INSTITUTIONAL AND SOCIAL RESPONSES TO HAZARDS RELATED TO KARTHALA VOLCANO, COMOROS

PART I: Analysis of the May 2006 eruptive crisis

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Abstract

This paper aims at understanding the failure of the crisis management system during the 2006 eruption of Karthala volcano on Grande Comore Island. Since 2005, the eruptive activity of Karthala volcano had increased, with higher intensity and frequency. These changes should have led Grande Comore to be better prepared for confronting a volcanic threat. But the following analysis demonstrates that the country remained unprepared to face even a minor eruptive event. The weaknesses that led to poor crisis management are detailed and analysed and suggestions for improvement are made.

Keywords

Crisis management, Karthala volcano, Grande Comore Island

Introduction

The Comoros archipelago, located at the northern end of the Mozambique Channel, midway between Madagascar and the East African coast (11-13°S, 43-46°E), comprises (from South East to North West) four volcanic islands: Mayotte (Maore in Comorian), Anjouan (Nzwani), Moheli (Mwali) and Grande Comore (Ngazidja) (Figure 1). Grande Comore is the youngest, the largest (65 km N-S, 25 km E-W, 1024 km²) and highest island (2361 m above sea level). The island is formed by two basaltic shield volcanoes. Northern La Grille volcano has erupted several times in the last few thousand years, probably with a hundred- or thousand-year frequency, and a new eruption cannot be ruled out, considering the relatively recent age of previous eruptions (1300±65, 740±130, and 625±130 years before present) but the probability is deemed to be very low (Bachèlery and Coudray, 1993). Therefore, it is not taken into account for this study. Karthala volcano, which forms the southern two-thirds of Grande Comore, is now the only active volcano in the archipelago and represents a continuing threat for the Grand Comorian population since the majority of the 320,000 inhabitants (PIROI, 2005) is exposed to volcanic hazards. While Grande Comore has only a few settlements (Figure 1), meaning that absolute material losses would be limited, the ratio of loss to national wealth is likely to be very high, even if only one location was affected by the volcano. That is the typical "proportional vulnerability" which is frequently observed as being an island characteristic (Lewis, 2009).

Several authors have researched Karthala's volcanology (Lacroix, 1920, 1938; Strong and Jacquot, 1970; Krafft, 1982, 1983; Bachèlery and Coudray, 1993; Bachèlery et al, 1995; Desgrolard, 1996; Lénat et al, 1998; Nassor, 2001; Savin, 2001; Savin et al, 2001, 2005). In contrast, issues of crisis management raised by a vulnerability census have only been superficially undertaken by Nassor (2001) and disaster risk reduction work is almost non-existent. Violent phreatomagmatic eruptions (generating gas and steam) in April and November 2005 (as precursors to two magmatic eruptions in May 2006 and January 2007) led to a renewed scientific interest in the volcano's eruptive history and mechanisms, as well as in volcanic risk assessment and crisis management in the Comoros in general.

This paper and its vulnerability counterpart (Morin and Lavigne, this issue) are perhaps the first published works dealing with volcanic risk and crisis management in Grande Comore Island. Interest in vulnerability to - and people's behaviour in facing - volcanic hazards has been evolving in recent decades (Chester, 1993). Gaillard and Dibben (2008) and Gaillard (2008) provide a thorough synthesis of the two principal paradigms that have been developed with regard to this topic. The first paradigm expounds that people's behaviour depends on how they perceive rare and extreme environmental phenomena and the associated risk (White, 1945; Kates, 1971; Burton et al, 1993). White (1945), focusing on floods, assesses that people with a high risk perception are the best prepared for extreme events. Risk perception is thus essential for scientists trying to understand people's behaviour in facing volcanic hazards (see detailed references in Gaillard and Dibben, 2008). The second paradigm considers that people's behaviour in the face of natural hazards is constrained by social, economic and political forces beyond the individual's control (O'Keefe et al, 1976; Hewitt, 1983; Dibben, 1999; Wisner et al, 2004).

