEMA, 2008). See the Glossary of Acronyms for further explanation.

The *MRVHRP* outlines the full monitoring programme used by the USGS. The plan uses the same four-level alert system used by the USGS at all volcanoes in the USA (although in the case of communicating hazards to aviation, the international standard code employed by all VAACs, which differs from the USGS system, is used). Despite having the same number of levels as the current systems at Merapi and Nevado del Ruiz, there are some differences. The USGS uses categories that reflect not only the likelihood of activity, but of *hazardous* activity. The categories reflect the level of concern of the volcanologists, not just the state of the volcano. A colour code is not used in order to avoid the impression that the alert levels are sequential (PCDEM, 2008; Table 5.1).

Table 5.1. USGS Summary of Volcano Alert Levels (USGS, 2017). This system is designed to reflect the non-linear behaviour of volcanoes. The “Advisory” category serves not just as the step between “Normal” and “Watch” but also as an alert in the period of reduced activity after a volcanic event.

SUMMARY OF VOLCANO ALERT LEVELS	
NORMAL	Volcano is in typical background, noneruptive state or, *after a change from a higher level,* volcanic activity has ceased and volcano has returned to noneruptive background state.
ADVISORY	Volcano is exhibiting signs of elevated unrest above known background level or, *after a change from a higher level,* volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
WATCH	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, OR eruption is underway but poses limited hazards.
WARNING	Hazardous eruption is imminent, underway, or suspected.

The *MRVHRP* details ongoing mitigation procedures and recovery operations. Mitigation encompasses improvement of evacuation routes; tax disincentives for moving into hazard-prone areas and public education initiatives (Table 5.2). Recovery procedures are planned to be initiated whilst the response is ongoing, the course of action taken will depend on the outcome of a damage assessment; if deemed inappropriate then repopulation of damaged areas may not be permitted for decades (PCDEM, 2008)

Table 5.2. Summary of mitigation measures against volcanic hazards in operation in Pierce County, Washington, the organisations responsible and the anticipated timeframe for implementation (PCDEM, 2008).

Implementation Mechanism	Mitigation Measure	Lead Jurisdiction(s) / Department(s)	Timeline (years)	Plan Goals Addressed					
				Life and Property	Emergency Services	Public Preparedness	Partnerships for Implementation	Natural Resources	Sustainable Economy
Volcanic Hazard									
Hazard Mitigation Forum: Multi-jurisdictional implementation mechanism	Evacuation Planning: New Roads and Development	PC DEM; Transportation Division (PC PWU)	1-2	✓	✓	✓			
	Mount Rainier Closure Zones	PC DEM; USGS; CVO; Mount Rainier National Park	5	✓	✓	✓			
	Bridge for Kids	B4Ks; PC DEM; WA EMD; Orting School District; City of Orting	5	✓	✓		✓		
	Dam Draw Down Agreements	PC DEM; Facility Owners	5	✓			✓	✓	
	Lahar Flow Control	PC DEM	5	✓				✓	✓
Hazard Mitigation Committee: County-wide implementation mechanism	176th Street East Extension	PC PWU	5	✓					
	Tax or Insurance Disincentives	PC PALS	5	✓		✓		✓	
Public Education	Public Education: Lahar	PC DEM	Ongoing	✓		✓			
	Public Education: Volcanic Ashfall	PC DEM	5	✓		✓			
	Public Education: Education for Self Warning and Evacuation	PC DEM	5	✓		✓			
	Public Education: Evacuation Routes	PC DEM	1-2	✓	✓	✓	✓	✓	✓
	Public Education: Bus Driver Evacuation Training Program	PC DEM; Valley School Districts	5	✓	✓				✓

The *MRVHRP* aims to present an integrated approach to volcanic risk governance with diverse components incorporated into a single policy framework. As well as seeking to "manage" any emergencies at the volcano, the *MRVHRP* aims to adjust social conditions around Mount Rainier in the long term to reduce the likelihood of future crises. Although the UCS is inevitably authoritarian, the collaborative approach to designing the plan aims to make the *MRVHRP* work for all stakeholders and the 'work group' is presented as a harmonious platform at which all interests are represented fairly. However, there have been no volcanic crises at Mount Rainier to validate its efficacy.

5.3.3. Recent Developments

Although the plan has never been put into practice in an emergency scenario, drills have been conducted to test its logistical functionality. The first of these was a simulation exercise with no public participation in May 2001. Confusion among authorities led to 5,000 'residents' still being present in the inundation zone of the imaginary lahar at the time it was projected to arrive. The chief of PCDEM stated "We learned a lot. We still have a ways to go" (Doughton, 2001). Since then, some parts of the plan have been practised annually, such as the evacuation of the town of Orting (Figure 5.7). These are participative drills conducted by school students, teachers and volunteers during an annual 'Volcano Preparedness Month'. Evacuation times have improved annually and these drills are embedded in community life (Pierce County Television, 2017). Furthermore, WEMD (2019) claims that a 'new plan for Mt. Rainier' is forthcoming.

In 2012, a 'Bi-National Exchange' programme was proposed by VDAP scientists who had worked on Mount Rainier and Nevado del Ruiz, noting similarities between the two (Pallister, 2017). They entered into collaboration with the SGC and, in 2013, organised exchange visits between scientists, emergency management authorities, emergency responders, the Red Cross, OFDA (who provided the funding) and others from both countries (USGS, 2015c). A further visit was conducted in 2017, during which the Colombians participated in the Orting evacuation drill (Pierce County Television, 2017). This programme's status as a formal collaboration between government institutions of the USA and Colombia marks it as an apparently mutual enterprise wherein both sets of actors contribute and benefit in equal measure (USGS, 2015c). This may stem from its origin in the close working relationships between the volcanologists who, although employees of different governments, are also colleagues in the expert community of volcanology. As the most recent iterations of VRR policy at Mount Rainier and Nevado del Ruiz are under development at the time of writing, tracking the assemblage and re-assemblage these exchanges is beyond this investigation. However, it is likely, given the number of individuals and institutions involved, that the full range of formal and informal policy consequences will be diffuse; sometimes overt, sometimes subtle, and thus difficult to encapsulate in full, supporting the premise that mobile policy is complex and unpredictable, even when engaged with deliberately and voluntarily.

The VRR policy field at Mount Rainier differs from our other cases in that it has materialised and evolved without activity at the volcano. At the other case study volcanoes, VRR policymaking has been demonstrated to be predominantly a reactive, *ex post* process. At Mount Rainier, it has ostensibly been entirely *ex ante* - however, it can be argued that the triggering events occurred at *other* volcanoes. Such a scenario is arguably the highest aspiration of policy mobility in volcanic risk governance.

Circulation on the global policy field of VRR, mainly through volcanological assemblages, brought volcanic risk governance to Mount Rainier, and scientists deliberately used the Decade Volcano project to institutionalise it. Afterwards, much of the process of developing the *MRVHRP* seems to have been conducted at the meso/micro levels. The UNDRO (1985) model provided the core 'emergency response' component of the *MRVHRP*. However, a more expansive policy framework has been assembled around it, demonstrating the now-familiar principle that the coming together of mobile policy and the unique attributes of new settings frequently causes significant mutation.

A prominent feature of this case is how *deliberate* much of the process seems, both in terms of the intentions of the policy actors and evidence-based decision-making. Everything from the proposal to the implementation suggests extensive planning. It is perhaps because policymaking has been conducted in 'volcanic peacetime' that the long timescales required for such deliberation have been possible. It could be argued that volcanic risk governance at Mount Rainier (theoretically at least) conforms more to the Complexity paradigm, due to its focus on community input and the long-term reduction of vulnerability. This has been the case since the first policy consultation, in contrast with the previous two cases where the full adoption of a DRR approach has only been attempted in the 2000s-2010s, driven by the UNISDR. It may be argued that policymakers had a 'blank canvas' with no vestigial policy infrastructure from the Behavioural model to accommodate, allowing a DRR-based system to develop 'organically'. It remains to be seen, however, how this policy framework will perform in a real volcanic crisis.

5.4. Popocatépetl, United Mexican States

Popocatépetl (19.023ºN, 98.622ºW; 5393 m; Figure 5.9) is a stratovolcano in central México, 60 km southeast of the capital, México City and 40 km west of the city of Heroica Puebla de Zaragoza (Puebla), bordering the states of México, Puebla and Morelos (Figure 5.10). Since the start of the 20th Century, 10 periods of activity between VEI 1-3 have occurred. There have been 32 such periods in approximately 500 years of observation. Radiocarbon dating and tephrochronology have revealed at least two Plinian and three sub-Plinian eruptions within the last 8,000 years (GVP, 2013). There have been few deaths recorded at Popocatépetl. Most recently, five climbers were killed during an eruption on 30th April 1996,. However, artefacts have been discovered in the deposits of the two most recent Plinian eruptions in Puebla, indicating that settlements were destroyed at some distance from the volcano (Siebe and Macías, 2003). Around 20 million currently live in communities that may be affected by Popocatépetl, De la Cruz and Tilling (2008) state that "Popocatépetl is arguably the most dangerous volcano in the country". The majority would likely be affected by ashfall in a major eruption, whilst the number exposed to flow phenomena is closer to 500,000 (Siebe and Macías, 2003).

Figure 5.9. Vulcanian explosion at Popocatépetl, looking south from Volcán Iztaccihuatl (National Geographic, 2019)

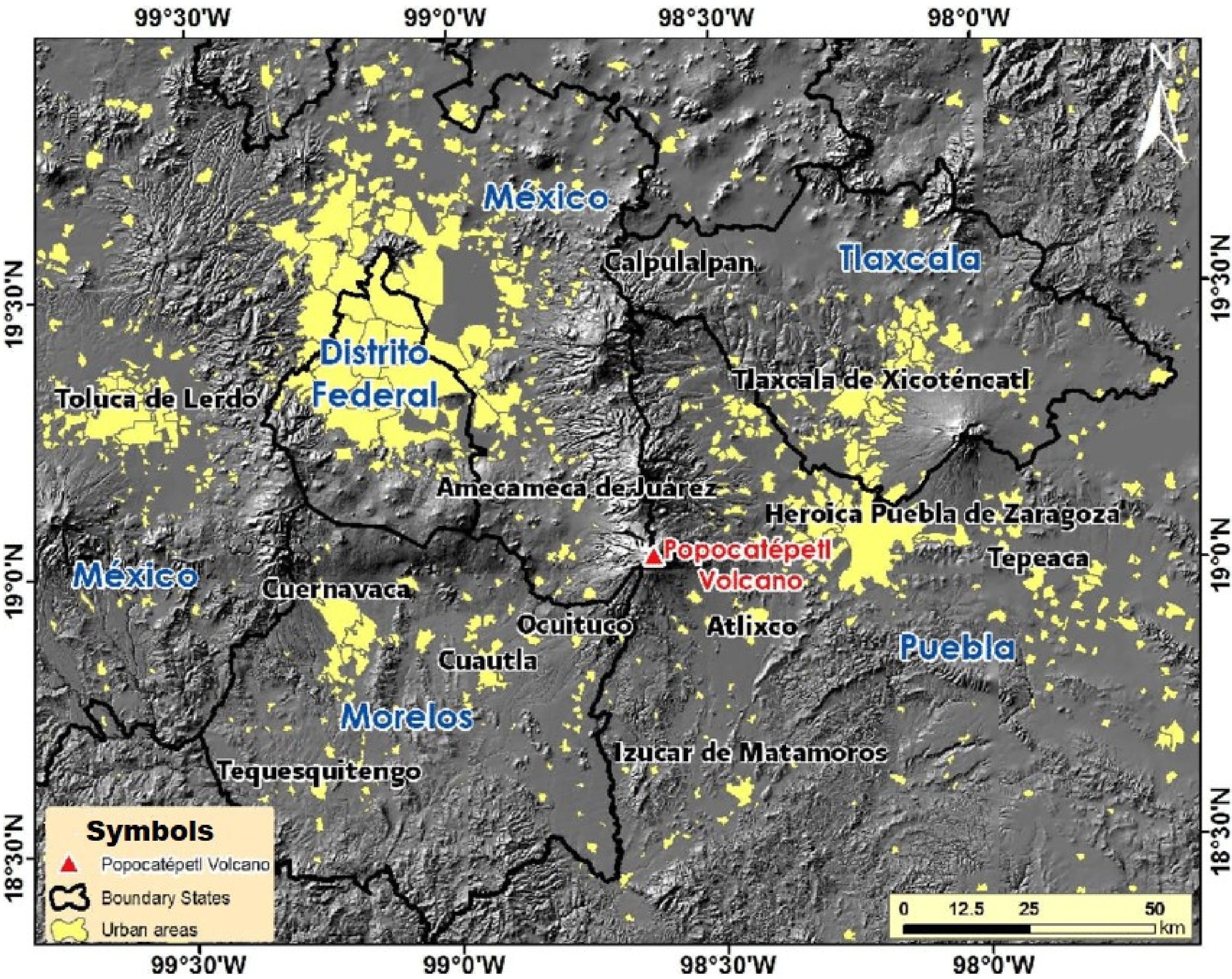


Figure 5.10 Map showing the location of Popocatépetl within central México, including state boundaries and population centres (González and De la Cruz, 2010). *Distrito Federal* was the administrative name for México City until 2016.

5.4.1. Early Volcanic Risk Governance in México

Rural México experienced two significant volcanic crises in the mid-20th Century: the 1943-52 eruption of the monogenetic cone, Paricutín, which resulted in the relocation of 1,200 refugees (Nolan, 1972); and the Plinian eruption of El Chichón in April 1982 which killed 2,000 and left 45,000 homeless (Macías and Aguirre, 2006). The governance of these crises was arguably reactive, ad hoc and inconsistent - at times laissez-faire and at times authoritarian. In the case of El Chichón, communities were evacuated by the military, then permitted to return (the climactic stage of the eruption killed most who did). Survivors were divided into camps and subsequently left as environmental refugees without government assistance or compensation (Macías and Aguirre, 2006). These crises did not inspire the developmment of DRR policy in México. However, after the Chichón eruption, two geologists from the *Instituto de Geofísica* (IG) at the *Universidad Nacional Autonoma de México* (UNAM) who witnessed the climactic phase became the country's first volcanologists (De la Cruz and Martin del Pozzo, 2009).

On 19th September 1985, an earthquake severely affected the capital, killing 4,541 and causing over $4 billion USD in economic losses. It was this that drove the federal government to establish SINAPROC, the National System of Civil Protection, in 1986 (OECD, 2013; Figure 5.11). The crises of Paricutín and El Chichón suggest that if a policy problem arises in a provincial location, then sometimes its 'lessons' do not even circulate to the more populous regions of the same country, nor into the priorities of central government.

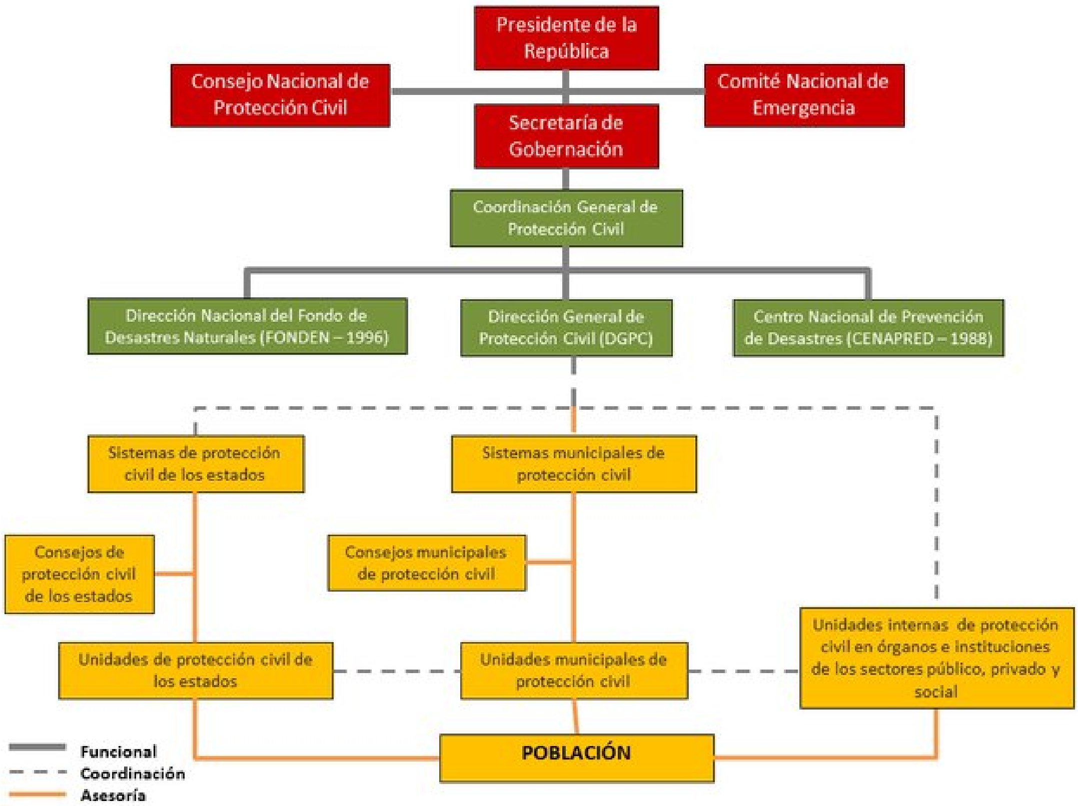


Figure 5.11. Structure of SINAPROC, the Mexican National System of Civil Protection (Campos et al. 2016). At the top tier is the executive power of the President and the national committees that can be convened at presidential behest. The administration of SINAPROC is conducted under the authority of the Secretary of the Interior and the Co-ordinator General of SINAPROC has direct authority over the three organs of the system at federal level: the general directorate; FONDEN, which manages the federal finances for disaster response; and

> CENAPRED, the scientific institution that seeks to research and develop technical approaches to reduce disaster risk and monitor hazardous phenomena. Beyond this, the legal autonomy of states and municipalities requires federal institutions to liaise with civil protection organisations that are otherwise free to implement policy strategies according to their own preferences. "One of its (SINAPROC's) key challenges is simply to ensure the many federal, state and municipal civil protection services function as a flexible whole together with companies, volunteer organisations and research institutes from different sectors" (OECD, 2013; see also Chapter 6).

5.4.2. The Reawakening of Popocatépetl and the Plan Operativo

In 1986, climbers noted fumarolic activity inside the crater of Popocatépetl, the first indicator that after approximately 70 years, the volcano was becoming active. There were no monitoring instruments on the volcano, the first telemetered seismometer on Popocatépetl was set up by the IG in September 1989. Also in 1989, two volcanologists from Clermont Ferrand, France, published an article on the recent eruptive history of Popocatépetl and created a preliminary hazard map (Boudal and Robin, 1989). A geodetic network was established in February 1992 (De la Cruz and Tilling, 2008). De la Cruz and Tilling note that although precursory seismicity probably began in 1990, by 1993, a significant increase alerted the IG to the possibility of an eruption. Flyovers to measure the emission of SO_2 began in February 1994. By October of that year, unrest had 'increased markedly' and an ad hoc committee comprising UNAM scientists, along with researchers from CENAPRED was convened. The Boudal and Robin (1989) hazard map was used as the basis for risk assessment. CENAPRED had no previous volcanological experience. Although both institutions collaborated in operating this seismic network, the Director of the IG at the time argued that he did not want the responsibility of monitoring the volcano, so the signal was routed to CENAPRED which became the *de facto*, and later official, observatory for Popocatépetl (Interview 5). CENAPRED was established in 1988, in collaboration with the Japanese government, and can therefore itself be viewed as a result of mobile policy (De la Cruz and Tilling, 2008)

On 21st December, 1994, at 01:54, Popocatépetl produced several phreatic explosions, ash was carried eastwards, reaching the city of Puebla (Martin Del Pozzo, 2012). De la Cruz and Tilling (2008) state that "Decision making had to be done with scant knowledge under acutely adverse conditions." The explosions occurred without identifiable precursors; real time monitoring of the volcano was limited to three seismometers; the eruption began at the start of the Christmas holidays so, availability of personnel was limited; the volcano was capped by two glaciers, so a Nevado del Ruiz-style lahar was a possibility; and most notably, no VRR policy framework existed.

An emergency committee was convened by the Minister of the Interior, particular attention was paid to glacier-burst lahars. Communications were made to the USGS, who suggested, based on their experience and the volume of ice on the volcano, that lahars may be large enough to reach the nearest towns (De la Cruz and Tilling, 2008). According to Macías and Aguirre (2006), the involvement of the USGS brought the UNDRO (1985) system of volcanic emergency management into the Popocatépetl crisis and the committee 'closely followed' the manual's recommendations. Later that day, the decision was taken to evacuate the communities deemed to be 'high risk' (Siebe and Macías, 2003; De la Cruz and Tilling, 2008). Macías and Aguirre (2006) state that the government intended to evacuate 75,000 people, however, only 26,000 complied and widespread social unrest accompanied the resistance. They argue that the evacuation did not account for local culture and traditions, including religious leaders known as *tiemperos* who supposedly act as conduits between the communities and the volcano: "This neglect of local customs had the unfortunate consequence of pitting scientists and government officials against traditional institutions" (Macías and Aguirre, 2006). None of the other accounts examined mention this resistance, De la Cruz and Tillling (2008) state only that approximately 25,000 were evacuated and that the evacuation was a 'prudent preventative measure'. Siebe and Macías (2003) note that those who were evacuated had to spend Christmas and New Year in temporary shelters. The activity declined after around a week, and evacuees were permitted to return to their homes (De la Cruz and Tilling, 2008).

In January, the explosions became less frequent and the meetings likewise (Martin Del Pozzo, 2012). CENAPRED issued an official request for VDAP assistance and USGS scientists had arrived on 1st January 1995 (Manley, 1995). They set up two additional seismometers and two tiltmeters, assisted with hazard assessment and participated in committee meetings. An updated hazard map by CENAPRED/IG/USGS scientists was published on the 17th of February. This was in use until 2018 (De la Cruz and Tilling, 2008; Espinasa et al., 2018). Phreatic explosions continued to occur throughout 1995. In March 1996, the first magmatic emission began, forming a dome on the crater floor. Subsequent activity has consisted of episodic growth and destruction of >20 lava domes (Siebe and Macías, 2003; Martin Del Pozzo, 2012; Interview 21).

As the activity progressed, so did the development of VRR policy around Popocatépetl. De la Cruz and Tilling (2008) describe 1995 as the 'assessment' period, during which the committee was formalised and a working group was established, comprising CENAPRED, committee scientists and authorities, with the aim of designing protocols. De la Cruz and Tilling state that the UNDRO (1985) manual was used in this process, however, some departures were made, notably around the alert code. The code advocated by the UNDRO system is a four-level colour code similar to that seen at Merapi and Nevado del Ruiz. It was argued by some of the senior Mexican volcanologists that the alert system was primarily to drive the response of the population, not reflect the activity of the volcano, and reducing the number of levels to three would eliminate any ambiguity about the need to act. The three-level code was adopted by the committee, despite pressure from the participating foreign scientists to adopt a four-level version. However, a unique aspect of the Popocatépetl committee's alert system is that it simultaneously seeks to be a three-level alert system and a seven-level alert system, the seven levels are intended for scientists and authorities, meanwhile the three levels are supposedly for the population (Figure 5.12; De la Cruz and Tilling, 2008; Interview 21).

Accompanying the alert levels were recommendations to SINAPROC authorities for developing their policy response to Popocatépetl. These predominantly consisted of creating, refining and implementing short-term emergency plans, restricting access to the volcano and educating communities about the hazards (De la Cruz and Tilling, 2008). The result was the *Plan Operativo Popocatépetl* (*POP*). Macías and Aguirre (2006) argue that the *POP* fully institutionalised the UNDRO model at Popocatépetl, and the UNDRO model subsequently shaped SINAPROC's strategy for handling all emergencies, volcanic or otherwise, reshaping the organisation. For instance, the National Emergency Committee and National Council of Civil Protection (Figure 5.11) were descendents of the Popocatépetl committee.

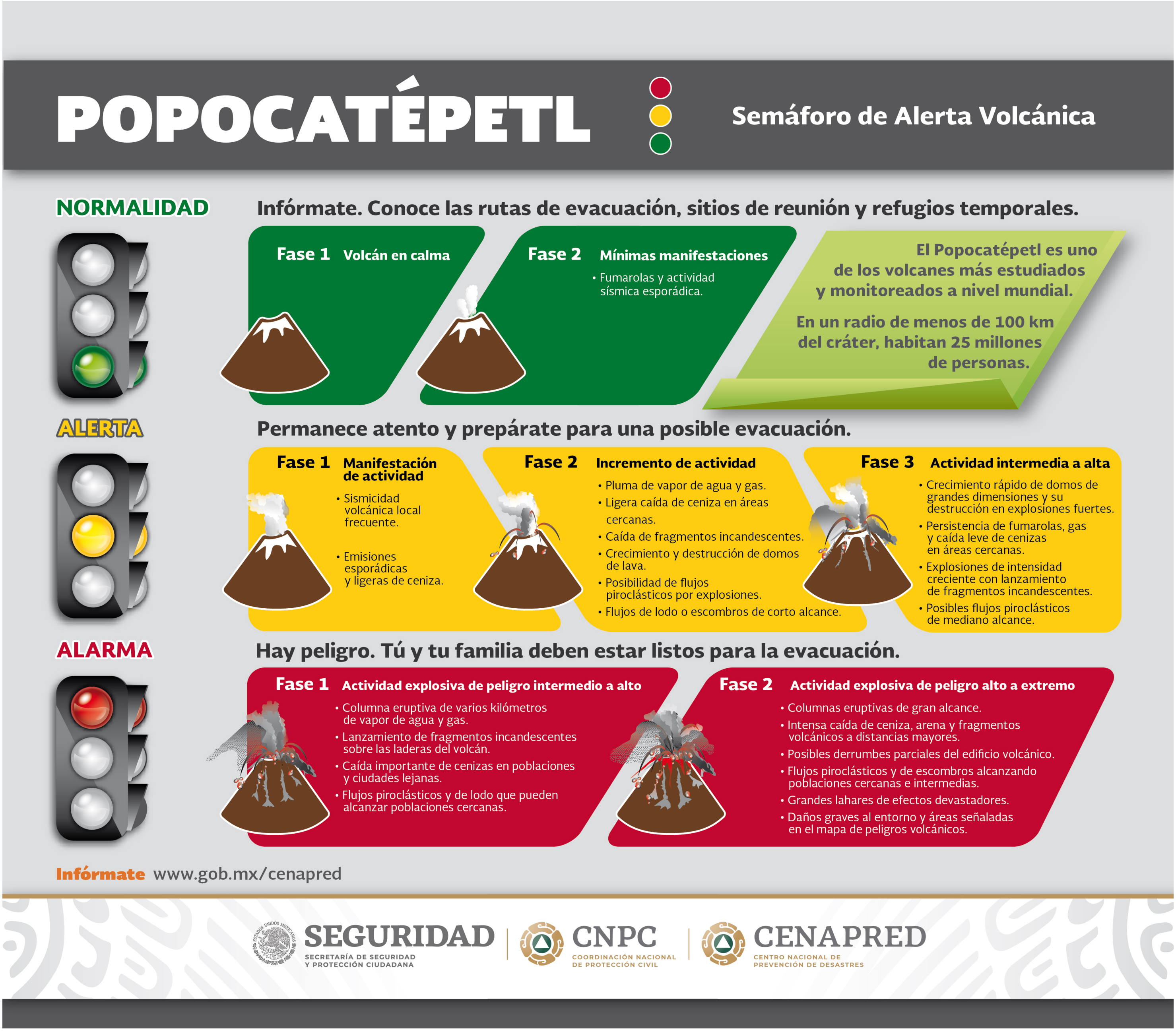


Figure 5.12. Popocatépetl Volcano Traffic Light Alert System (Gobierno de México, 2016). The text attached to each colour code indicates the recommended response from the affected communities, whilst the text in the boxes for each subdivision explains the increase in observed activity associated with the issuing of each alert level.

Although the influence of the UNDRO (1985) model is strongly evident, it is not the only piece of mobile policy that shaped the *POP*. The first *Plan Operativo* for a volcano in México was created by the *Protección Civil* (PC) organisation of Chiapas state in 1986, shortly after the establishment of SINAPROC, in response to unrest at Volcán Tacaná. This document was a technical guide for co-ordinating emergency operations in terms of communication and transport, public health, finances, security, etc. It was used in 1987 by the PC organisation of the state of Colima as the basis for the first iteration of the *Plan Operativo Volcán de Colima* and also provided the initial template for the emergency response components of the *POP* (Interview 21; Section 6.2).

The first test for the embryonic *POP* was on 30th June, 1997, when a series of large explosions caused ashfall over México City. Civil aviation authorities were forced to close the international airport and PDCs melted part of the summit glaciers. Although a lahar descended to the settlement of Xalitzintla, no casualties were caused (Siebe and Macías, 2003). The Popocatépetl committee recommended the highest level of alert bringing the *POP* into action:

> *All of the elements of the disorganized response system previously discussed occurred again. Thus, while the governor of Puebla state heeded SINAPROC's evacuation orders, the governors of Morelos and the state of Mexico interpreted it as a yellow alert, or a threat that merited initial preparations. The failure of the warning system was shown by the confusion between those who gave the warnings and those who were supposed to implement the responses. The responses diverged at the federal and state levels, with one governor adopting a significantly divergent set of measures. In the state of Puebla there were three different color schemes with different sets of meanings attached to them* (Macías and Aguirre, 2006).

De la Cruz and Tilling (2008) note that the Federal administration of SINAPROC decided that an evacuation was unnecessary, contrary to the advice of the committee. The *POP* was revealed to be not only ideologically outdated in terms of disaster risk science, but dysfunctional by its own standards. It can be argued that distinct mutations of the model had come to exist within the different jurisdictions and levels of government around Popocatépetl as the UNDRO and *Plan Operativo* mobile policy 'ingredients' were circulated and reformulated against different backdrops.

