The effects of volcanoes on health: preparedness in Mexico

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Introduction

The enormous destructive power of volcanic eruptions has held a fascination for humanity throughout history. The story of Mount Vesuvius, with the disappearance of Pompeii and other cities in 79 AD, is classic. In modern times, there have been some very deadly volcanoes: Tambour in Indonesia took the lives of 92 000 people in 1815; Krakatoa in that same country produced 36 417 victims in 1883; Mount Pelée in Martinique caused the deaths of 29 025 people in 1902; and in 1985, the Nevado del Ruiz in Colombia caused the deaths of 23 000 people *(1)*.

The destructive power of volcanoes originates in phenomena such as pyroclastic flows, whose burning fragments can attain speeds of 150 km/hour and temperatures ranging from 900 °C to 1200 °C, showers of volcanic ash which can affect a radius of 80 km or more; lava flows that destroy all vegetation in their path; lahars or mudstreams produced by the thawing of the volcanic cone, the mixture of ash, rain or water from lakes; volcanic gases that, like carbon dioxide, are denser than air and can cause death by asphyxiation; and the earthquakes and tsunamis that often accompany volcanic eruptions. It is estimated that more than 200 000 people may have lost their lives in recent years to volcanic eruptions *(2)*.

The health effects on populations exposed to volcanic eruptions vary and can usually be classified as either physical or psychological:

Physical effects: Trauma and wounds from pyroclastic material; second- and third-degree burns, death by suffocation, acute irritation of the respiratory tract caused by ash, or exacerbation of prior respiratory disease caused by inhaled particles such as silica; respiratory tract and lung burns caused by inhalation of hot steam; conjunctivitis or corneal abrasion; intoxication by gases such as carbon dioxide, hydrogen sulfide, sulfur dioxide, hydrogen fluoride, carbon monoxide, and radon, gastroenteritis, skin irritation from acid water, and drowning in sudden volcanic mudflows *(1-3)*.

Psychological effects: Depression, anxiety, nightmares, psychomotor disorders, irritability, insomnia, confusion, neurosis and stress *(3)*.

For example, during the El Ruiz Volcano eruption which took place in Colombia in November 1985, the lahars (mixture of melted snow, rocks and mud) falling from above 5 432 m buried 23 000 people. The 4 main categories of injuries among the 834 survivors attended in the neighboring hospitals were 578 lacerations (69.3%), 343 penetrating injuries (41.1%), 312 fractures (37.4%) and 272 eye injuries (32.3%) *(7)*. Many survivors had more than one kind of injury.

The main causes of death were suffocation due to mud aspiration, multiple trauma, hypovolemic shock and gangrene complications *(7)*.

During the eruption of Mount Saint Helens in Washington State in 1981, asphyxia from ash inhalation was the main cause of death in 18 of 23 cases, while 4 deaths were due to burns and 1 to head injuries. A hospital surveillance system detected increases in asthma and bronchitis cases in communities with heavy ash fall after eruptions on 18 and 25 May and on 12 June *(8)*. Crystalline-free silica which may be contained in ash fall is a cause of concern for potential pneumoconiosis in exposed occupational groups *(8)*.

A correlation between exposure to ash emitted by the Popocatépetl and acute respiratory infections was demonstrated during the ash emission in December 1994 *(9)*. Exposure to volcanic ash may affect immunological parameters as explained during a study of occupational exposure in loggers, after the Mount Saint Helens eruption in 1981 *(10)*.

Volcanic gases can be asphyxiants or irritants. A build-up of asphyxiant gases to lethal concentrations like carbon dioxide (CO_2), is likely only in the vicinity of the volcanic crater or fissures, while irritant gases such as sulfur dioxide (SO_2) may exert their effects in much lower concentrations for many kilometers downwind, and cause acute irritation to the respiratory tract or produce asthma in susceptible persons *(1)*.