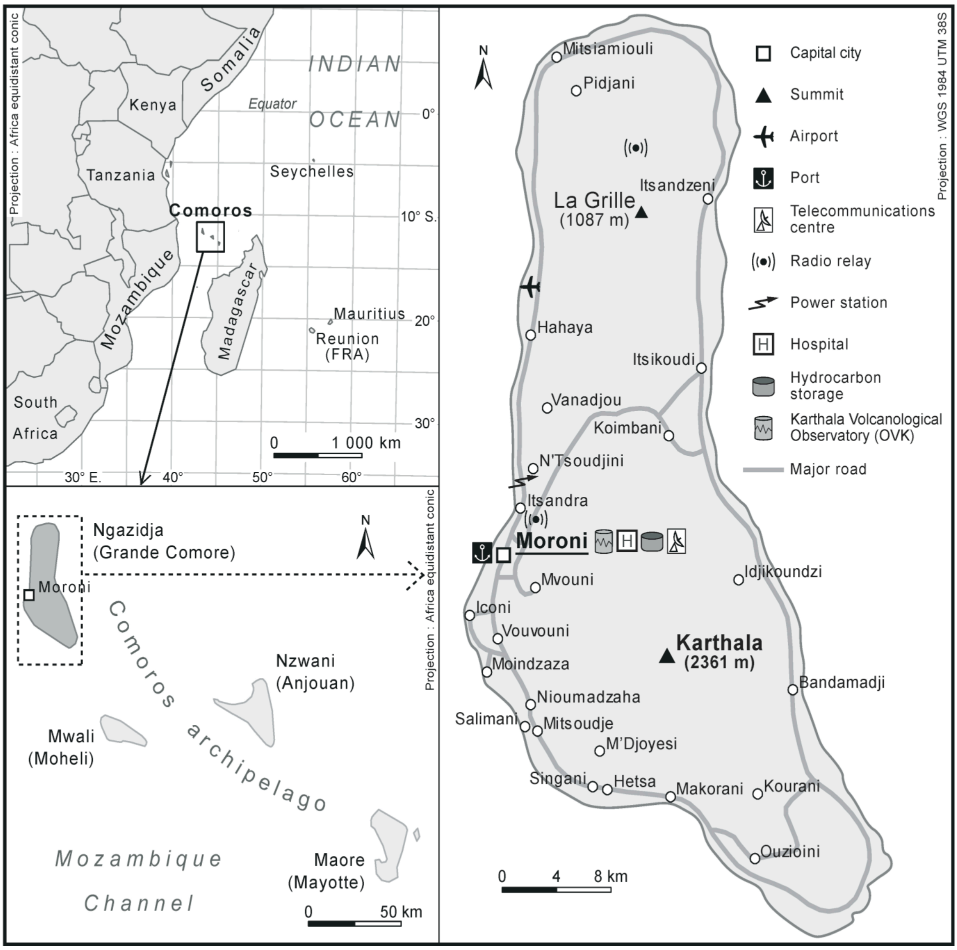

Figure 1 - Location of the Comoros archipelago (relative to the East African coast), the archipelago and Grande Comore Island (and its main places and features) (L. Vacher and J. Morin, 2008)

Chester (1993) offers a classification of responses to historical volcanic eruptions (based on the physical characteristics of the eruptions and the development level attained by several countries) that categorises the responses to Karthala volcanic eruptions in the 1970s as 'underdeveloped'. The authorities' level of preparedness was still low in 2005 when two explosive eruptions occurred. For the first time in living memory, the Comorian population experienced ash fallouts causing daily disruption (the 1991 eruption's impacts were limited to the vicinity of the caldera). These major eruptions should have led to improved preparedness. Did it really change? Is Comoros ready to face volcanic hazards linked with Karthala today? To answer such questions, this research drew on two one-month field campaigns in May 2006 and in April-May 2007. Data was collected through surveys, interviews, and informal discussions with the population and key informants, including local authorities, policymakers, effective or potential risk managers, and media representatives. In addition, the authors were directly involved in the May 2006 crisis management.

In the first section of this paper, we describe the geological island setting and the resulting volcanic hazards of Karthala volcano to underline how Grande Comore Island is entirely exposed to volcanic hazards. In the second section, we review the recent eruptions. In the third section, we document and analyse the management of the 2006 volcanic crisis. The fourth section is dedicated to the population's behaviour during the 2006 eruption.

I. Geological settings and resulting volcanic hazards

Karthala's main structural features consist of two opposite rift zones diverging from a polylobate summit caldera generated by successive collapses during prehistoric eruptive activity (Lacroix, 1920; Strong and Jacquot, 1970; Pavlovsky and de Saint-Ours, 1953). The caldera, 3.5 km N-S and 2.8 km E-W, is occupied in its centre by the Choungou Chahale ('old crater'), a 1.4 km x 0.8 km crater 290 m deep. The 21st Century eruptions took place in Choungou Chahale, except the most recent one in January 2007, which occurred in Choungou Chagnoumeni ('new crater'), a 200 m deep pit-crater in the northern part of the caldera that filled in entirely during this event.

The vertical walls of the caldera are about 100 m high, except on Itsandra Door, an indentation creating an opening to the North, which is a potential escape route for lava flows generated inside the caldera (Strong and Jacquot, 1970; Figure 2's insert). Many young cones along the rift-zones (N-S oriented in the north and NW-SE in the south) testify to intense past activity. Most historic eruptions took place along the rift zones (Savin, 2001). Volcanic risk studies need, among other priorities, to factor in those rift zones which provide opportunity for fissures to open and for lava to flow into occupied areas. For example, in 1859, a fissure opened more than 25 km from the summit.

Most of the eruptions during the last two centuries were magmatic. They were characterised by eruptive fissures opening, lava flows sometimes flooding through tunnels and spatter cones building. This kind of eruption can take place along rift zones (as in 1857, 1858, 1859, 1860, 1862, 1872, 1882 and 1904); within the caldera (1948, 1952, 1965, 1972); or at low elevations far from rifts and the caldera, as in 1977 (Pavlovsky and Saint-Ours, 1953; Bachèlery and Coudray, 1993). The 1977 eruption provided the most destructive of Karthala's historic lava flows. A vent opened on the south flank at 360 metres above sea level, only 1 km from N'Djoyesi village (Krafft, 1983). Approximately 280 homes were destroyed in Singani and 13 in Hetsa, while 4000 people were evacuated. That showed that eruptions occurring at low elevation near inhabited places can occur. Yet whatever their starting point is, lava flows can reach inhabited areas and the coastline (Figure 2). In 1858, a lava flow travelled 13 km from the uphill north rift-zone to the western coast, going close to the capital Moroni. Karthala's eruptive style is mostly effusive; however, phreatic explosions (involving rapidly heated groundwater) also occur (eg 1918, 1948, 1952, 1991, and maybe 1904: Krafft, 1983) as well as phreatomagmatic explosions (involving rapidly heated groundwater and magma) (eg the two events in 2005). These eruptions are generally linked to the presence of a water lake in Choungou Chahale. Hydromagmatic eruptions (involving surface water) may also occur along coastal areas, resulting from magmatic emission in the shallow seawater. They create hyaloclastites (cones) as in Iconi and Moindzaza (Bachèlery and Coudray, 1993).