After this incident, an initiative launched in the state of Puebla to redevelop the *POP* into a *Plan de Preparativos para la Emergencia del Volcán Popocatépetl*, augmenting emergency planning with a long-term strategy to improve resilience, with input from disaster sociologist Russell Dynes. Dynes recommended working with the existing social infrastructure in at-risk communities and providing them with resources to participate in community-based DRR strategies (Macías and Aguirre, 2006). This initiative was, therefore, an effort to transform the Behavioural *POP* into a framework more in line with the DRR ethos, by this point being promoted through the IDNDR and in the process of being institutionalised 'elsewhere' on the policy field (e.g at Mount Rainier). However, according to Macías and Aguirre, the effort only manifested on paper, as corruption, cronyism and voter suppression led to a simulated democracy in which a genuinely democratised VRR plan was counter-intuitive to the interests of those in power. The *POP* was never replaced by Dynes' alternative.

Dome growth and destruction cycles continued throughout 1998-2000 without any significant crisis. Explosions increased throughout October-November 2000, and on 12th December, 200 occurred in a single day, generating ash columns on average 6 km above the vent. This was followed by a period of harmonic tremor during which the seismic energy released exceeded that of the entirety of 1997, until then the most volcanically active year. A forecast of a significant eruption was made, and the committee called an evacuation (De la Cruz and Tilling, 2008). Approximately 40,000 were requested to evacuate, however, initially only 15% did so (Siebe and Macías 2003). Macías and Aguirre (2006) state that much of the reluctance was because the *tiemperos* resisted the order. They argue that a near-complete evacuation was prompted by a hoax media campaign in which doctored footage was used to give the impression that a severe eruption had begun, and that this decision was only 'vindicated' when a large eruption occurred on the 19th of December.

De la Cruz and Tilling (2008) do not mention such a media event, stating that: "Fortunately, the eruption was not as powerful as suggested by the strength of tremor signals, and while no volcanic products damaged any town of [sic] infrastructure, thousands of evacuees could watch the striking view of showers of hot debris falling on the volcano flanks from the safety of their shelters." However, Macías and Aguirre (2006) paint a different picture of life at the shelters: "Although little was covered by the news, the refugees arrived at public shelters to find that, despite repeated claims to the contrary, the local, state and federal officials were unprepared; there was no food or other necessities. The experience further evoked the perception that disaster planning in Mexico was of a simulated nature." De la Cruz and Tilling (2008) do note that once the full-scale departures began, community leaders in towns that were not intended to be evacuated made the decision to evacuate, thus the number at the shelters was larger than anticipated.

5.4.3. Recent Developments

The 2000-2001 evacuations were the most recent at Popocatépetl. Since then, the volcano has been in near-constant eruption. The summit glaciers have completely melted, and thus the threat of secondary lahars has superseded primary lahars. Throughout the last 18 years the public alert level has been maintained continuously at Yellow. Most of the time, this has been Yellow Phase II, and has not required any implementation of the *POP*. There have been several instances of heightened activity (April 2003; April-September 2012; May 2013; July 2013) that have raised the 'internal' alert level to Yellow Phase III. However, it has been lowered in each of these instances without a subsequent red alert (Siebe and Macías, 2003; De la Cruz and Tilling, 2008; GVP, 2013).

The volcano is monitored 24/7, 365 days per year by CENAPRED, with five seismic stations, gas emissions analysis, geochemical analysis of spring waters, visual monitoring and infrasonic monitoring for lahars. This is done in conjunction with the IG, where longer-term studies of the volcano are conducted in collaboration with many members of the global expert community of volcanology (Interview 5; Espinasa, 2018). Popocatépetl was also the subject of a special issue of the JVGR in 2008, comprising studies of volcanic history, seismicity, geochemistry, glaciology, archaeology, and one paper on VRR (Delgado et al. 2008). A significant structural change was made to SINAPROC in 2012, altering the number and function of Civil Protection committees throughout the country (Section 6.5). However, the Popocatépetl committee survived the restructure and continues to preside over the alert system for the volcano (Interview 23). Recently, the IG has overseen the publication of the successor to the 1995 hazard map. This is a suite of maps based on probabilistic simulations. This work forms part of the Risk Atlas of México, a long-term SINAPROC project to create a digital database of all potential disaster risk scenarios in the country (Instituto de Geofísica, 2018; Section 6.5).

Although the *POP* has not been deployed practically since the 2000-2001 crisis, it remains the incumbent VRR policy framework at Popocatépetl. The structure consists of a 'master' version, under the jurisdiction of the Secretary of the Interior, and subsidiary state-level versions that can be triggered by federal order in all potentially affected states (México, Puebla, Morelos, México City and Tlaxcala) (Interview 5; Interview 23). However, only the states of México and Puebla have publicised their versions of the *POP*. México state has published updated iterations of its *POP* in 2013, 2017 and 2018; Puebla in 2013, 2015 and 2018. (Espinasa, pers. comm. 2018). The federal level 'master' plan is not public, although, the federal government have published general outlines (Gobierno de México, 2013; Gobierno de México, 2015). These documents indicate that the UNDRO (1985) manual and the *Plan Operativo Volcán Tacaná*, still provide the backbone of this policy model. It continues to conform to the Behavioural paradigm of disaster management, with a focus on short-term emergency response and an authoritarian style of governance. For example, in the 2015 federal plan outline, the pre-crisis planning phase consists of the following actions:

- *Maintain constant monitoring of the Volcano through surveillance posts and patrols, in coordination with the corresponding civil authorities.*
- *Determine the support that may be provided by civil authorities and non-governmental organizations.*
- *Intensify the campaign of awareness to the population regarding the preventive measures that must be adopted, the observance of the volcanic alert system and the application of civil protection family plans.*
- *Conduct simulations in order to design a scenario regarding the possible danger to which the communities are subject.*
- *Designate responsible parties for shelters and evacuation routes* (Gobierno de México, 2015).

There is no indication of community participation other than as a passive entity to be dictated unto. The 2018 edition of the Puebla *POP* notes that it seeks to incorporate the most recent advances in emergency planning, establishing better links with special emphasis on the population. To this end, they aim to create a federal level 'Group Specialised in Relations with the Communities'. They argue that traditionally, apathy has stemmed from a lack of involvement at municipal level. They aim to establish groups headed by municipal presidents to help enact this version of the *POP*. The future tense used suggests that the planned roles and responsibilities will be 'handed down' to the communities, but gives no hint that the communities were consulted in the development process (Gobierno del Estado de Puebla, 2018). No such content is found in the 2018 plan for the state of México (Gobierno del Estado de México, 2018).

Popocatépetl has the shortest VRR policy history of any volcano examined by this study. The full institutionalisation of the Behavioural model began here at the point where the field of disaster risk science was already in the process of moving on from it. The fact that no VRR policy infrastructure manifested in México after the crises of Paricutín and El Chichón reinforces the point that under certain conditions it is entirely possible for 'lessons' to fail to mobilise across time and space, even within the same country. The small number of volcanic crises following the Mexican revolution and the centralisation of the Mexican state seem to have prevented these 'distant' events (including one of the largest volcanic disasters of the 20th Century) from influencing the priorities of national government. Even after the establishment of SINAPROC, the country's two active volcanoes (Tacaná and Colima) seemed only to be a micro-level concern of the governments of the adjacent states (Chapter 6). At this stage, the role of mobile policy on VRR in México could arguably be described as 'limited' at best, although Mexican volcanology had begun to connect to the global VRR assemblages.

The 1994 Popocatépetl crisis transformed volcanic risk governance in México at the national level. The volcano's proximity to the capital made it a political priority, and many of the country's largest and most powerful administrative entities shaped the policy field around Popocatépetl. The crisis evolved rapidly and these timescales meant that policymaking was inevitably ad hoc and reactive. The already-established connections in the volcanological community were the conduit that allowed a supposed best-practice policy model to arrive from 'elsewhere' to a government in crisis with limited previous experience. This may provide a fresh perspective on what Peck and Theodore (2010) refer to as 'fast' mobile policy, where 'best practices', with the endorsement of a technocratic community, are circulated through quick-fire knowledge exchanges. The UNDRO model once again became the centrepiece of assemblages of institutions, personalities and existing policy producing unique permutations in different states. One professional who has worked within the system since its inception states: "I still have my main concern, we do not have a fully integral *Plan Operativo* for the whole area at the state, federal and municipal levels" (Interview 21).

In every instance of use, the POP model has exhibited the typical features of the Behavioural approach. It has repeatedly failed to fully engage the communities it is supposed to protect. There is evidence that the *POP* has continued to evolve. However the fact that all its constituent parts are not available for analysis perhaps speaks of continued disjointedness. Moreover, there is little evidence of a long-term structural shift towards DRR. At Popocatépetl, it is arguable that *one* policy mobility event has profoundly and enduringly shaped practice from its inception to the present day. However, it is notable that it has proven very difficult for 'new' mobile policy knowledge to unseat, or substantially dilute the existing system. Perhaps the 'community relations' strategy being incorporated by the Government of Puebla in their 2018 *POP* marks the start of a shift. However, for a process that began with the fastest of policy, it will be interesting to see if the current glacial rate of political change can accelerate without being driven by a major eruptive crisis.

5.5. Synthesis

These case histories have followed the development of volcanic risk governance at four volcanoes in distinct national (meso-level) contexts, highlighting the role of mobile policies and their mutations in building and reshaping unique policy assemblages at each.

The history of volcanic risk governance at Merapi, is the longest of any case study. Dutch colonialism extended European industrial-era governance to Merapi, resulting in the emergence of institutionalised volcanic risk governance that arguably conformed to the Behavioural model, long before this became prevalent globally.

VRR at Merapi experienced slow mutation throughout the 20th Century, punctuated by political turmoil and recurring disasters. Merapi gradually became one of the best-connected sites on the global policy field of VRR. However, short-term emergency management failed to reduce vulnerability. Since the mid-2000s, Indonesia's participation in the UNISDR has seen an attempted transition towards a DRR-based approach, gradually increasing community participation in the reduction of risk. It remains to be seen how this trend will manifest in the future.

Nevado del Ruiz had arguably existed in a 'policy vacuum' for much of the 20th Century. Between 1984-85, volcanic unrest drove the rapid manifestation of a policy field (founded on the Behavioural model), divided between Caldas and Tolima, which systematically failed to prevent disaster in November 1985. The Colombian government's DRR 'revolution' in the aftermath of the 1985 eruption played a key role in the emergence of the Complexity paradigm on the global policy field (although still arguably short-term 'disaster risk management' rather than true DRR) and served to focus the international volcanological community on VRR as a priority. The UNDRO manual (1985), saw one of its first 'deployments' here, ensuring that the Behavioural model continued to play an influential role despite other advances. However, the ensuing quiescence of Nevado del Ruiz diminished the volcano's status as a priority and during its return to activity in 2012, problems with community engagement were again encountered. The Colombian government is in the process of implementing their interpretation of the UNISDR's DRR framework. Parallels and differences with Merapi will be interesting to observe.

Mount Rainier has been largely inactive during the post-settlement history of the USA. As a result, it too existed in a 'policy vacuum' until the 1990s when USGS scientists, influenced by observations of eruptions at other glaciated stratovolcanoes recognised the risk. The scientists initiated a process of consultation with authorities and other participants from civil society, creating a 'work group' based approach to VRR policymaking that arguably reflects the DRR ideal to a greater extent than other examples in this study. Although the UNDRO (1985) manual was brought into the embryonic assemblage at Mount Rainier as a template (perhaps unsurprisingly given the USGS' role in its global dissemination), the *Mount Rainier Volcanic Hazards Response Plan* with its apparently harmonious policy field, incorporation of community engagement and vulnerability reduction, demonstrates how the nature of the surrounding components can drive unique and transformative mutations. It nonetheless remains to be seen how this system will evolve during continued inactivity or perform in the event of a future crisis.

The history of volcanic risk governance at Popocatépetl, is the shortest of any of this project's case studies. The 1994 eruption prompted the rapid assembly of a policy response. Proximity to the Mexican capital saw the responsibility for various VRR policy functions assumed by national (meso-level) institutions such as the CENAPRED, the Secretary of the Interior, and UNAM, - and the creation of a policy framework based on the UNDRO (1985) manual. Evacuations under this system have experienced difficulties in eliciting the participation of vulnerable communities. The global-level circulation of disaster risk reduction theory does not appear to have yet had a tangible impact on the meso and micro-level policy field around Popocatépetl.

These case studies show that policy mobilities, mutations and assemblages have profoundly impacted volcanic risk governance in different ways and at different rates around the globe. The uneven circulation of information, resources and 'best practices' has intermeshed with the volcanic and socio-political fabric in each setting, producing unique and continually evolving VRR assemblages on each local policy field. These considerations complicate the work of those seeking to improve VRR policy and practice through macro-level processes of knowledge exchange. The following chapter will illustrate the extent of these complexities by presenting an in-depth micro-level study of volcanic risk governance at Volcán de Colima, México.

Chapter 6

Pueblo Chico, Infierno Grande
Policy Mobility and Volcanic Risk Governance at Volcán de Colima, México

Chapter 5 employed four case studies from the global policy field to illustrate the role that processes of policy mobility have had on the relationship between volcanoes and the societies around them. It has been shown that: the *movement* of policy (formal and informal); the fluctuating *topologies* that take policy and knowledge from one volcano to another; the *assemblage* of that mobile knowledge with the politics, culture and volcanic activity of the settings in which it arrives; and the resulting *mutations* that policy undergoes, have been fundamental to the unique form that VRR policy has taken at each volcano. The marked differences between case studies also demonstrate that the development of volcanic risk governance at each volcano has not run concurrently alongside the theoretical evolution of DRR 'best practices' - rather, that the timescales are offset, frequently dictated by volcanic and human systems. As such, an uncontested transition to an idealised VRR framework cannot be expected from proponents on the global policy field. Given that effective volcanic risk governance may prove the difference between life and death, it is crucial to consider how mobile VRR 'best practices' may change when assembled in a volcanic setting.

This chapter presents a detailed case study to explore how micro-level interactions between mobile policy and volcanic environments can have enduring effects on volcanic risk governance. It follows on from Section 5.4 by focussing on another active Mexican volcano, Volcán de Colima; demonstrating that processes of policy mobility have the capacity to produce drastically different outcomes, not just internationally, but within the same polity.

6.1. Volcán de Colima, Setting and Background

Volcán de Colima (19.514ºN, 103.622ºW; 3,850 m; Figure 6.1) is a stratovolcano in western México, divided between the Pacific coast states of Colima and Jalisco (Figure 6.2). It is the youngest of three edifices that together form the N-S trending Colima Volcanic Complex, also known as '*Volcán de Fuego de Colima'* (Volcano of Fire of Colima) to distinguish it from the extinct *Volcán Nevado de Colima* (Snowy Volcano of Colima) that sits to the north, separated by a southward-breached caldera wall (GVP, 2013; Figure 6.2).

Figure 6.1. Small Vulcanian explosion at Volcán de Colima (2014) seen from the western edge of the breached Palaeofuego caldera (see also Figure 6.4).

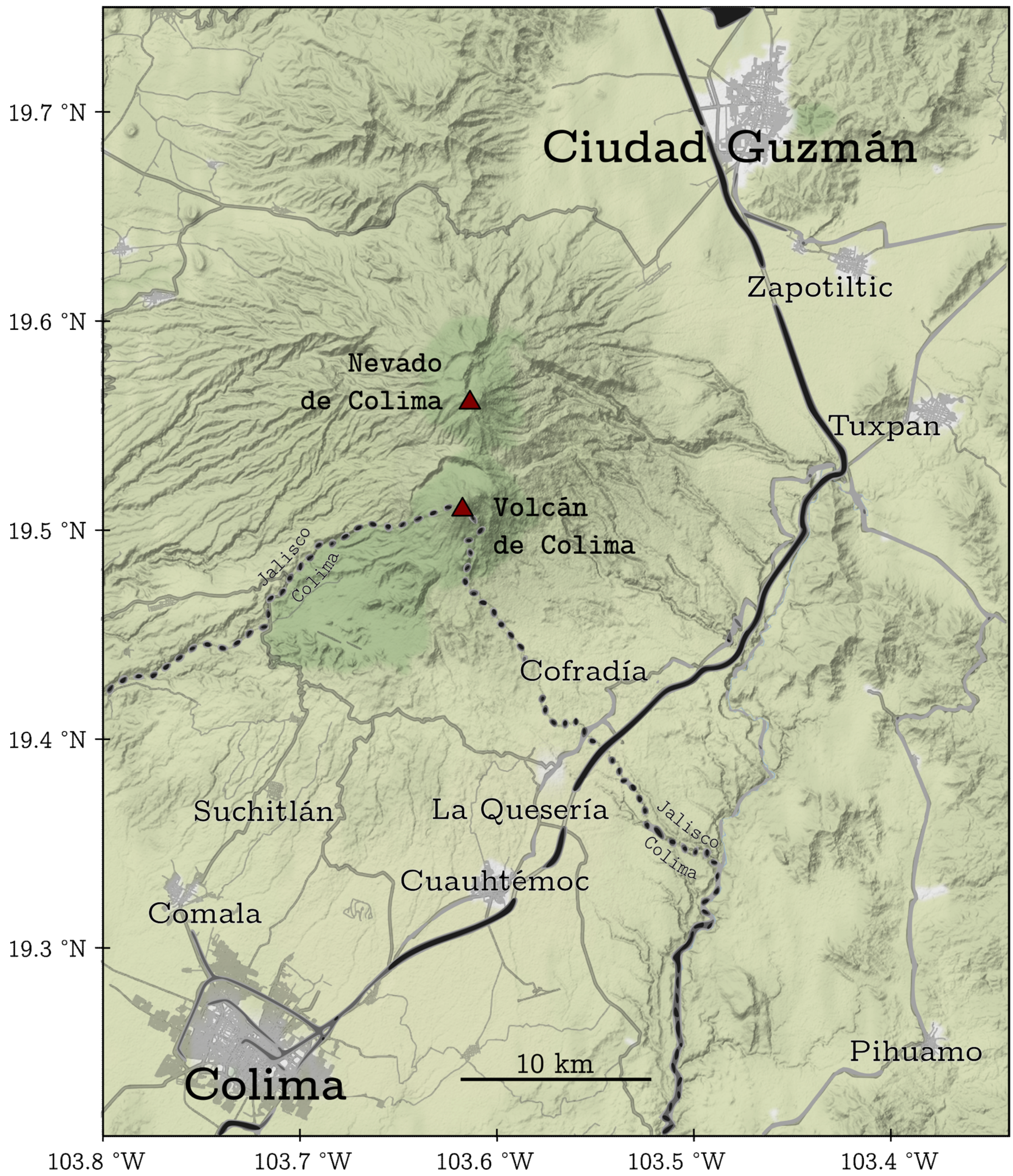


Figure 6.2. Map of Volcán de Colima and surrounding major population centres. The edifice is intersected by the state border of Colima and Jalisco (dotted line). The active crater is 30 km north of the city of Colima and 26 km southwest of Ciudad Guzmán in southern Jalisco, linked by the interstate highway (thick black line) (Image courtesy of Jamie I. Farquharson).

Volcán de Colima is one of the most active volcanoes in North America, with at least 29 eruptive periods since 1560. These have mostly consisted of andesitic lava-dome growth and collapse cycles, accompanied by Vulcanian explosions. However, the volcano has also produced sub-Plinian or Plinian eruptions with a recurrence interval of approximately 100 years (in 1576, 1690, 1818 and 1913) (Bretón et al. 2002).

There have been 12 sector-collapse debris avalanches at Volcán de Colima during the last 22,000 years (Cortés et al. 2010). Activity from Volcán de Colima has not caused any casualties since the Plinian eruption of 1913, which killed around 8 people (Saucedo et al. 2010; Reyes et al. 2016). Saucedo et al. note that a similar eruption today would destroy 10 small towns and ranches and potentially affect up to 320,000 people within a 30 km radius. The majority would only be affected by ashfall. However, at the last census in 2010 there were 17,367 inhabitants within 15 km of the summit who could be affected by pyroclastic density currents (PDCs) and lahars (Table 6.1). The geographical distribution of these populations is illustrated in Figure 6.3.

Table 6.1. 2010 census data for the closest population centres to the active vent at Volcán de Colima in the states of Colima and Jalisco, their distance from the crater and hazards to which they are vulnerable according to the hazard maps of Abel and Cortés (2003) and the simulations of Saucedo et al. (2005) (adapted from López, 2016).

Name of Locality, State	Distance from crater (km)	Volcanic Hazards	Number of Inhabitants (2010)
La Yerbabuena, Colima	8	PDC, Lahar, Ashfall, Debris Avalanche	47
Juan Barragán, Jalisco	9.5	PDC, Lahar, Ashfall, Debris Avalanche	51
La Becerrera, Colima	12	PDC, Lahar, Ashfall, Debris Avalanche	283
El Naranjal, Colima	12.6	Ashfall, Debris Avalanche	136
Tonila, Jalisco	13.5	Ashfall, PDC, Lahar, Debris Avalanche	3110
San Marcos, Jalisco	14	Ashfall, PDC, Lahar, Debris Avalanche	3383
Cofradia, Colima	14.5	Ashfall, Debris Avalanche	1746
Queseria, Colima	14.5	Ashfall, PDC, Lahar, Debris Avalanche	8611
El Platanar, Jalisco	16.8	Ashfall, Debris Avalanche	493
Suchitlán, Colima	18.1	Ashfall, Debris Avalanche	4450
Comala, Colima	26.1	Ashfall, Debris Avalanche	9442

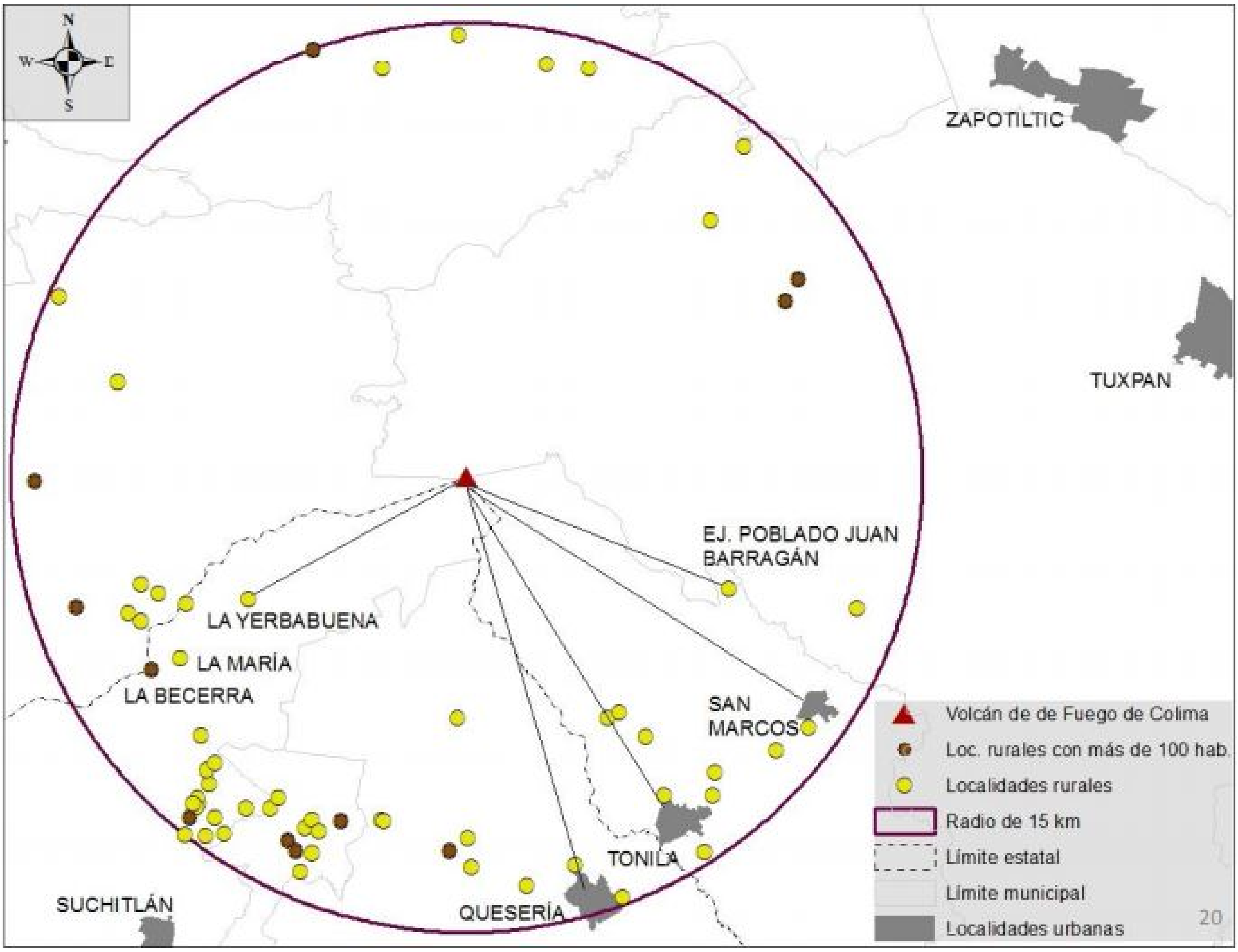


Figure 6.3. Map of populations within a 15 km radius of the active vent (Hernández, 2014). The Spanish in the key reads as follows: 'Rural localities of more than 100 inhabitants'; 'Rural localities'; 'Radius of 15 km'; 'State border'; 'Municipal border'; 'Urban localities'.

Bretón et al. (2002) summarise historical activity of Volcán de Colima from 1519 onwards. Eruptions intermittently covered towns, ranches and homesteads with ash, shaking buildings with explosion shockwaves and, on occasion, PDCs killed livestock. The volcano was not widely inhabited even by the early 20th Century, so lethal impacts were rare.

In the 19th Century, international and local scientists conducted intermittent field studies. On 30th March, 1872, during the eruption of a parasitic dome '*el Volcancito*' on the north-eastern flank, residents of Quesería (Figure 6.3) self-evacuated. Two observatories were established in Zapotlán in Jalisco and Colima city, allowing activity to be recorded daily between 1893 and 1905. After 1905, volcanic activity gradually diminished, and a quiet period preceded the Plinian eruption of 1913.

The Plinian eruption of 1913 began with a series of explosions between the 17th and 19th January, generating PDCs that descended to distances of ~4 km and onto the caldera floor (el Playón) to the north (Figure 6.4). On 20th January, explosions increased in intensity. At 11:30, continuous explosions began and a Plinian eruption column rose to ~27 km a.s.l. The plume was carried northeast towards Ciudad Guzmán (Figure 6.2) where, by 13:00 the darkness was near-total and ash began to fall to a depth of 15 cm (Saucedo et al. 2010). Citizens entered the church and asked for the statue of San Felipe de Jesús to be toured around the city. When the statue was brought back to the church at 20:00-20:30 the eruption diminished and, by 22:00, the sky was clear (Bretón et al. 2002; Raymundo Padilla-Lozoya, Interview). The Jalisco community of San Marcos (Figure 6.4) self-evacuated a few hours after the Plinian phase began (Gavilanes, 2004). The collapse of the Plinian column generated PDCs that descended radially to distances of 15 km. The PDC deposits substantially altered the landscape and blocked water supplies to San Marcos (Figure 6.4); when villagers tried remove the blockage, hot debris killed several workers (Saucedo et al. 2010).

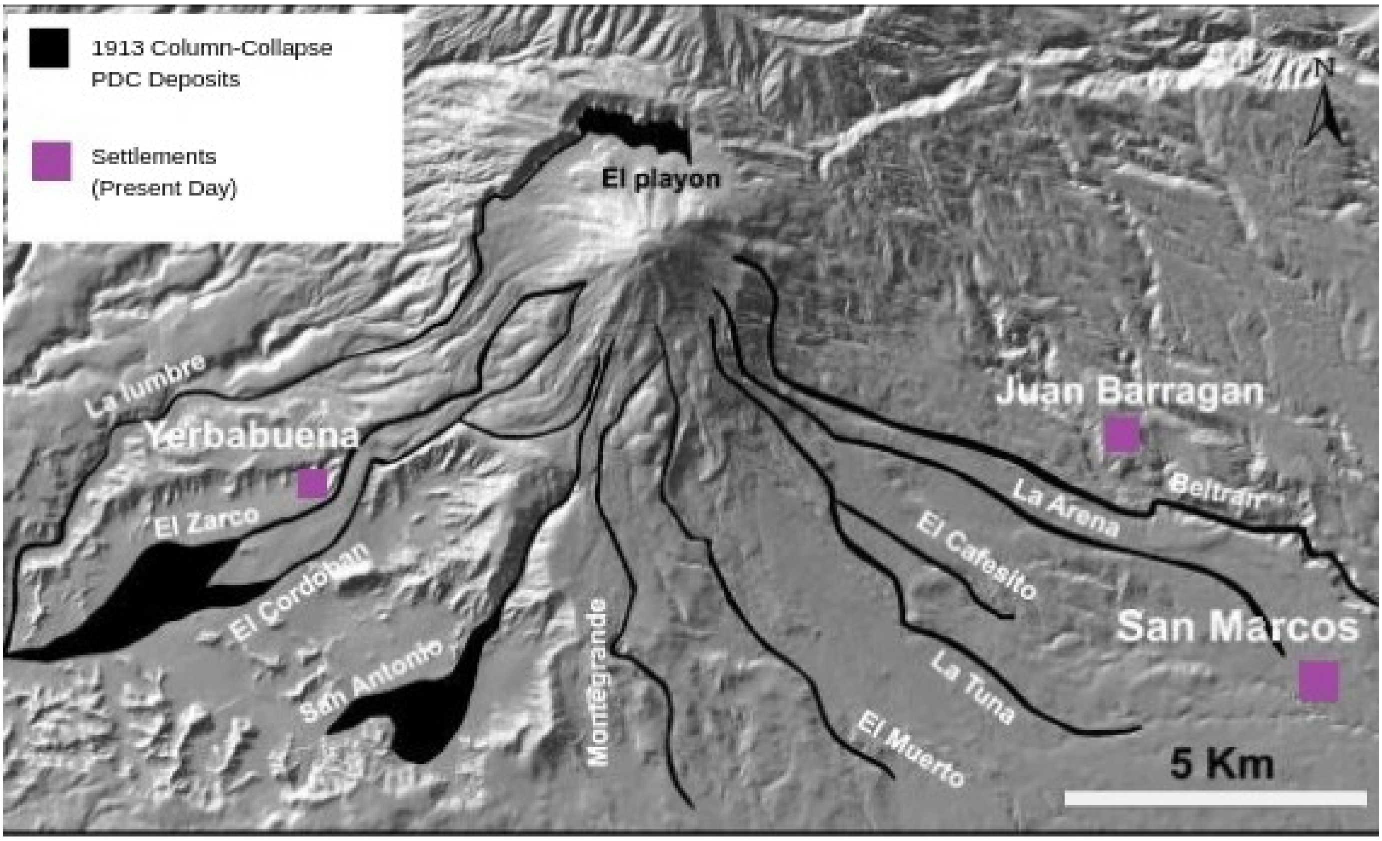


Figure 6.4. Digital elevation model of Volcán de Colima, showing in black the pyroclastic density current (PDC) deposits emplaced during the climactic phase of the 1913 Plinian eruption (adapted from Saucedo et al. 2010). These deposits are confined to the drainage channels or 'Barrancas' that originate on Volcán de Colima which have to this day provided the routes for PDCs and lahars. The caldera wall of the older 'Palaeofuego' edifice provides a natural barrier to the north. These barrancas are: El Zarco, Cordobán, San Antonio and Montegrande in the state of Colima; La Tuna, El Cafecito, La Arena and Beltran in the state of Jalisco. Barrancas La Lumbre and El Muerto form the border between the two states. The communities of La Yerbabuena and Juan Barragán were founded after the eruption of 1913.

