

## SHORT NOTE

# NEOGLACIAL TO RECENT GLACIER FLUCTUATIONS ON THE VOLCANO POPOCATÉPETL, MEXICO

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**ABSTRACT.** Neoglacial to historic and recent fluctuations of the firn field and one glacier on Popocatepetl, Mexico, include advance prior to 1519 to possible mid-Neoglacial stadal position on gentle, north flanks at 4 150 m, then retreat up-valley to 4 335 m by 1906, and to 4 435 m by 1920 at 7 m/year. After volcanic eruptions and melting to about 4 800 m in 1921, growth of firn field and advance of a thin ice lobe before 1949 to 4 573 m by 1950, then retreat in next eight years at about 34 m/year, re-advance of the firn edge as an ice bulge to about 4 700 m by 1968, and as a thick double-lobed glacier to about 4 600 m by 1978 and 1979. A 37 year crevasse study shows continuous active firn-field movement on the north-west side of the cone.

**RÉSUMÉ.** *Le néoglacière jusqu'aux récentes fluctuations du glacier du volcan Popocatepetl au Mexique.* Le néoglacière jusqu'aux récentes et historiques fluctuations des champs de névé et du glacier du Popocatepetl, Mexique, comporte une avance antérieure à 1519 jusqu'à un possible stade du milieu du néoglacière sur un flanc en pente douce à 4 150 m, puis un retrait vers le haut de la vallée jusqu'à 4 335 m en 1906 et jusqu'à 4 435 m vers 1920 soit 7 m par an. Après les éruptions volcaniques et la fusion jusqu'à environ 4 800 m intervenues en 1921, il y eut une croissance des champs de névé et l'avance d'un mince lobe de glace avant 1949 jusqu'à 4 573 m en 1950, puis le retrait dans les huit années qui suivirent à la vitesse d'environ 34 m par an, une nouvelle avance des champs de névé et d'une langue de glace jusqu'à 4 700 m en 1968 et enfin un épais glacier à deux lobes jusqu'à environ 4 600 m en 1978 et 1979. Une étude d'une crevasse de 37 ans montre un mouvement continue d'un champ de névé actif sur la face Nord-Ouest du cône.

**ZUSAMMENFASSUNG.** *Gletscherschwankungen im Neoglazial und in jüngster Zeit am Vulkan Popocatepetl, Mexiko.* Neoglaziale bis zu historischen und jüngsten Schwankungen des Firnfeldes und eines Gletschers am Popocatepetl, Mexiko, umfassen einen Vorstoss vor 1519 bis zu einem — möglicherweise mittneoglazialen — Stand auf dem flachen Nordflanken in 4 150 m Höhe, dann einen Rückzug talaufwärts bis 4 335 m um 1906 und bis 4 435 m um 1920 mit 7 m pro Jahr. Nach vulkanischen Ausbrüchen und Rückschmelzen bis etwa 4 800 m im Jahre 1921 trat ein Anwachsen des Firnfeldes und der Vorstoss einer dünnen Eiszunge vor 1949 ein, die um 1950 die Höhe 4 573 m erreichten. Es folgte ein Rückgang während der nächsten 8 Jahre um etwa 34 m pro Jahr, ein neuerlicher Vorstoss des Firnrandes als Eisbeule auf etwa 4 700 m um 1968 und als dicker, zweizüngiger Gletscher auf 4 600 m um 1978 und 1979. Die Beobachtung einer Spalte durch 37 Jahre zeigt eine ständige aktive Bewegung des Firnfeldes auf der Nordwestseite des Kegels an.

In 1954 White described the permanent firn field on the volcano Popocatepetl, Mexico, offered his observations of the precipitation regimen on the volcano, and recorded recent firn-field fluctuations through 1953; for additional details see White (1954). The purpose of this paper is to report changes over a longer time-span from possible mid-Neoglacial through 1979, and call attention to a recent glacier advance since 1968. Since 1954 Secretaría de la Defensa Nacional, Mexico, published accurate and useful topographic maps. In 1958 Lorenzo (1959, 1964) with a team of mountaineering geophysicists lived on the firn field and quite properly divided it into three small glaciers. Since 1953, trips by White to the volcano were in 1955, 1956, 1959, 1968, 1978, and 1979.