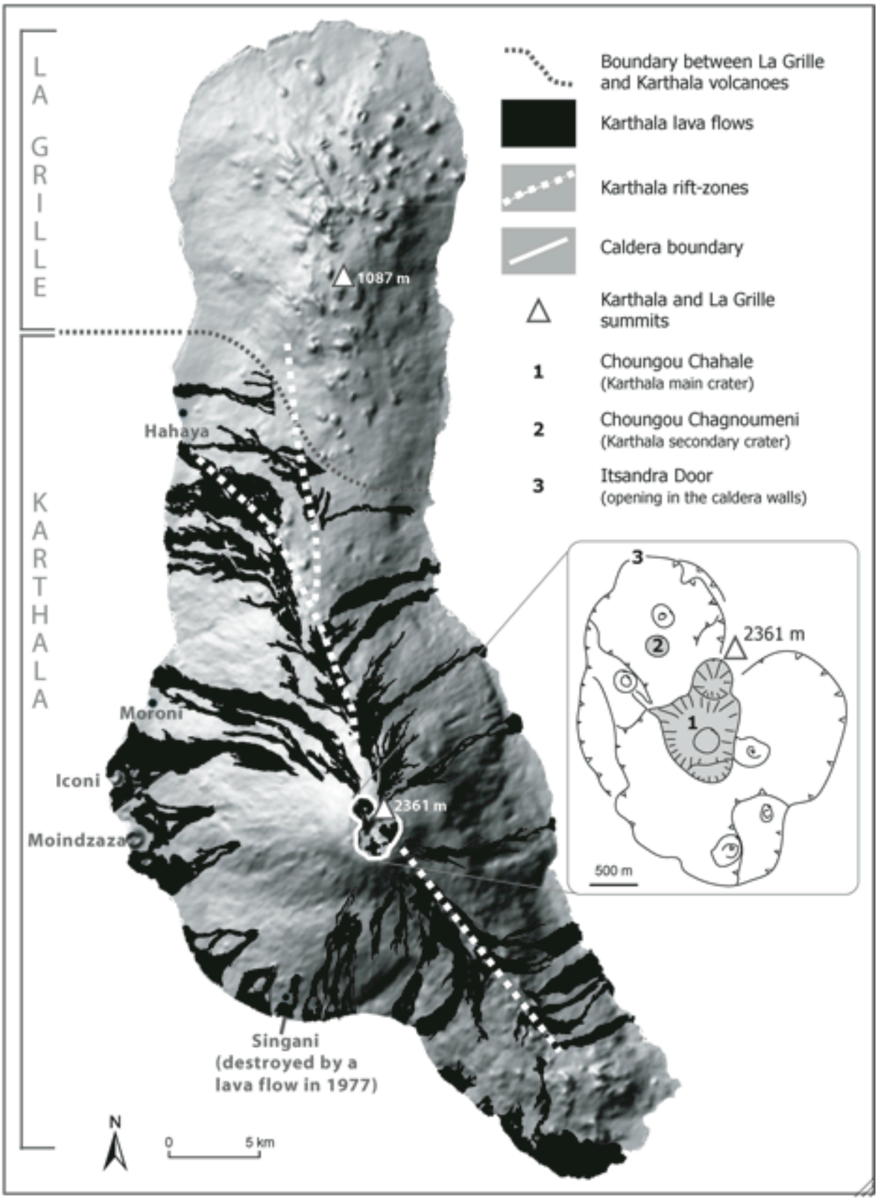

Figure 2 - Main geological settings of Grande Comore Island and Karthala caldera (after Bachèlery et al, 1993)

Phreatic and phreatomagmatic eruptions represent the greatest volcanic hazard for a shield volcano. Consecutive aerial fallouts can affect large areas or even the whole island. Fallout deposits can then be mobilised by rain, creating mudflows called lahars, as occurred during the 2005 Karthala eruptions along the island's southeast coast. Paroxysmal eruptions, which took place in 4695, 3960 and 2390 years before present (Nassor, 2001), as well as large debris flows potentially resulting in a tsunami, cannot be ignored, although their occurrence probability is low. Finally, irrespective of effusive or explosive activity, gas volatiles and seismicity represent an additional threat. In 1903, gas was reported to have killed 17 people on the south east rift zone (Bachèlery and Coudray, 1993). In 1991, mild earthquakes in the south part of the island (measuring 3.4 on the Richter scale) led 1000 people to evacuate to Moroni. In 2007, seismic activity collapsed one building and damaged others in Moroni.

II. 21st Century eruptions

Karthala has erupted at least 25 times since 1808, and perhaps up to 38 times; that is, its eruption recurrence interval is 5.3 to 8.0 years on average (Table 1). This frequency has recently been exceeded with a succession of four eruptions occurring at approximately half-year intervals: April 2005, November 2005, May 2006 and January 2007. Contrary to the 1991 phreatic eruption, during which ash fallouts were confined around the summit area, the highly dynamic eruptions of 2005 caused ash fallouts over the majority of the island. In April, ash fallouts accompanied by a strong sulphur smell began on Karthala's eastern flank, leading frightened inhabitants to flee from their villages. In addition, 10,000 more people were evacuated by the local authorities. Ash then began to fall on the western and northern areas, including Moroni and Hahaya international airport. According to OCHA (2005), 40,000 people were affected by this event. In November, the same scenario was repeated. Three quarters of Grande Comore was covered by ash fallouts, affecting 244,520 people in 76 villages (PIROI, 2005), including Moroni, where it became difficult to breath without a mask. About 2000 people fled from Bambao western villages to escape to perceived safer areas in the north. Volcanic ash contaminated water supplies, raising concerns about the health of people and livestock, along with the effects on agriculture. This eruption placed Comoros as sixth in country rankings of total number of people affected by a volcano since 1900 (Center for Research on Epidemiology of Disasters, 2006).