In 1913, risk at Volcán de Colima was relatively low due to the low vulnerable population. Nonetheless, the ashfall in Ciudad Guzmán (Figure 6.2) and the community's religious response left a lasting legacy: "Stories like that are in the memory of the society. Because of this, in Colima as well, when people think of the volcano and how they relate to the volcano, they add elements of belief, of religion, of what they believe, into the natural environment" (Raymundo Padilla, Interview).

Between 1913 and 1961, lava gradually filled the crater left by the 1913 eruption, occasionally accompanied by small explosions. In 1961, a 0.006 km^3 blocky lava flow descended approximately 1 km northwards into the Playón (Figure 6.4). This activity was observed by geologists from the *Universidad de San Luis Potosí* and the *Universidad Nacional Autonoma de México* (UNAM) (Bretón et al. 2002).

On 1st December 1975, a lava flow descended the east flank towards the Volcancito parasitic dome, where it split. A separate flow descended into Barranca Cafecito (Figure 6.4) (Bretón et al. 2002). This eruption occurred at the time when the international volcanological community was beginning to become more mobilised and structured (e.g. the first IAVCEI general assembly in Durham - Section 4.2): "From the activity of Volcán de Colima in 1975-1976, many researchers from México and further afield began to take interest in different aspects of the volcano, however there was no research centre to co-ordinate these efforts and this impeded the continuity of many projects" (University of Colima, 2015). Thorpe et al. (1977) published an article on the block and ash flows from this eruption. However, there was no local institutionalised volcanology.

Small dome growth and explosions in 1981 were documented by geologists on behalf of the Smithsonian Institution and a small lava flow ran from late 1981 into 1982, reaching approximately 1 km from the crater (Bretón et al. 2002). In 1984, the Centre for Research in Basic Sciences was established at the *Universidad de Colima* (UCol) in Colima city (Universidad de Colima, 2015; Gabriel Reyes-Dávila, Interview). However, by the mid-1980s, Volcán de Colima was still not subject to volcanic risk governance.

6.2. Assembling Mobile Policy Around an Active Volcano: The Roots of Volcanic Risk Governance at Volcán de Colima

The 19th September 1985 earthquake and its impacts on México City drove the establishment of SINAPROC, the Mexican national system of Civil Protection on 6th May 1986 (Section 5.4.1). This required each of the 31 (now 32) Mexican states and their municipalities (2,457) to establish civil protection organisations. The incumbent President, Miguel de la Madrid-Hurtado was from Colima and, according to employees of *Protección Civil Colima* (PCC), Presidential connections meant that Colima became the first state to create its own organisation. The Governor of Colima, Elias Zamora-Verduzco approached Melchor Ursua-Quiroz, the owner of a chain of auto garages, who had founded and headed the state's voluntary fire brigade, to ask him to become director (Melchor Ursua, Interview; Javier Velasco, pers. comm. 2017). In this, the first piece of relevant mobile policy had 'arrived', providing the foundation for a policy field, and had already begun to 'mutate' within the local environment.

The earthquake also generated interest in seismology at UCol. The chief of the National Seismological Service asked the director of the Centre for Research in Basic Sciences for help in installing a seismograph. The first permanent, telemetric seismic station in the state of Colima was installed on 1st December 1985. Once operational, the chief of the National Seismological Service visited Colima accompanied by volcanologists and seismologists from UNAM's *Instituto de Geofísica* (IG) to propose a seismic network. The Colima researchers agreed and a joint request was submitted to the Colima state government. At the beginning of 1987 the request was approved and $300 million MXN (£66 million) was granted for 10 seismic stations (Gabriel Reyes-Dávila, Interview). As the visitors (initially through the pursuit of their own academic interests) 'nudged' scientists at UCol into engaging with volcanic processes, a further constituent of the embryonic policy field at Volcán de Colima began to emerge, again with roots 'elsewhere'. The investment of the Colima state government could be seen as the local administration taking ownership of this mobile idea and beginning to reshape it.

Activity at the volcano remained low during late 1985 and 1986. On 2nd July 1987, however, a phreatic explosion blew a 100 m diameter, 40 m deep crater in the extant dome and generated a PDC (Bretón, 2002). This was the first significant activity to occur at Volcán de Colima after the establishment of *Protección Civil* (PC). The *Plan Operativo Volcán Tacaná* (Section 5.4.2) had been published in December 1986 by the three-person staff of the PC organisation in the state of Chiapas as a response to the activity of that volcano. In July 1987, an "almost identical" *Plan Operativo Volcán de Colima* was signed off by Governor Zamora. A second draft was completed in September 1987 (Sistema Estatal de Protección Civil Colima, 1987; Interview 21).

The *Plan Operativo Volcán de Colima* is structured around a sequence of five phases:

A - Latent (the volcano is in a 'stationary' state)

B - Can Occur (volcanic activity is manifesting with Earth movements of greater intensity and periodicity)

C - High Probability of Occurrence (volcanic activity is at the point of evolving, within an expected period of 13-18 hours)

D - Occurrence (volcanic activity is evolving, expulsion of lava, ash and gases, earthquakes etc.)

E - Elapse (volcanic activity is considered to have ended).

These phases provided the antecedent to the Traffic Light alert system developed at Popocatépetl in 1995 (Interview 21). Following a statement from Governor Zamora, some 'General Considerations' and a structural outline of PCC, the *Plan Operativo Volcán de Colima* contains separate lists of instructions for state government departments and subdivisions (Reception Centre; Communication and Transport; Health; Trade and Supply; Urban Development and Ecology; Agriculture; Security and Public Order; and Shelters). PC have the authority to establish a 'Centre of Operations' and the so-called 'Co-ordination of information to the population' - the location and direction of evacuees. The remainder of the document consists of; population data for the communities (within 15 km of the summit, [Figure 6.3]); lists of the shelters and responsible personnel; a map of schools; medical facilities and personnel available; the state of the roads around each community; and two pages outlining the volcanological history of Volcán de Colima (Sistema Estatal de Protección Civil Colima, 1987).

It is not stated who the author of the volcanological section was, but given that the nascent seismic research at the *Universidad de Colima* was being performed by "a group of electronics scientists who knew how to install and maintain the equipment, but knew nothing of volcanology" (Tonatiuh Domínguez, Interview), an UNAM volcanologist may have written this. There is little evidence of volcanological input in the procedural sections. The phases do not reflect a comprehensive understanding of the hazards presented by Volcán de Colima (PDCs and lahars are not mentioned), nor of the non-linear evolution of volcanic activity. The 'General Considerations' state that "Geophysical information obtained from the accredited researchers will be communicated directly and exclusively to the General Secretary of Government" (Sistema Estatal de Protección Civil Colima, 1987). Strict confidentiality was an integral feature of the *Plan Operativo Volcán de Colima*. Each copy was stated only for the eyes of the government employee it had been given to. The plan was never published.

The *Plan Operativo Volcán de Colima* arguably institutionalised the Behavioural model at Volcán de Colima. Features that support this claim include: the lack of engagement with, and view of the population as passive participants; and the plan's focus on a reactive response to ambiguously defined volcanic activity. Despite the association of the Behavioural model with a scientific/technical approach to disasters, it could be argued that the *Plan Operativo* lacked even the scientific component and represented an attempt to address volcanic risk purely through authoritarian population management.

The *Plan Operativo Volcán de Colima* may be viewed as another piece of 'fast' mobile policy driven by volcanic activity. The explosion of 2nd July 1987 is explicitly noted as the most recent activity, and there are multiple references to the plan being developed in that month. The Tacaná model was the only extant policy directed at volcanic risk in México at the time and was deliberately 'brought' to Colima by the recently-created PCC. The incorporation of this mobile component into the assemblage made the volcano a focal point on the budding policy field.

After July 1987, activity remained low (Bretón et al. 2002). Scientists from UNAM and the *Universidad de Guadalajara* (UdG) visited the volcano and reported to the Smithsonian Institution (GVP, 2013). UCol scientists also visited the volcano, looking for sites for seismometers: "They started to orient themselves, they received resources so that they would understand what they were doing" (Tonatiuh Domínguez, Interview). On 1st June 1989, the first telemetered seismometer in the *Red Sismica del Estado de Colima*/Seismic Network of the State of Colima (RESCO) was installed. The equipment was owned by the state government, but given to UCol to operate (Gabriel Reyes, Interview).

In 1988 UCol held the first of a series of bi-annual *Reuniones Internacionales Volcán de Colima* that ran from 1988 until 2012 and brought together scientists from México, the USA, Italy, Japan, Papua New Guinea, the UK and other countries (Colima

Noticias, 2009; Carlos Navarro, Interview). This established lasting topological connections between Volcán de Colima and the international community of volcanology. The director of PCC was invited to the meeting: "At some point they had national, international level meetings here, with relation to Volcán de Colima and they invited us, well, me, to the meetings. So, I formed a relationship with volcanologists from all over the world. There was a very strong connection." (Melchor Ursua, Interview). Ursua says that during these meetings, USGS volcanologists brought the UNDRO (1985) *Volcanic Emergency Management* manual: "...They brought it with them, they brought us those documents. Here I have a book that was made at that time by the United Nations Organisation with regard to volcanoes, and that has been the basis for me to form *Protección Civil* here in Colima." This concurs with Macías and Aguirre's (2006) assessment of the USGS' role in mobilising the UNDRO (1985) model and suggests that, through these meetings, the UNDRO model became part of the assemblage of formal and informal policy that had coalesced around Volcán de Colima.

6.3. Prueba de Fuego: The First Crises of Volcanic Risk Governance at Volcán de Colima

In 1990, Volcán de Colima was selected by IAVCEI as one of the 'Decade Volcanoes', incorporating it into that global assemblage with (among others) case study volcanoes Merapi and Rainier (Universidad de Colima, 2015). The UCol scientists conducted volcanological field studies with visitors from USA universities. Scientists from UNAM continued with their long-term project to establish baseline values at Volcán de Colima through topographical and geological surveys, deformation monitoring and spring-water sampling (GVP, 2013; Interview 22). In January 1991, physicist-turned-seismologist Gabriel Reyes-Dávila and geologist Carlos Navarro-Ochoa of UCol were assisted by UNAM seismologist Jaime Yamamoto to attend a volcanology course in Japan, organised by the Japan International Co-operation Agency (Gabriel Reyes, Interview). This would be the first formal training of any UCol volcanologists:

> *The course was six months, and we're talking about the 1990s, when volcanology was in a period of transition, with new methodologies in all aspects. There was a revolution in monitoring methods, for example, with*

> *very strong roots in the eruption of Mount Saint Helens in the 1980s. All that information was still very fresh, and obviously Japan was also very much at the vanguard* (Carlos Navarro, Interview).

It was not until 14th February 1991 that RESCO started detecting volcanic earthquakes. Swarms and degassing registered throughout February and, in early March a dome grew, generating occasional rockfalls. Seismologist Francisco Nuñez-Cornú had started working at UCol on 1st February and convened the 'first volcanic risk committee in México' with Juan Manuel Espindola and Servando de la Cruz-Reyna (UNAM) and Jean-Christophe Komorowski (IPGP). Gabriel Reyes returned from Japan for a month to digitise the seismograms (Francisco Nuñez, pers. comm. 2017; Gabriel Reyes, Interview; Carlos Navarro, Interview). Authorities in Colima and Jalisco were concerned by developments at the volcano and solicited daily reports from the scientists:

> *We were able to monitor how the activity was changing, how the dome was growing, how the springs were changing, and that's why we had the relationship with the governor's office directly and the office of the military, so every day after doing fieldwork we'd have to go and report to both. We'd show them how the seismicity was growing and how the dome was growing, how things were changing* (Ana Lillian Martin del Pozzo, Interview).

Ana Lillian notes that authorities from both states asked the scientists if they should evacuate and the scientists attempted to clarify that this was not their decision to make. The dome continued to grow until 16th April, when it partially collapsed generating PDCs in Barranca Cordobán (Figure 6.4). The *Plan Operativo Volcán de Colima* was activated, Colima airport was closed and the evacuation of ~2,000 people was ordered. However, most did not participate (Bretón et al. 2002; GVP, 2013). From Japan, Carlos Navarro followed the unfolding situation through newspaper cuttings:

> *In the reports that I read, there was a scandal and all that, because of disorganisation. It happened like the case of Guadeloupe in the 1970s*

> (Section 4.2)*; very few people knew about this volcano that was suddenly awake, there were no local scientists, they arrived from elsewhere and everybody believed they knew what was happening, they called a big evacuation, there was a lot of loss of revenue and in the end there was no eruption behind the emergency. A study in what not to do.*

After this crisis, UCol established a centre for Earth sciences. During a WOVO meeting in Guadalupe in 1993, it was formally recognised as a volcano observatory (Universidad de Colima, 2015). Francisco Nuñez left UCol in September 1991 following a disagreement with the Co-ordinator for Scientific Research. After a spell in northern México, he ended up at the UdG (Francisco Nuñez, pers. comm. 2017).

> *During this crisis of 1991... there were a lot of lessons. The first is that politicians have a very short memory. They soon forget things. They attend to the emergency, but they don't work with a vision of the long term. So, during this time, they installed more stations on the volcano, six eventually and two more that were distant from the volcano to distinguish between volcanic and non-volcanic signals. And, at the end of 1991, beginning of 92, everything stopped. No more volcanic activity, so the government of the state threw away the key, there was no more money* (Gabriel Reyes, Interview).

Activity at Volcán de Colima remained low, apart from a phreatic explosion on 21st July 1994 (Bretón et al. 2002). Following this, Gabriel Reyes states that interest from civil society rapidly waned "everything stopped, movement, reporters, people, politicians, journalists, television. That's how it was."

UCol scientists started making regular trips to the crater to collect samples and measure temperature, gas emissions and fractures. They held the first talks in La Yerbabuena (Figure 6.3) using an IAVCEI-UNESCO educational video also used at Pinatubo (Abel Cortés, Interview; Carlos Navarro, Interview; Section 4.3). UdG scientists created a 'risk map' for Volcán de Colima (Suárez and Saavedra, 1993). This used preliminary 1980s UNAM geological surveys for its hazard projections, and offered a brief, qualitative breakdown of possible impacts. UNAM scientists were, at the same time, producing a more hazard-focussed map (Gavilanes, 2004). Lugo et al. (1993) published a geomorphological study. Based on this work, the same team created a hazard map in collaboration with the University of New York at Buffalo (Martin del Pozzo et al. 1995), published in the UNAM journal *Geofísica Internacional*. UCol geologists had also submitted a proposal to the government of Colima and the National Council for Science and Technology (CONACYT) to develop a hazard map:

> *There, we basically entered into a competition. When we started the work, Ana Lillian already had her map finished, practically. But we saw the map, I had all my ideas from Japan and I said 'no, this map lacks this, this and this...' she had an idea where the lava and pyroclastic flows were, and she only based her distribution of ash on the history of the eruption of 1913, that went to the northeast. We didn't just do this, we dedicated ourselves to a statistical revision of wind direction/velocity data* (Carlos Navarro, Interview).

Navarro states that the map was based on geological surveys of >100 sites and revised various times by international volcanologists participating in the *Reuniones Internationales* and Decade Volcano Project, including Robert Tilling (USGS) and J.C. Komorowski.

It is notable that the creation of hazard/risk maps - by the early 1990s an established component of volcanic risk governance - was undertaken separately by the UdG in Jalisco, UNAM in México City, and UCol in Colima. The former two were academic projects with the potential to influence policy informally, whilst the UCol project straddled the interface between science and formal policy. Colima, Jalisco and México City, are arguably the three most obvious divisions (topographically and topologically) on the policy field around Volcán de Colima, although the further divisions within these entities must be acknowledged (i.e. the relative autonomy of the universities from state governments, and of the state governments from the federal government, the further autonomy of municipalities and the loose relationship between the federal government and UNAM). The way in which mobile policy has traversed (or failed to traverse) these boundaries has profoundly shaped volcanic risk governance at Volcán de Colima.

Volcán Popocatépetl came to the attention of the Mexican federal government upon erupting in December 1994 (Section 5.4.2). Subsequent developments show a marked difference in volcanic risk governance between Popocatépetl and Volcán de Colima, despite some of the same mobile policy 'ingredients'. The Scientific Advisory Committee at Popocatépetl also notably became a template used for other hazards (e.g. chemical spills, earthquakes) and therefore became a keystone of federal disaster risk governance (Macías and Aguirre, 2006; Carlos Valdés, Interview).

In 1996, Ricardo Saucedo, a geologist at UCol's *Observatorio Vulcanologico* led an initiative to establish an educational programme about volcanic risk for communities in both states. Juan Carlos Gavilanes-Ruiz, a geographer at UCol, wrote to Robert Tilling (USGS) asking him to endorse a proposal to obtain government funding and Tilling obliged. The educational programme gained funding from both state and federal governments, formalised in late 1997 (Juan Carlos Gavilanes, Interview). Gavilanes notes that the existing VRR framework consisted of only mapping, monitoring and emergency planning:

> *So, we saw that really, the socialisation of the information was very poor, or, absent, so the project initiated working with two women who had a bachelors' degree in communication science and I, as a geographer. So we decided then a strategy for each village - there were seven villages - in order to tell them which hazards were especially potentially pertinent to them* (Juan Carlos Gavilanes, Interview).

Gavilanes notes that at first the community participation was small, but gradually increased with time. Thus, in a period of 'volcanic peacetime', the interest of UCol scientists in the application of their research was the driving force in shaping what ultimately became part of the policy framework at the volcano. This was a step beyond the Behavioural model that had been assembled from the *Plan Operativo* and UNDRO (1985). It directly engaged the communities around the volcano and gave them a forum to voice their concerns.

However, it can be argued that this programme only served as a slight counterweight to an authoritarian approach. 13 km southwest of the summit crater is a 510 hectare estate, the Hacienda San Antonio. Former owner, Antenor Patiño constructed a village called Barranca del Agua for the estate's workers and their families. In 1987, the Hacienda was acquired by Patiño's son-in-law Sir James Goldsmith, who began to convert it into a luxury hotel. In 1995, Goldsmith asked PCC to conduct a risk assessment for Barranca del Agua. PCC solicited the assistance of UCol volcanologists Carlos Navarro and Abel Cortés-Cortés (Cuevas, 2005; Melchor Ursua, Interview). In 1997, the Government of Colima completely and permanently evacuated Barranca del Agua. Most residents left without resistance, either going to new government-provided accommodation or accepting $35,000 MXN (£5,120) in state funds to relocate themselves. However, at least one resident claims to have been evicted at gunpoint by law enforcement (Cuevas, 2005). There are differing narratives regarding this event. Melchor Ursua, director of PCC states that relocation was conducted out of concern for the population. He claims that fifteen days after the relocation, a lahar struck the empty village, destroying some houses. On 23rd August, 2003, a lahar completely buried the abandoned settlement (Gavilanes, 2004). However, questions have been raised regarding the motives behind the resettlement:

> *The community was on land owned by the San Antonio ranch, but Mexican law states that if a property is occupied for more than 5 years then it is owned by whoever lives there. The owner wanted access to the land and being that he was friends with Melchor, he asked him if there was any way of moving the people. Melchor got Carlos and Abel to write a report recommending the relocation on the grounds that they could be threatened by a Plinian eruption, but this was totally irregular, La Becerrera is closer and noone speculated about evacuating that community. I know it was true that they used the volcano as the reason, I saw the report, but I think... I would like to think that Carlos and Abel took part innocently* (Interview 13).

The official reason recorded for the relocation was volcanic risk (Cuevas, 2005). This was during a period where there was no ongoing volcanic unrest and there were two closer communities (La Becerrera and La Yerbabuena) not considered for relocation. Irrespective of the motives, it reflects an inconsistent and authoritarian approach to environmental risk that views the vulnerable communities as passive participants to be controlled and removed at the whim of those in charge with little to no input of their own.

6.4. Behavioural Issues: Mobile Origins and Conflicting Visions of Volcanic Risk Governance during the 1997-2003 Eruptive Activity at Volcán de Colima

On 12th December, 1997, RESCO detected volcanic earthquakes, continuing through 1998 (Gabriel Reyes, Interview). By the summer UCol scientists concluded that magmatic eruption was probable (GVP, 2013; Juan Carlos Gavilanes, Interview). Meetings began informally between PCC and UCol researchers (Tonatiuh Domínguez, Interview). Gabriel Reyes notes that the seismicity was the only continuously monitored parameter.

The 'twin volcanoes' exchange between Volcán de Colima and Merapi (Section 5.1) stemmed from the involvement of VDAP at both volcanoes. The rationale was a perceived similarity between the two volcanoes (Chris Newhall, pers. comm. 2018). Newhall states that the first visit was conducted in 1998, when an Indonesian delegation came to Colima.

In September 1998, the government of Colima legally established the *Comité Técnico Científico Asesor Volcán de Colima* (Volcán de Colima Technical Scientific Advisory Committee) (Gavilanes, 2004). This formalised the relationship between scientists and authorities. It also represented the incorporation of a further mobile policy component into the assemblage at Volcán de Colima - the Scientific Advisory Committee. This originated in the UNDRO (1985) manual and had subsequently been adopted at Popocatépetl, then adapted and proliferated throughout the federal apparatus of *Protección Civil*. Carlos Navarro notes that Servando de la Cruz of UNAM, who had served on the Popocatépetl committee since its inception, had a strong influence on the Colima committee. At its largest, the Committee included 14 UCol researchers (geologists, seismologists, geochemists, geographers and anthropologists) two UdG researchers, three representatives of PCC, three representatives of PCJ, and occasional external guests (Rodríguez, 2018).

Although, the legislation belonged to the state of Colima, the Committee, from its inception, straddled the divisions around the volcano:

> *In 1998, there was a direction, a Scientific Advisory Committee existed that worked, not just with* Protección Civil *Colima, but with* Protección Civil *Jalisco, the UdG, CENAPRED in México and UNAM. That is to say, there were various organisms involved in the volcano monitoring, the management of risk, and it was an integrated vision, everyone participated, everyone opined, everyone contributed information about the condition of the volcano. Moreover, a fund existed on the part of the state of Colima, to provide resources for volcano monitoring* (Mauricio Bretón, Interview).

November 1998 brought 17 days of sustained unrest (GVP, 2013). According to Juan Carlos Gavilanes, the Committee concluded (with guidance from Servando de la Cruz) that the signals were likely precursors to an effusive eruption. An evacuation of the closest communities was recommended. Gavilanes states that Committee members who had been part of the communication programme suggested including representatives from La Yerbabuena (Figure 6.3): "So six guys came here and they were in the meeting, they saw the graphs, the graphics and all the explanations given from different points of view and said 'yes, this is... we better evacuate.' And the evacuation was successful" (Juan Carlos Gavilanes, Interview). Former Committee members Abel Cortés and Alicia Cuevas also mention the positive impact of the educational programme. On 18th November, PCC evacuated La Yerbabuena (180 residents) and PCJ did likewise with Juan Barragán (120 residents) (Figure 6.3) 'voluntarily and in an orderly fashion' (GVP, 2013). By 21st, a lava dome had filled the crater (3.8×10^5 m^3) and overspilled to the southwest. This marked the beginning of a continuous period of magmatic eruption that lasted until June 2011 (Gabriel Reyes, Interview). By 1st December, the furthest lava flows had advanced 800 m southwest and the other parameters were considered relatively stable. At that point, the evacuees were permitted to return (GVP, 2013).

On 10th February 1999, an explosion generated PDCs with run-outs of <3 km, ballistic fall to distances of 4 km and ashfall over communities in southern Jalisco. Evacuations were again performed by both PCC (La Yerbabuena) and PCJ (Juan Barragán), lasting 17 days (Gavilanes, 2004; GVP, 2013). Cuevas (2005) notes that nine residents of La Yerbabuena initially refused to evacuate, although they were later convinced by PCC.

On 10th May 1999, RESCO interpreted seismicity as a precursor to a significant explosion and two hours later, an explosion ejected an ash column to approximately 6.5 km above the summit (>10 km a.s.l.), resulting in ballistic fallout to distances of 4.5 km from the vent. PCJ evacuated before the explosion took place, PCC evacuated La Yerbabuena later that day. This third evacuation lasted 32 days (Gavilanes, 2004; GVP, 2013). Strain in the relationships between the evacuees and the volcanic risk governance system became increasingly apparent due to life in the shelters, time away from land/livelihoods and uncertainty. After 26 days, 22 returned home whilst the evacuation order was still in place (Cuevas, 2005). Another large explosion on 17th July 1999 generated PDCs with run-outs of 4-4.5 km to the west and southwest: "This was the fourth time in eight months that authorities called for evacuations. Some families refused to leave, electing instead to sign waivers and remain" (GVP, 2013). This evacuation lasted only two days (Cuevas, 2005).

As the evacuations lasted longer, participation waned (Juan Carlos Gavilanes, Interview; Alicia Cuevas, Interview). Gavilanes claims that those involved in the educational programme tried to explain to evacuees that scientists were learning about the volcano and were unsure if the current activity was a precursor to a larger eruption. However, no official justification was forthcoming.

A recurring theme throughout interviews with UCol volcanologists is that the traditional boundaries of responsibility defined in the 'emergency management' model whereby scientists provide scenarios and probabilities, and the authorities conduct the decision-making, have not applied. From the earliest evacuations, PC have asked the volcanologists themselves to make the evacuation decisions (Interviews 1, 5, 7, 8, 9, 12, 27).

> *It has always been this way. Melchor says 'you are the ones who know, so if you tell me that this area is in danger and it's better to get people out of there, I'll get them out of there.' And perhaps, in those years, in the 1990s, and 2000s, as a group we were very prone to making that type of recommendation. To say to them 'yes, evacuate them', but we were making big mistakes* (Carlos Navarro, Interview).

This period of activity exposed divergences, tensions and divisions within the policy assemblages at Volcán de Colima. Some of these concerned the use of certain policy features in different jurisdictions. Jalisco adopted a three-level traffic light alert system, in part similar to Popocatépetl (Figure 6.5). The Jalisco traffic light has been set to 'Yellow' without change since 1998 (Interview 12; Interview 26). Colima did not adopt a colour-coded public alert system: "In Colima, they were reluctant to adopt the traffic light and the main argument is that they understood, but the population at risk was so small that there was actually no need for a traffic light" (Interview 21).

Legally, the two moderators of the Committee were the Technical Secretary of PCC and the Co-ordinator of Scientific Research at UCol. However, apparently, with time, the UCol Co-ordinator, Jesús Muñiz increasingly assumed the responsibility of spokesperson (Carlos Navarro, Interview; Juan Carlos Gavilanes, Interview). Muñiz was a biomedic with no volcanological background: "He often would give interviews to the press and that would upset people because there were often errors" (Nick Varley, Interview). According to Gavilanes, Muñiz was determined that the Committee would speak with one voice, to the extent that he sought to stifle debate when the governance of the crisis was polarising opinion between Committee members.

Figure 6.5. Volcanic Alert Semaphore, Juan Barragán (Figure 6.3), Jalisco (2017). The three 'stages' described are: 'Normality' (the volcano is calm, it is our obligation to know the location of evacuation routes, meeting points and shelters); 'Alert' (the volcano is restless, stay attentive to official information. Stay prepared for a possible evacuation, have your important documents to hand, make sure you know your meeting point); 'Alarm' (There is danger, it is the moment to evacuate. Remain calm, head to your meeting point and follow the instructions of the authorities of *Protección Civil*). The current level is 'Yellow/Alert'.

The principal divergence of opinion developed between those who had been involved in the educational programme and the remainder of the Committee. Juan Carlos Gavilanes states that one senior volcanologist decided to limit the information to the communities - for instance, insisting that the word 'explosion' be prohibited because it may induce panic.

> *By then I didn't know that that was not true, but I suspected it was not true because I... It was really dodgy, the thing was really illogical for me because I was with my friends, including several geologists, in constant contact with people of the communities and when you do that... Your points of view of hard science change, and science in general change. It's when you see that there's a world shared by authorities and scientists that is not the same as that in which people at risk live* (Juan Carlos Gavilanes, Interview).

In 1999, Jesús Manuel Macías, a Mexican specialist in disaster risk and Mary Fran Myers from the Natural Hazards Centre in Boulder, Colorado, visited Colima to speak to those involved in the community education programme, claiming that it was the first of its kind in México (Juan Carlos Gavilanes, Interview). Gavilanes states that the visitors introduced the community education group to the social science of disaster risk. Macías, a proponent of integrated DRR, used Volcán de Colima as a case study (e.g. Macías, 1999; Macías and Aguirre, 2006). Gavilanes claims that participating in the VRR system became increasingly challenging: "It was a breaking point in our academic life, that moment, the visit of Jesús Manuel Macías."

This especially became the case when the discussion turned to potentially relocating La Yerbabuena like Barranca del Agua. Both Juan Carlos Gavilanes and Carlos Navarro note that the decision to relocate La Yerbabuena was taken by the governor of Colima, Fernando Moreno-Peña, when the crisis began in 1998. Navarro claims that once Moreno learned what a PDC was, and that La Yerbabuena was constructed on top of PDC deposits from 1913, he was convinced that the town needed to be moved. It took some time for this decision to be carried out, including to obtain the endorsement of the Committee.