Popocatépetl and its activity

Mexico has 13 volcanoes that have demonstrated some kind of activity in recorded history. *Fig. 1*

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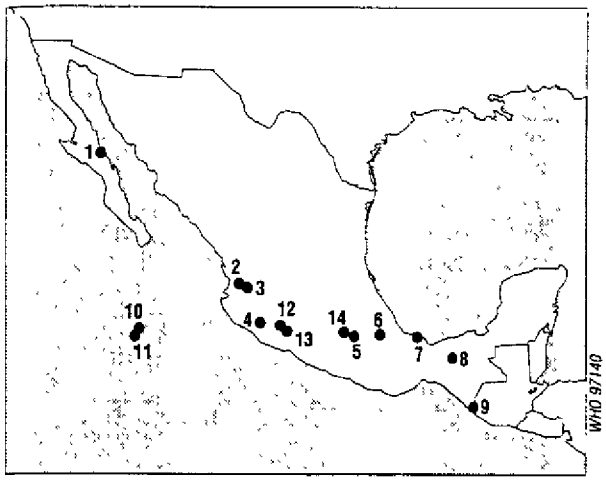
Fig. 1
Distribution of main active volcanoes in Mexico
Répartition des principaux volcans actifs du Mexique



1 Tres Vírgenes
2. Sanganguey
3. Ceboruco
4 Colima
5. Popocatépetl
6. Pico de Orizaba
7. San Martín Tuxtla
8. El Chichón
9. Tacaná
10 Bárcena
11. Evermann
12. Paricutín
13 Jorullo
14. Xitle

Source. CENAPRED/SINAPROC (Centro nacional de prevención de desastres/Sistema nacional de protección civil). Mexico, *Vulcanismo en México*. Vol 4, Volcanes, 1994

and *Table I* show their geographical distribution and activity over the years *(4)*.

Popocatépetl, at 5 452 meters, is the most famous volcano in Mexico. It lies on the borders between the states of Mexico, Puebla, and Morelos at 19°02′ N and 98°62′ W. Its name in Nahuatl means "hill that emits smoke", because of its constant emission of fumaroles. Popocatépetl is located in a densely populated region of Mexico. Authorities from the National Disaster Prevention Center (CENAPRED) estimate that there is a population of 500 000 within a 25 km radius around the volcano. The area is a rich agricultural zone, and the foothills are covered by lush vegetation, including a variety of evergreens and other trees. The average annual temperature in the area ranges from 18 °C to 20 °C. There are three important cities within a 100 km radius: metropolitan Mexico City, with a population of approximately 15 million, situated directly northwest of the volcano at a distance of 60 km; the city of Puebla, capital of the State of Puebla, 45 km to the east, with a population of 1 057 454; and Cuernavaca, the capital of the State of Morelos, with a population of 281 294, located 43 km west of Popocatépetl *(Fig. 2)*. Geological studies estimate that Popocatépetl emerged approximately 12 million years ago There are records of eruptions dating from 2999 BC up to 1920 AD, and more than 12 of these explosive eruptions, accompanied by abundant ash showers and fumaroles, have occurred in recorded history. The volcano's crater measures 750 to 850 m in diameter, with a maximum depth of 400 m, and it is crowned on its northern side by a layer of glacial ice measuring 10-60 m thick *(5-6)*.

After years of calm interrupted by only occasional fumarole emissions, in 1993 the fumaroles intensified, with greater gas and steam emissions coupled with seismic activity. On 21 December 1994 there was a strong emission of gases and ash,

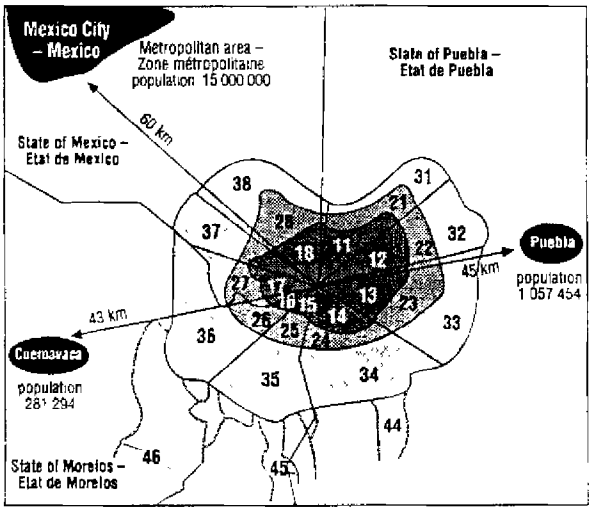
Table 1
Volcanic eruptions recorded in the history of Mexico