As a consequence of the 2005 eruptions, a new hazard was born on the island. The ash deposits effectively waterproofed the soil, so rainfall cannot percolate any more and runoffs carry the ash, forming lahars. Lahars tend to occur after each period of rainfall, even those of moderate intensity. Lahars are more frequent on the western flank of Karthala, where the total precipitation is higher and the rain showers are stronger than on the eastern side (2695 mm per year in Moroni compared to 6000 to 9000 mm per year near the Karthala summit: Savin, 2001). Slopes on average have a 20% gradient (Strong and Jacquot, 1970). Lahars now play an important role in the daily life and culture of Grande Comore's inhabitants, as detailed in Morin and Lavigne (this issue).

The May 2006 magmatic eruption was confined in Choungou Chahale without any threat to the population; however, memories of the 2005 eruptions caused anxiety and there were some tremors, especially on the western side of the island. The January 2007 magmatic eruption was also confined to Choungou Chagnoumeni but was preceded, accompanied and followed by seismic swarms that damaged buildings in Moroni. Frightened residents slept outside, fearing collapse of their homes.

Year	Date	Location	Erupt. type	Lava →sea	Area	Vol.	Seism.	Damage
2007	13 Jan.	Chagn	M Sum	no	0.03	0.1	yes	yes, a building collapsed after earthquake
2006	28 May -1st June	Chaha	M Sum	no	0.2	18	yes	-
2005	25 Nov - 8 Dec	Chaha	PM & M Sum	no	> 1/2 of the island	> 50	yes	yes
2005	16 - 20 April	Chaha	PM & M Sum	no	2/3 of the island	> 50	yes	yes
1991	11 July	Chaha	P Sum	/	-	no magma	yes	-
1977	5 - 10 April	SW fl.	M Ecc	yes	1.8	10.8	yes	yes, Singani and Hetsa villages ruined
1972	8 Sept - 5 Oct	cald.	M Sum	no	2.5	12	-	-
1965	12 July	cald. & Chagn	M Sum	no	0.05	0.15	-	-
1959	1 June	Chaha	M Sum	no	-	-	-	-
1952	10 - 14 Feb	Chaha	M Sum	no	-	-	-	-
1948	13 - 16 June	Chaha	M Sum & PM	no	16	6	yes	yes
1948	22 April - 4 May	Chagn	M Sum	no	-	-	-	-
1941	-	cald.	M	no	-	-	-	-
1926-1929	several times	cald.	M	no	-	-	-	-
1918	25 - 26 August	Chaha	P	/	25	no magma	yes	yes
1918	11 - 13 August	NE fl.	M fl.	no	2.7	10	yes	-
1910	-	N r-z	-	-	-	-	-	-
1904	25 Feb - April	N r-z	M fl.	no	11	44	yes	yes 1 killed
1903	-	SE r-z	Gas d.	/	-	-	-	yes 17killed
1883	March 1883-1884	SE r-z	M fl.	yes	-	-	-	yes, one village ruined

1880	-	SE r-z	M fl.	yes	2.4	10	yes	yes
1876	-	SE r-z	M fl.	yes	4	17	-	yes, one village ruined north of Foumbouni
1872	-	N r-z	M fl.	yes	1.6	7.2	-	-
1865	-	-	M	-	-	-	yes	-
1862	-	SE r-z	M fl.	yes	-	-	-	-
1860	Dec.	SE r-z	M fl.	yes	5.5	30	-	yes
1859	-	N r-z	M fl.	yes	3.9	20	-	-
1858	-	cald. & N r-z	M fl.	yes	12.5	63	yes	-
1857	-	SE r-z & cald.	M fl.	yes	10	56	-	yes
1855	June or July	SE r-z	M fl.	yes	-	-	-	yes, 30 homes ruined
1850	-	WSW fl.	M fl.	yes	-	-	-	-
1848	-	SE fl.	M fl.	yes	3	16	-	-
1833	-	cald.	M	-	-	-	-	-
1830	-	-	M	-	-	-	-	-
1828	May	-	M	-	-	-	-	-
1821	-	-	M	-	-	-	-	-
1814	-	-	M	-	-	-	-	-
1808	-	-	M	-	-	-	yes	-

Columns' titles:

Erupt. Type = type of eruption; Lava →sea = lava flow reaching the sea; Area = area covered (10^6 m^2); Vol. = Volume estimated (10^6 m^3); Seism. = Seismicity experienced

Location » column: Chagn = Choungou Chagnoumeni; Chaha = Choungou Chahale; cald. = caldera; r-z = rift-zone; fl. = flank;

Erupt. Type » column: M = magmatic; PM = phreatomagmatic; P = phreatic; Sum = summit; Ecc = eccentric; fl. = flank; d. = discharge.

Table 1 - Karthala eruptive activity since 1808. After Bachèlery et al (1993) and Krafft (1983)

The consequences of the last four eruptions have largely affected the population living on the southern two thirds of Grande Comore. As the current activities related to Karthala testify, the awareness that the volcano could be a major threat is shared by everyone: the population, Comorian authorities and international organisations. COSEP

(Operational Centre for Rescue and Civil Protection) has been put in place by Comorian authorities, the French embassy increased the Karthala Volcanological Observatory's (OVK) resources, the United Nations created an Intervention Plan in case of volcanic hazards, and the Red Cross in association with the Red Crescent created awareness and education campaigns for the population.