Glaciers that develop on Popocatepetl down-slope from the firn field are Glaciar Norte above the north volcano flanks, Glaciar del Ventorrillo above Barranca del Ventorrillo, and Glaciar Noroccidental above the west side cliffs (Fig. 1). In 1950 the lower limit of Glaciar Norte was estimated at about 4 800 m. Lorenzo (1964) recorded it on the convex north side of the cone down to 4 850 m in 1958, but he noted it was then only a glacier remnant. Using Lorenzo's map, Glaciar Norte, as he subdivided the firn field, was about 600 m long with gradient of 600 m/km, and covered about 200 000 m<sup>2</sup> of the cone (Fig. 2).

Glaciar Noroccidental, western counterpart of the glacier-like extensions of the firn field, became delineated as glacier in 1958 at 5 300 m. It ended above lava cliffs at 5 015 m, was 440 m long with gradient of 430 m/km, and occupied 120 000 m<sup>2</sup> of the cone.

Glaciar del Ventorrillo and its fluctuations are more significant in determining the history of the Popocatepetl firn field and glaciers. Neither 1942 oblique aerial photographs nor 1945 vertical aerial photographs show any prominent expansion of the firn edge as glaciers. But by July 1949 two distinct,

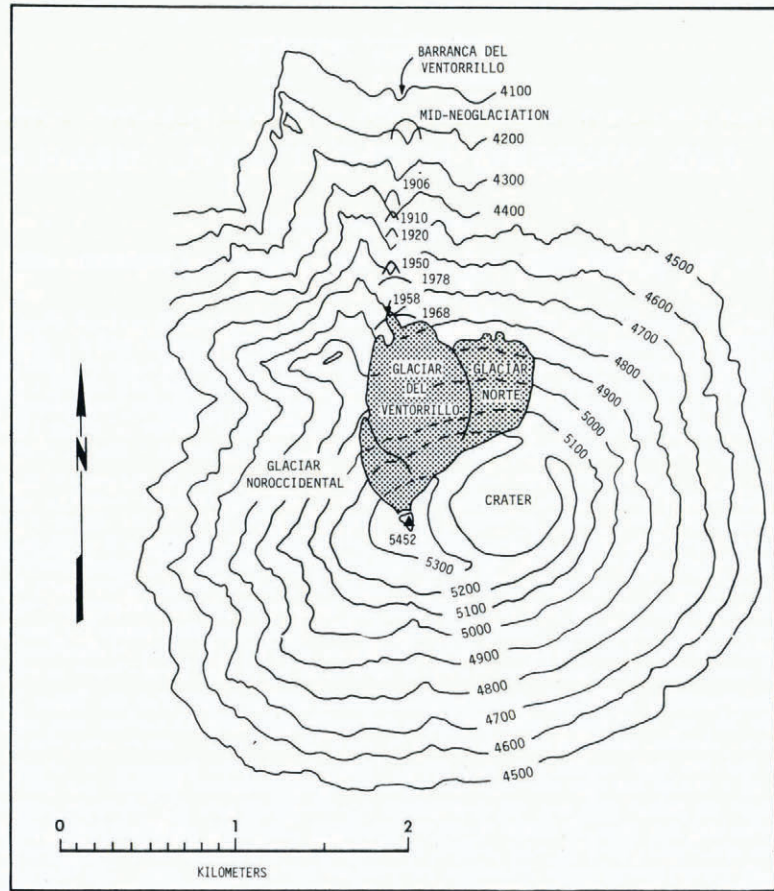


Fig. 1. Volcano Popocatepetl, Mexico, and positions of its three glaciers as of 1958, as mapped by Lorenzo. In Barranca del Ventorrillo, terminal positions of Glaciar del Ventorrillo are shown during a mid-Neoglaciation stage, and in 1906, 1910, 1920, 1950, 1958, 1968, and 1978.

small ice tongues extended into the head of Barranca del Ventorrillo (White, 1954, fig. 2). In August 1950 the lowest ice tongue was measured at 4 573 m, in May 1953 it had melted back 4 m in altitude, and in 1958 Lorenzo (1964) found it at 4 690 m. This is a recession of 117 m altitude over a distance of about 270 m, or a retreat rate of about 34 m/year in the eight years. After 1958 this lowest ice tongue disappeared. From Lorenzo's record (1964), the glacier above began below the north crater rim at about 5 200 m, was about 800 m long with 640 m/km gradient, and occupied about 400 000 m<sup>2</sup> of the cone (Fig. 2). This steep gradient pulls the ice apart into huge crevasses; on the cone above 5 030 m Glaciar del Ventorrillo was about 40 m thick in 1951, and about 30 m thick in 1958.