Tableau 1
Eruptions volcaniques enregistrées au cours de l'histoire, Mexique

Volcano – Volcan	State – Etat	Eruption dates – Dates d'éruption
Tres Vírgenes	Baja California Sur	1746, 1857
Sanganguey	Nayarit	1742, 1859
Ceboruco	Nayarit	circa/vers 960, 1870-1875
Colima	Nayarit-Jalisco	1560, 1576, 1590, 1606, 1611, 1622,1690, 1771, 1795, 1818, 1869, 1872, 1886, 1889, 1890, 1891, 1893, 1903, 1909, 1913, 1960, to date?
Popocatépetl	Mexico-Puebla-Morelos	1347, 1354, 1519, 1530, 1539, 1542-1592, 1664-1667, 1720, 1802, 1920
Pico de Orizaba	Veracruz	1537, 1545, 1566, 1569, 1613, 1630, 1687
San Martín Tuxtla	Veracruz	1664, 1793, 1797
Le Chinchón	Chiapas	circa/vers 300, circa/vers 623, circa/vers 1300, 1982
Tacaná	Chiapas	1855, 1878, 1903, 1949-1951, 1986
Bárcena	(a)	1952-1953
Evermann	(b)	1848, 1896, 1905, 1951
Paricutín	Michoacán	1943
Jorullo	Michoacán	1759

(a) Located on San Benedicto Island in the Revillagigedo Archipelago (19°27′N, 110°8′W). – Situé dans l'archipel Revillagigedo (19°27′N, 110°8′O)
(b) Located in the Pacific Ocean (18°75′N and 110°95′W) – Situé dans l'océan Pacifique (18°75′N et 110°95′O)
Source. Servando de la Cruz, R. Instituto de Geofísica de la UNAM, Monograph, 1994

Fig 2
Risk map Popocatépetl Volcano, Mexico
Carte des risques, volcan Popocatépetl, Mexique



High-risk areas – Zones à haut risque 11–18
Low-risk areas – Zones à faible risque: 31–38
Medium-risk areas – Zones à risque moyen: 21–28
Potential risk of lahars – Risques potentiels de lahars 44,45,46

Source Adapted from – D'après: CENAPRED/SINAPROC , Mexico, 1996
Notes Estimated total population of entire shaded area 450 000 – 500 000. The numbers show evacuation sectors for gathering village-based and dispersed population at designated points. – Estimations de la population totale de l'ensemble de la région en grisé: 450 000 – 500 000. Les chiffres montrent le secteurs d'évacuation prévus pour regrouper la population des villages et la population dispersée en des points désignés

accompanied by moderate tremors that alarmed the neighbouring population. The ash shower even reached the city of Puebla (population, 1 057 454) 45 km to the southeast. A total of 50 000 people in 23 localities were evacuated and eventually returned to their homes once the emergency was over *(6)*. Strong gas and ash emissions occurred again in early 1995 and March 1996.

On 29 and 30 April 1996 a number of seismic events occurred that led to an explosion marked by the ejection of small fragments (pyroclasts) that fell some 15 to 20 km away. Unfortunately, on 30 April, a group of 5 mountain climbers who were exploring the volcano without authorization died as a consequence of the unexpected explosion. The volcano has recently entered a new stage of activity with lava emissions at the bottom of the crater forming a continuously growing dome. In addition, an emission of 8 000 to 15 000 tonnes of sulfur dioxide per day has been measured *(6)*. This new situation has intensified round-the-clock monitoring of the volcano in order to put emergency measures into operation in the event the volcano becomes a high risk for the population.