III. The May 2006 eruption crisis and its management

When the 1977 eruption razed Singani, authorities did not have any structure for emergencies and appealed to national solidarity to help evacuated villagers. After a false volcanic alarm in 2003, Grande Comore was equipped with a National Plan for the Preparedness and Response to Emergencies (PNPRU, Union des Comores, 2004), which describes the crisis management modalities. Nevertheless, the media and the population criticised the management of the 2005 eruptions, with many feeling abandoned by the State and powerless in facing eruptions. The question "Are Comorian authorities able to manage a serious volcanic event?" was prominent.

In contrast to the 2005 eruptions, the May 2006 eruption should have remained an eruptive crisis in only its scientific meaning, rather than in a disaster risk reduction or cultural meaning, because the hazard was confined inside the caldera and did not present a threat to people or infrastructure at any time. An emergency management crisis nevertheless appeared as soon as the volcano erupted, with some panicked reactions and major difficulties in applying the PNPRU.

We choose to further examine the May 2006 eruption for three main reasons. First, our direct involvement in the crisis management of this event allowed us to collect details about the crisis development to which we did not have access for the previous eruptions. Second, the May 2006 eruption was a non-threatening magmatic summit eruption, so it is interesting to understand from a cultural perspective how this kind of eruption can generate a crisis for the population. Third, the two 2005 eruptions leading to disaster-related challenges should have provided enough political and cultural impetus to have led to strong preparedness that would have avoided future crises.

When Karthala erupted on the evening of 28 May 2006, two of the three summit seismic stations were inoperative due to technical problems and lack of repair, so that - without being able to triangulate seismic activity or to corroborate data streams - it was almost impossible for OVK to build up a picture of precursors or of the volcanic activity, to issue advisories or warnings before the eruption, or to deliver any detailed information after it was clear that an eruption was in progress. The uncertainty about the exact location and type of the eruption was one of the focal points for the May 2006 crisis. What would have happened if the volcanism had been a vent opening near an inhabited area? OVK would have been incapable of furnishing the elements needed by Comorian authorities to make decisions that would have ensured the population's safety.

The considerable light cast upon Karthala (from the lava) was visible from Moroni and its surroundings. Within a few minutes, dozens of frightened people convened on OVK to gather information on what was happening, while mosques and stadiums were invaded by thousands of people praying together. Most of them had taken the eruptive plume of smoke, coloured red from the lava lake below it, to be a huge lava fountain hundreds of meters high. This misinterpretation fuelled the fear in the eruption's first hours. All night long, dozens of members of the government, national and international institutions, media and the people came to OVK seeking information. The situation was complicated by the volcano erupting during the transition between the old and newly elected national governments of the Union of Comoros. Ministers in the previous government had not yet completely relinquished their duties while the incoming ministers had not yet been completely established in their offices. That doubled the number of government members who came to OVK to inquire about the situation. If PNPRU procedures had been followed, OVK would have had a single mediator with the Comorian authorities through the Emergency Operations headquarters. In consequence, the continual flood of official and unofficial people to OVK became difficult to manage for the OVK team.

In the early morning of 29 May, a South African plane used by AMISEC (the African Union Mission in the Comoros, sent to ensure that the presidential elections went smoothly) allowed one of us to fly over Karthala. While no extra caldera activity was observed, it was evident that a lava lake had formed in Choungou Chahale. Even now that the eruptive activity and location were better known and reported, anxiety persisted because OVK could not state how the volcanic activity would evolve and how long it would last. Everybody kept the 1977 Singani eruption in mind, fearing a repeat of that event. People were also afraid of ash fallouts, as happened during the last two eruptions, in 2005. Several felt continual tremors, contributing to their concerns. The stream of people coming to OVK stayed constant for the next few days while OVK spent time denying false rumours that appeared in the media. During this time, other AMISEC flights helped OVK to observe the volcanic activity's evolution. The eruption finally ended on 1 June without further consequence.

This summary introduces the limitations of Comoros' crisis management at all levels including OVK's limited capacities, the disorganisation of the Comorian authorities, transmission of false and alarmist information by the media, deference of crisis management to foreign groups, and poor risk perception contributing to crisis development. These elements are further detailed and analysed in Table 2. The institutional shambles is a strong component in the inappropriate behaviour presented in the next part of this paper, supporting the overall view of Hewitt (1983) and Wisner (2004) in highlighting external factors leading to disasters rather than Burton et al (1993) emphasising internal factors.

IV. Population behaviour during the 2006 eruption

A 45-item risk perception questionnaire had been conceived before the 2006 eruption with the aim of building a targeted education and awareness campaign for young Comorians in high schools, junior high schools, and the university. Due to the high illiteracy rate on Ngazidja (43.8%: Ministère des Affaires Etrangères et Européennes, 2007) we decided not to distribute questionnaires outside schools. The May 2006 eruption made us change our initial research plans and instead use the questionnaire for understanding more about this eruption.