> *We told the Governor that it was not necessary, could we please agree on this first? We have a monitoring system, and we believe that, as has worked in other countries, before a strong eruption, the volcano is going to alert us, we're going to see changes in the composition of the gases, we will see it in the seismicity, it will show that magma is rising, we will see deformation. None of this is happening yet, so there's no need to relocate the people. As I said, he overreacted, although also perhaps he had a political vision, at state level or national level, to say 'I was the first governor to relocate a community because of volcanic risk'* (Carlos Navarro, Interview).

Nevertheless, according to Juan Carlos Gavilanes "most of the Earth scientists here recommended the resettlement". On hearing of the decision to relocate, Jesús Manuel Macías organised a workshop on resettlement in Colima, with invited attendees including disaster and relocation expert Anthony Oliver-Smith: "The general conclusion of the workshop was 'be careful'. This resettlement can increase the risk and can be unsuccessful" (Juan Carlos Gavilanes, Interview). Gavilanes claims that Macías alerted the incumbent director of CENAPRED to his intention to hold the workshop: "...the director of the main, the top institution of risk prevention in this country answered: 'Don't worry, don't do it, it is not necessary, they are very poor people, they will receive whatever you give them, even if it is this much.'" Gavilanes claims that learning of this was 'shocking' and the moment at which he realised that social science was a 'hard route to take' in México.

The second (and final) exchange visit in the Colima-Merapi 'twin volcano' initiative occurred as part of the 2000 IAVCEI Scientific Assembly in Bali. VDAP funds permitted five UCol volcanologists (including Gavilanes, Navarro and Cortés) to attend a conference field trip to Merapi, incorporating a visit to the village of Turgo, which was partially destroyed by a PDC in 1994 (Section 4.1.2) (Gavilanes, pers. comm. 2016). Chris Newhall (pers. comm. 2017) states that lack of funding prevented the exchange project from continuing in any formal sense, but he believes that at subsequent CoV conferences, volcanologists associated with both volcanoes have used the connections established to meet and exchange ideas.

In late 2000, the funding for the educational programme was not renewed (Gavilanes, 2004). "Without resources, we could not do the work. The main thing is economic support. The idea and the vision is one thing, but it doesn't work without support" (Abel Cortés, Interview).

> *I was absolutely disappointed when it had to stop. I think it was a great opportunity to initiate real exchange, real communication. It was a very good beginning, but I think maybe the authorities thought that for some reason it was not good that people would have information..., Mexican politics is based on control of the public, and it means the big component is that people do not make decisions by themselves. They must obey what politicians do* (Juan Carlos Gavilanes, Interview).

Alicia Cuevas claims that the community education project was, at the time of interview (2017), the only community work on risk reduction that had been done in the villages around the volcano at an academic level.

Throughout 2000, volcanic activity did not provoke further evacuations. However, residents were encouraged to avoid valleys around the volcano, due to lahar hazards. In May 2001, a new effusive phase began (Bretón et al. 2002; GVP, 2013). According to English volcanologist Nick Varley, who started working at UCol in late 2000, the Committee convened monthly throughout this period.

The Committee members from the UdG, Francisco Nuñez and Carlos Suarez-Plasencia, published two maps in 2002. One was a map of lahar hazards from Volcán de Colima and Nevado de Colima, and the other was entitled *Volcán de Fuego 'El Colima', Eruptive Process 1999-2002, Exclusion and Buffer Zone for VEI 2-3, February 10th-type Explosions*. This latter map formed the basis of policy in Jalisco regarding access to the volcano, with a 'buffer zone' in which people are permitted to work and an absolute exclusion zone of 8 km. This exclusion zone was based on a calculation of the potential energy release of an explosion larger than that of 10th February 1999, which the Jalisco scientists believed could send ballistics to distances of 8 km from the crater.

By 5th February 2002, the extant dome had filled the crater and began to generate incandescent rockfalls on the southwest flank (Gavilanes, 2004; GVP, 2013). Rockfalls had not been seen at the volcano since before 1998, and a committee meeting was called. The Committee concluded, almost unanimously, that there was no risk beyond 2 km from the summit and evacuation was unnecessary. However, two Committee members voted in favour of evacuation and took matters into their own hands at the conclusion of the meeting:

> *There was a moment in which the Governor spoke on all television channels, at national level about the glowing lava and the rockfalls descending during the night. It looked very impressive, but we were saying 'it's not a problem, this is normal for the volcano'. But, those two people together with Jesús Muñiz went to the Governor and when he*

> *asked 'do we evacuate the people?' they said 'yes, evacuate them' when on the same day in a committee meeting we had all said that it was not necessary. So, we woke up with news in the papers in Colima that they had been evacuated. This made us very angry and we asked 'why have you done this?'* (Carlos Navarro, Interview).

Several families resisted the evacuation, which lasted five days (Gavilanes, 2004). Once it had been concluded that the rockfalls did not represent a threat to La Yerbabuena, the evacuees were allowed to return. However, Nick Varley notes that, ironically, the rockfall activity was more frequent and of greater magnitude when the evacuees returned than when they left.

The next evacuation occurred on 18th May 2002. The Committee recommended the evacuation, not because of an eruption, but because RESCO had registered 30 hours of continuous harmonic tremor, something never seen before at Volcán de Colima (Gavilanes, 2004; Nick Varley, Interview). Differing perspectives on this evacuation exist. Gavilanes notes that, as no significant eruptive activity manifested after this, it could be seen as an 'overreaction' on the part of scientists and an indication that the committee had not learned from 1998-1999. Varley, on the other hand states: "I think that was a very well-called evacuation that they did because they hadn't seen it before and actually haven't seen it since, it was a very interesting bit of seismicity. Something strange happened then." This perhaps speaks of a divergence in focus on hazard and vulnerability between the two scientists at this point.

After the 18th May evacuation, the relocation of La Yerbabuena began: "The number of inhabitants who refused to evacuate increased. Those who resisted declared that the government acted against their human rights, upon seeing that they refused to evacuate, the government cut off the electricity and potable water with the aim of forcing them to leave the community" (Gavilanes, 2004). Cuevas (2005) notes that those who remained received the support of several organisations, including the Zapatista Army of National Liberation, an agrarian left-wing revolutionary organisation originating in Chiapas, southern México. La Yerbabuena declared itself a 'community in resistance' (Alonso, 2006). Melchor Ursua emphasises the role of the Zapatistas in convincing those who chose to stay:

At the beginning, they all accepted, but later, I don't know where the idea came from, I have an idea, but I am not sure, but they told them 'don't accept being moved', the Zapatista army from Chiapas came here to tell them 'don't accept being moved.' So five families didn't leave, and haven't yet. They're still there, fifty-something people. We stationed the military up there for some time so that if there was an emergency, we could get them out.

Ursua argues that the relocation was conducted in the best interests of the people and was intended to remove them from a zone of high risk, likewise that stationing the military in the community was to expedite evacuation in the case of a dangerous eruption. Macías and Aguirre (2006) cite claims that military personnel were responsible for intimidation, violence and sexual assault against the residents. The involvement of the Zapatistas can be seen as the at-risk community establishing topological links of their own and creating an assemblage of knowledge and personnel from 'elsewhere' in order to reinforce their position on the policy field. Processes of policy mobility are not purely the preserve of those with 'authority', ideas from 'elsewhere' can be brought into a local assemblage by those ostensibly without power, and used to influence the course of policy mutation.

The relocation was contested, not just by the community, but also from within the volcanic risk governance apparatus. Criticism came predominantly from those who had been involved in the community education programme (although Carlos Navarro also claims that he let the governor know he felt the evacuation was unnecessary).

That was a decisive thing in the perception of risk management by people, because people tend to see the resettlement as a failure. Our authorities never have accepted that, nor the geoscientists here. Most of the resistance were considered by authorities as rebels, inconscious [sic] *people, people influenced by the communist people of the Zapatistas. They came here to support the resistance, so Alicia and I, we were invited. They organised a festival of the volcano, it was like a response to the local meetings every two years, International Meetings of Volcán de*

> *Colima... So Alicia and I were considered like rebels by our colleagues here, by the authorities, the Co-ordinator considered that we were even Zapatistas. He told that to Alicia. It was a very big tension between us and the geoscientists, a very big tension..., I went out of the Observatory and was assigned to the environmental science centre in Coquimatlán. Ricardo Saucedo was fired, the leader of the programme, I think it was a personal thing between the director of the observatory who didn't like us* (Gavilanes, 2004).

Carlos Navarro confirms the split between the Committee researchers: "...all those crises, above all 1998-1999 and the management that was conducted, the relocation of the population, created a division between us too. That is to say, Juan Carlos left us to go and study social sciences and the same with Alicia".

The 1997-2003 events at Volcán de Colima, saw a conflict develop within the volcanic risk governance system between the dominant (Behavioural) components of the policy assemblage and the increasingly marginalised vulnerability-focussed community education programme. As noted earlier in the chapter, processes of policy mobility played a key role in 'emplacing' many elements of the policy system at Volcán de Colima. At this stage in the global discourse (Section 4.3), the Behavioural model had 'come of age' and was largely accepted by practitioners of civil protection as 'best practice'. However, the concept of disaster risk reduction had emerged to challenge the shortcomings of 'emergency management' in reducing risk.

Curiously, it could be argued that at Volcán de Colima, the community education programme did not arrive from 'elsewhere' but evolved organically from volcanologists taking interest in the application of their research. However, through the visit of external 'experts', this initiative was subsequently connected to the broader DRR discourse on the global policy field, and this exposure altered the convictions and actions of the individuals involved to the extent that co-existence within the system gradually became untenable.

The end of this conflict saw the VRR system at Volcán de Colima revert to an undiluted version of the Behavioural model, based on hazard mapping, monitoring and emergency planning, arguably still the case today. This serves to illustrate that, although this investigation has talked extensively of ideas 'arriving from elsewhere' and the significant impact that these have had in shaping volcanic risk governance systems, knowledge of DRR had 'arrived' at Volcán de Colima by 1999 (and has been there ever since) but has not manifested in policy or practice. The personalities and relationships on the policy field of VRR at Volcán de Colima have played an extensive role in the governance of volcanic crises. Subsequent sections will explore how these have continued to impact upon VRR policymaking and practice at this volcano.

6.5. Cuanto Más Cambian las Cosas, Más Siguen Igual: Local 'Mutations' in the Volcanic Risk Policy System at Volcán de Colima

In 2003, Carlos Navarro and Abel Cortés completed their Volcán de Colima hazard map (Carlos Navarro, Interview). Colima and Jalisco now both had separate hazard maps developed by their respective flagship universities. At this stage, Jalisco scientists were still active participants in the Scientific Advisory Committee. However, around 2005, a disagreement led to them permanently leaving the Committee. Francisco Nuñez (pers. comm. 2017) claims that the dispute originated from funds granted to UCol for volcano monitoring. Mauricio Bretón, scientist formerly in charge of volcanic risk at UCol's *Observatorio Vulcanológico,* states that during 2005, Mexican President Vicente Fox visited the Observatory and offered financial support. Funding was not granted reciprocally to the UdG and the fall-out was severe. Gabriel Reyes, then-director of the *Observatorio Vulcanologico* at UCol is candid about the quarrel: "We fell out in 2005, and the whole relationship ended. The exchange, the work, everything. I don't need to deny it or lie about it. It's a reality, it happened." The animosity apparently extends to the whole institution: "...he (Francisco Nuñez) doesn't have a good relationship with anyone here" (Interview 11). One explosion on 5th June 2005 produced the longest PDC since 1913, with a run-out of 5.1 km. This prompted PCJ to evacuate Juan Barragán (Figure 6.3; GVP, 2013).

In 2005, Ricardo Ursua-Moctezuma (nephew of Melchor Ursua) started work at PCC. Ricardo outlines PCC's official stance on the communities around the volcano post-2002: "The community closest to the volcano that we have is La Becerrera. Effectively, it is La Yerbabuena, but these are dissident people. That community has been relocated at the moment. They are there, but the closest community to the volcano is La Becerrera." Ricardo and Melchor decided it would be ideal to have a group of citizens in La Becerrera with basic training in emergency response. Ricardo claims that, after initial difficulties gaining the trust of the locals, eight people from La Becerrera volunteered to become part of a *Brigada Comunitaria* (Community Brigade). This could be seen as a form of community-based disaster risk reduction. However, there are claims that the initiative did not translate into a lasting arrangement:

> *I don't remember the year, but at some point, State* Protección Civil (Colima) *decided to create a group of people from La Becerrera to keep watch or act in case of an emergency. It was to be a* Protección Civil *group formed of people from the community, a group of volunteers, unpaid. So they made the group and gave them a few tools, they had waterproofs some oilskin boots and a radio for communicating. But the idea was more or less abandoned, they didn't keep up much communication, they didn't talk. This was the first such group that had existed at the time and today it's more abandoned than ever before* (Interview 3).

Ricardo Ursua states: "With the passage of time, the frequency of the exercises has dropped. Now we don't do them that frequently, because we have already done various." Here, there is evidence of another initiative (this one from within PCC) that might have engendered a culture of community resilience and encouraged citizens to participate in the system over the long term. However, this would only be possible with ongoing training, support and supply of resources.

The late 2000s were characterised by continuous dome growth, rockfalls, small explosions and occasional lahars to distances of <10 km from the vent. The activity ended on 21st June 2011, leaving a dome that had been growing since 2007 (GVP, 2013). At this time, Lucia Capra, an Italian lahar specialist based at UNAM began a project on Volcán de Colima. In exchange for logistical support, all the data are sent directly to UCol (Lucia Capra, Interview). Capra notes that she approached the two volcanologists at the UdG to find out if they would also be interested in collaborating, but they were only interested in learning about how to emulate the monitoring.

In 2005-2006, the funding for the Committee from the Government of Colima stopped and Gabriel Reyes ceased to participate as a form of protest, encouraging others to do the same. Some attempted to carry on, but with limited success (Rodríguez, 2018). Mauricio Bretón notes that by 2007-2008 the Committee had largely ceased to function. Juan Carlos Gavilanes recalls one of these latter meetings:

> *I started to talk about the basic rules of warning systems by Mileti, Sorenson and all those people and Lindel and Perry, about communication management in crisis, etc. And I insisted in the point that there shouldn't be a single channel of communication, it is much better for people to trust several channels saying the same. I remember two of my colleagues just left. They believed that was crazy, but that moment I realised that it was, my road there was just... I didn't have a case to stay there. After that, they changed the committee and they kept a new committee without 'undesirable' people, I think.*

On 29th October 2011, the Government of Colima passed the 'Law of Civil Protection of the State of Colima'. This altered the structure of the state apparatus of PCC to more closely reflect the national system (Section 5.4.2). The law established a general *Comité Técnico Cientifico Asesor* (Technical Scientific Advisory Committee) with five 'subcommittees', corresponding to each of the national-level, hazard-specific subcommittees originally derived from the Popocatépetl Committee in 1995. The 'Subcommittee for Geological Risk' assumed the function of the Scientific Advisory Committee for Volcán de Colima (Ricardo Ursua, Interview; Rodríguez, 2018). Carlos Navarro was approached by PCC to head the Subcommittee and to choose its membership (Carlos Navarro, Interview). Navarro chose a small group: fellow geologist Abel Cortés; seismologists Gabriel Reyes, Tonatiuh Domínguez and Raúl Arambula-Mendoza; and Servando de la Cruz from UNAM (Carlos Navarro, Interview). Ricardo Navarro (a biologist) assumed chairperson's role previously taken by Jesús Muñiz (Ricardo Navarro, Interview). Ten UCol researchers who were part of the original committee were not included (Rodríguez, 2018).

In 2012, the federal government passed a new General Civil Protection Law that sought to restructure SINAPROC at every level. The law aimed to establish apparatus for addressing disaster risk, including:

- Financial Mechanisms (e.g. mandatory creation of funds for local civil protection activities from state governments).
- Guidelines (e.g. 'National Development Plan', co-ordination between different PC entities, the establishment of scientific advisory committees, links to climate change policy).
- Risk Assessments (e.g. the creation of a National Risk Atlas comprising multiple Local Risk Atlases).
- Education and Capabilities ('the population at risk has the right to be informed and to participate in risk management activities').
- Emergency Preparedness (e.g. the establishment of a National Centre for Civil Protection Communication and Operation).
- Recovery (e.g. management of aid donations post-emergency; also notes 'improving the resilience of society is one of the objectives of the civil protection system') (OECD, 2013).

The UNDP (2014) argues that the 2012 law represents the paradigm shift between the Behavioural and Complexity models of disaster risk governance in the Mexican context:

> *In recent years México has shifted the focus of its National Civil Protection System (SINAPROC) from emergency management to DRR, with the overarching concept of Holistic Risk Management (GIR)* (Gestión Integral de Riesgos) *integrated into its present legal and institutional framework.*

There is a clear contrast between this rhetoric and the practical reality exposed throughout this case study. Until this point, risk governance at Volcán de Colima had resolutely revolved around short-term emergency planning. Steps towards a DRR-focussed approach had been made anaemically (and frequently aggressively contested). The adoption of a national-level framework, transitioning from emergency management to DRR is seen in two of this study's other case polities (Indonesia, 2007 and Colombia, 2012 - Sections 5.1.3 and 2.4), both of which can be linked to the UN Hyogo Framework for Action (Section 4.3). The UNISDR's policy strategy can be seen as a deliberate attempt to replace the Behavioural model with DRR through processes of policy mobility from the macro level to the meso level (with the understanding that actors on the meso level will facilitate the percolation to the micro level). At Volcán de Colima, difficulties had been experienced by proponents of a DRR approach when trying to implement their ideas as bottom-up or informal policy. However, now it was ostensibly being mobilised with authority, from the top down.

The restructuring of the Committee was the first significant manifestation of the new framework on the policy assemblage at Volcán de Colima. The change in law ensured that there was still a scientific committee fulfilling the function of its predecessor. However, the Subcommittee was now more exclusive. Moreover, one of the first consequences of the new framework was to further separate Colima and Jalisco, as the law necessitated that Jalisco form its own Geological Risk Subcommittee. The PCJ employees who had attended meetings in Colima, even after the departure of the UdG scientists, now joined the Jalisco committee:

> *It's interesting because you see now, that law was obviously trying to do a good job but in terms of Colima, I think it's not entirely a good job because it's kind of re-affirmed the Colima-Jalisco problem because now we don't have meetings together, they have their own committee... they only ever have them when there's a real crisis.* (Nick Varley, Interview)

It could thus be argued that a national-level policy framework, based on a concept of 'integrated DRR', driven by a global level mobile policy initiative, had actually contributed to the *dis*-integration of a significant component of risk governance when it 'arrived' at Volcán de Colima, rendering both states' VRR systems more topologically insular.

> *For political reasons, yes, they have broken a thing to which we had been accustomed where we had meetings with PCC, PCJ and the Scientific*

> *Advisory Committee... The situation has changed, before we would meet up. Now? We communicate, but we don't do meetings. When I'm going to evacuate, I call Trinidad (*López-Rivas, Director of PCJ) *and I tell him 'I'm going to evacuate, because here the situation is very problematic' and he'll say to me 'Well, I'm not going to.' How do I make him? So, what you say is correct, and it's lamentable* (Melchor Ursua, Interview).

Despite this, UCol have continued to share data with PCJ. However, Carlos Navarro explains that UCol "...don't exactly have the responsibility to inform PCJ of developments at the volcano, it's more of a moral duty. It's not a strict responsibility in law." Gabriel Reyes-Alfaro (PCJ, son of Gabriel Reyes-Dávila of UCol) notes:

> *PCJ have always been very close to the* Universidad de Colima *because they have the seismic network that works the best, so they've always had advice from them around being aware of the volcano. They have tried to set up a regional seismic network, but it doesn't function the way this one does... They listen totally, or principally to the people from Colima, from my point of view.*

This informal data sharing between UCol and PCJ may be considered the only surviving remnant of the post-1998 arrangement between the two states. Carlos Navarro, however claims that even this is largely a one-way process. Some note that, although in both states the day-to-day policymaking of volcanic risk governance is conducted separately, in periods of heightened activity, both states will collaborate:

> *They don't fully agree with one another, they have some differences but if the activity grows, they immediately start communicating with each other, they immediately start working together. So, this situation of difference disappears when the activity goes above a certain level. That's my impression. The same happens with the scientific groups. They're sometimes strongly critical, Jalisco to Colima and vice versa but in the case of a really significant increase of activity, they come together and they reach joint agreements, and both PC systems try to co-ordinate as*

> *much as they can... That's interesting, because you need the volcano to trigger the co-operation* (Interview 21).

Other interviewees (e.g. 1, 7, 9, 12, 23, 24, 25, 27) have also noted the tendency of the two states to open themselves to collaboration only when prompted by the activity of the volcano. This could be seen as a symptom of the reactive, emergency-focussed approach to volcanic risk that the UNDRO model has implanted in both states, even if the 'mutations' on either side of the border have diverged. Some individuals on the policy field at Volcán de Colima have argued that this is not necessarily problematic: "...each one is independent and this isn't bad, it's just that there is no integrated co-ordination" (Mauricio Bretón, Interview). However, others believe that it could prove dangerous: "...if Colima decides to do one thing and Jalisco another, if each of them has a committee and there is no agreement over what is the expectation of the volcano, we are constructing the disaster" (Carlos Valdés, Interview). "It's already a crisis in that case, it's already too late" (Nick Varley, Interview).

On the 19th-23rd November 2012, UCol hosted the 7th IAVCEI 'Cities on Volcanoes' conference, an event dedicated to the role of physical and social science in volcanic risk reduction (Section 4.3). During the conference, PCC arranged a mock evacuation of La Becerrera and La Yerbabuena in which delegates were invited to participate. However, they found it difficult to get the communities on board, as one resident of La Becerrera recounts:

> *Two years ago, Civil Protection Colima left disappointed because there was no participation of the people. After, they told us that if we participate in a drill, they will give us a box with grocery supplies. Of course, the people said yes and everyone was in line to participate* (López, 2016).

Melchor Ursua confirms that this was PCC's approach to the drill. Ursua notes that PCC have used handouts as an incentive for participation more than once in simulated and real evacuations, for evacuees and for the families of those evacuees who choose to stay with relatives, with the intention to ease the economic burden on evacuees and their hosts. However, this practice has been criticised by local social scientists:

> *They are buying participation, and if you don't have an incentive, a gift, they are not going to participate. They participate through the necessity to eat, because they are poor* (Raymundo Padilla, Interview).

> *If you have a population at high volcanic risk, who are only going to evacuate for a dispensation of gifts, that is dangerous. This is dangerous because they are not taking note of the danger of the volcano, but in some ways I understand why the people respond like this... they need food, they need to eat, but the authorities do not understand it in this way* (Alicia Cuevas, Interview).

The gulf between the authorities and social scientists was further exposed in a conference forum on volcanic risk, with Juan Carlos Gavilanes as moderator. Nick Varley recalls the event as a PR 'disaster':

> *This is the problem Juan Carlos had at Cities on Volcanoes, trying to produce some sort of constructive advancement and it blew up in his face... It was an open forum and someone came along and said 'Melchor Ursua, you should have done this, not that' and Melchor just wasn't used to that kind of criticism. A younger guy, perhaps a bit more educated, would have handled it better, but he didn't. His reaction was 'Why the hell has Juan Carlos subjected me to this?' I think if Juan Carlos had realised it would affect Melchor this badly, he could have been the chairman and intervened, but he didn't* (Nick Varley, Interview).

The events of 2012 compounded the division between those who 'belonged' to the volcanic risk governance system in the state of Colima (PCC/the physical scientists of the Subcommittee) and the 'policy outsiders' arguing for empowerment of the vulnerable communities. It could be argued that, in the same way the federal government's 'integrated risk management' model had inadvertently segregated Colima and Jalisco to a greater extent, it had also (if possible) further alienated practice in Colima from the social science of DRR (ironically the opposite of the stated intention of the 2012 legal framework).

Nick Varley claims that there is a difficulty experienced continually by the social scientists at UCol in presenting their ideas as constructive, rather than critical. When asked if tensions have prevented these social scientists' ideas being considered on merit, Varley replies: "Definitely, without a doubt. I think that's a sad reality...". These disagreements have resonated across the policy field at Volcán de Colima: "Sometimes the social researchers criticise us, sometimes very hard" (Interview 7); "I think it's due to the fact that in the past Juan Carlos and Alicia criticised the guys in PC a lot. Colima is a small place, they heard that criticism, they knew who it came from and they didn't like it" (Interview 11).

> *Actually, in some instances at Colima volcano we had more issues discussing with social scientists than discussion among volcanologists, because with volcanologists you could shout or whatever but you could more or less understand what the other person was saying. With social scientists, there were times where I just could not understand what they were saying. Just no way* (Interview 21).

Alfredo Aranda, Co-ordinator of Scientific Research at UCol since 2013, who has since moderated the Subcommittee, notes that executive power has continued to align itself with physical science "...the technical part dominates. The other part is lagging behind and they feel separated, intentionally. So it becomes a competition rather than a collaboration, and that's a worry because we definitely need both sides working together for this subject." There is evidence that the personalities of individuals on the local policy field and the relationships between them can define how mobile policy manifests (or does not) to a significant extent. Carlos Navarro claims that the fallout between UCol scientists during the 2012 conference is the reason that it was the last such event. The bi-annual international reunions did not resume afterwards.

On 6th January 2013, 1.5 years of quiescence at Volcán de Colima came to an end. Explosions excavated a 2.5×10^5 metre-deep crater and a new dome began to grow, beginning a period of activity that would last until 4th February 2017. The four largest explosions of 2013 all occurred in January. PDCs were generated with run-out distances up to 2.8 km west of the vent. Smaller explosions and rockfalls accompanied slow dome growth throughout the remainder of the year (GVP, 2013). At this point, feeling that his data may be useful, Nick Varley approached PCC about joining the Subcommittee and was encouraged to submit an official request. A majority vote saw Varley's membership formalised, the first expansion of the Subcommittee (Nick Varley, Interview).

The 2013 eruption was the first activity at Volcán de Colima during the Presidency of Enrique Peña Nieto of the *Partido Revolucionario Institucional*, coming to power in December 2012. The new administration sought to expand the role of the federal government under the new PC law:

> *CENAPRED, in the 1990s, and the 2000s, the first crises at the volcano, was an observer and trusted in what Colima did. They said 'leave them to do their work', but a few years ago, we could say after 2013, CENAPRED have stuck their hands in a bit more, the same in Jalisco. So, they are a new actor* (Carlos Navarro, Interview).

Despite its status within SINAPROC as the principal scientific/technical institution for the preventative element of disaster risk governance, in terms of volcanic risk, CENAPRED had, from 1995 onwards, mainly functioned as the local observatory for Popocatépetl (Section 5.4). However, CENAPRED's Director of Volcanology, Ramón Espinasa Pereña, claims that the January 2013 explosions of Volcán de Colima piqued the interest of the new Co-ordinator of SINAPROC, Luis Felipe Puente-Espinosa.

> *The director of the national co-ordination of PC, Luis Felipe Puente, knows nothing about civil protection. He is a tourism intern, he has a degree in tourism. His son is the boyfriend of Enrique Peña Nieto's daughter, the President of México, and this is what put him in this position* (Raymundo Padilla, Interview).

CENAPRED volcanologists Ramón Espinasa and Amiel Nieto-Torres claim that in 2014 when local Colima photographer Sergio Velasco installed a webcam, continuously streaming footage of Volcán de Colima, Puente began to drive for greater federal involvement at the volcano:

> *The Co-ordinator said 'We can't have this. We can't have* Webcams de México *informing the Mexicans of things that we, as Civil Protection should be doing.' So, that's when he started pushing, so that we could connect with Colima* (Ramon Espinasa, Interview).

Amiel Nieto suggests that the centralist vision of the Peña administration played a strong role:

> *The party that is in power at this moment, has the idea of concentrating everything, so that's why CENAPRED go to Colima, to the Committee, because the Co-ordinator has more trust in CENAPRED than in other institutions because CENAPRED is federal* (Amiel Nieto, Interview).

Ricardo Navarro (Co-ordinator of Scientific Research at UCol, 2011-2012) claims that during his tenure on the Subcommittee, before the Peña administration, there was 'practically no relationship' with the federal government. Likewise, Gabriel Reyes highlights the difference in CENAPRED post-2013:

> *...over 30 years there have been different governments from different political parties... There are times of complete neglect, times when they give us complete support as well as the freedom to do what we need to do and there have been times where the federal government have arrived and have taken control of the whole situation, this has been in recent times, in the last 6 years...* (Gabriel Reyes, Interview).

Ramón Espinasa states that, with the webcam providing a daily window into the activity of the volcano for people across México and beyond, the Co-ordinator felt it was important to the image of the organisation that PC should be publishing daily activity reports, a long-established practice at Popocatépetl. However, Gabriel Reyes resisted the pressure:

> *Institutionally, they have always fought for us to generate media information about the activity of the volcano and I've said to them all my*

> *life that I can't do it, because I have very few people, I have a seismic network to operate and maintain, to monitor a volcano, to do many things as the director of the research centre for 10 years. I couldn't, I didn't have people to put to work on a document I couldn't put making a daily bulletin on top of my existing duties. I would say, 'I'll do it, give me the people and the money to do it' right down to the sheets that I'd need to print in order to send the bulletins. If I don't have the money to do it, how do you want me to do it?* (Gabriel Reyes, Interview).

Reyes also refused to share the real-time data with CENAPRED, again in protest at the lack of financial support, but claims that the information was accessible: "I gave all of the information to the authorities of PC in the PC meetings. I never hid anything. Moreover, the displays have always been here for everyone to see" (Gabriel Reyes, Interview). In the absence of an agreement with UCol, CENAPRED unilaterally began publishing daily reports:

> *In the past, the role of CENAPRED has been nothing. They haven't done anything and then all of a sudden there was a change in personnel and they started producing reports, reports that the University of Colima often disagreed with... The first I was made aware of it was when I got an email with the PDF. They used* Webcams de México *data combined with a bit of seismic data they'd been sent, and satellite data, all freely available data, and it's like 'what's the logic of putting an extensive report out based on minimal data from people who've got no experience of Colima when we've got large amounts of data and tons of experience?'* (Nick Varley, Interview).

