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Short Communication

Popocatépetl's crater filled to the brim: significance for hazard evaluation

José Luis Macías*, Claus Siebe

Departamento de Vulcanología, Instituto de Geofísica, Universidad Nacional Autónoma de México, Ciudad Universitaria, Coyoacán, C.P. 04510, México, D.F., México

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Abstract

After ~67 years of quiescence Popocatépetl volcano reawoke on December 24, 1994 emitting vigorous ash plumes. Juvenile magma appeared for the first time on March 29, 1996, with the emplacement of a dacitic lava dome inside the crater. Since then, more than 25 dacitic domes have been extruded and destroyed by subsequent explosions. On January 22, 2001 the activity peaked with a strong explosion that produced pyroclastic flows that reached the timberline and ignited fires at a distance of 4.5 km from the crater. These pyroclastic flows were contained within the red zone of the volcano hazards map. After 10 years of discontinuous activity Popocatépetl's crater is almost completely filled with lava dome rock. This scenario poses a new threat to the populations settled in the orange zone (intermediate hazard level) because future explosions will not be contained by the crater walls and pyroclastic flows will probably reach greater distances from the crater.
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Popocatépetl represents the most dangerous volcano in Mexico because more than 10 million people live within a radius of 70 km from the summit crater. Its reactivation in December 1994 has confronted scientists and authorities with this new hazard. Popocatépetl's pattern of activity is still poorly understood, and the fear of a large eruption and its consequences are therefore amply justified.

Popocatépetl volcano (5452 m a.s.l.) is located 71 km south-east of downtown Mexico City and 40 km west of the city of Puebla. The modern cone of Popocatépetl consists of interlayered andesitic to dacitic lava flows and pyroclastic deposits (Robin, 1984), all erupted in the last ca. 23,000 years, following a cataclysmic eruption that included edifice collapse and debris avalanche emplacement (Siebe and Macías, 2004). Since 23,000 years ago Popo has had at least seven Plinian eruptions that produced extensive

* Corresponding author. Tel.: +52 55 5622 4146; fax: +52 55 5550 2486.

E-mail address: macias@tonatiuh.igeofcu.unam.mx (J.L. Macías).

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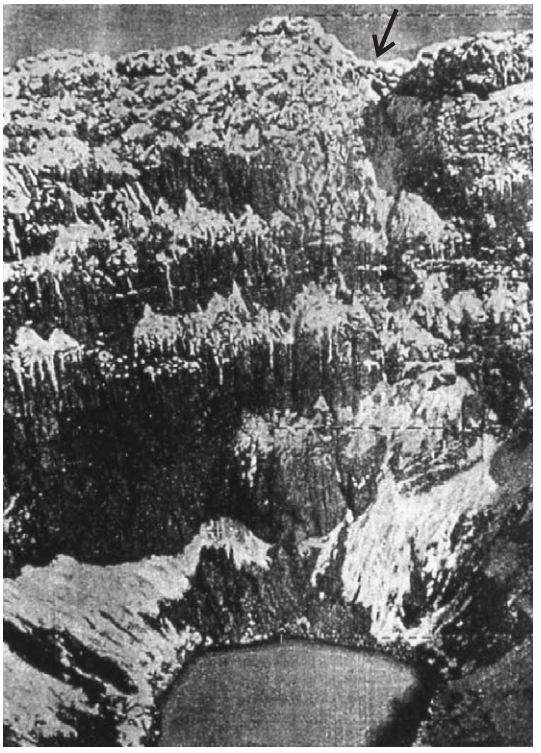

Fig. 1. View from the northwest of the interior of Popocatépetl's volcano showing the base of the crater filled with a lake. Arrow points to notch at the topmost site of the eastern rim that is used as a reference marker for comparison with more recent pictures. Photograph taken in August 1906 by I. Friedländer (1921).

pumice-fall and ash-flow deposits. The last three Plinian eruptions took place ca. 5000, 2100, and 1100 years BP (Siebe et al., 1996), well within the period of human settlement, as shown by archaeological remains buried by ash beds and pottery shards incorporated in ash-flows and lahars. The morphology of the elliptical, E–W (820×650 m) modern crater was mainly inherited from the last major Plinian eruption that left a >300 m-deep crater with steep inner walls. The lowest point of the crater is at an altitude of 5180 m a.s.l. on the eastern rim, whereas the summit is on the opposite western rim. This crater of Popo has been the focus of interplinian activity that seems to be dominated by eruptions of minor magnitude as reported in pre-Hispanic and Colonial historic documents (De la Cruz et al., 1995). These eruptions do not produce identifiable deposits around the volcano.