Constraints' description* *All factors interact with others, influencing their respective power of vulnerability generation	**Ways in which constraints are translated into vulnerability and may lead to a disaster**
Political instability - Conflicts, military coups - Territorial integrity in jeopardy: autonomy interests - Tense relations between Comoros and France **State inefficiency** **-** Inefficient, wasteful (and in some cases corrupt) civil administration	**→State unable to:** - Support social protection - Prepare for disasters and apply PNPRU (see Morin et al, this issue). - Provide adequate early warning systems (tensions with France could further hinder the warning process) - Organise effective evacuations - Support rescue organisation and emergency response - Provide enough shelters for displaced people - Inform population - Maintain essential aid stockpiles **→People:** - Are vulnerable to loss of harvest by natural hazards - Have low ability and interest to try to develop self-protection strategies - Deliberately increase their exposure to natural hazards for better daily living conditions, sometimes through punishable behaviour (eg theft of solar panels) - Have inadequate knowledge implying inadequate behaviour during eruptions (eg move without waiting for information) - Do not trust the government (an essential element) →Major risk of water supply pollution by volcanic ash fallout
Position in the world economy - Debt - Structural adjustment programmes - Dependence on overseas food and secondary imports - Exchange rate of cash crops - Low food stocks and savings **Local economy** - High percentage of households dependent on subsistence farming and sharecropping: livelihoods at risk - Inadequate economic progress to provide alternative livelihoods - Low income levels - Lack of local markets **Social indicators** - Widespread poverty - Poor social protection (limited insurance options) - Poor nutrition - Poor health standards, prevalence of endemic (malaria and cholera) - Low access to electricity, good water, infrastructure and telecommunications - Low level of education: population ill-informed - Illegal emigration	

Customs - No investment in the national economy or in sustainable livelihoods because people invest their money in customs, such as *Grand Mariage* which also gives access to a superior social status - Promotion of emigration **Religion** - Wait-and-see attitude	→Potential for disease expansion from massive and rapid population displacement **→Infrastructure:** - Roads, harbour and airport do not allow orderly massive evacuation
Hazard-related factors (eg volcano, weather) **Small island context** - Country is geographically divided amongst several islands which enhances autonomy interests - Relative inaccessibility - Difficulties in maintaining self-sufficient economies - Difficulties in maintaining adequate water and energy supplies - Limited arable land - Narrow coastline, stormy sea conditions leads to reduced fishing activities - Difficulties in preventing emigration	- Insufficient shelter capacity in case of population displacement Infrastructure unsafe (eg ash-induced collapses) **→Insular issues:** - The whole territory is threatened by volcanic hazards - No refuge area in case of a major event - Low materiel losses, but a high ratio of monetary losses to total national wealth

Table 2 - Summary of weaknesses in institutional crisis management brought to light by the 2006 eruption.

The questionnaires were distributed to pupils mainly in Moroni and Mvouni four days after the eruption ended. One of the authors remained with the respondents while they were answering the questionnaire to enforce the survey's protocol that no communication is permitted between respondents in order to obtain only personal responses from individuals. The response rate was 135 readable questionnaires out of the 250 surveys initially distributed. The respondents were on average 19 years old (from 13 to 31) and 61% were male.

At the same time, village chiefs and residents were interviewed in nine main places around Karthala volcano: Moroni, Mvouni, Vouvouni, Salimani, Singani, Makorani, Kourani, Bandamadji, and Idjikoundzi. Moreover, the concern and interest generated by the May 2006 eruption led to numerous meetings with officials and the media. Seventy unstructured interviews were completed with key informants from Ngazidja, Union of the Comoros, NGOs, and European, South African and UN institutions, permitting us to enrich our questionnaire database. All these interviews cover the main ideas tackled in the questionnaire, ie the respondents':

- perception of risk from volcanic hazards, feeling of personal vulnerability, and concern about a potential eruption

- knowledge of Karthala's eruptive history, volcanic processes, and hazard mitigation strategies

- information received during pre-, syn- and non-eruptive periods and the method through which they prefer receiving this information

- behaviour in response to an eruption, their feeling of their ability to protect themselves from volcanic threats, and personal choices for risk management

- perceived preparedness of and trust in government, scientists and the media, including confidence in warning systems, hazard mitigation, and crisis communication strategies

- demographic and socio-economic characteristics, covering gender, age, level of education, household income, goods owned, housing architecture and structure, and water supply access, amongst other data

In addition, dozens of informal discussions were held with the population. Key informants often gave similar responses to those given by population, especially regarding their risk perception, behaviour, and expectations.

The responses obtained through these surveys allow a better understanding of the factors affecting people's behaviour during the volcanic crisis. For each figure, we discuss only the main data that helped to explain and analyse the crisis situation. There is a good match between the post-eruption behaviour that we observed and the behaviour described by interviewees when they were questioned about their reaction during an eruption (figures 3 and 7). The main result is that more than a quarter of them immediately escape without waiting for any information (most of them congregating at key places such as the hospital, OVK, or the police force's barracks) and 11% more moved to join family elsewhere. Usually, migrants headed from villages near the volcano towards Moroni, and then from Moroni and central areas towards the northern parts of the island which are considered to be safer. In total, one third of the population considered migration as a primary option, yet in parallel, a quarter of respondents considered displacement as the main problem posed by eruptions (Figure 4).

Knowledge concerning past eruptions was limited, except regarding the 1977 eruption (Morin and Lavigne, this issue). This low level of knowledge and experience concerning Karthala's eruptive mechanisms and hazards led people to interpret the eruptive cloud as a huge lava fountain, as described above. This knowledge may be summarised as what was experienced through ash fallouts in 2005, the gas smell in 2006 and the destructive lava flow in 1977.

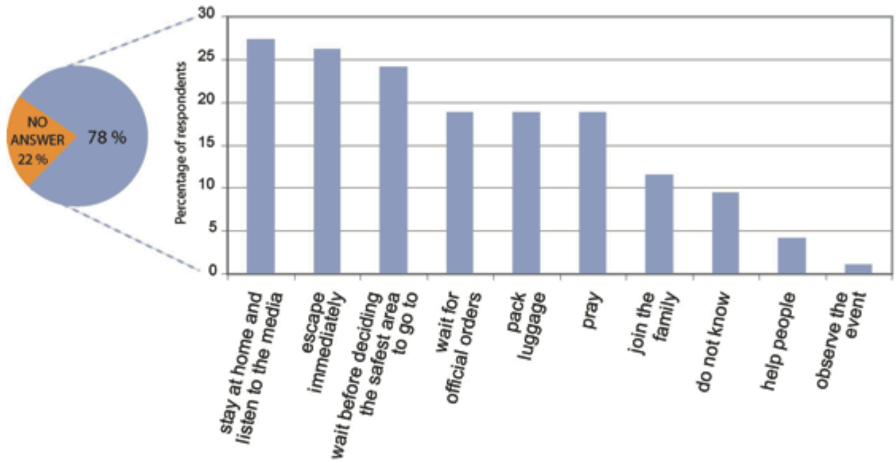

Figure 3 – Responses to the question “How did you react when a volcanic eruption occurred?”