This study has highlighted that distinct policy assemblages and mutations have been constructed around Volcán de Colima and Popocatépetl, through the interaction of various pieces of mobile policy and the unique social and volcanological environments of both volcanoes. The post-2013 changes can arguably be seen as a product of the federal government realising (due to increasingly rapid mobility of information in the social media age) that it had very little presence in volcanic risk governance at Volcán de Colima, having focussed almost exclusively on Popocatépetl which stood within sight of its central institutions. As a result, policy and practice around Volcán de Colima had evolved in a manner over which it had limited control. When the attempt to extend the practice of producing daily bulletins was rejected on the local policy field in Colima, the federal government adopted the task itself, to the chagrin of the UCol academics, a contested form of policy mobility where a topographically distant higher-level administration attempts to insert a component into a localised assemblage that is perceived as unwelcome by the existing field constituents.

According to Ramón Espinasa, Puente also began to push for the establishment of a *Servicio Vulcanologico Nacional* (National Volcanological Service):

> *There is also something important that, in 2013 came out the Civil Protection law, so the law said that CENAPRED has the responsibility of any volcanic eruption in the whole country, so you know, even if there is the observatory of Colima and* Protección Civil *Colima, we have the responsibility. Not them, but us. And it's the law...(laughs). So that's why Ramón told you about the* Servicio Vulcanologico Nacional*, that is our main project. The point is that we need to organise different universities and observatories in order that they can provide us with information about the situation of volcanoes* (Amiel Nieto, Interview).

If the decision to publish bulletins was an attempt by the federal government to start to influence governance at Volcán de Colima from afar, the *Servicio Vulcanologico Nacional* can perhaps be viewed as an effort to annexe policy at Volcán de Colima into a framework over which the federal government would have more control.

Three of this project's case study volcanoes (Merapi, Nevado del Ruiz, and Mount Rainier) are monitored by national-level organisations that also monitor other active volcanoes within their countries (the CVGHM, SGC and USGS). Each of these (or their antecedents, e.g. the Dutch Indian Volcanological Survey) were the first institutions to assume that responsibility and were therefore able to establish themselves in this role uncontested. One notable exception was Nevado del Ruiz where, before the 1985 eruption, the committee in Caldas and the national apparatus in Bogotá did not achieve a working relationship (although the two were quickly amalgamated after the disaster). These institutions embedded themselves on the local policy fields at each volcano, either by establishing topographically proximal infrastructure and practices (e.g. observatories/monitoring) or institutional topologies (e.g. protocols with local governments/institutions).

At Volcán de Colima, the federal government had been topographically and topologically distant for over two decades of institutionalised volcanic risk governance. It is perhaps unsurprising, therefore, that the 2012 PC law's aim to establish a top-down institutional topology has not been swift or straightforward.

> *It isn't going to happen. It's a plan that's at least 10 years old. It's a plan that was born halfway through the previous presidency, the government of Felipe Calderón, when there were other people in CENAPRED, other people at the head of SINAPROC. The idea came to establish the Mexican Volcanological Service. We had meetings in México City, we went to Acapulco, and nothing came of it, but the plan continues. The years have passed and nothing has happened. This government has already ended, and whatever may be in the government that comes is going to change the public servants, all of them. There is no continuity in government policy...* (Gabriel Reyes, Interview).

Ramón Espinasa notes that the *Servicio Vulcanologico Nacional* would partially be based on the *Servicio Sismologico Nacional* (the Mexican National Seismological Service). This organisation has operated throughout México since 1910 and, in 1929 was placed under the control of the IG at UNAM. It is therefore autonomous from the Mexican government (Pérez et al. 2018). However, the *Servicio Vulcanologico Nacional* has been envisioned as a collaboration between the IG and CENAPRED, and would seek to draw upon the *Servicio Sismologico Nacional* and other examples of government-based volcanological surveys from around the world, particularly other examples in Latin America such as the *Servicio Geologico Colombiano* or the National Service for Geology and Mining in Chile (Interview 4; Interview 22). It can therefore be viewed as an assemblage of mobile policy ingredients from outwith, and within the Mexican context.

Under the Peña administration, SINAPROC demonstrated a desire to establish the *Servicio Vulcanologico Nacional*, but without significant financial investment:

> *There was a plan to do the National Volcanological Service. It was probably a nice idea, because like that you can join a lot of people, distribute different studies; gases, geochemistry etc. The project was presented by Ramón Espinasa two years ago in a PC meeting, an international meeting. The conclusion was 'we don't have the money to do this.'* (Lucia Capra, Interview).

The current strategy behind the *Servicio Vulcanologico Nacional* has been to convince the universities that study volcanoes in México to share their researchers' data with CENAPRED, on the understanding that the data will not be used for publications, but exclusively for PC (Ramón Espinasa, Interview). In this sense, the idea is to avoid financing new infrastructure by assembling the service from institutions that already exist, an approach that has raised concerns:

> *I think the reason there's opposition is because it's not coming out well, that people believe they're going to expropriate their equipment or take the data from networks that exist currently. Better, form the service from nothing, buy equipment, and leave people to do their own research with their own networks* (Tonatiuh Domínguez, Interview).

> *Who is going to work in this service? Those of us who already have instrumentation, who've been working for years? We're going to give it to the service in exchange for what? What is your responsibility within this service? What are the conditions? If you become part of a service, what is your status? Are you an employee of the Government, are you an employee of the University? What is your scope? What are your responsibilities? You know the case of l'Aquila in Italy? At what point could we come to? Federal functionaries have certain obligations. This should remain very clear, no? Who wants to form part of a National Volcanological Service?* (Mauricio Bretón, Interview).

The l'Aquila trial occurred in Italy between 2011 and 2012. Six scientists and a government official were found guilty of involuntary manslaughter for having failed to predict an earthquake and recommend an evacuation based on premonitory tremors in 2009. The earthquake killed 300 (Bretton et al. 2015). Although six defendants were acquitted and the seventh received a reduced sentence, the implications for science in disaster risk governance have been far-reaching. Following l'Aquila, UCol researchers began to resist the pressure to make evacuation decisions, encouraging PCC to take the responsibility (Interviews 1, 8, 12, 27):

> *More recently, at least during the last five years, we have insisted to Melchor to try to rectify that responsibility. We have said to him, "look, all of this has had an evolution, also internationally, there has been an evolution in how to take these sorts of decisions and in many places the responsibility has fallen to the scientists and they have insisted on evacuating in order to help PC take a decision that they have not taken. So we have to work now to convince them that things have changed and that now the responsibility should not fall to us* (Carlos Navarro, Interview).

Under Gabriel Reyes, UCol did not agree to share data with CENAPRED. Ramón Espinasa notes that this was a problem experienced with Colima and several other universities:

> *Gabriel was very closed and, in part it was because, I think, well, he actually told me that the reason he didn't share all his information is because he didn't get support in the form of money or equipment for monitoring, so why would he share all his data if nobody gave him any support? But that's the problem! His ultimate goal, as happens with many of the researchers in the universities, is not saving lives, it's studying volcanoes and publishing papers, and that's the main problem. In Colima they had a sort of arrangement, in the sense that Gabriel would give the information, already digested, to the head of Civil Protection in Colima, Melchor Ursua, so that Melchor would take*

whatever measures he thought were necessary, but it was sort of informal.

*The monitoring that was carried out in Colima was basically for scientific purposes and that's one of the reasons that we've been promoting the idea of signing agreements with the different universities, so that they will share those data and we agree that we won't use those data for scientific publications. And that's been the main problem with all universities and all agreements, we've since tried to... with Chiapas, with Veracruz, with Jalisco... Well, with Jalisco, they basically said we're not signing any agreement if CENAPRED is not paying us at least *this* amount of money* (Ramón Espinasa, Interview).

Francisco Nuñez of the UdG claims that in addition to insufficient financial incentive to participate, a further stipulation of the offer that he rejected was that he would need to obtain permission from CENAPRED to publish his own data (Francisco Nuñez, pers. comm. 2017). When asked if he sees this resistance as a significant obstacle to the creation of the *Servicio Vulcanologico Nacional*, Ramón Espinasa states:

Well, not really, I think that if the idea of having a national system keeps going forward, they will eventually have to capitulate. Especially, the day that we do have this entity working and we can get money for monitoring volcanoes, they will want... eventually I hope, that we will have money for equipment to put on volcanoes, and obviously we will go and put instruments on Ceboruco (an active volcano in Nayarit state where the UdG currently maintains a private monitoring network) *and things like that, and they will, have to eventually, I hope that they will eventually see that it is for their own benefit.*

Espinasa's most commonly used word is 'eventually'. The *Servicio Vulcanologico Nacional* did not come into existence during the presidency of Enrique Peña-Nieto and it remains to be seen if it will under his successor, Andres Manuel López-Obrador. It can therefore perhaps be regarded as a piece of 'latent' mobile policy - an idea that many actors on the policy fields of VRR at the local and national level have been aware of for some time, but which has not been translated into practice and thus exists in 'mobile policy limbo'. This is a clear contrast with the 'fast' mobile policy seen elsewhere in this study.

Volcán de Colima remained active throughout 2014, with ongoing dome growth, Vulcanian explosions, rockfalls, occasional PDCs to distances of >2 km, and 13 lahars with typical run-out distances of approximately 12 km. No damages were reported (GVP, 2013).

In 2014, work began on another component of the 2012 *Protección Civil* legal framework, the creation of a 'Risk Atlas' (Section 5.4.3) for the state of Colima incorporating digital simulations of hazard scenarios with vulnerability data, with a budget of $16,000,000 MXN (£655,000). Nick Varley took the job of generating the digital hazard simulations for the volcano (Nick Varley, pers. comm. 2018).

Seismologist Dulce Vargas-Bracamontes became the latest arrival at UCol in 2015 with a funded project from CONACYT. She was invited upon arrival to join the Subcommittee, but chose to defer until the project was underway, ultimately joining in June 2016 (Dulce Vargas, Interview).

On 9th July, 2015, Volcán de Colima experienced a significant increase in rockfalls and degassing, marking the beginning of the most intense activity since 1913 (Reyes et al. 2016). As the 10th July progressed, continuous effusive activity generated incandescent rockfalls and PDCs (GVP, 2013). This was the first night of the school summer holidays, and in the communities around the volcano, residents were preparing a celebration. Hugo Rodríguez, a PhD candidate at the *Colegio de Michoacán* (who was in La Yerbabuena and La Becerrera on the day in question conducting research) states that due to the activity of the volcano, PCC held a talk in La Becerrera at 19:00:

> *Most people were getting ready for the party and didn't go to the talk. There were practically only those from the community brigades there, noone from the wider population. We can say a lot about the way in which PC work with the people. PC believe that if they want to arrive on*

any given day, hour etc. the people are going to be there to listen to them. They don't count on arriving on a day or hour that is inconvenient... which says a lot about the degree of communication between PC and the communities.

I watched the talk, one of the people there was Carlos Navarro, the geologist. In his talk there was not a moment in which he said explicitly that lots of ash could fall over the next few days... there was nothing specifically said that indicated to me personally that there was an immediate danger in the days to come that would merit evacuating the people. It was a talk for the calm periods of the volcano.

At 20:16, a partial collapse of the dome generated PDCs with run-out distances of 9.1 km, descending the south flank of the volcano and channelled into Barrancas San Antonio and Montegrande (Figure 6.4). The event lasted 52 minutes and produced a deposit of ~2.4×10^6 m^3 (Reyes et al. 2016). This completely surprised the UCol scientists, *Protección Civil* and the communities around the volcano: "The day of the eruption was the beginning of the vacations, and it was just like 'okay, can we go on holiday? because the volcano has been like that many times in the past'" (Dulce Vargas, Interview).

First, in 2015, my colleagues said 'Right, we have another dome growing, we will have lava flows and then we will have explosions.' It was a Friday. Friday 10th of July and on this afternoon we had the lava dome collapse and a PDC for 9 kilometres. The people were amazed and surprised, they didn't know why we had a collapse like this (Raúl Arambula, Interview).

He (Raúl Arambula) had given an interview in the morning telling people to expect more of the same activity from the volcano. I would have also been worried about that. We were lucky that nothing happened... The newer scientists deferred to the guys with more experience that have been here for 30 years, Gabriel, Carlos Navarro, and it was a mistake on our part not to put more pressure on them and say 'this is something that *really looks different, don't be overconfident.' But I think it's difficult, how do you tell a person that has been doing forecasting for 30 years? How can you change the way that they think?* (Interview 11)

According to Hugo Rodríguez, following the talk in La Becerrera, PCC went to the Hacienda San Antonio to speak about the volcano, and were at the hotel when ash clouds filled the sky (Figure 6.6). Ricardo Ursua received communication from Melchor that he had been alerted by Gabriel Reyes and was en route from Colima city to evacuate La Becerrera and whoever could be convinced from La Yerbabuena, having already alerted the *Brigada Comunitaria*.

Figure 6.6. View of ash clouds from 10th July 2015 eruption from the road to La Yerbabuena, 8 km southwest of the crater (photo credit, Sergio Velasco, 2015).

Even in such circumstances, some of the residents of La Yerbabuena chose not to participate in an evacuation officiated by PCC:

We evacuated the zone. People stayed, there were about five who remained in La Yerbabuena, who did not want to go. Lamentably, in the plan we do not have the ability to force them to go, but we do have documents to give them the responsibility in case they lose their lives

> *which ensures that it's legally not our fault, that we gave them the opportunity, we were willing to help and they chose not to follow the recommendations that PC had made for them* (Melchor Ursua, Interview).

Hugo Rodríguez claims that those who left La Yerbabuena were brought down to La Becerrera (12 km from the summit, Figure 6.3).

> *At first they gathered the people in the school at La Becerrera as a shelter, but then decided to take them to Comala. It was all decided in the moment. They started to evacuate people in the trucks, but they didn't have more adequate vehicles to deal with the ashfall. Supposedly in the plans for the Volcano there is an agreement between certain public transport companies and PC to send vehicles. Those vehicles arrived a long time afterwards and they had already evacuated a lot of people in the trucks...*
>
> *Ricardo said to Melchor that he had spoken to Gabriel Reyes and had confirmed that the event had already finished and that the volcano was much calmer than it had been... Melchor replied that the people were feeling very nervous and for this reason they should be evacuated. Ricardo insisted 'Melchor, we don't have adequate space for all these people and the community can't handle it.' For these reasons as well as economic ones he argued that the people should stay. Melchor said 'I don't care, the people want me to evacuate them, I want to evacuate them and tomorrow, if everything seems calm then we can let them return to their houses.' Therefore, they took Melchor's word, they didn't ask the opinion of volcanologists or of other authorities. Based on what he alone said, they evacuated the people.* (Hugo Rodríguez, Interview).

Despite the fact that emergency planning forms the central 'executive' component of volcanic risk governance at Volcán de Colima, PCC have never disclosed these protocols. Outwith the PCC directorate, none of this investigation's interviewees, including 11 current or former Committee members, the Director of CENAPRED and the Director of Volcanology at CENAPRED claim to have seen the current plans, or to have had any input into their development. The one exception is Mauricio Bretón, who claims to have created plans with PCC during the first years of the Committee, but to have had no subsequent involvement. It is unclear how many iterations of the plans have existed since 1987, nor the extent of the changes. Investigations into volcanic risk governance at Volcán de Colima have brought to light three internal PCC documents pertaining to volcanic risk (including this investigation with the 1987 plan). Gavilanes (2004) obtained a document entitled the *Manual de Procedimientos Operativos en caso de Emergencia*:

> *State Civil Protection have written the Manual of Operational Procedures in Case of Emergency, which contains a part dedicated to volcanic risk. According to the authorities, this document is in revision for local authorities and it* [sic] *still not finished or approved by the state governor. This document describes the general character of volcanic activity, lists the routes of evacuation and highlights the function of the Committee and the observatory of the University of Colima, which consists of diagnosing the activity of the volcano and the degree of danger as recommendations to the respective authorities. Finally, this document describes the significance of the colours of the alert system and establishes a list of steps to follow for the public according to each colour.*

Although the traffic light alert system was never publicly adopted in Colima, PCC appear to have, at some point, internally followed its structures. This suggests the influence of the UNDRO manual, or its derivative mutation, the Popocatépetl alert system. Alicia Cuevas claims to have seen a mid-1990s plan for Volcán de Colima which was copied from the Popocatépetl plan to the extent that some place names still made reference to the state of Puebla. This implies that the plans that had existed since the late 1980s had been (wholly, or partially) reshaped by 'importing' ideas from the *POP* after 1995. There is no date attached to this document, however Gavilanes (2004) claims it was produced in mid-2002.

Rodríguez (2018) obtained a further document, the *Manual de Organización y Operación 'Volcán de Colima'*. Hugo Rodríguez claims to have first asked Ricardo Ursua for a copy of the current emergency plans: "I asked him in the interview if he could share the plans with me and he said 'no' that this information is reserved for 'interested parties', for those from *Protección Civil*, municipal *Protección Civil* and some scientists but it's certain that in 2015, *Protección Civil* in the municipality of Comala (in which La Yerbabuena and La Becerrera lie) didn't know the plans" (Hugo Rodríguez, Interview). Melchor Ursua later shared this document with Rodríguez. It appears more recent than the 2002 manual (it cites census data from 2004). The contents of the 11-page document include: a 64-word summary about the volcano; towns at risk (from PDCs, ashfall and lahars); approximate distances (of evacuation routes); zones at risk (based on radii of 8, 15 and >15 km); volcano monitoring (seismic, visual, deformation, geochemical, volcanic ash analysis, summaries of 14-55 words); map of impacts (listed in contents, not actually included in the document); map of communications infrastructure; informative bulletins (internal) and organisational structure; population at risk (breakdown of the demographics of La Becerrera and La Yerbabuena by age and sex); shelters; participating government dependencies and their functions (14 organisations at state, federal and municipal level, plus volunteer groups and the El Jabalí ranch near La Yerbabuena).

None of the text from the 2002 document has been directly copied into the post-2004 one suggesting the plan was completely rewritten. In the later document, the details of the UCol monitoring and the command chain are clarified in greater detail. However, it omits the colour-coded alert system. The responsibilities pertaining to each government dependency, which formed the bulk of the 1987 version of the *Plan*, have seemingly been 'outsourced' to each organisation, confirmed by Ricardo Ursua: "We have already assigned the responsibilities and all the different government institutions know what their role is and what they have to do in a conjoined manner."

However, the overall strategic structure arguably remains the same. The plan is triggered when those monitoring the volcano (through the Committee) alert PCC of 'dangerous activity' (although there appears to be no acknowledgement of different volcanic scenarios within the plans). PCC make the decision (although, in many instances it has been the volcanologists who do this), send vehicles and extract the population to shelters. There is no mention of involving the population in any capacity other than as evacuees, nor of strategies for the long-term reduction of vulnerability. On this evidence, the policy approach is firmly rooted in the Behavioural model.

Despite the limited insights afforded by these documents, this component of the VRR assemblage has largely been defined by opaqueness:

> *We've discussed it many times in the committees, but I don't understand why they are reluctant to have a statement, a public, available statement. I know what we tell them they should include because I've heard our scientists talking to them, but the truth of the matter is, whenever something happens, it's not clear what they're following and there is no official pamphlet or set of instructions that they share with everyone, so it's a little obscure, even for me... My guess is... PC and many of the official communities that are involved and responsible for this, in many states, not just in Colima, have been formed in a very idiosyncratic way, not through professionals, not through people that are specialised in these areas but very enthusiastic people who try to help, eventually they learn stuff, they take some courses, diplomas, throughout the years, but the academic foundation is not there. So, I think they are a little bit hesitant to expose themselves* (Alfredo Aranda, Interview).

Various other interviewees have made similar observations:

> *I believe that PCC lack people capable of constructing a plan, and I also believe that the people who work in PC do not have the humility to admit that to the people who could help them make a plan.* (Interview 5).

> *Civil protection are not really given courses or anything. There's very little training. From the academic point of view you're slowly trying to get ideas across. I think they don't fully appreciate the need. I think Melchor's outlook is very naive, that they can cope with everything with the resources they have...* (Interview 6).

> *The director of PCC, Melchor Ursua did not finish secondary school. And he is the person who takes the most important decisions in PC in the state of Colima. So you have two people at the head of the federal and state levels who don't know... technically, principally, they are not up to date. They don't know what to do. Ricardo is a systems engineer, he has been on some courses, he's participating in activities, but he doesn't have professional training specialised in integrated risk management, nor in volcanology, nor in geology.* (Interview 20).

It is therefore a common opinion that the plans have been developed without the input of experts in volcanology and disaster risk science, due to worries from PCC that they may be 'shown-up'. If Hugo Rodríguez is to be believed, then the evacuation of July, 2015 was based on the personal judgement of Melchor Ursua rather than a formal protocol: "I think that's probably putting it quite well, arbitrary decisions based on gut feeling" (Nick Varley, Interview).

The morning of 11th July, Hugo Rodríguez returned to La Becerrera to talk to the few residents who had not evacuated. A group from PCC were stationed in the village with a broken down truck they were using as a radio transmitter. Rodríguez describes an atmosphere of insecurity and uncertainty (Hugo Rodríguez, Interview).

At 11:58, a second, larger collapse occurred, generating PDCs with run-out distances of 10.3 km, predominantly along Barranca Montegrande with overspill into Barranca San Antonio (Figure 6.7). This event lasted for 1 hour and 47 minutes, leaving deposits of $\sim 8.0 \times 10^6$ m^3 (Reyes et al. 2016).

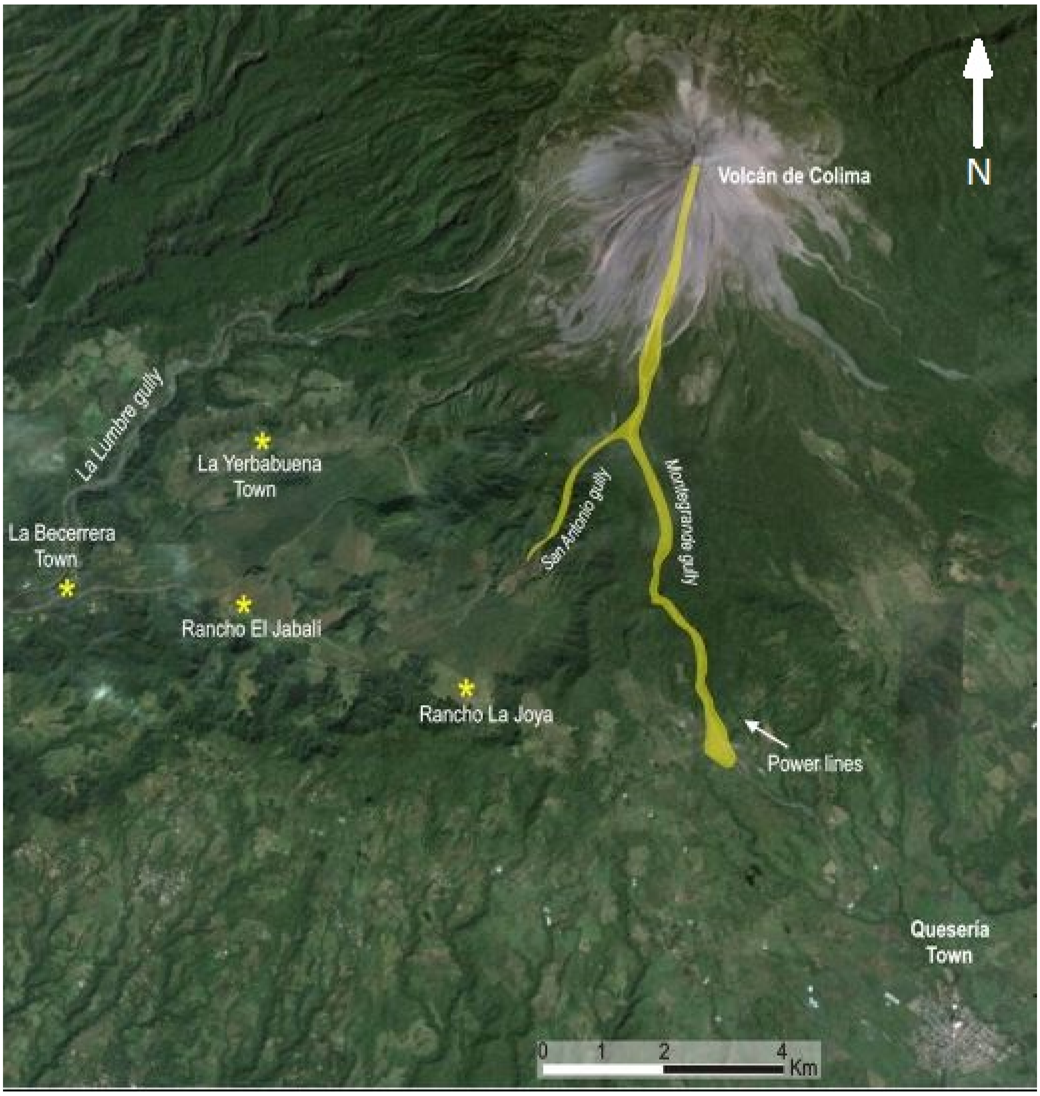


Figure 6.7. Satellite image of Volcán de Colima showing the distribution of the July 2015 PDCs along Barrancas San Antonio and Montegrande (area in yellow) and nearby population centres (adapted from Reyes et al. 2016).

Abel Cortés notes that workers from the *Comisión Federal de Electricidad* were working on power lines (Figure 6.7) when the event began:

> *Fortunately, their car was to the side of the path of the PDC and when they saw the clouds, they were able to leave, but if that PDC had been in Barranca San Antonio or La Lumbre, there would not have been time to leave for people in La Becerrera or La Yerbabuena. But nobody knew in such a short time that material could arrive so fast.*

Hugo Rodríguez was en route to Colima when the second event occurred. He encountered a blockade and those manning it explained that the exclusion zone had been expanded. They had received erroneous reports that the bridge that formed the only route from La Becerrera to Colima had been destroyed by a lahar and the remaining population were being evacuated northwards over the Nevado instead. Poor visibility caused by ashfall mixed with rain had caused a vehicle to crash while crossing the bridge and they reported the 'collapse' by radio. The evacuation was eventually completed using the standard route. Rodríguez notes that those in the shelters were much more comfortable than in past evacuations, the practice of dividing evacuees by gender had been abandoned and families were kept united.

Ramón Espinasa claims that CENAPRED had convinced UCol to grant them limited access to the RESCO seismograms during the incrementing activity of July 2015 and were aware of the potential for a dangerous eruption:

> *They* (the UCol scientists) *were surprised, but we did notice that something had changed and we did make a report for the Co-ordinator so that as soon as that started, there were people from CENAPRED who were sent over there and from the* Dirección de Protección Civil*, we had a helicopter for overflights and all that, because I think that's probably when Raúl said 'Oh, maybe Gabriel is not right, maybe it is a good idea... The data, because we're getting all this change' and well, back then at a certain point, Gabriel said 'We're losing stations!' and I made a phone call to VDAP and a week later we had four stations.*
>
> *The problem is they got stuck in the border, and that was a problem. But the fact is, there were the instruments, we did manage to get them, and I'm sure that if the crisis had still been going on when the equipment was stopped at the border, I'm sure the coordinator would have made a few phone calls and it would have been installed much earlier* (Ramón Espinasa, Interview).

The seismometers were detained at the Mexican border for nearly two years before being installed on 4th April 2017 in the village of Montitlán (2.5 km southwest of the furthest extent of the 2015 PDC deposits) and on Nevado de Colima. The fact that the instruments were tied up in Mexican customs for such a long time, and Espinasa's confidence that, had the crisis persisted, they would have been released sooner is arguably indicative of how crisis-driven the political prioritisation of Volcán de Colima is for the federal government:

> *They come, they help but it's *snaps fingers* like that... They know Colima volcano exists, they know it's a risk, but it's not that important of a risk. Bottom line. They won't say it like that, but in their priorities, when they think of the whole country, it's completely secondary* (Alfredo Aranda, Interview).

Carlos Navarro claims that the involvement of the federal government was initially fraught with difficulty when they arrived to convene joint meetings of the Subcommittees of Colima and Jalisco:

> *In the crises of 2015 and 2016, when CENAPRED decided to stick their hands in over here, the authority of SINAPROC came and he wanted to control the whole situation. We didn't let him. There was friction with the previous director we had, Gabriel Reyes, he entered into conflict with them because they wanted to control the whole situation and he said 'No sir, here you are inside the University, which is autonomous.' They came here to be authorities and to take control, but they came to understand that the situation would not be like that, that here there was experience and knowledge with regard to managing a volcanic situation and afterwards, when we had meetings with the governor, SINAPROC and CENAPRED, they always let us from Colima talk first, because of what was happening, because we could explain all of the seismic and geological phenomena that were occurring. So, at that point CENAPRED and SINAPROC gave us our place as 'those who know' and there was a higher level of respect, but I don't know if that's going to last for a long time* (Carlos Navarro, Interview).

The activity diminished following 11th July. Effusive activity persisted, emplacing a lava flow that continued to advance until 25th August, with a final length of 2.74 km (GVP, 2013; Reyes et al. 2016).

> *After 8 days they* (the evacuees) *returned and in this time, they made the declaration of emergency... through this declaration they can access certain resources at national level for cases of disaster. They made the declaration and like a week or two later, resources began to arrive like bottled water, sleeping mats and, like ponchos or bed sheets? But here in Colima it's very hot, these things were useless. So it is, and anyway, these things were too late.*
>
> *...Afterwards, we could say that things returned to normal but in returning to normality, there was no provision for working more with the people, talking to the people, updating operational plans, creating risk maps. Once again, it was the same, the people up there, the volcano continued in its activity* (Hugo Rodríguez, Interview).

The volcano continued to produce hundreds of small Vulcanian explosions into 2016. A new dome was observed growing in the crater on 19th February 2016 (GVP, 2013). Nick Varley, however, claims that Subcommittee meetings ceased, signalling a lack of interest in volcanic risk governance as a continuous process - even during a period when the volcano was visibly active:

> *There's not enough* (ongoing volcanic risk reduction between periods of activity). *That's my opinion. Often politics take a front seat. This happened last year, the meetings stopped and noone said why. I actually sent an email saying, 'well, aren't we gonna have a meeting of the committee?' and the reply was 'no'. I think at the time it was because there was nothing on paper - until there was an official definition of the members of the committee.* (Nick Varley, Interview).