At the turn of the 20th century several geologists, travelers, and artists were attracted by the imposing view of Popocatépetl looming over the surrounding valleys. Many of them climbed to its crater rim and provided useful descriptions (including photographs and paintings) of the crater's interior. A photograph taken in 1906 by Friedländer (1921) shows that the crater's interior consisted of >300 m deep vertical walls with scarce fumarolic activity originating at the bowl-shaped bottom (Fig. 1). In 1919 Popocatépetl reawakened with the emission of ash-rich columns that attracted the attention of scientists (Friedländer, 1921; Waitz, 1921; Atl, 1939; Camacho, 1925) who climbed the volcano and witnessed the growth of a lava dome at the crater floor, as well as explosions that partially destroyed the dome producing a small inner crater. That eruption ended around 1927–1928 leaving at the bottom of the main crater a ca. 160-m wide and 50-m deep inner crater. The deepest point of this inner crater was located at 4963 m a.s.l. (GVN, 1998),

Fig. 2. Photograph taken from Popocatépetl's summit on the western crater rim. The image shows the southwestern steep inner walls of the main crater, and the small 160-m wide inner crater left by the 1919–1927 eruption. Photograph taken by Claus Siebe in November 1978.

completely different to the morphology observed by Friedländer in 1906. Since then, Popocatépetl entered a period of quiescence that lasted more than 60 years, during which thousands of mountain climbers reached the crater rim and had the opportunity to photograph the volcano's main crater walls as well as the 1919–1927 inner crater (Figs. 2 and 3a). With the aid of these photographs the average elevation of the main crater floor was estimated at 5030 m a.s.l. Accordingly, the volume Popocatepetl's crater could hold was estimated at ~35×10^6 m^3 (GVN, 1998).

Popocatépetl reawoke on December 21, 1994, through the continuous to pulsating emission of ash that blanketed the city of Puebla, causing great concern among the population. Authorities ordered the immediate evacuation of more than 50,000 people from the most vulnerable towns. Funds for the implementation of a geophysical monitoring system were allocated in great haste and a volcanic hazards map was produced using the available geological information (Macías et al., 1995). This map served as an important tool for selecting evacuation routes and locating shelters by the civil protection authorities. Juvenile lava first appeared in March 1996 and a new dome was observed growing in the summit crater on March 29, 1996. Activity peaked with a strong explosion and the formation of an eruptive column of ash and pumice on June 30, 1997. The column was dispersed towards Mexico City during the night and a clearly noticeable veil of silty ash accompanied by rain blanketed the city. Another episode of dome growth reached a peak on January 22, 2001, when a strong explosion produced small pyroclastic flows that traveled ca. 4.5 km from the crater and reached the timberline, igniting forest fires on Popocatépetl's northern slopes not far from Tlamacaz (Sheridan et al., 2001). These pyroclastic flows also affected the glacier on its northeast slopes triggering a lahar that came down the Huiloac barranca and reached the outer limits of the Xalitzintla village (Capra et al., 2003). It is worth mentioning that these pyroclastic flows were emplaced within the highest risk area of pyroclastic flows (red zone) of the hazards map. The last important dome explosion occurred on July 19, 2003, when wind blowing to the WNW carried fine ash again to the southern suburbs of Mexico City.

Between March 1996 and July 2003, more than 25 domes have grown within Popocatépetls crater (De la Cruz, personal communication). Each of these viscous