The firn field on Popocatepetl undoubtedly did not survive the post-Wisconsin Hypsithermal interval. Yet Toltec and Aztec sketches of the mountains depict much ice and snow on both Iztaccihuatl and Popocatepetl. Cortes' captains in 1519 had great difficulty in crossing the perpetual snows of the Popocatepetl cone. Packard (1886) stated that in 1885 a stream flowing in the largest valley on the north side was "fed by the snows of the peak". No stream flows there today even with the firn field above except on sunny days when it is melting. When Anderson (1917) climbed in 1906, he found a glacier in Barranca del Ventorrillo down to 4 335 m, as estimated from his photograph. Due to excellence of detail, photographs taken in 1910 by Hugo Brehme of Mexico City show the glacier at a position estimated to be 4 390 m. Melgarejo's photograph (1910, No. 2) taken from Brehme's photosite, discloses the glacier at this same altitude. Weitzberg (1923) pictures in 1920 the glacier at about 4 435 m just before volcanic eruptions in late 1920 and early 1921.



*Fig. 2. View of north side of Popocatepetl, Mexico. The firn field is above arcuate crevasses. Glaciar Norte is on cone under recent snowfall above leftmost tree. Glaciar del Ventorrillo is in upper center of photograph below crevasses as a double-lobed glacier moving into head of Barranca del Ventorrillo to about 4 600 m. Glaciar Noroccidental is on upper cone at right edge of firn field above sloping castellated rock crag. Photograph taken at 3 830 m, 23 March 1978, by Mary L. White.*

In addition, other distinctive photographs by Brehme in 1910 clearly reveal thick ice or firn at about 4 700 m on the west flanks of the volcano below high lava cliffs beneath Glaciar Noroccidental, and also at about 4 650 m on Popocatepetl due west of the highest summit peak, places where no ice or firn has existed at least since 1950 when the writer was there.

The 100 m recession in altitude of Glaciar del Ventorrillo from 1906 to 1920 agrees with field evidence of fresh glacial striations and polish on bedrock knobs down to 4 440 m, with weathered, partially disintegrated but striated bedrock knobs below 4 335 m and on down to 4 236 m (White, 1954). The position where Anderson found the glacier in 1906 may match the retreat from a late-Neoglaciation stadial position, the Arapaho Peak advance of the southern Rocky Mountains (Benedict, 1973). Furthermore, evidence of a still older glaciation, certainly prior to 1519 and possibly matching a mid-Neoglaciation stadial position, the Audubon advance of the southern Rocky Mountains (Benedict, 1973), exists where Barranca del Ventorrillo emerges from the steeper part of the cone. Here, and 100 to 200 m beyond to the gentler north flanks at 4 150 m, are glacially striated and grooved but weathered surfaces on lava flows, an end moraine almost crossing the floor of Barranca del Ventorrillo, an inner lateral moraine on the east side of this valley, and striated lava blocks in a now greatly-dissected alluvial fan north of the end moraine (White, 1954).

When Waitz (1921) climbed the mountain after the eruptions in early 1921, he saw the glacier still "well preserved" in Barranca del Ventorrillo and attributed this to its sheltered position and the thickness of volcanic sediments on this north-west side of the cone. Waitz estimated the glacier then reached about 4 800 m. How much of this recession from Weitzberg's 1920 position at 4 435 m is due to volcanic heat or hot ash fall is not known, but growth again down to 4 573 m by 1950 attests to a healthy positive budget for the 29 years since 1921. Rapid recession in the next eight years to 1958 of 117 m in altitude suggests a sudden change to a negative budget.