Varley notes that the meetings restarted when heightened activity made ignoring the volcano untenable. On 26th September, 2016 seismicity began to increase. A lava flow descended the south flank, generating rockfalls and PDCs. Explosions caused ashfall approximately 40 km to the southwest (GVP, 2013). Carlos Navarro claims that it was difficult to motivate authorities to act:

In the crisis of 2016, the parameters of seismic activity that Raúl manages, the curve began to climb very rapidly, exponentially. Therefore, we were indicating that soon there would be strong activity. So, with these data, we wrote to Melchor saying 'we recommend that you evacuate, because the activity is strong.' They did not take it into account, so next, when the activity was stronger we went to say 'What are you doing? Why did you not pay attention?' He said 'No, I was waiting for us to meet in the committee, so that you could tell us all what we should do.' Raúl and I, a little annoyed, said 'no, the two representatives of the Committee have sent you a document in which we are indicating a recommendation to preventatively evacuate the population, because the activity is very strong.'

This Governor is not interested in anything. So, we tried to meet the Governor, until finally he could see us, we went with PC, with Melchor and he gave us only five minutes. We had to explain to him very rapidly and, there's a division of power between the Governor and the Secretary of Government. They have the competency of authority between them. So, we went to the Secretary of Government to have another meeting with him, the military and all of the government dependencies, so we said to them: 'We talked to the Governor 10 minutes ago and we have proposed that we carry out the evacuation of the population and the Governor has given us the go-ahead' and then the Secretary said 'No. I have not talked to him.' We said 'We talked to him a moment ago', but the Secretary became very serious and said 'No, until I talk to him and he gives me the order, this will not go ahead, there is a chain of command here.'

And the military leaders did not want to perform the evacuation, because all of this is a cost, an economic cost. Putting up the shelters, getting the beds, feeding the people, taking teachers for the children, and not just that, you break all of the social fabric. They felt like they couldn't be bothered doing this. But the activity was incrementing and incrementing. Fortunately, they removed the population and afterwards we had a PDC

> *with a large quantity of acid rain, but fortunately nothing happened, just damage to plantations and livestock, but in this experience we saw that the authorities would put off paying attention to us several times, that this does not interest them. Disgracefully, in México, we still significantly lack good education about natural disasters. How we have to act before, how we should take preventative action, not to be reactionary, not to start doing things in the moment when something's already happening, when people start to die and you already have everything piling up* (Carlos Navarro, Interview).

Dulce Vargas also portrays the manner in which PCC acted during this period of heightened activity as lackadaisical:

> *During the last new stage of activity in the last week of September, all the signals were like 'Okay, there's something coming, we need a meeting.' They knew that the activity was dangerous... Then that day or the next day we had a meeting and they were really slow, they were like 'let's have a coffee' and we were not that happy with that because the last year (*2015*) we had this activity in July that was quite dangerous. They already knew that they were supposed to be ready, the signals were really clear, it wasn't like July 2015 when the volcano was so active already that it was difficult to distinguish it from the background. This was like a textbook of volcano seismology* (Dulce Vargas, Interview).

PCC ultimately evacuated La Becerrera and La Yerbabuena, and PCJ evacuated Juan Barragán (Figure 6.3). Extensive PDCs like those of 2015 did not occur. However, acid rain fell on the southwest flank of the volcano, killing vegetation (GVP, 2013; Rodríguez, 2018). CENAPRED convened a meeting of PCC, PCJ and both states' scientific contingents, after which both states reverted to acting independently (Interview 1). Despite the involvement of the federal government, no action was taken to expedite the USGS seismometers from Customs.

Dulce Vargas argues that the 2015 eruption changed the attitudes of the UCol volcanologists:

> *I think that the eruption of 2015 changed the way everyone looks at the volcano. Even Gabriel with more than 30 years of experience. Every time something new appeared in the seismicity, he was more concerned about that... that eruption was so different, it changed everything. Last year when there was this new onset of activity, everyone I saw was more... even, paranoid. That wasn't at all the case in 2015, even with higher levels of seismicity.*

However, Vargas believes that the volcanologists' change of perspective was not mirrored in the actions and attitudes of PCC, further illustrating that individual personalities can (deliberately or unwittingly) provide a barrier to the mobilisation of 'lessons' and their translation into policy/practice, even between closely-linked bodies on the same policy field.

On 1st November 2016, Gabriel Reyes retired. Raúl Arambula took over as director of RESCO, and as director of CUEIV on 1st February 2017 (Raúl Arambula, Interview). This change of personnel altered the relationship between UCol and CENAPRED: "Raúl Arambula, he was a student of Carlos Valdés, the present director of CENAPRED, so he's a little bit more open" (Ramón Espinasa, Interview). UCol began to share real-time seismograms with CENAPRED and to publish weekly bulletins, reducing federal pressure for daily activity updates: "If the volcano has another crisis then we will publish reports, but not every day. That's fine for CENAPRED, but they don't have to teach" (Dulce Vargas, Interview). Arambula is amenable to UCol becoming part of the *Servicio Vulcanologico Nacional*, should it come to fruition, but anticipates support and resources in exchange for participation. Despite establishing a more collaborative association with CENAPRED, Arambula feels that their role at Volcán de Colima should be limited:

> *I think that it's much better if the people at CENAPRED only work with Popocatépetl because to monitor a volcano you have to stay close to the volcano, you can see it, you can smell it, many things... They help us, but sometimes we need to have the control of the situation because we have*

the people in Colima, the people in Colima are different from the people of México City. The people think differently (Raúl Arambula, Interview).

After agreeing to share data and release bulletin reports, there is now pressure from CENAPRED for UCol to undertake 24-hour monitoring. Raúl Arambula argues that UCol monitoring already provides sufficient coverage:

When the volcano is active, I have to look at the seismograms every two hours. I sleep with the seismogram in front of me and refresh and refresh and refresh and if I see something, I'll call PCC (Raúl Arambula, Interview).

However, the director of CENAPRED disagrees:

Everything is being monitored to see if it is stable, if something changes then actions are taken, that should be the idea, and to provide the confidence where we can say we have people 24 hours a day here monitoring the volcano. Colima doesn't do that and we keep telling them 'find a way to do that', they tell us 'no, no, no, we're fine monitoring with the cellular phone and...' No. You need to have someone directly at the lab. If something happens, technology sometimes doesn't provide you with the information that you can get just with a very quick look at the images and the seismograms, you will be able to tell (Carlos Valdés, Interview).

Although there is now a more consensual relationship between the two organisations, it is still arguably an informal policy arrangement based on the association between directors, without roles and responsibilities defined in writing:

Their jobs, I don't think anyone really knows. They've obviously got an idea in their heads, but it's something that's never been discussed, what is the role of CENAPRED, and what is the role of the University? I've got no idea. No idea. It's ridiculous and after the last crisis I remember we

> *decided to discuss it. We haven't had the meeting, there'll be another crisis and we still won't know* (Nick Varley, Interview).

> *In 2015, when I started working here, Gabriel was not sharing data with them and they started sending reports that they were doing of the activity of Colima and Gabriel shared them with us. There were a lot of scientific mistakes in the report, for different reasons. Then we had the crisis in 2015, then Gabriel retired and now we share everything with them... Maybe they are just recording events in their own way, but we don't know what they are doing. It could be useful, but we don't know what it is* (Dulce Vargas, Interview).

The activity between late 2016 and 3rd February 2017 was marked by strong explosions, frequently generating plumes to altitudes of >7 km a.s.l. Following an explosion (7.6 km a.s.l.) on 3rd February, activity declined. Several low-intensity explosions occurred in February 2017 before one final small explosion was recorded on 7th March (GVP, 2013). This was the last eruptive activity at Volcán de Colima at the time of writing apart from a small explosion on 11th May 2019.

In the ensuing period of 'volcanic peacetime' processes of policy mobility have continued to influence risk governance at Volcán de Colima. In 2017, the Subcommittee undertook the task of establishing a volcanic alert protocol for Colima:

> *I've been trying to get this done for 15 years. I've mentioned it many times in the past. It's incredibly slow. There's a lack of importance placed on it by... well, no, it's strange, when you talk to Ricardo* (Ursua) *I think he does understand what it is and the importance of it, but then why is he not putting it as a priority on his activities that he needs to do?* (Nick Varley, Interview).

According to Varley, UNAM volcanologist Servando de la Cruz - designer of the Popocatépetl traffic light system - endorsed the Popocatépetl model as the basis for the system at Colima. However, the Colima committee did not directly adopt this, electing to examine it alongside other existing systems:

> *We've been debating here about whether or not to have something similar to Popo, there's been a lot of debate where I think people have been concentrating too much on parameters which are fairly arbitrary in terms of how much seismicity there is, how much gas is coming out. Servando actually helped us to suggest that wasn't actually the way to go, and I think that's been kind of accepted now, but the last meeting we had, there were still arguments, people saying we need three levels of yellow, and Ricardo Ursua saying he doesn't want three levels of yellow and justifying it very clearly.. .I fully agree with him, and I told him this in person, I agreed I'd back him up at the next meeting. So, I've actually prepared a PowerPoint, which no-one really ever does, for the next meeting and I'll personally be trying to convince them that we don't need to follow Popo... what's the logic behind having three levels of yellow? It's confusing. Instead we should just go for the much more standard procedure of having four levels.* (Nick Varley, Interview)

Varley's presentation was based on a personal study of volcanic alert systems from around the world and participation in a workshop on volcanic alert levels at the CoV 9 conference in Puerto Varas, Chile. In this sense, the creation of the Colima state alert system can be viewed as a rare example that aligns relatively closely with the 'classic' policy transfer literature. That is to say, those involved in policy development have voluntarily 'scanned' the global policy field and sought to 'import' ideas they believe to be best for their situation. This is a contrast with the less 'deliberate' forms of policy mobility this study has frequently identified (at Volcán de Colima and beyond). However, the importance of international technocratic communities in providing a topological conduit for some of these ideas is evident in the integral role of a conference workshop in this process.

Both Nick Varley and Carlos Navarro note that it was the intention of the Colima Subcommittee to involve PCJ, to avoid having two separate systems in operation on the same volcano. In early 2018, meetings were held between the Subcommittees of both states:

> *It was attended by the state PC director, Mayor Trinidad, Alfredo Hernández, who is the boss at Guzmán, so the main centre for the volcano. There were a couple of other operatives... Then it was Melchor and Ricardo from Colima, Raúl, Carlos Navarro and myself, and that was it. There were no Jalisco scientists* (Nick Varley, Interview)

Varley claims that the meeting ended with an agreement that the two states should meet every two months, and to discuss the alert system. However, one week later, PCJ organised a helicopter flight over the volcano without inviting participation from Colima and published a report:

> *When they do a flight, the helicopter has a lot of spaces and there's usually someone who's just going along for a pleasure ride, when it could have been a Colima scientist. So, the report came out and the report is abysmal, it's just full of mistakes, written by their scientists and it's just... It's loaded with errors and after that came out, Carlos Navarro and myself, we both made the comment that at the moment it's laughable, whereas in a crisis, it could be something dangerous* (Nick Varley, Interview).

> *We have always had this conflict in that, Carlos Suarez* (UdG) *might publish a report from a flyover, we sometimes see these reports and say 'what the hell is this?' Things like that, of that magnitude. This is dangerous, because if he gives his incorrect opinions on the behaviour of the volcano, the actions of PC based on those are dangerous* (Carlos Navarro, Interview).

In March 2018, due to perceived inactivity of the volcano, the Colima Subcommittee reduced PCC's exclusion zone from a radius of 8 km from the vent to 5 km (Nick Varley, pers. comm. 2018). This occurred shortly before the second scheduled meeting between both states:

> *We started off talking about how low the activity was and that Colima have dropped their exclusion zone. 'Do you intend doing it?' 'Oh no!'*

> *'Why not?' and then they came out with the explanation of why not and it was very difficult to remain calm because they've got no idea about anything to do with risk... 'It's always at 7.5 km'. 'Why is it at 7.5 km?' Because during the explosions of '98 - they didn't even get the date right, there were no explosions in '98 - they found a ballistic at 7.5 km from the volcano. A ballistic. So that's where they've got the limit. Doesn't matter what the scenario is. I mentioned I've got a study of 1500 ballistics, I've got maps that show the density. They don't go to 7.5 km. Then Carlos Suarez said 'It was actually hot!'. Everyone knows that's a lie. It was just really sad that he had to come out with a lie to justify his data. He didn't go there immediately after the explosion. Nobody does that. It's ridiculous that he said that*
>
> *Raúl asked him, if the current level of activity persists for five years, would he lower the limit? 'No.' He didn't even think about it.... That's their idea, they don't want to change. Their justification is that they don't want people to think it's safe to start building their houses closer up, but that's not what the limit's for* (Nick Varley, Interview).

Gabriel Reyes-Alfaro of PCJ signals that it is unlikely that Jalisco will alter this in the foreseeable future:

> *I understand their position and the academic aspect, the reason for reducing the distance but Jalisco took the decision not to do it because of the social problem that it implicates, or that they believe that it implicates. They don't want there to be much more activity in that zone, or that the floating population becomes much bigger. They think it's better to maintain it for the distribution of the population and agriculture.*
>
> *This radius was decided because of a big rock that fell in 1991, that fell at this distance, therefore they say that it is the minimum distance for the risk. The zone is calculated for this reason. With relation to the social*

> *aspect, we're not going to lower it. We don't want to reduce this minimum exclusion zone* (Gabriel Reyes-Alfaro, Interview).

Moreover, the Jalisco participants apparently rejected the proposal from the Colima Subcommittee to engage in their development process for the alert protocols with a view to establishing a single system for the entire volcano:

> *We talked about the alert system, we said we're working on it, the idea is that you have your input and we have a unified alert system, and again they were very defensive, they said 'oh, we've got our three levels, we think it works.' We talked about the research into different systems around the world and the fact that nobody uses three anywhere apart from Jalisco. Popo uses three but they're subdivided into seven. Everywhere uses four or five or more. The most common is four.*
>
> *And then they said that they liked just to keep it on yellow and then I made the point that doesn't help the perception of risk, it doesn't prove the authorities are active. We asked 'Did you put it up in July 2015?' 'No.' 'Why not?'... It hasn't ever changed from yellow and they actually defend that. They think that's the correct way to be. We asked 'when would you consider putting it down to being green?' and the answer was 'never'* (Nick Varley, Interview).

The result of this impasse is that there are now two separate exclusion radii in operation on Volcán de Colima at the same time, 5 km in Colima and 7.5 km in Jalisco. From 21st December 2018 when PCC published their new four-level alert protocol (Figure 6.8) there have also been two separate alert systems, Jalisco's set to 'Yellow/Alert' and Colima's set to 'Green/Base level of activity or repose' (Protección Civil Colima, 2018).

Nick Varley (pers. comm. 2019) claims that the Colima system was ultimately published earlier than planned due to an unforeseen complication. The *Protección Civil* organisation of the municipality of Comala, in which both La Becerrera and La Yerbabuena are located, announced that they were establishing their own volcanic risk committee, which would include Mauricio Bretón, former member of the old Scientific Advisory Committee, and Raymundo Padilla, a Professor of journalism and anthropology at UCol. This committee have apparently stated their intention to establish a volcanic alert system to rival the state one. The response from the state government was to expedite the publication of their own system in the hopes of establishing its legitimacy.

COLIMA
GOBIERNO DEL ESTADO

Unidad Estatal de Protección Civil
COLIMA

VOLCÁN DE COLIMA

Semáforo de Alerta Volcánica

Estado del volcán	Efectos visibles en el volcán	Indicación a la población
Erupción significativa. Colapso de sector.	Crecimiento acelerado de domo y/o flujos de lava. Deformación visible. Explosión con columnas eruptivas sostenidas de varios Km de altura. Flujos piroclásticos grandes. Caída de ceniza intensa que deposite capas de centímetros de espesor. Lahares de largo alcance. Colapso de sector del edificio volcánico.	Si la indicación para evacuar corresponde a su ubicación, ¡hágalo! . Cubra sus ojos, nariz y boca. Deje alimento a sus animales de compañía, tome su mochila de emergencia y cierre su vivienda. Si puede autoevacuar, hágalo y tome la ruta previamente establecida, si no, trasládese al punto de reunión de la comunidad. No regrese a la zona evacuada a menos que las autoridades lo indiquen. Respete la zona de exclusión establecida.
Actividad de moderada magnitud	Crecimiento moderado de domo y/o flujos de lava. Explosiones moderadas a grandes. Caída de ceniza fuerte y persistente. Flujos piroclásticos moderados. Lluvias con posibilidad de generar lahares de moderado alcance.	Realizar actividades indispensables. Mantenerse atento del semáforo. No alejarse mucho de la comunidad. Cubra sus ojos, nariz y boca. Estar preparado para evacuar cuando se indique (mochila de emergencia). Tenga alimento suficiente para sus animales de compañía. Respete la zona de exclusión establecida.
Actividad de baja magnitud.	Crecimiento lento de domo y/o flujos de lava. Pequeñas explosiones esporádicas. Caída leve de ceniza (sin cubrir por completo la superficie). Lluvias con posibilidad de generar lahares de corto alcance. Flujos piroclásticos pequeños.	Realizar actividades normales. Tener presente el procedimiento de evacuación. Mantenerse informado del nivel del semáforo. Respete la zona de exclusión establecida
Nivel base de actividad o en reposo.	Desgasificación ligera (esporádica o continua).	Realizar actividades normales. Conocer los procedimientos de autoprotección y evacuación. Mantenerse informado del color del semáforo. Respete la zona de exclusión establecida.

Figure 6.8. *Semáforo de Alerta Volcánica Volcán de Colima* (Protección Civil Colima, 2018). The four 'states of the volcano' described are: 'Green/Base level of activity or in repose'; 'Yellow/Activity of low magnitude'; 'Orange/Activity of moderate magnitude'; 'Red/Significant eruption or sector collapse'. With each level of activity, the system details the expected associated volcanic phenomena and recommended actions for the population.

Various interviewees (e.g. Nick Varley, Hugo Rodríguez, Lucia Capra) claim that municipal PC organisations frequently experience a problematic relationship with the state government of Colima because, since the Mexican revolution, Colima has been continuously governed by the *Partido Revolucionario Institucional* (PRI), whereas municipal governments have tended to belong to a range of opposition parties.

According to Carlos Valdés of CENAPRED, whilst the federal and state governments last six years, municipal governments last three, so it is very difficult to develop institutional continuity in terms of policy. On 28th June, 2019, when this thesis was close to completion, an official federal PC twitter account posted an announcement of a meeting between federal PC, PCC and PCJ with the intention of 'homogenising' the plans for Volcán de Colima and announcing their intention to hold a drill (Congreso Nacional de Protección Civil, 2019). This may herald the start of a new era under the López-Obrador presidency, however much remains to be seen regarding how this process will unfold, the way in which these new policy ideas will manifest and whether they will truly repair the 'fractures' in the policy field, or generate 'progress' towards long-term DRR that empowers and involves the vulnerable communities around the volcano.

6.6. Synthesis

This study has shown that processes of policy mobility have been crucial in the development of volcanic risk governance at Volcán de Colima. However, they have not produced a straightforward linear progression towards 'best practice' DRR. As noted in Section 5.4, the creation of a legal framework for disaster risk governance in México is relatively recent in comparison to its emergence on the global policy field, and at other case studies. The establishment of SINAPROC was driven by the earthquake of 19th September 1985 and the subsequent ripple effect that carried institutionalised civil protection to every state in México is another clear example of the role that Earth processes can play in driving mobile policy. However, although its roots lie in a policy framework exported downwards from the meso-level, it is the micro-level that has arguably defined the evolution of VRR at Volcán de Colima.

As volcanic risk was not a priority of the federal government until the re-activation of Popocatépetl in 1994, assembling the volcanic risk policy framework at Volcán de Colima was a process that largely bypassed the federal level during its early years. Driven by the minor volcanic activity of the late 1980s, the *Plan Operativo Volcán de Colima* was constructed from mobile ingredients drawn directly either from other micro-level policy fields (e.g. the *Plan Operativo Volcán Tacaná*) or from establishing direct connections to the macro level (e.g. the UNDRO manual; the bi-annual *Reuniones Internacionales*). These processes established Volcán de Colima as a topologically distinct site on the global policy field of VRR, further divided between the states of Colima and Jalisco.

It is perhaps unsurprising that the emergent volcanic risk governance system at Volcán de Colima was based on physical science and reactive emergency planning, given the UNDRO manual was a keystone of the assemblage. The system was notionally at its most 'complete' during the activity of 1998-2003 when the Committee united the scientists and authorities of Colima and Jalisco and there was guaranteed funding. However, the early evacuations owed a significant degree of their success to the one component of the policy assemblage that did not conform to the Behavioural model, the community education programme - which had emerged locally. As evacuations became successively less successful, and relations worsened between the volcanic risk governance system and the people it was supposed to protect, a divide began to form between those involved in this project and the rest of the assemblage. The tension was compounded when connections were made between the community education group and the global discourse of DRR, introducing an alternative vision of risk governance to the local policy field.

There is evidence that the established policy framework has become entrenched through a number of influential individuals. As such, alternative ideas circulating onto the policy field have frequently been strongly contested. The rupture triggered by the relocation of La Yerbabuena is the first example of this phenomenon, and has arguably emplaced an enduring barrier to the participation of social scientists, and between the community and the governance system.

The influence of individual field constituents is an important consideration for the role of policy mobility in the circulation of 'best practices'. Knowledge of an alternative to the Behavioural model has existed at Volcán de Colima for ~20 years. However, it has not translated into practice due in large part to the power of personal relationships. Indeed, this case study demonstrates that policy development (and mobility) is not a linear path towards 'more advanced' or 'better' policy. It could be argued that the VRR system at Volcán de Colima has regressed in various respects, even by its own standards (e.g. the end of the community education programme; the end of the working relationships between Colima and Jalisco; the loss of state funding; the end of the international meetings).

Recent events at Volcán de Colima have illustrated that there is still much work to be done in developing an integrated system of volcanic risk reduction. As things stand, it is unclear if the new initiative from the federal government will seek to advance all sections of the policy field from an approach rooted short-term emergency management to the long-term reduction of disaster risk. The policy field is fragmented and collaboration across the boundaries has been limited. This has the potential to lead to a volcanic crisis where a poorly-co-ordinated or understood response increases vulnerability (there are already some in the communities around the volcano who would prefer to risk their lives in a hazardous eruption than to collaborate with the existing volcanic risk governance system). There are many contributing social factors, not least political will, funding and education. However given that processes of policy mobility have demonstrably taken Volcán de Colima from a 'policy vacuum' to the volcanic risk governance system it has today, the circulation of knowledge will also be key to the future. Understanding the individuals who occupy these divisions on the policy field, their perspectives and their motivations, may go some way towards identifying strategies to start to seal the fractures before the next volcanic crisis.

Chapter 7
Harnessing Processes of Policy Mobility in the Development of Volcanic Risk Reduction: Aspirations, Complications, Considerations

7.1. General Lessons from Chapters 4-6

The previous three chapters have presented evidence for policy mobility in the development of volcanic risk governance at individual volcanoes and across the global policy field that has grown to encompass them. The study introduces social responses to volcanic risk as (predominantly) isolated episodes, affecting communities exposed to volcanic hazards at particular moments in time, with limited spatial and temporal mobilisation of knowledge that might have permitted other vulnerable communities (at the same volcano or another) to reduce losses based on 'lessons learned' (excluding some word-of-mouth stories surviving for generations). This has been the case for much of history, prior to the unprecedented acceleration of globalisation over the last two centuries (e.g. Northrup, 2005). The study subsequently outlines the development of human infrastructure for the retention, circulation and implementation of VRR knowledge at the macro level (influencing practice at volcanoes in multiple nation states). This is characterised as a 'policy field' (Hannigan, 2012), a realm of social interaction that coalesces around a particular policy problem, populated by various 'field constituents' with varying connections (or absences thereof).

This study has shown that policy is continually produced, mobilised and reshaped through dynamic interactions between the constituents and processes that span the global policy field (the macro level), those within different national contexts (the meso level) and those surrounding individual volcanoes (the micro level), including the volcanoes themselves. In this regard, VRR policies can be viewed as *assemblages* (Section 2.4). The growth of the global policy field of VRR has been inevitably bound to the broader global policy field of DRR as depicted by Hannigan (2012), and social processes of globalisation. However, the volcanic risk policy field possesses its own distinct history, driven by unique variables (notably the irregular intervals between significant volcanic episodes and the development of volcanology).

In Chapter 4, this study chronologically outlines the growth of the global policy field of VRR. The timeline is divided into three sections according to the state of development of the policy field and wisdom of the day regarding 'best practice' in volcanic risk governance. Before 1945 there was generally a dearth of policy directed toward volcanic risk. However, from the mid-19th Century, a growing movement to internationally co-ordinate disaster relief efforts laid the foundations for what became the global policy field of DRR. Moreover, the international expert community of volcanology began to coalesce around the turn of the 20th Century and (in a piecemeal fashion) to build a body of knowledge pertaining to volcanic processes and crises. Responses to volcanic risk in this period were typically arbitrary, reactive and of limited effectiveness, whilst the related processes of knowledge exchange were slow, disjointed and not conducive to consistent progression towards 'improved' practices. Between 1945 and the mid-1980s, the concept of 'civil defence' spread across the global policy field, which was becoming more populated and interconnected through advances in communications technology, the emergence of international governmental organisations and the growth of the academic community of volcanology. However, as Hannigan (2012) notes, the international regulation of disaster risk policy has been characterised by 'soft law' with emphasis on autonomy of the nation state allowing for highly variable interpretations between and within countries. Despite these differences, governments typically adopted reactive, short-termist and authoritarian approaches to volcanic risk based on volcano monitoring, hazard mapping and 'emergency planning'. Several significant volcanic disasters, culminating in the 1985 eruption of Nevado del Ruiz illustrated the limited efficacy of this approach, which Smith and Petley (2009) name the 'Behavioural paradigm', in terms of reducing disaster losses - particularly in developing countries. Subsequently, the concept of Disaster Risk Reduction (the 'Complexity paradigm' according to Smith and Petley [2009]) has emerged. This approach advocates - amongst other considerations - the long-term reduction of vulnerability and the involvement of the exposed population. The global policy field has become more densely occupied and interconnected in recent decades, characterised by rapid exchanges through transient topologies. This study finds little evidence for consistency or predictability in terms of the circulation of information, or homogeneity in terms of the 'direction' of VRR policy development at individual volcanoes. The policy field is currently a space where the two paradigms and many more ideas are contested by various constituents.

The distribution of policy is far from uniform and mobile ideas undergo 'mutations' when incorporated into the unique assemblages surrounding each volcano.

Chapters 5 and 6 extend this study to five volcanic settings. The construction and evolution of policy assemblages around each volcano is chronologically 'followed', studies are of: Merapi (Indonesia); Nevado del Ruiz (Colombia); Mount Rainier (USA); Popocatépetl and Volcán de Colima (México). This thesis has shown how unique aggregations of circulating knowledge from across the global policy field and specific local circumstances have produced distinct versions of volcanic risk governance, some of which have developed attributes that align more closely with the DRR paradigm (or are in a process of transition with this goal in mind) and others where this is not the case.

It is clear, that processes of policy mobility are embedded in the development of volcanic risk governance, and will be key to its future. Policy mobility studies is a discipline that tends to focus on analysis *of* policy (Section 3.1). However, because applied volcanology is a 'goal-orientated' discipline that occupies the frontier between academia and political decision-making with the aim of reducing losses of life and property (e.g. Calder et al. 2015; see also Section 2.3.2) it is also an aim of this research that its findings contribute to 'improving' volcanic risk governance. This chapter therefore seeks to discuss the implications of these observations across the global policy field and at each of the case study volcanoes, including the aspirations of field constituents for future policymaking, the complications of policy mobility in volcanic risk governance and some considerations for potentially addressing these.

7.2. Aspirations

DRR is currently an influential ideal within certain echelons of the global policy field, yet to become a widespread functional reality (Section 4.3). The pursuit of this goal features throughout Chapters 4-6 from the 1990s onwards. The roots of DRR lie in academic criticism (e.g. Smith and Petley, 2009; Hannigan, 2012; UNISDR, 2015) of the Behavioural model's failure to reduce disaster losses in developing countries (exemplified in Sections 4.2, 5.1.2 and 5.2.3). The 'Development' view was a critical response to the Behavioural model's focus on hazard over vulnerability and subsequently the 'Complexity' theory of disaster risk came to view disasters and their governance as an intersection of the two (Smith and Petley, 2009; Section 2.3). DRR has subsequently been adopted by the UN (e.g. UNISDR, 2015) as its flagship policy goal, although it has limited power in enforcing participants to adopt its recommendations wholesale.

The UN (predominantly through the UNISDR and its predecessor UNDRO) has been a key macro-level field constituent. The UNDRO (1985) *Volcanic Emergency Management* manual is a mobile policy model that has circulated onto the local policy fields of at least four of this project's case volcanoes (Nevado del Ruiz, Mount Rainier, Popocatépetl and Volcán de Colima) and others around the world. Chapters 4-6 have documented the significance of this manual as a piece of mobile policy, expanding on the work of Macías and Aguirre (2006) by contextualising its role within the overall history of the global policy field of VRR, the evolution of the broader assemblages at each case study volcano and including fresh examples. With the exception of the *Mount Rainier Volcanic Hazards Response Plan* (Section 5.3.2), which has arguably mutated so far as to leave its 'source material' unrecognisable, the UNDRO (1985) manual has played a crucial role in establishing volcanic risk governance frameworks with a focus on short-term 'emergency management' (i.e. the Behavioural paradigm). Moreover, the participation of the national governments of Indonesia, Colombia and México in the UNISDR has (to varying extents) driven efforts to transition from 'emergency planning' to a DRR-based approach (Sections 5.1.3, 5.2.4 and 6.5). In this sense, the UN has attempted to mobilise policy knowledge in an effort to replace a system it itself had mobilised two decades prior.