Monitoring the volcano and the early warning system

Since 1994 a complex network using sophisticated equipment to monitor the volcano has been set up in a joint venture by the National Civil Defense System (SINAPROC), the National Disaster Prevention Center (CENAPRED), and the National Autonomous University of Mexico (UNAM). The monitoring system makes it possible to measure geological events, deformation of the volcano, temperature changes, gas emissions, and other variables. The observation network includes. *(a)* visual surveillance by means of video cameras, photographs, and observation flights; *(b)* seismic monitoring through a seismograph network to transmit data by means of telemetry; *(c)* geochemical monitoring for the measurement of gases and water, and *(d)* geodesic monitoring to measure the deformations produced by internal pressure *(4,6)*.

The SINAPROC/CENAPRED Scientific and Technical Advisory Committee has developed an early warning system to keep the population permanently informed about the behaviour of the volcano and to support decision-making. The warning system consists of the use of color-coded semaphores: green for normal, yellow for alert, and red for alarm and evacuation. Knowledge of this system is widespread in the predominantly agricultural communities living in the foothills of the volcano.

An emergency plan has also been prepared that includes evacuation routes, sites for lodging refugees, and preparations by medical centres and hospitals in the region. The central command post for monitoring the volcano is located in the CENAPRED facilities. The alert levels and the use of color coding are summarized in *Table 2 (6)*.

Twelve hospitals, each with an average of 60 beds, are accessible from the volcano area. These hospitals will serve as the first response area. Hospital staff have been trained for emergency situations and are taking the necessary precautions. The response systems will be under the general coordination of the Civil Protection authorities who are in charge of planning and implementing the overall emergency response and evacuation plans.

Jointly with the preparation of contingency plans, population censuses of the area have been updated, along with directories of key personnel and resource inventories. An intense public information campaign has also been launched, together with evacuation simulation exercises, training of health personnel, and maintenance projects on roads that may serve as evacuation routes.

Notwithstanding the preparations made and the existence of contingency plans, the potential response of populations living in small settlements poses a great challenge; the population being strongly rooted in the land might, for cultural reasons and tradition, resist evacuation in the event of an emergency.

Table 2
Popocatépetl, Mexico – Alert levels

Tableau 2
Volcan Popocatépetl, Mexique – Niveaux d'alerte

Levels – Niveaux	Associated phenomena – Phénomènes associés	Alert code for the population (action required) – Codes d'alerte pour la population (mesures à suivre)
0	The volcano is dormant. (Months, years, centuries) Le volcan est éteint. (Mois, années ou siècles.)	**Green – Vert :** Keep apprised of the status of the volcano. Annual "Volcano Day" evacuation simulation. – Se tenir informé sur l'état du volcan. Simulations d'évacuation annuelles «Journée volcan»
1	Abnormal but moderate increase in seismic activity, fumaroles, or the temperature of fumaroles or springs. Changes in their composition. (Months or Years) Accroissement anormal mais modéré de l'activité sismique, des fumerolles ou de la température des fumerolles ou sources. Modification de leur composition (Mois ou années.)	
2	Significant increase in above parameters. Some deformation. Clear presence of plumes or fumaroles. (Weeks or months) Accroissement considérable des paramètres susmentionnés. Certaines déformations. Existence évidente de panaches ou de fumerolles. (Semaines ou mois.)	
3	Significant increase in above parameters. Begining of some weak eruptive or non-magmatic activity (phreatic). (Day, days or weeks) Augmentation considérable des paramètres susmentionnés. Début d'une faible activité éruptive ou non magmatique (phréatique). (Jour, jours ou semaines.)	**Yellow – Jaune:** Maintain alert and stay in frequent contact with the local authorities. Listen to radio or television frequently. Obey instructions of the local authorities, Civil Defense or the Armed forces. Be prepared for possible evacuation. – Se maintenir en alerte et garder un contact fréquent avec les autorités locales. Ecouter la radio ou la télévision fréquemment. Obéir aux instructions des autorités locales, de la défense civile ou des forces armées. Se préparer à une évacuation éventuelle.
4	Acceleration of above parameters or explosive emission of magmatic material (Hours or days). Accélération des paramètres ci-dessus ou émission explosive de matériel magmatique. (Heures ou jours.)	**Red – Rouge:** Obey the instructions of the civil or military authorities. In the event of evacuation, take only what is indispensable. Go to the assigned shelter. In the event of self-evacuation, notify the appropriate authorities. – Obéir aux instructions des autorités civiles ou militaires. Dans l'éventualité d'une évacuation, ne prendre que ce qui est indispensable. Se rendre à l'abri assigné. Dans l'éventualité d'une auto-évacuation, notifier les autorités compétentes.
5	Solid evidence of the presence of large quantities of magma within the volcanic cone, large deformations, or development of explosive eruptive activity on a large scale. Preuve manifeste de la présence de grandes quantités de magma dans le cône volcanique, déformations importantes, ou activité éruptive explosive à grande échelle.	