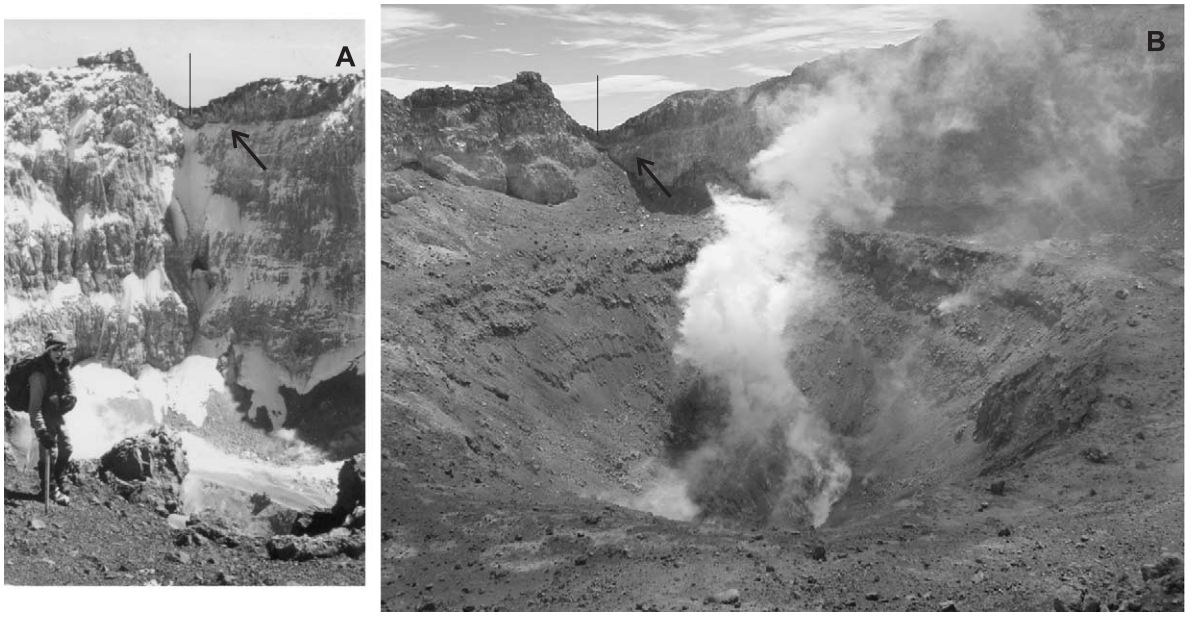

Fig. 3. Photographs showing the ESE crater walls of Popocatépetl volcano. These two pictures were taken approximately from the same location in November 1978 by Claus Siebe (A) and on February 24, 2004 by Jose Luis Macias (B). Notice that in 1978, the ESE crater walls were clearly visible, while in 2004 the crater walls have been buried by lava flow and dome materials, as shown by the black arrows. Today it is possible to descend from the border of the crater to the fuming dome inside the ca. 300-m wide inner crater.

lava domes was emplaced rapidly over a period of a few days. After cessation of dome growth, days to weeks of quiescence would elapse until a strong explosion would destroy the dome producing several km-high eruptive columns and ash fallout. On February 24, 2004, a group of volcanologists climbed to the rim of the crater and documented the changes that have occurred in its interior since 1994. The crater is now filled almost to the rim with dome material (Fig. 3b). Comparing photographs shown in Figs. 2 and 3 (both taken from the lower crater rim towards the SE) it becomes evident that the 1994–present eruption has filled Popocatépetl's crater with more than 250 m of coarse lavadome breccia produced by dome explosions. As the crater filled and the level of the crater floor rose the frequency of pyroclastic flows has gradually increased. We expect that this tendency will become accentuated in the future when future domes and subsequent explosions will not be contained by the once steep crater walls, and instead spill over the crater rim and flow down the steep slopes of the upper cone, producing more voluminous pyroclastic flows and subsequent lahars. Under this new perspective several towns located within the orange zone (intermediate hazard level) are at greater risk than before and could be reached by pyroclastic flows. On the other hand, Popocatépetl's signs of activity have decreased over the past months, indicating that its present eruptive episode may have come to an end. It is difficult, however, to ascertain whether this is truly the case. Certain sectors of the local population are already pressing for permission from the authorities to re-enter restricted areas. The authorities will thus be confronted with a difficult decision because of the ambiguity of the situation.

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References

Atl, 1939. Volcanes de México. La Actividad del Popocatépetl vol. I. Editorial Polis, México. 67 pp.

Camacho, H., 1925. Resultados de la visita al cráter del Popocatépetl el 9 de marzo de 1922. An. Inst. Geol. 2, 64–66.

Capra, L., Poblete, M.A., Alvarado, R., 2003. The 1997 and 2001 lahars of Popocatépetl volcano (Central Mexico): textural and sedimentological constraints on their origin and hazards. J. Volcanol. Geotherm. Res. 131, 351–369.

De la Cruz, S., Quezada, J.L., Peña, C., Zepeda, O., Sánchez, T., 1995. Historia de la actividad del Popocatépetl (1354–1995). Volcán Popocatépetl: Estudios Realizados Durante la Crisis de 1994–1995. CENAPRED, México, D.F., pp. 3–22.

Friedländer, I., 1921. La erupción del Popocatépetl. Mem. Soc. Cient. "Antonio Alzate" 40, 219–227.

GVN, 1998. Volcanic events: Popocatépetl volcano, cyclical dome extrusions that by late 1997 filled one-third of the crater capacity. Smithsonian Institution. Bull. Glob. Volcanism Netw. (GVN) 23 (2), 2–4.

Macías, J.L., Carrasco, G., Delgado, H., Del Pozzo, A.L., Siebe, C., Hoblitt, R., Sheridan, M.F., Tilling, R.I., 1995. Mapa de peligros volcánicos del Popocatépetl. Publicación Especial del Instituto de Geofísica. UNAM, México D.F.

Robin, C., 1984. Le Volcan Popocatepetl (Mexique): structure, evolution pétrologique et risques. Bull. Volcanol. 47, 1–23.

Sheridan, M.F., Hubbard, B., Bursik, M.I., Siebe, C., Abrams, M., Macías, J.L., Delgado, G.H., 2001. Short-term potential volcanic hazards at Popocatépetl, Mexico. EOS Trans. - Am. Geophys. Union 82 (16), 187–189.

Siebe, C., Macías, J.L., 2004. Volcanic hazards in the Mexico City metropolitan area from eruptions at Popocatépetl, Nevado de Toluca, and Jocotitlán stratovolcanoes and monogenetic scoria cones in the Sierra de Chichinautzin volcanic field. Fieldtrip Books, vol. 1. Geological Society of America. 77 pp.

Siebe, C., Abrams, M., Macías, J.L., Obenholzner, J., 1996. Repeated volcanic disasters in Prehispanic time at Popocatépetl, Central Mexico: past key to the future? Geology 24, 399–402.

Waitz, P., 1921. Popocatépetl again in activity. Am. J. Sci. 1, 81–85. (5th Ser.).