Arguably the most significant macro-level field constituent in the development and circulation of VRR information has been the 'expert community' of volcanology. The case narratives (Chapters 5 and 6) are laden with examples of globe-spanning knowledge-exchange initiatives including IAVCEI's Decade Volcano Project and CoV conferences, the USGS/VDAP, the VUELCO, STREVA, MIA-VITA and GVM projects, the Bi-National exchanges between Mount Rainier and Nevado del Ruiz, and many more at all levels of the policy field. Even the UN initiatives to mobilise policy and knowledge related to volcanic risk have been driven by volcanologists - the UNDRO (1985) manual was created after the IAVCEI general assembly approached the UN (Section 4.2); the Decade Volcano Project was supposed to be part of the

UN's International Decade for Natural Disaster Reduction before it failed to attract UN funding (Section 4.3); and volcanic risk was only incorporated into the UNISDR's framework for action following the GVM submission to the 2015 GAR (GVM, 2014). This study has illustrated that, for many field constituents at all levels, volcanic risk is a low political priority during periods of volcanic quiescence. Four of the case studies (Merapi, Nevado del Ruiz, Popocatépetl and Volcán de Colima) have provided examples of 'fast policy' - the development of a local policy assemblage on a timescale of days to months - during periods where it is perceived that a 'crisis' may be imminent. In these instances, topological connections may be established in short order with those circulating so-called 'best practices' at the global level. However, the longer-term processes of defining, promoting and sharing 'best practice' VRR have arguably been shown throughout Chapters 4-6 to be dominated by the volcanological community, for whom volcanic risk is a continual priority.

It is for this reason that in Section 5.3.3, this study suggests that the policy assemblage at Mount Rainier may (theoretically at least) represent the 'highest aspiration' of policy mobility in volcanic risk governance. It is a policy system that has developed entirely in 'volcanic peacetime', before any activity affecting modern human communities has occurred at the volcano. Volcanologists recognised the risk at Mount Rainier from their observations of the volcano and the surrounding infrastructure - and through comparisons with other volcanoes (most notably Mount Saint Helens and Nevado del Ruiz). This knowledge gave volcanologists the impetus to identify other field constituents and bring them together to form a policy response. The resulting policy framework has undoubtedly benefitted from the status of the USA as a Global North economy, i.e. the well-funded infrastructure across the local policy field, and the interconnectedness enjoyed by field constituents internally at the micro level and with the macro level (for example, the USGS volcanologists at Mount Rainier were part of the same organisation that housed VDAP). In this regard, it could be argued that the policy field at Mount Rainier has benefitted not just from the socioeconomic status of the USA, but from topological proximity to the 'core' of the expert communities where knowledge of 'better' practices tends to reside.

The basic principle that those working at Mount Rainier were able to obtain information from 'elsewhere' that allowed them to pre-emptively identify a potential problem and also to design a policy solution, arguably represents a goal for those seeking to 'harness' mobile policy in volcanic risk governance. In this vision, policymakers at all active volcanoes (irrespective of socioeconomic constraints) would be able to rationally and deliberately access the global repository of knowledge curated by the technocratic communities at the 'core' of the global policy field of VRR and to voluntarily shape policy solutions using that information during volcanic peacetime (or before a volcanic disaster). This view aligns well with the assumptions of the 'classic' policy transfer literature (Section 2.4). However, this study suggests that in most cases, as has been a key argument in policy mobility studies, the reality is far more complex and those pursuing this policy goal in relation to VRR would do well to be aware of the complexities of mobile policy generally and of the volcanic risk policy field.

7.3. Complications

This study has shown that the policy field of VRR and its assemblages are constructed through the transient interactions of heterogeneous constituents. It is important, therefore, when discussing aspirations pertaining to volcanic risk governance, to acknowledge that this heterogeneity can (and often does) extend to the visions, strategies and actions of field constituents at all levels, and complicates the pursuit of a single policy ideal. There are numerous such instances throughout the case narratives. At Merapi, after the Indonesian declaration of independence, the expulsion of Dutch nationals and the Sukarno regime's political leanings towards the Soviet Bloc meant that the Volcanological Survey of Indonesia could no longer rely on the experience of the Dutch scientists who had previously run the institution, and their ability to collaborate globally was limited (Section 5.1.2). This remained the case until the New Order regime's pro-Western leanings opened up the possibility of working with a broader cross-section of the global community of volcanology and helped turn Merapi into the prolific site of knowledge circulation it has subsequently become. This illustrates that decisions and postures from other parts of a policy assemblage ostensibly unrelated to volcanic risk can have knock-on effects for the access to topologies of knowledge exchange at certain volcanoes.

During the volcanic unrest that preceded the 1985 eruption of Nevado del Ruiz (Section 5.2.3), the policy field that rapidly emerged around the volcano was fragmented, most noticeably between the departments of Tolima and Caldas. This divide extended beyond the local level, as the national geological survey in Bogotá refused to share data with the ad-hoc Caldas committee. The division also shaped relations with the members of the international technocratic communities as incoming experts from foreign volcanological surveys and UNDRO had to choose the 'side' that they would be collaborating with (therefore restricting the topological circulation of knowledge).

Chapter 6 provides examples of multiple micro and meso-level divisions on the policy field around Volcán de Colima, extending to personal disputes between individual scientists and public servants that have demonstrably had a profound effect on the overall assemblage. Key examples include the rupture in the Scientific Advisory Committee between the *Protección Civil* authorities and scientists who believed that the repeated evacuation and eventual relocation of La Yerbabuena was the correct course of action, and those who believed an approach requiring greater community engagement was required. Indeed, it could be argued that this break in relationships has been one of most significant barriers to the acceptance of community-based DRR, and demonstrates that mobile knowledge which meets resistance on a local policy field can exist for a long time in a 'latent' state, deepening divisions between field constituents.

It is important to give communities an active role in the development of volcanic risk governance systems. Exposed populations are a ubiquitous feature of volcanic risk governance assemblages, and arguably the most 'important' constituents. However, this study has demonstrated that in many instances the public are marginalised until a 'crisis' arises (in the perspective of more 'powerful' field constituents) and then expected to do as instructed. This marginalisation also frequently renders communities topologically distant from VRR knowledge that circulates more readily into other parts of the assemblage. Thus, when this knowledge is forcibly applied to a community in the context of a short-term volcanic event, it can clash with the perspectives that have emerged within that community, or as a result of their own processes of knowledge circulation (as in the case of La Yerbabuena and the Zapatistas). At times, 'technocratic' systems can fail to take into account indigenous understandings of volcanic phenomena which do prove effective when applied in volcanic crises, such as the Carib evacuation of Morne Ronde during the 1902 eruption on Saint Vincent, arguably the most appropriate social response on the island. It is therefore imperative not just to ensure that mobile knowledge pertaining to 'improving' volcanic risk governance 'arrives' and is accessible in vulnerable communities, but also to work hard to ensure that mobile knowledge interacts with local knowledge in a positive way, addressing any scientific misconceptions in a culturally sensitive way and taking on board local perspectives such that any resulting policy assemblage is imbued with the 'best of both worlds'. Arguably, an example of this can be found in the first evacuations of La Yerbabuena when the community education programme involved the villagers in a respectful, inclusive and informative manner. However, it is also evident that this is something which needs to be maintained over time, as the disintegration of the relationships established profoundly altered the overall VRR policy assemblage at Volcán de Colima, with enduring effects.

The 2005 personal dispute between scientists at the UCol and the UdG created a functional rift between volcanologists in the two states spanned by the volcano, which was further expanded when the PC law of 2012 (ironically the Mexican government's attempt to implement the Hyogo Framework for DRR) ended the participation from both states in the same Committee. These divisions have defined the policy field of VRR at Volcán de Colima and are responsible for key features of the policy system such as the two separate alert systems and two different-sized exclusion zones on two sides of the same volcano.

This study shows that volcanic risk governance is subject to continual evolution as parts of the assemblages change over time and at varying rates. These might include the retirement of an individual who inhibited collaboration between two departments of an institution, a change in government budget that means a volcano observatory has to reduce its monitoring capacity or the establishment of an international collaborative project that brings fresh knowledge to the local level. Any one of these events could cause the overall policy assemblage to mutate to a greater or lesser degree. However, there is no guarantee that all such mutations will bring the overall framework closer to contemporary understandings of 'best practice' from the heart of the global policy field. The gradual divergence of Colima and Jalisco is one example that not all change constitutes progress towards an ideal.

A key part of any VRR policy assemblage, and one that distinguishes this area of public policy from those typically examined by policy mobility studies, is the volcanoes themselves. Volcanic activity does not conform to the cycles that frequently dictate the 'rhythm' of other forms of policymaking such as government terms, the financial year or the academic year. Indeed, the pattern and form is unique to each volcano. In many instances, it has only been when a volcano has shown signs of activity that it becomes a political priority - the policy fields at every case study volcano with the exception of Mount Rainier were formed thus. However, just as activity can establish a volcano's presence within a policy assemblage, inactivity can cause it to fall away. A prominent example is the observatory at Mont Pelée on Martinique, which lasted from the eruption of 1902 until it was decommissioned in 1925, before the volcano became active again and it was re-instated (Section 4.2). When a volcano 're-awakens', it may be to a completely different social or political reality. There is no guarantee that the *Mount Rainier Volcanic Hazards Response Plan* will still exist in its current form the next time that Mount Rainier generates lahars sufficiently large to reach the surrounding populated floodplains. This becomes still more complicated at volcanoes characterised by long periods of unrest (months to years) with intermittent peaks in activity; the volcano's behaviour can become 'normalised' and larger eruptions can catch the local policy field unawares, as happened at Merapi in 1994 and 2010 (Section 5.1) and Volcán de Colima in 2015 (Section 6.5). Dedicating funds to maintaining VRR projects during periods of volcanic quiescence may be a hard sell in political settings where resources are scarce.

Although this chapter has discussed the role of the international community of volcanology as a macro-level actor in the circulation of VRR knowledge, this too is a heterogeneous assemblage, made up of researchers from a multiplicity of backgrounds, geographically, scientifically and institutionally, most of whom do not just share knowledge internationally, but are themselves embedded within localised policy assemblages. There are diverging perspectives within this community over the role that volcanologists should play in VRR. Traditionally volcanologists have conducted studies in order to (1) learn about volcanic processes (2) understand the current behaviour of particular volcanoes with a view to informing authorities and vulnerable populations. Multiple volcanologists cited in Chapter 6 have stated that this is their desired role, despite the tendency of PCC to force them into decision-making. At the September 2018 CoV 10 conference in Naples, Italy, I attended a session during which the role of volcanologists was debated within the context of designing volcanic alert levels. One speaker (the convenor of the session) stated that attempting to occupy a purely scientific position was 'not best practice' and alert levels should be simplified to help communicate with non-specialists. This speaker was immediately followed by another who argued that they were a researcher, not a political decision-maker, and volcanologists should focus on researching and quantifying the hazards, rather than reducing risk. A robust debate ensued, with the two sides not managing to see eye-to eye.

7.4. Considerations

The findings of this investigation reinforce the point that sometimes volcanologists cannot avoid straddling the boundary between science and politics, or the 'science-policy interface' (e.g. Donovan et al. 2012; Calder et al. 2015). The 'lens' of policy mobility studies extends this view beyond the short-term involvement of volcanologists during crises, and expands it to encompass the long-term processes of identifying, circulating and using information across the global policy field. The aforementioned session on alert levels, in which the debate on the 'politicisation' of volcanology occurred was, in fact, part of the scientific initiative that also influenced the state of Colima's 2019 alert semaphore (Section 6.5). The effects this has had on the policy field at Volcán de Colima (e.g. giving the state of Colima an alert system; furthering the divergence between Colima and Jalisco) exemplify the tangible political manifestations that can stem from scientific knowledge exchange. Thus, when viewed from the perspective of policy mobility studies, it is difficult to see science as politically neutral. This is particularly the case when, even if volcanologists are not generally the most politically powerful constituents at local or national level, they tend to be the most active globally in the circulation of VRR knowledge. If policies are viewed as assemblages, comprising individuals, institutions, stories and experiences, the act of introducing circulated information or practices into an assemblage arguably constitutes *policymaking* - as policy is not 'made' merely by the conscious efforts of those writing policy documents but through the actions (overt and understated) of all constituents.

As such, an essential goal of this research is to highlight to volcanologists who are reticent about involvement in political decision-making, that they are likely already part of assemblages which span the local, national and global levels. The positions they occupy within these, their actions and relationships with the other constituents, may play significant roles in shaping and reshaping volcanic risk governance over time. Ideally, awareness of the 'shape' of VRR assemblages and the policy fields they span would be extended to other constituents besides volcanologists to turn the assembly of VRR policy into a more consistently self-conscious exercise. However, some participants have traditionally been more topologically isolated from the macro-level fora in which 'better' practices are defined. Instilling a culture of self-awareness throughout the whole assemblage may facilitate smoother circulation of ideas, the identification of potential points of friction, the reconciliation of differences (as it becomes apparent how damaging divisions can be to the whole), to give a voice to the marginalised, and to allow those engaged in processes of trans-boundary knowledge exchange to acknowledge the topography and topologies of the policy fields they occupy and traverse. In this way, those involved in knowledge exchange may be more mindful of the processes in which they are participating, the assemblages they are taking ideas from or into and to adjust their actions and expectations accordingly. This may give actors throughout the assemblages a greater degree of understanding of their own agency as well as when, why and how certain pieces of knowledge have 'arrived', the existing features of the assemblage that these will interact with, and more informed speculation regarding potential outcomes.

As with any effort to circulate an idea, the goal of instilling a heightened sense of self-awareness amongst field constituents on all strata of the global policy field is itself, unlikely to be straightforward. Whilst this project has sought to identify key field constituents, it is certain that there will always be less obvious actors and processes that influence the development of policy in unforeseen ways, particularly when linked to the volatility of volcanic activity and multi-scale geopolitics. However, by identifying and involving as many actors as possible, it is feasible that (at least) a partial transformation of the pursuit of 'best practice' VRR may be achieved, with a grasp of the 'big picture' and the 'finer' details. In this way, it may be possible not just to generate closer ties between the advancement of applied volcanology and efforts to promote DRR through the technocratic assemblages at the macro level (i.e. the quest to establish 'what works'); but to allow actors on all levels to deliberately access knowledge that is pertinent to them and to 'harness' processes of policy mobility to assemble volcanic risk policies in tune with the needs of the societies around particular volcanoes. This may, to some extent, shift priorities in the pursuit of 'best practices' in VRR from 'what works' to '*what might work here*' (Savage, 2019). The latter concept involves an adjustment in expectations from participants that acknowledges both the benefits and the challenges that can come with learning from 'elsewhere'.

Chapter 8
Conclusions

This project has investigated the role of global knowledge exchange in the development of the governance of volcanic risk. The theories and methods of policy mobility studies have been used in conjunction with the political science of disaster risk and applied volcanology to identify and explore how, why, where and with what effects complex interactions of social and Earth processes have shaped this area of public policy over time and across scales. Analyses have been performed through the construction of narrative histories, 'following' the formation and evolution of volcanic risk governance internationally, within different national contexts, and at individual volcanoes. These narratives detail the impact of the circulation of knowledge, policy and practice in producing parallels and divergences in social responses to volcanic risk when they 'arrive' in different volcanic environments. Here is a summary of key lessons from this research.

- This study has presented a history of volcanic risk governance from 122 BC until the time of writing. It has been shown that for much of human history, social responses to volcanic risk have tended to be inconsistent (depending on time and place), arbitrary, reactive, relatively uninformed and limited in their capacity to reduce losses. However, within the last ~150 years, there has been an incremental transformation that has seen the worldwide emergence of societal apparatus for reducing the occurrence of volcanic disasters. This can be strongly linked to processes of population growth and globalisation. The development and proliferation of volcanic risk governance is a sub-division of the broader policy arena of disaster risk governance. However, this study finds that volcanic risk governance is distinguished by its own unique timescales, constituents and attributes (e.g. the spatial and temporal distribution of volcanic activity bringing political attention to different volcanoes at irregular intervals).

- The realm of social interaction related to volcanic risk governance can be depicted as a *global policy field* (Hannigan, 2012). This theoretical approach does not rely on preconceptions of consistent organisational links or structural interdependence between actors. The reduction of volcanic risk is viewed as the central issue around which various 'field constituents' have come to interact, with differing connections (or absences thereof), goals and understandings. These may include: national states and local governments; regional organisations; international financial institutions; UN disaster agencies; NGOs; multi-actor initiatives and partnerships; scientific communities; private actors; and the mass media. This study suggests the addition of vulnerable populations to Hannigan's (2012) original nine categories.

- VRR policy is produced through the actions and interactions of field constituents. Policies are consequently viewed as *assemblages*: loosely-bound, fluctuating arrangements of heterogeneous components - policy documents, institutions, groups, individuals, and various actors from 'elsewhere' who, through *topological* relationships proliferate certain ideas and bring certain sites 'closer' to one another (potentially distancing others) irrespective of physical proximity. In the case of volcanic risk, this study illustrates that exposed communities and active volcanoes themselves are also key components with agency in policy assemblages. The policy mobilities literature (e.g. McCann and Ward, 2012; Temenos and McCann, 2013; Kennedy, 2015; Savage, 2019) argues that, processes of circulation and assemblage cause policy to *mutate* in transformational and unpredictable ways. This study demonstrates the role of policy mobilities, mutations and assemblages, spanning every layer of the global policy field and shaping volcanic risk governance in theory and practice.

- The chronological development of the global policy field of VRR is roughly divided into three periods. Before 1945 there was little to no formal volcanic risk governance. Between 1945 and 1985, the concept of 'civil defence' emerged and proliferated. However, the resulting short-termist and authoritarian 'emergency planning' approaches to volcanic risk (what Smith and Petley [2009] name the 'Behavioural' model) were unsuccessful in preventing several severe volcanic disasters, notably the loss of approximately

23,000 lives at Nevado del Ruiz, Colombia. Subsequently, 'disaster risk reduction', an approach to disasters that aims to complement short-term emergency management with long-term community engagement and the reduction of vulnerability (known to Smith and Petley [2009] as the 'Complexity' model), has come into contention. Although this is an influential idea and has been enthusiastically promoted at the macro level, the modern policy field has seen the insurgent Complexity theory resisted by the established Behavioural model at the national and local levels due to difficulties in unseating established policies and the challenges of empowering vulnerable communities. This study identifies the UN as the main agent promoting the transition to DRR (within its limited capacity to influence sovereign governments) and the international academic community of volcanology as the most active participants in the pursuit of identifying and sharing 'best practices' in VRR. Although separate, in recent years these goals and their proponents have increasingly aligned.

- Historical narratives 'following' the development of volcanic risk governance at four case study volcanoes in distinct national (meso-level) contexts highlight the role of mobile policies and their mutations in building and reshaping policy assemblages at individual volcanoes. The case study volcanoes are: Gunung Merapi - Indonesia; Volcán Nevado del Ruiz - Colombia; Mount Rainier - United States of America; and Popocatépetl - México. These case studies demonstrate that: movement of policy (formal and informal); the transient topologies that carry knowledge between volcanoes; the assemblage of mobile knowledge with the evolving politics, culture and volcanic activity of the settings in which it arrives; and the resulting mutations, have been fundamental to the unique form that volcanic risk governance has taken at each volcano. The marked differences between case studies also demonstrate that the development of volcanic risk governance at each volcano has not run concurrently alongside the theoretical evolution of DRR 'best practices' - the timescales are unique to each process, frequently dictated by the uncertain behaviour of volcanic and human systems. These considerations complicate the task of those disseminating knowledge at the macro level with the goal of improving VRR policy and practice.

- The case study of Volcán de Colima, México is used to illustrate the significance of the interactions between mobile policy and individual field constituents at the micro level. VRR at Volcán de Colima has its origins in an assemblage of mobile 'ingredients' from the meso and macro levels of the policy field - the Mexican national system of civil protection; the emergency plans from another Mexican volcano; and the UNDRO (1985) manual. However, most policy development at Volcán de Colima has taken place locally, with little involvement from the federal government (in stark contrast to Popocatépetl) illustrating the varying approaches to volcanic risk governance that can be encountered within the same country and the topological marginalisation of certain volcanic sites in favour of others with more political 'capital'. By the late 1990s, a policy assemblage incorporating scientists and civil protection authorities from both states spanned by the volcano (Colima and Jalisco) had formed. Due to its roots in the UNDRO manual and the authoritarian nature of Mexican politics, VRR policy was strongly symptomatic of the Behavioural model. However, within this assemblage, a component emerged locally that expanded its scope marginally beyond this - a community education programme. As a breakdown in relationships between the exposed populations and the authorities progressed, those involved in the education programme became topologically connected to the global discourse of DRR and aimed to introduce it to the policy assemblage. This was resisted by other field constituents and, as a result, the Complexity approach has only existed on the policy field at Volcán de Colima as a form of 'latent' mobile policy - an idea that has 'arrived' but failed to manifest in practice. In subsequent years, the assemblage at Volcán de Colima has further disintegrated due to personal disagreements between individuals in Colima and Jalisco, inhibiting collaboration and the flow of data (illustrating the importance of individual perspectives). Now the policy assemblages in both states are, to all intents and purposes, separate entities with entirely different positions on parallel policy issues (e.g. exclusion zones, alert levels) that are occasionally briefly brought together (superficially, at least) under the authority of the federal government during perceived 'crises'. Risk at Volcán de Colima has historically been something of a non-issue for the federal government, however the social media age has seen the volcano's activity ripple across new topologies, making it far harder to ignore. This, combined with the centralist vision of recent Mexican administrations has seen efforts from the federal government to 'annexe' the local policy field at Volcán de Colima or to 'insert' components into its various assemblages. However, evidence suggests that these efforts have had limited success due to intermittent funding and political will, and the aforementioned resistence to change. The case of Volcán de Colima illustrates that mutations in local assemblages can produce drastically different VRR frameworks, even within the same national setting and using some of the same mobile policy 'ingredients'; that high-profile mobile policies may encounter micro-level resistance that renders them largely impotent; that these ideas may lie 'dormant' on local policy fields for decades; and that the temporal evolution of a VRR policy assemblage does not automatically entail 'progression' towards the ideals of technocracies - sometimes it arguably constitutes the opposite.

- This research carries important lessons regarding the future role of policy mobilities in volcanic risk governance. The 'ideal' for VRR policymakers is arguably most strongly represented in the case of Mount Rainier, where the 'policy problem' (volcanic risk) was identified during a period of 'volcanic peacetime' using experiences from 'elsewhere' (Mount Saint Helens and Nevado del Ruiz) and the resulting policy framework was deliberately constructed by accessing the 'best' available information on the global policy field in continuous consultation with a broad cross-section of local field constituents. In this idealised vision, policymakers at all active volcanoes would be equally able to rationally and deliberately access the global repository of knowledge curated by the technocratic communities at the 'core' of the global policy field of VRR and to voluntarily shape policy solutions by mobilising that knowledge into their settings, constructing a policy assemblage in harmony with the interests of local field constituents. Whilst it cannot be ignored that the VRR framework closest to the 'ideal' has emerged against the most affluent backdrop, in principle, this knowledge exchange would allow VRR practitioners in volcanic settings with limited resources and expertise to subvert some of the challenges of forming a social response to volcanic risk.

- Most of this study is given to demonstrating that reality is more complex than the ideal outlined in the previous point. As VRR policy assemblages are composed of diverse components, there is also heterogeneity in the visions, strategies and actions of those who occupy the policy field at all levels. These differences in perspective complicate the pursuit of a single policy ideal. This includes macro-level assemblages such as the international 'expert community' of volcanology as well as local assemblages in individual volcanic settings. The most important goal is arguably ensuring that the local populations are continuously exposed to VRR knowledge (local and mobile) and actively participate in generating and using that knowledge to shape policy strategies that reflect their needs and concerns. This is complicated where vulnerable communities are marginalised (politically, academically, socially or economically) and must take into account these communities' own inherent heterogeneity.

- VRR policy assemblages continually evolve through changes in their constituent parts (both overt and 'understated'), and many of the timescales involved are unique to each part of the assemblage, making outcomes difficult to predict. Volcanic activity is a distinct problem for policymakers for precisely this reason. With many different components of the social-volcanic assemblages engaged in different processes at different rates, it can be very difficult to predict the confluences of hazard and vulnerability that lead to disaster and act accordingly. Volcanoes operate on timescales that are both completely independent of the societies that surround them and have no consistent, perceptible 'rhythm' for many field constituents (even volcanologists). Within this project's narratives, there are examples of volcanoes that have produced hazardous eruptions after being inactive for many human lifetimes (e.g. Nevado del Ruiz, Mount Lamington) and others that have existed in near-constant activity for a large part of living memory only to produce an eruption unexpected in scale, style or impacts (e.g. Merapi, Volcán de Colima). As well as impacting developments on the local policy field, the irregular recurrence of volcanic activity has played a crucial role in directing policy mobilities at the global level - creating topological links by attracting international political and scientific attention or by causing those on a local policy field to look beyond their own borders for assistance and expertise. In this sense, the field of policy mobilities should consider Earth processes as *agents* in processes of policy mobility, assemblage and mutation (volcanoes are arguably unique among these due to their geographical distribution and versatility as a source of hazard - moreover, every volcano itself is arguably unique).

- The social components of VRR assemblages are also complex and unpredictable. It is easier to determine the impact of 'fast policy' assembled during volcanic crises than changes in an assemblage (rapid or gradual) during periods of quiescence or low-intensity activity. However, subtle changes such as a replacement of personnel, or the breakdown of a working relationship can have far-reaching impacts - the Volcán de Colima case study illustrates how important positive and negative relationships between actors can be. As such, although this study aims to reflect reality as thoroughly as possible, it is likely that there will always be 'hidden' actors and processes.

- Processes of policy mobility will shape the future development of volcanic risk governance. Despite the complications detailed above, it is entirely feasible that those seeking to reduce human losses from volcanic activity can 'harness' these in their pursuit of more effective volcanic risk governance. Extending a greater awareness of the following considerations to as many field constituents as possible, across all levels of the global policy field, may constitute the start of progress towards this goal:
  (1) the general structure of the policy field
  (2) the nature of volcanic risk governance as assemblages of local and mobile knowledge, people, volcanoes and practices
  (3) the processes of mobility and topologies that carry policy between particular sites
  (4) the mutations that policy is likely to undergo over multiple timescales.

- The international community of volcanologists is uniquely placed to facilitate the circulation of this information due to its status as the most consistently active entity on the global policy field in the identification and circulation of VRR knowledge; the related fact that the pursuit of 'better' volcanic risk governance is a continual priority in applied volcanology, whereas many field constituents have priorities that eclipse volcanic risk during volcanic quiescence; and the fact that this assemblage encompasses most countries and active volcanoes. There are, however, challenges to overcome in terms of accommodating the existing heterogeneity within volcanology and convincing those who consider themselves purely researchers of Earth processes to acknowledge and embrace the political implications of their actions. This does not just include providing information to authorities or being drawn into decision making during volcanic crises, but the long-term production, dissemination and implementation of many forms of knowledge pertaining to VRR.

Further Work

- There is significant scope for future investigation stemming from this study. It seeks to examine a world in which there are almost 1,500 known active volcanoes, over a time span of more than 2,000 years, using a somewhat whistlestop tour of the worldwide history of volcanic risk governance and a closer examination of just five volcanoes and the societies around them. Although I have endeavoured to make it as extensive, factually accurate and representative of the phenomena it examines as possible, it is the work of one individual (albeit under experienced supervision) in a post-positivist field where perspective is crucial. Therefore, my background, prejudices and gaps in my knowledge will inevitably have played a role in shaping the narratives, the way in which they have been analysed and the conclusions drawn from them. In the case of my central case study at Volcán de Colima, a substantial amount of my data (and my inerpretations thereof) were accumulated through direct interaction with my surroundings and with people whom I could immediately ask to clarify doubts and consult regarding my analytical thoughts as and when they arose. My sources for the archival research that formed the bulk of Chapters 4 and 5 were considerably less interactive and therefore potentially subject to the flaws in my observational 'lens' to a greater degree. This is particularly the case when I did not have access to written policy documents and had to extrapolate conclusions about the nature of the volcanic risk governance systems based on the observable effects they had on the rest of the policy field (e.g. throughout the Merapi case study, or at Nevado del Ruiz post-1985). Were I able to undertake the study again, I should like to have had each case narrative examined by at least one individual from within the VRR policy assemblages at each volcano to provide me with first hand information, an additional viewpoint to my own and perhaps a direct insight into the content and development process of VRR policies that the narratives currently lack.

- The global history of policy mobilities in volcanic risk governance could almost certainly be expanded into a complete work (perhaps several volumes) expanding on the existing entries in the chronology and adding a multitude of others. Further case studies could be conducted in different volcanic settings (e.g. Europe, Africa, Oceania and different sites in Asia and the Americas) to build upon the outline of the global policy field established in this work. This study has predominantly focussed on andesitic stratovolcanoes; it would be interesting to expand to include other forms of volcano (e.g. shield volcanoes, large calderas and monogenetic volcanic fields) to understand how processes of policy mobility have influenced the governance of their unique hazards and how sites that share these may benefit from more specific connections and exchanges. An entire policy mobility investigation could be performed on the global assemblages of volcanic risk governance related to ash hazards and aviation. In summary there is great potential to further expand our understanding of the role of globalised knowledge exchange on volcanic risk governance, and to use this to reduce the likelihood of future volcanic disasters. We (quite literally) have mountains yet to learn!