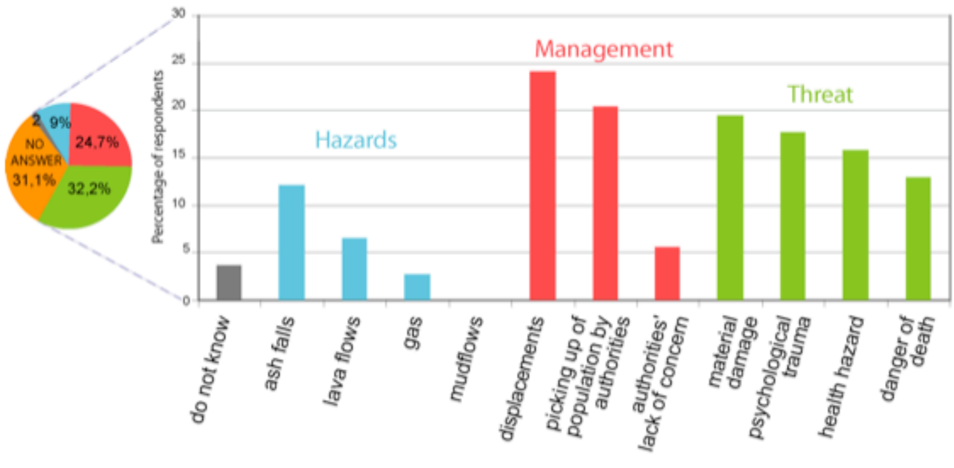

Figure 4 - Responses to the question “What is the most problematic for you when an eruption occurs?”

For 95% of the respondents, Karthala represents a danger for people and for goods/infrastructure, while 66% thought that the place where they live would be threatened if an eruption occurred. The new eruptive frequency and activity from Karthala’s recent eruptions, created the fear that led to the previously described inappropriate behaviour during the May 2006 eruption. It also led 89% of respondents to think that the volcano will erupt every six months. This data support previous studies that volcanic risk perception and positive adjustments to that perception are often determined by previous personal experience and by information received rather than by people actively seeking their own material (Murton and Shimabukuro, 1974; Johnston et al, 1999; Paton et al, 2001; Becker et al, 2001; Johnston and Houghton, 1995; Gregg et al, 2004; Perry and Lindell, 2008).

People's anxiety was reinforced by the lack of warning systems and by the feeling of being abandoned by the authorities. In May 2006, people were informed of the eruption's beginning mainly by word-of-mouth or by their own observations (Figure 5). Yet 100% of the respondents stated that a warning system would be needed for them to feel safe in the future - even though trust in officials is very limited because 85% of the respondents lack confidence in the authorities (see also Figure 6).

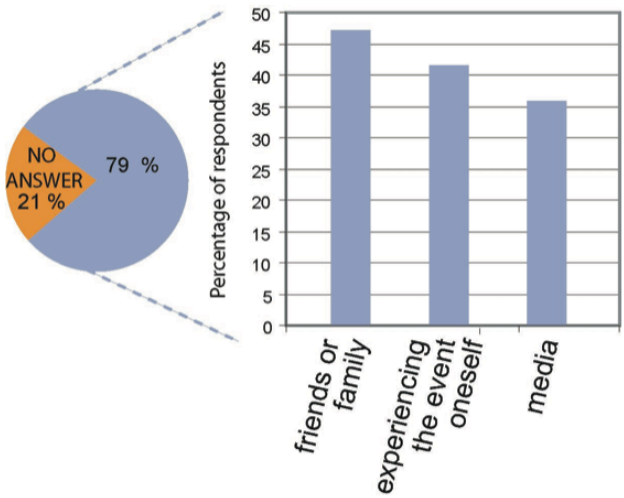

Figure 5 - Responses to the question "How are you alerted when an eruption occurs?"

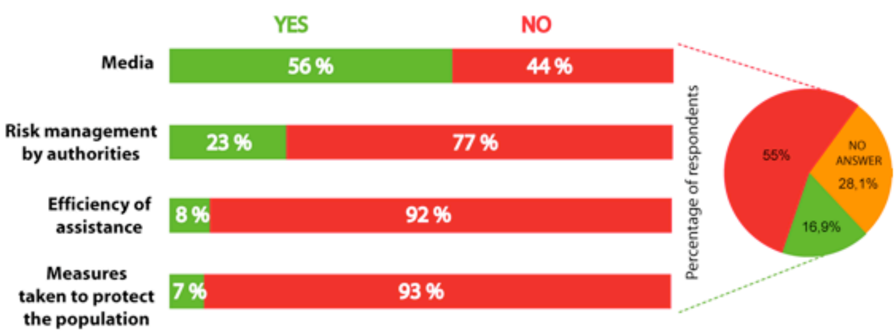

Figure 6 - Responses to the questions "Do you trust the media to provide objective information? Do you consider that the risk management by the authorities, the efficiency of assistance in case of an eruption, and the measures taken to protect the population from volcanic risk are sufficient?"