Source : Adapted from: – Adapté de: *(Ref. – Réf. 6).*

Summary

The article reviews the most important aspects of volcanic eruptions and presents a summary of the harmful materials they emit. The main health effects can be classified as either physical (trauma, respiratory diseases, etc) or psychological (depression, anxiety, nightmares, neurosis, etc)

Popocatépetl, the most famous active volcano in Mexico, lies on the borders of the States of Mexico, Puebla and Morelos In 1993, seismic activity intensified, as did as the emission of fumaroles, followed in December 1994 by moderate tremors and strong emissions of gases and ash In 1996, a number of seismic events led to an unexpected explosion. A daily emission of 8 000 to 15 000 tonnes of sulfur dioxide has been measured

Popocatépetl is located in a densely populated region of Mexico A complex network to monitor the volcano using sophisticated equipment has been set up, including visual surveillance, seismic, geochemical and geodesic monitoring. An early warning system (SINAPROC/ CENAPRED) has been developed to keep the population permanently informed The warning system uses colour codes. green for normal, yellow for alert, and red for warning and evacuation An emergency plan has been prepared, including evacuation and preparation for medical centres and hospitals in the region, as well as intense public information campaigns

Résumé

Effets des volcans sur la santé : préparation aux situations d'urgence au Mexique

Le présent article examine les aspects les plus importants des éruptions volcaniques et présente un récapitulatif des matières nocives qu'elles émettent. Les principaux effets sur la santé peuvent être classés soit comme physiques (traumatismes, maladies respiratoires, etc) soit comme psychologiques (dépression, anxiété, cauchemars, névroses, etc).

Le Popocatépetl, le volcan le plus actif le plus célèbre du Mexique, se trouve sur la frontière des Etats de Mexico, de Puebla et de Morelos En 1993, l'activité sismique s'est intensifiée, de même que l'émission de fumerolles, suivie en décembre 1994 de secousses modérées et de rejets virulents de gaz et de cendres. En 1996, plusieurs manifestations sismiques ont débouché sur une explosion que l'on n'attendait pas On a mesuré une émission quotidienne de 8 000 à 15 000 tonnes de dioxyde de soufre

Le Popocatépetl est situé dans une région du Mexique à forte densité de population Un réseau complexe destiné à surveiller le volcan à l'aide d'un équipement perfectionné a été mis en place, et comprend une surveillance visuelle, et un suivi sismique, géochimique et géodésique Un système d'alerte avancée a été mis au point afin que la population soit informée en permanence Ce système d'alerte fonctionne à l'aide de codes de couleur vert pour une situation normale, jaune pour alerte et rouge pour alerte maximale et évacuation. Un plan d'urgence comprenant l'évacuation et la préparation des centres médicaux et des hôpitaux de la région, ainsi que d'intenses campagnes d'information du public, a été élaboré

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