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Appendix I
Glossary of Acronyms

B4K: Bridges for Kids (United States)
BNPB: National Disaster Management Agency, (Indonesia)

CENAPRED: National Centre for the Prevention of Disasters (México)
CHEC: Hydro-Electric Centre of Caldas (Colombia)
CIIV: Colima Intercambio e Investigación en Vulcanología (Universidad de Colima)
CONACYT: National Council for Science and Technology (México)
COE: Operative Emergency Centre (Colombia)
CoV: Cities on Volcanoes conference (IAVCEI)
CRC: Colombian Red Cross
CUEIV: University Centre for Research and Studies in Volcanology (Universidad de Colima, México)
CVGHM: Centre for Volcanology and Geological Hazard Mitigation (Indonesia)
CVO: Cascades Volcano Observatory (USA)

DFID: Department For International Development (United Kingdom)
DNR: Department of Natural Resources (Washington, USA)
DOH: Department of Health (Washington, USA)
DOT: Department of Transportation (Washington, USA)
DSHS: Department of Social and Health Services (Washington, USA)

DRR: Disaster Risk Reduction

EOC: Emergency Operations Centre (Washington, USA)
EU: European Union

FEMA: Federal Emergency Management Agency (USA)
FONDEN: Natural Disaster Fund (México)
FOPREDEN: Natural Disaster Prevention Fund (México)

GAR: Global Assessment Report (UNISDR)
GFDRR: Global Facility for Disaster Risk Reduction (World Bank)
GIR: Holistic Risk Management (México)
GVM: Global Volcano Model
GVP: Global Volcanism Program (Smithsonian Institution, USA)

HFA: Hyogo Framework for Action (UNISDR)
HTC: High-Tech Computer Corporation (Taiwan)
HVO: Hawai'i Volcano Observatory (USA)

IAVCEI: International Association of Volcanology and Chemistry of the Earth's Interior
ICAO: International Civil Aviation Organisation (UN)
IDNDR: International Decade for Natural Disaster Reduction (UN)
ICRC: International Committee of the Red Cross
ICSU: International Council of Scientific Unions
IFRC: International Federation of Red Cross and Red Crescent Societies

IG: Institute of Geophysics (UNAM)
IGO: International Governmental Organisation
INGEOMINAS: National Institute of Geology and Mining (Colombia, now SGC)
INGV: National Institute of Geophysics and Volcanology (Italy)
IPGP: Paris Institute of Earth Physics (France)
IRU: International Relief Union (League of Nations)
IVHHN: International Volcanic Health Hazard Network
IUGG: International Union of Geodesy and Geophysics

JVGR: Journal of Volcanology and Geothermal Research

LN: The League of Nations

MIA-VITA: Mitigate and Assess Risk from Volcanic Impact on Terrain and Human Activities (European Commission)
MRVHRP: Mount Rainier Volcanic Hazards Response Plan
MVO: Merapi Volcano Observatory (Indonesia)
MXN: Mexican Peso

NPS: National Park Service (USA)
NGO: Non-Governmental Organisation

OFDA: Office of Foreign Disaster Assistance (United States)

PAN: National Action Party (México)
PC: Civil Protection (México)
PCC: Civil Protection Colima (México)
PCDEM: Pierce County Department of Emergency Management (United States)
PCJ: Civil Protection Jalisco (México)
PCPALS: Pierce County Planning and Land Services (United States)
PCPWU: Pierce County Public Works and Utilities (United States)
PDC: Pyroclastic Density Current
PDI: Democratic Party (Indonesia)
PKI: Communist Party (Indonesia)
PMS: Policy Mobility Studies
PNPAD: National Plan for Prevention and Attention to Disasters (Colombia)
POP: Popocatépetl Operative Plan (México)
PPRR: Prevention, Preparedness, Response and Recovery
PRI: Institutional Revolutionary Party (México)
PRD: Party of the Democratic Revolution (México)
PVO: Pinatubo Volcano Observatory (Indonesia)

RESCO: Seismic Network of the State of Colima (México)

SFA: Sendai Framework for Action (UN)
SGC: Colombian Geological Service (Formerly **INGEOMINAS**)
SINAPROC: National System of Civil Protection (México)
SNPAD: National System of Prevention and Attention to Disasters (Colombia)
SNGRD: National System for Disaster Risk Management (Colombia)
STREVA: Strengthening Resilience in Volcanic Areas

TMVB: Trans-Mexican Volcanic Belt

UCol: University of Colima (México)
UdG: Universidad de Guadalajara (México)
UK: United Kingdom of Great Britain and Northern Ireland
UN: United Nations
UNAM: National Autonomous University (México)
UNDP: United Nations Development Programme
UNDRO: United Nations Office of the Disaster Relief Co-ordinator
UNESCO: United Nations Educational, Scientific and Cultural Organisation
UNFCCC: United Nations' Framework Convention on Climate Change
UNICEF: United Nations International Children's Emergency Fund
UNISDR: United Nations International Strategy for Disaster Reduction
UNISDR-STAG: United Nations International Strategy for Disaster Reduction - Scientific and Technical Advisory Group
USA: United States of America
USD: United States Dollar
USAID: United States Agency for International Development
USFS: United States Forest Service
USGS: United States Geological Survey

VAAC: Volcanic Ash Advisory Centre
VDAP: Volcano Disaster Assistance Programme (USGS)
VEI: Volcanic Explosivity Index
VHub: Collaborative volcano research and risk mitigation tool (GVM)
VPI: Volcano Population Index
VRR: Volcanic Risk Reduction
VSI: Volcanological Survey of Indonesia
VUELCO: Volcanic Unrest in Europe and Latin America Project

WEMD: Washington Emergency Management Division (United States)
WOVO: World Organisation of Volcano Observatories (IAVCEI)
WSP: Washington State Patrol (USA)

Appendix II
Interviewees

Universidad de Colima:

Raúl Arámbula-Mendoza: Current Director of the University Centre for Studies and Research in Volcanology (Seismology/Volcanology)

Alfredo Aranda-Fernández: Present Co-ordinator of Scientific Reseach/Chair of Scientific Advisory Committee (Physics)

Mauricio Bretón-Gonzalez: Faculty of Sciences (Volcanology)

Abel Cortés-Cortés: Faculty of Sciences (Geology/Volcanology)

Alicia Cuevas-Muñiz: Faculty of Sciences (Geography/Anthropology)

Tonatíuh Domínguez-Reyes: Faculty of Sciences (Seismology/Volcanology)

Juan Carlos Gavilanes Ruiz: Faculty of Sciences (Geography/Volcanology)

Carlos Navarro-Ochoa: Faculty of Sciences (Geology/Volcanology)

Ricardo Navarro-Polanco: Former Co-ordinator of Scientific Research/Chair of Scientific Advisory Committee (Biomedicine)

Raymundo Padilla-Lozoya: Faculty of Letters and Communication (Journalism/History/Anthropology)

Gabriel Reyes-Dávila: Former Director of the University Centre for Studies and Research in Volcanology (Seismology/Volcanology)

Dulce Vargas-Bracamontes: CONACYT - Based in Faculty of Sciences (Seismology/Volcanology)

Nick Varley: Faculty of Sciences (Geochemistry/Volcanology)

Proteccion Civil Colima:

Melchor Ursua-Quiroz: Director

Ricardo Ursua-Moctezuma: Operational Director

Proteccion Civil Jalisco:

Gabriel Reyes-Alfaro: Seismologist

Universidad Nacional Autonoma de México:

Anonymous: Instituto de Geofísica (Geology/Volcanology)

Ana-Lillian Martin del Pozzo: Instituto de Geofísica (Geology/Volcanology)

Lucia Capra: Instituto de Geofísica (Lahar Specialist)

Centro Nactional de Prevención de Desastres:

Carlos Valdés-González: Director

Ramon Espinasa Perena: Subdirector of Volcanology

Amiel Nieto-Torres: Volcanology

Lancaster University

Appendix III
Consent Form for Interviewees (English)

Project Title: Understanding Policy Mobilities in Volcanic Risk Reduction

Name of Researchers: Graeme Alexander William Sinclair

Email: g.sinclair1@lancaster.ac.uk

Please tick each box

1. I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time prior to publication of the data, without giving any reason. If I withdraw from the study, my data will be removed. ☐

3. I understand that any information given by me may be used in future reports, academic articles, publications or presentations by the researcher/s, but my personal information will not be included and I will not be identifiable unless I explicitly give my consent under item **4** of this document. ☐

4. **OPTIONAL:** I give consent for this study to make the information I provide in this interview identifiable to me (i.e. to use my name and my organisation's name in reports, articles and presentations). ☐

5. I understand that my name/my organisation's name will not appear in any reports, articles or presentation without my consent. ☐

6. I understand that any interviews will be audio-recorded and transcribed and that data will be protected on encrypted devices and kept secure. ☐

7. I understand that data will be kept according to Lancaster University, UK guidelines for 10 years after the end of the study and then destroyed. ☐

8. I agree to take part in the above study "Understanding Policy Mobilities in Volcanic Risk Reduction". ☐

____________________	____________	____________
Name of Participant	Date	Signature

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

Signature of Researcher/person taking the consent________________________ **Date** __________ Day/month/year

One copy of this form will be given to the participant and the original kept in the files of the researcher at Lancaster University, UK.

Lancaster University

Appendix IV
Participant Information Sheet for Interviewees (English)

I am a PhD student at Lancaster University, UK and I would like to invite you to take part in a study about the significance of knowledge exchange in the development of volcanic risk reduction policy.

Please take time to read the following information carefully before you decide whether or not you wish to take part.

What is this study about?

Volcanoes are found throughout the world and many governments have the responsibility of protecting their citizens from volcanic hazards. This study aims to understand the manner in which different jurisdictions employ diverse approaches to the reduction of risk from volcanoes within their territories and how the international exchange of information regarding volcanic risk influences governance decisions in individual locations.

Why have I been invited?

I have approached you because I believe your knowledge and experience may provide my study with valuable information about one or more of the following three aspects of volcanic risk policy:

- The international exchange of knowledge related to volcanoes and volcanic risk.
- The development and implementation of volcanic risk reduction in a specific location.
- The experience of volcanic risk reduction as a citizen in a volcanically active area.

What will I be asked to do if I take part?

If you decide to take part, this would involve an interview with me, at your convenience, in order to share your experiences of volcanic risk reduction. The interview will be recorded as an audio file and any additional notes will be made on my laptop. The interviews may last as long as you deem appropriate and may be conducted over multiple meetings if this is more suitable.

What are the possible benefits of taking part?

If you participate in this study, your insights will contribute to understanding the processes by which "best practices" are developed in the reduction of risk at individual volcanoes and on a global level. This information may be used to strengthen networks of knowledge transfer and improve volcanic risk reduction policies and practices in the future.

Do I have to take part?

No, your participation is completely voluntary and you are free to withdraw at any time prior to the publication of data, without justifying your decision.

What if I change my mind?

You are free to withdraw at any point prior to the publication of data from this study. If you wish to withdraw, I will extract any data that you contributed to the study and destroy it. "Data" means the information, ideas, opinions etc. that you and other participants have shared with me

What are the possible disadvantages of taking part?

It is unlikely that there will be any disadvantages to taking part. However, participation will require a brief investment of your time.

Will my data be identifiable?

After the interview, only I (the researcher) will have access to the data you share with me, prior to publication.

The consent form for this study will ask if you would prefer your participation to be identifiable or anonymous. If you would prefer to remain anonymous, then I will keep all information about you (e.g. you name and other information by which you may be identified) confidential, that is, I will not share it with others. I will anonymise audio recordings and hard copies of the data. This means that I will remove any personal information.

If you wish to be identifiable, but make a comment that you would prefer not to be attributed to yourself, then you may request the information relating to that particular comment to be anonymised.

You will be able to request for your data to be anonymised at any point prior to the publication of data from this study.

How will my data be stored?

Your data will be stored in encrypted files (no-one other than the researcher will be able to access them) on password-protected computers.

I will store hard copies of any data securely in a locked cabinet in my office.

In accordance with Lancaster University guidelines, I will keep the data securely for 10 years, after which it will be destroyed.

How will the information you have shared be used and what will happen to the results of the study?

I will use the data you have shared with me only in the following ways:

I will use it for academic purposes only, this will include my written PhD thesis and other academic publications (e.g. published journal articles). I may also present the results of my study at academic conferences.

When writing up findings from this study, I would like to reproduce some of the views and ideas you have shared with me. If you have specified that you would prefer to remain anonymous, I will use only anonymised quotes so that, although I will use your exact words, you cannot be identified in any of our publications.

Who has reviewed this project?

This project has been reviewed by the Ethics Committee of the Faculty of Science and Technology at Lancaster University.

What if I have questions or concerns?

If you have questions or are unhappy about any aspects of your participation in this study please contact me:

Graeme Alexander William Sinclair
Lancaster Environment Centre
Lancaster University
Lancaster
UK
LA1 4YQ
g.sinclair1@lancaster.ac.uk
+44 (0)7449342357

Supervisors:

Professor Nigel Clark
Lancaster Environment Centre
Lancaster University
Lancaster
UK
LA1 4YQ
n.clark2@lancaster.ac.uk

Dr. Jennie Gilbert
Lancaster Environment Centre
Lancaster University
Lancaster
UK
LA1 4YQ
j.s.gilbert@lancaster.ac.uk

If you have any concerns and complaints you wish to discuss with a person who is not directly involved then please contact:

Philip Barker

Lancaster Environment Centre
Lancaster University
Lancaster
UK
LA1 4YQ
p.barker@lancaster.ac.uk
+44 (0)1524 510230

Thank you for your participation in this project.

Appendix V
Sample Extracts of Interview Transcripts

Mauricio Bretón González, 09.05.2018
MBG: The system of volcanic risk reduction in the state of Colima functions in an intermittent way because the organ that does scientific research is the University of Colima. This implies that communication should exist between the University of Colima and the state unit of PCC which is charged with the issue of the management of risk. It's not completely satisfactory, because they don't take into consideration all the work that is being done to research the volcano to issue an alert or to make an integrated effort towards risk management.

To perform integrated risk management, you need various elements, and one of those is the element of prevention. The state PC system has been reactive, not preventative. Their system that has worked during recent years has reacted to what has happened at the volcano, they have not worked on prevention. To work on prevention, you need to work on the monitoring and this has not been a priority for PC in the state. Therefore, it's an element that should be under consideration, because when you want to work to manage risk, the first problem is that you don't even put all of the monitoring work that should be done on the table. What does that implicate? That you have only a partial vision of what is happening on the volcano. So, if you have a partial vision, your diagnosis is not a complete diagnosis and this can incur a risk for the neighbouring populations.

GS: Do you feel that there has been no direction since the start?

MBG: In 1998, there was a direction, a Scientific Advisory Committee existed that worked, not just with PCC, but with PCJ, the UdG, CENAPRED in México and UNAM. That is to say, there were various organisms involved in the volcano monitoring, the management of risk, and it was an integrated vision, everyone participated, everyone opined, everyone contributed information about the condition of the volcano. Moreover, a fund existed on the part of the state of Colima, to provide resources for volcano monitoring. Having volcano monitoring in the reduction of risk is essential, you can't have appropriate risk reduction if you don't have volcano monitoring, and to do volcano monitoring, you need money, monthly, in order to update equipment, emplace instruments, change batteries, make changes, sort things.

Nowadays the issue of instrumentation has improved a lot, they're much more efficient than they were 20 years ago. 20 years ago it was very different, but even so, the resources existed. Petrol for the vehicles, infrastructure... In this, therefore there was co-ordination, PC had an advisory body. This doesn't exist now. It disappeared years ago.

GS: How long did this situation last?

MBG: From November 1998 until 2007-2008, more or less. It had already disappeared by that time. It had a fund that helped us to maintain the monitoring, so in this sense, you had opinions of different experts, you had the opinion of the state systems of PC, of the municipal PC unions, and this allowed for a general panorama of what was happening. When you have all those actors and moreover, you have people from the civil population, this allows you to have a better communication, better diagnosis, better management of risk.

This was still part of a predominantly reactive system, however to already be invested in the matter of good surveillance, helped the preventative part. We gave talks to the populations about the activity, what could happen before, during, after. We worked on preventative issues that nowadays are ignored. They've lost that in Colima.

GS: And for what reason do you think that's the case?

MBG: The principal reason is a lack of interest. That is to say, the governments in turn... At some point we had a government that was more sensitive to the issues of volcanic risk and risk reduction and later the situation received less interest from all areas.

GS: Therefore, perhaps the reason that this committee was created in 1998 was because in that year the volcano had very visible activity and it was something new for the government of the state, and nowadays if there is activity at the volcano, the state has become accustomed, so there isn't so much interest?

MBG: It could have been the sensibility of the then-governor of the state, because he had been director of the University, so he knew the problem, a very visible problem. This meant that he had worked with people at the University and he was very sensitive to the issue.

Afterwards came changes, every 6 years, the governor changes and the next governor also showed interest. The then-President of México, Vicente Fox also showed interest in what was happening in the activity of the volcano, he came to Colima, he talked to us and offered us money to buy equipment. This was in 2005. After 2005, that was the last big purchase of equipment. Afterwards, there have been separate projects for each of the researchers who have played their part in putting instruments on the volcano, but the 'great instrumentation' happened in 2005.

GS: Then, the majority of the equipment that is on the volcano was bought in 2005?

MBG: Well, not now. Lots of this equipment has disappeared, but nonetheless a boost was given to the monitoring and the reduction of risk. When you install equipment, you need money to maintain it.

How has it been since then? Some researchers have worked on obtaining projects, sometimes related to the volcano, sometimes not, but related to risk reduction. We have obtained money with the intention of putting instruments into our line of research. In my case, I have focussed on visual monitoring, I have situated cameras with my own resources, allocated to my own projects. However, up to now there hasn't been a boost at national level. A short while ago they brought three seismic stations, but this isn't really a national effort towards risk reduction.

GS: So the interest at national level has dropped since the Presidency of Vicente Fox?

MBG: I think so. I think the national level, despite there having been many changes in what have been the issues of legislation, new laws, greater interest in hazardous phenomena, anthropogenic climate change, the creation of the National Risk Atlas... Really, in the other area, the area of instrumentation. México is not just Volcán de Colima, there are other active volcanoes and a need to understand them. There's a big population around those volcanoes, so there's a need to work and integrate this. I don't think this is being done.

GS: I've talked to various people who work in CENAPRED and UNAM and I have the impression that the co-ordination between the states at Popocatépetl is more integrated than here between Colima and Jalisco.

MBG: There is no co-ordination at Volcán de Colima. We could say that the exchange of information isn't high. There is some co-ordination but, for example, in Jalisco, they use an alert semaphore, in Colima we don't, so there are certain differences in the management of risk. There are occasions when the volcano is active, they evacuate one community and in others that are very close, they don't do anything. That is to say that each one is independent and this isn't bad, it's just that there is no integrated co-ordination.

In the case of México, it seems to me that the same thing happens. There are various states that are involved in the case of Popocatépetl, and it could be that some react in one way and others in another. However, Popocatépetl is not instrumented the way it should be either, its the highest-risk volcano in the country and the instruments are not the best. A volcano of this magnitude with the population that it has.

You can see a general co-ordination there on the part of CENAPRED, but this does not mean that the volcanic risk reduction is being done efficiently. It works, but I don't know if it will deal with stress the way they hope.

GS: Do they have to reestablish the Scientific Advisory Committee in order to improve the division between the two states?

MBG: Yes. I think it should be brought back with people and institutions from both states. The decision-making cannot be put in the hands of researchers, it has to stay in the hands of the authorities. For this, you need it so that everyone works with the same objective. This needs to be the volcano and the population living around the volcano. Not if I have more resources than you, or vice-versa, I have more instruments than you, etc. That is to say, that we work in a co-ordinated manner. That's a word that the politicians like a lot. If we work in a really co-ordinated way, then we will have lots of elements to achieve a better diagnosis/prognosis and much more efficient early warning that would benefit the management of risk.

GS: Yes, and with that objective in mind, some people have talked to me about the possibility of a National Volcanological Service, do you think this could provide a solution?

MBG: It could provide a solution, but it's a centralised vision, no? From the centre, we're going to watch everything that happens in the country. I think a Volcanological Service would be good in a certain sense, if they always respect and consider all the areas of research that are being conducted in the country, universities, research centres, municipal PC. If you achieve that, then great, but the centralist vision is that the centre is going to control everything... Who is going to work in this service? Those of us who already have instrumentation, who've been working for years? We're going to give it to the Service in exchange for what? What is your responsibility within this service? What are the conditions? If you become part of a Service, what is your status? Are you an employee of the Government, are you an employee of the University? What is your scope? What are your responsibilities?

You know the case of l'Aquila in Italy. At what point could we come to? Federal functionaries have certain obligations. This should remain very clear, no? Who wants to form part of a National Volcanological Service.

GS: So, in place of this idea, do you believe there is another solution to improve the situation?

MBG: I believe that, simply, they need to establish conditions between the governments, that is to say, who wants to work together, the conditions they want to work under and they can share information with the central system, in this instance CENAPRED can take the information and distribute it at national level but under an integrated scheme of co-operation of universities, research centres, municipal and state PC offices.

It needs resources, it needs money. In large part, the problem is money because everything exists, there are research centres, there is monitoring, there are researchers, there are people from PC, there are voluntary groups, there is everything. The problem is the necessary co-ordination and the money for it to work.

GS: But they have no problems accumulating money during periods of high activity?

MBG: Sure, because here they always make a promise, if the volcano produces activity, there are always promises, who's going to come, what they're going to bring, what they're going to do... The activity ends and that all ends. It's a problem with a timescale, no? One day we're national-level news, everyone comes, civil servants, big meetings, people with lots of employees, lots of bureaucracy and politics, but this doesn't solve the problem at its root. The problem at its root is an integrated management of risk, it will be resolved little by little. We did not have a risk atlas, today we do.

It is not possible that in the meetings about the state of the volcanic activity that those who are doing the monitoring are not present, haven't even been invited. So there's a political issue as well, they're sat there, 30 people with no idea what a volcano even is. That's grave. They were going to choose one, but this is not how you do integrated management. In the old Scientific Committee, there were meetings where there were discussions about what we found in each of the areas that were monitored and at the end we tried to arrive at a consensus and from this, to make a recommendation. Made by the Committee, we would recommend to PC and they would take a decision.

It's one of the parts required for it to function. It's not the only one, but it's one of them.

Lucia Capra, 27.04.2018
LC: I've been working at Colima for ten years, on volcanic hazards. Before that I worked on basic volcano stratigraphy for the last 10-20 years. I think in México, hazard and risk management has not been developed from a single institution, but for each volcano there are several groups that are contributing to a single aspect. In my case, for lahars, warning system and monitoring system, I had to provide all the funds, all the station and there was an agreement, actually, it was my decision, to give all the data to PC. I need the data from real time monitoring to study the phenomenon, but PC need the data to make warnings or mitigate damages.

It was my individual project. It was not PC or CENAPRED asking me to do this. I wanted to study lahars on active volcanoes in México, so I went to build up the stations. I asked "Do you want the data?" "Oh yes", also because they didn't have the money to do this. The government isn't giving CENAPRED much funding to set up a monitoring system, so I think they're trying with different groups around México to obtain all the data they can without spending much money. They provide you the capacity to build up a transmission system, if you buy the station, they can build it for you but they don't have much funding and they get specific funds for a specific project.

I think a weak part is that PC doesn't have enough funds to be autonomous and decide "we need a monitoring system at this volcano to do a better hazard assessment." They need funds from universities and from people who can submit a project to CONACYT to build up instrumentation. I now have three projects from CONACYT for lahar monitoring at Colima, Popocatépetl and maybe Tacaná. All the data are free to see for RESCO, CENAPRED and other institutions if they want to.

Now, locally, there is another problem because, for example, last year, I had problems with the transmission of my station in Montegrande to here, so I went to Cuauhtémoc to see if they have a tall tower. They were very happy, because they don't connect very well with PC of the state. Even inside the same state there are problems between the community and the central organisation. It was quite surprising, but not very much, maybe because Cuauhtémoc is from a different political orientation to the state government. They cannot be on top of the political state and this is problematic.

One of the main problems about the monitoring system is the funds to build the system. Presently I've been working on Popocatépetl. Last year there was a very strong earthquake in CDMX but also on the volcano, because of the earthquake, a lot of landslides occurred then rain remobilised a lot of material and lots of lahars formed along channels that before the earthquake were not active, so people were very scared about it because they thought it was lava flowing down from the volcano because of the earthquake.

They felt they didn't get any answer or any information about the phenomena from CENAPRED. They told me that up to 5-7 years ago CENAPRED was very active in those small villages, they would periodically give some information, some data, but now they feel like they are quite alone. So I compromised with them, in three weeks I will go there to explain what happened during the earthquake, what happened three weeks after, what will be happening now in the new rainy season. But, I'm a researcher from an institution, I'm not responsible for working with the communities. I'm mainly responsible for studying the phenomena and making maps to let the people who can better do this job translate information to the community. For me, it's not easy because hazard and risk are quite different.

I called CENAPRED and told them about the situation, I said to them "They need someone there to explain what's happening." I'm happy to show photos and give a talk, but I would like your support. They told me they could give me the sound system to help me do my talk, instead of giving me a person. I can't go to Popocatépetl every three months to give a talk, it's not my job. It's not in my academic profile and it's difficult for me. If I can, I'll do it because I like to be with people, but people from local PC told me they'd like to make a group and go to CENAPRED to get some information, to find out what to do in case of a lahar. They're a small organisation inside the village. So, they were self-organising to respond to a new crisis, but it was a decision from the community, not from CENAPRED. But no-one was interested to do it, only one, so right now I saw people who were very scared about what could happen and if it could happen again because the earthquake was very strong and the same day the volcano produced a small eruption. Three weeks after, a very muddy lahar came down and they thought it was lava. When a dog crossed the river and was still alive, they relaxed as they realised it's just water and mud. After that event, no-one was there from the institution to explain what to do in case of this event.

I know it's difficult because there are more than 100 communities exposed to this, but I don't see systematic work on that.

GS: With your monitoring, do they consult you about the alert systems they use?

LC: We are working on a warning system. We already have a lot of years of data from Colima, and I think that we already have the new sensors that we just got. We already have the algorithm, so we can try this here with the new rain station. The alert would be transmitted only to PC, not to the people living there, because they should know what to do, not just turn on a light and that's all.

Now we want to test if the warning system is detecting real events and then work out with PC how to set up the warning system inside the village.

GS: So are you looking to implement the same warning system for PCC and PCJ?

LC: I'm just working at the moment with people from Colima. This is another problem, I think, they are not very co-ordinated.

And the same for Popo... Well, actually I think it's quite different because CENAPRED is really -on- Popocatépetl, so although there are four states...

GS: This is the impression I've got from my interviews so far is that planning for VRR at Popo is much more centralised. Because Colima is in a bubble, the institutional attitudes and approaches are probably more divided between these two states than they are across the four at Popocatépetl.

LC: Yes, sure, exactly. But also because all of the people working on Popo are at UNAM, there are very few people from Puebla university working on the volcano, so it's much easier. I know that at UdG and at Colima, there are people working that don't share data, that don't want to share funds and so it's much more complicated, even with the investigation of the phenomenon.

GS: Do you think there's a better relationship between the scientists who work at UNAM with those who work at Colima in comparison to Jalisco?

LC: Much better with Colima. I have tried to do something with Jalisco but they asked me only "how are you planning the monitoring station?" They just want to know how to do it rather than letting me build up my monitoring station in Barranca La Arena and we can share data. They were much more interested in, not stealing, but understanding what I was doing so they could duplicate it. They know I have a station in La Lumbre, which is the limit between Colima and Jalisco and I know they wanted to put another station there... Why? You can have the data, we can share...

No, here in Colima, I always had support from RESCO without any problems, now we are improving a lot of monitoring for lahars, we are sharing data, we are sharing data with CENAPRED and I don't have any problems. For me, it could even be enough to put the sensors there and go three months after to get the data and work on it but because I think it's important to have data in real time I'm buying everything to transmit the data here.

GS: So RESCO receive the data from your sensors in real time as well?

LC: Yes.

GS: So that means that, although you're in charge of the project, if there's a crisis, they get the data straight away?

LC: No, the data are arriving here directly, and that means if there's something nice in it that I want to study, they can give me it and I can work on it, but I don't need the data in real time. It's nice for me to see that it's raining and I can connect to the camera and see what's happening, but all the data are arriving here so they can use it during crises.

Carlos Valdés González, 24.04.2018
CV: ...We have an emergency committee related to the volcano. We have different committees, but the one that started many years ago was the Subcomité Cientifico Asesor Volcán Popocatépetl, a scientific advisory board, composed of most of the volcanologists of the IG and some other authorities.

GS: So, does that committee still exist?

CV: Yes, it does.

GS: So, that's a different situation for the advisory Committee for Volcán de Colima?

CV: Yes, Colima is a more complicated situation *laughs*. Here, the Committee started many years ago. It started probably a few weeks or months after the start of the activity of the volcano and it is very interesting. We, at CENAPRED share a lot of the information that we have, we also call them when we feel that something is changing and we show them why we've asked them for a meeting and if there's a sudden change of activity, several parameters, then we show them that and people start discussing what they think the problem is and what the outcome of that will be. Based on that deliberation, it's not easy, I will tell you that, those meetings are very interesting, we need to convince people. I would like in this moment to acknowledge Servando de la Cruz, he's probably the leader, the way he thinks, the way he takes the information from everyone, the way he blends that and gets a reasonable decision of what to do is very important. From there, there is a recommendation that goes to the authorities, sometimes it's "should we change the alert level of the volcano" in critical situations, if towns need to be evacuated, what towns and what position. These are recommendations, they are not responsible for the decision but the authorities in PC, they will be the ones that will decide to take the recommendations, and then they are responsible for that.

It is very important, and you have the backgrounds of all these people. Sometimes we have called people from other countries and you've had people from the VDAP programme, from the USGS to give an evaluation and to see if the way we're doing things is okay, once you realise the population that is exposed to major activity of the volcano. So, the committee has been critical and very important. I believe that there have probably been more than 60 meetings with the committee, sometimes I remember we have been called -now I'm the one who has to call them, but before- on a Saturday at 10 o'clock at night and we have lasted deliberating and writing some conclusions until 4 o'clock in the morning. That is very appreciated, because of the time of the people there, and we try to focus them, not only on the scientific part but from their point of view, how to land that information so that things are done in a better way, and then, at least for the top level authorities, it's easier to convince them when you tell them "There is this committee and here is the recommendation", they are not going to say "I don't believe it" or "I don't agree with them and I will take another decision".

After that committee started, other committees here formed, one for hydrometeorological problems, one for geological problems, mainly dealing with earthquakes and subsidence. There is one for chemistry, or chemical problems and one for social unrest.

GS: So, did that happen when the PC law changed in 2012-2013, did those other committees form?

CV: No, they started before. The first one was Popocatépetl and the outcome of the committee was so good that the other committees formed and then, the one that, for instance, has to do with the chemical risk, it meets every month. We are in the 220th meeting. It is very impressive. But all they do is recommendations, their only function is to provide a recommendation and the committees will tell you who that recommendation should be pushed to and we, as part of the federal government, we go and tell the Ministry of Transport for instance and say "there is this recommendation" and try to push, they are not obliged to.