The lack of alert is combined with an absence of preventive information whereas 88% of respondents would like to receive such material and the literature stresses the importance of information received (in frequency, quality, and relevance) for enhancing volcanic risk perception (Greene et al, 1981; Perry et al, 1982; Perry and Lindell, 1990; Lindell and Perry, 1993). More than half of the respondents identify audio-visual media as their main information vector, in preference to information supplied directly from scientists or the authorities. Nonetheless, only 56% of respondents trust the media to give them accurate information (Figure 6). The denials that the OVK scientists had to give to refute media reports during the May 2006 crisis lend support to those who do not trust the media. Interestingly, the feeling of neglect by the authorities led the population to accept less individual responsibility for preparing for future eruptions because they prefer to await better official support. More than one third of respondents thought that the best way to protect themselves against eruptions was to be evacuated by the authorities and to receive more assistance (Figure 7). Responses to the question "What is the best way to protect yourself from eruptions?" demonstrated the low ability or interest of people to try to protect themselves from an eruption's effects. Finally, the surveys revealed a low feeling of community responsibility in that only 4% use mutual aid to react to a crisis.

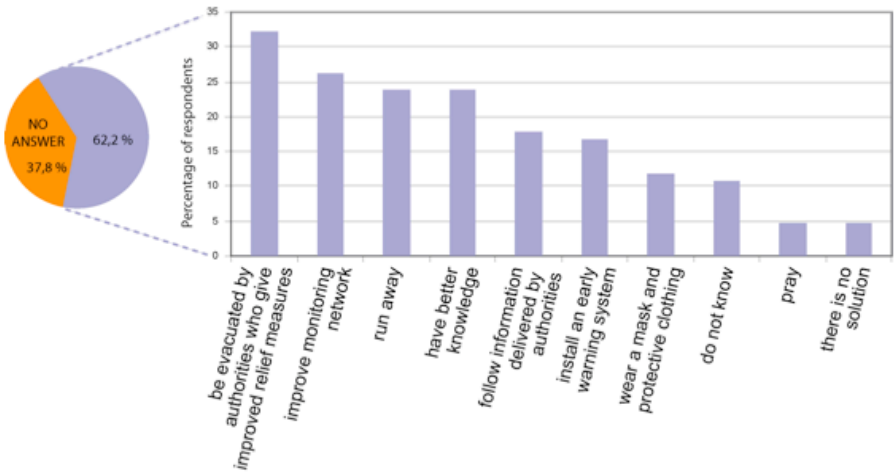

Figure 7 - Responses to the question "What is the best way to protect yourself from eruptions?"

From the above discussion and linking that to the literature referenced, we suggest that risk perception and people's behaviour are linked with OVK's inability to provide information, the alarmist information disseminated by the media and the understanding that the country's capacity is exceeded by even a minor event, the feeling of being abandoned by the authorities and a lack of education on the topics. Thus, people's behaviour during the May 2006 eruption exemplified the limitations previously described (eg Table 2), the origins of which rest in the long-term Grande Comore political and socio-economic situation, exactly as articulated by Lewis (2009) regarding island vulnerability. Examining and dealing with institutional management and people's behaviour in a wider context should take into account non-hazard related factors to support disaster risk reduction over the long-term (Gaillard, 2008; Lavigne et al, 2008; Dibben, 2008; Wisner et al, 2004).

Conclusion

The Grande Comore Island is entirely, and for the moment frequently, exposed to volcanic hazards. The 2005 eruptions should have brought the country to a higher level of preparedness but efforts made to improve the situation were insufficient, as exposed by the May 2006 crisis. Analysing the May 2006 eruption has provided rich information about deficiencies that increase the potential for social crises, irrespective of the volcano's behaviour. Some needs to improve the capability of dealing with the volcanic activity have been underlined:

- a clearer institutional framework and division of responsibilities, especially between the Union of Comoros and the island of Grande Comore
- a volcanological monitoring network that is better developed and maintained
- trained and competent people at all levels of risk management who stay in these jobs
- strengthened national coordination and Civil Protection corps
- a continuing education programme for authorities, institutional partners, and population, including with the help of media
- improved hazard, vulnerability, and risk mapping
- statutory zoning based on the maps and delineated responsibilities for infrastructure maintenance
- improved use of NGO capacities
- based on Paton et al (2008), social processes establishing the belief in the benefits of mitigation, community involvement, and trust in institutions (where justified)

All these needs emerge from deep-rooted social and cultural challenges that need to be resolved within the contexts of individuals, families, villages, Grande Comore and Comoros. Some of the reasons for these challenges are explored in Morin and Lavigne (elsewhere in this issue). Resolving the volcano-related difficulties undoubtedly requires working towards resolutions of the long-term and broader social and cultural Comorian "crises".

Acknowledgements

OVK, COSEP, French Embassy in the Comoros, Autonomous Government of Grande Comore and Union des Comores, Reunion regional council, Carol Develter, and Dominique Meyer-Bish provided technical support during fieldwork in Comoros. We greatly thank Stéphanie Barde-Cabusson from Clermont-Ferrand

University, Magali Smietana and Hamidou Nassor from La Réunion Island University, Christopher Gomez from Paris 1 Sorbonne University, Hamid Soule from OVK, Christian Pailler from PIROI, Nancy Juvin from French Red Cross, and passionate teachers Abderemane and Ahmed from Comorian National Education have taken an interest in this work. Thanks to ever-present Tortu Patchod. We also thank Jean-Christophe Gaillard and Ilan Kelman for the confidence and patience they offered us, as well as David Johnston and an anonymous reviewer for their reviews. IPGP contribution n°2350.

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