A similar negative budget, incidentally, is shown by glacier retreat on the next volcanic range to the north, Iztaccihuatl. Termini of three glaciers were measured by White (1956) in 1953 or in 1955, and all Iztaccihuatl glaciers were studied by Lorenzo (1964) and his team in 1959-60. Glaciar de Ayolotepito

retreated from 1953 to 1959–60 90 m in altitude about 125 m distance, or about 19 m/year. Glaciar de Ayoloco receded from 1955 to 1959–60 57 m in altitude over a 100 m distance, or about 22 m/year. From its position estimated at a Neoglaciation inner stadial moraine at 4 465 m (White, 1956, table 1) as seen in a photograph taken by Mexican geologists on 1 November 1898, this same glacier retreated 260 m in altitude about 810 m distance, or about 13 m/year in the 61–62 years. Glaciar Atzintli also retreated from 1953 to 1959–60 70 m in altitude over 140 m distance, or about 21 m/year. From other mountain climbers' reports, all Iztacchuatl glaciers are continuing to retreat.

Activity of the firn field on the cone above Glaciar del Ventorrillo is revealed by a 37 year study of the appearance and disappearance of crevasses. No crevasses showed in the firn in 1942 on the oblique aerial photographs. Vertical aerial photographs of November 1945 show only one crevasse about 225 m long. By July 1949 four crevasses about 300 to 400 m long and several smaller ones appeared. By August 1950 only two of the larger crevasses had not disappeared due to snow-fill. By May 1953 no new crevasses appeared and all old ones were nearly snow-filled. By April 1955 the small ice tongues of Glaciar del Ventorrillo retreated high onto the cone, the old but unopened crevasses of 1950 still showed, and a set of new short *en échelon* crevasses opened between Glaciar Noroccidental and the upper west edge of Glaciar del Ventorrillo. By August 1956 one new crevasse above the healed 1950 crevasses and four



Fig. 3. View of Glaciar del Ventorrillo on north side of Popocatepetl, entering head of Barranca del Ventorrillo to about 4 600 m. Terminus is about 70 to 100 m thick. Photograph reveals ice stratification and ice fall and crevasse area due to severe glacier draw-down, taken 23 March 1978, by Mary L. White.

new ones opened up in the head of Glaciar del Ventorrillo, and the 1955 *en echelon* set were being snow-filled. Also in 1956 the firn edge above the position where the small ice tongue had been since 1949 was so thin, many rock ledges showed through. The set of *en echelon* crevasses between Glaciar Noroccidental and Glaciar del Ventorrillo appear in Lorenzo's 1958 photograph (1964, fig. 31). By November 1968 three partially snow-filled crevasses on the north crater rim and one several tens of meters lower down had formed above Glaciar del Ventorrillo. As a result of this crevasse study, no doubt should exist as to the continual activity of the firn field and the importance of that 640 m/km gradient on the north-west side of the cone.

The most significant change, however, that occurred in the ten years since 1958 is the growth of a thick bulge of ice into Barranca del Ventorrillo over the former site of the small 1949–58 ice tongue. From the 1968 photographs, its lower limit is estimated at about 4 700 m and its thickness at about 30 to 40 m. By March 1978, however, this ice bulge became a broad lobed glacier (Figs 2 and 3), probably 70 to 100 m thick, and extending across the north-west side of the cone and down into Barranca del Ventorrillo as a double-lobed glacier at about 4 600 m. Stratification of the ice reveals at least ten layers (Fig. 3). In the ten years since 1968, strong draw-down by this double-lobed glacier produced above its head four to five deep wide crevasses and a chaotic ice fall of seracs on the cone. In August 1979 the sides of this double-lobed glacier appear as 50 m high vertical cliffs, except where the lowest lobe projects as a steep ramp into Barranca del Ventorrillo. Several tens of meters below the crater rim, another new long crevasse cut across the cone in 1979.

In summary, the most measured and photographed glacier, Glaciar del Ventorrillo, has had so far the following fluctuations: advance prior to 1519 to a possible mid-Neoglaciation stadial position at 4 150 m; then retreat to 4 335 m in 1906, to 4 390 m in 1910, and to about 4 435 m by 1920, a loss of 100 m altitude or 7 m/year in the last 14 years. Following interruption by volcanism and melting to about 4 800 m in 1921, advance of a thin ice lobe to White's 1950 position, then retreat of 117 m altitude to Lorenzo's 1958 position or about 34 m/year. Re-advance of the firn edge to become a thick bulge of ice at about 4 700 m by 1968, and continued advance and thickening as a double-lobed glacier at about 10 m/year to about 4 600 m by 1978. Growth is continuing in 1979. Fluctuations of firn field and glaciers on Popocatepetl, therefore, disclose local and regional average weather conditions over short spans of time with little or no lag time, becoming thus a short-term climatic thermometer.

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