CHARACTERIZATION OF A TROPICAL ICE BODY ON IZTACCÍHUATL VOLCANO, MEXICO

Román Alvarez
IIMAS-UNAM, Circuito Exterior, CU, México DF, 04510
rab@leibniz.iimas.unam.mx

and

Hugo Delgado
Instituto de Geofísica, UNAM, Circuito Exterior, CU, México DF, 04510
hugo@tonatiuh.igeofcu.unam.mx

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ABSTRACT

In the last century ice bodies have changed significantly worldwide in response to climatic changes, apparently enhanced during the last decades, presumably owing to anthropogenic influence. Shrinkage of glaciers in the northern latitudes has been extensively documented; however, the behavior of glaciers in tropical or inter-tropical latitudes has been difficult to document. In Mexico, small glaciers are present in the highest mountains: Citlaltépetl (5675 m), Popocatépetl (5452 m) and Iztaccíhuatl (5286 m), all of them volcanoes. The glaciers of Mexico offer important clues about climate change at this latitude. Current inventory and monitoring of Mexican glaciers includes determination of glaciated areas and volumes. A survey has been carried out using ground-penetrating radar in order to get a figure of thickness and a preliminary volumetric estimate of an ice body of Iztaccíhuatl volcano named Ayoloco glacier. A radar profile 415 m in length was obtained at a mean altitude of 5000 m with an azimuth of 190º, in a relatively flat area known as *La Panza* on top of the mountain. 100 Mhz antennas were used in the reflection mode with a separation of 2.5 m and a step-size of 2.5 m. A common mid-point survey was performed comprising 12 stations, at 0.5 m steps, to determine the wave velocity propagation in the ice-rock mixture that constitutes the glacier. Results yield a value of 0.17 m/ns, which is close to the reported value for ice of 0.16 m/ns. We find a layered structure perturbed by faulting at various inclinations, and an interface between the glacier and the underlying rock along a concave surface, shallow at the profile's extremes. There appears to be a transition at 50 m depth, from brittle to ductile ice. Since Iztaccihuatl volcano has many craters near the summit, we infer that this profile reveals the shape of one of the craters, which has been filled by the glacier's ice and a mixture of rock fragments and volcanic debris. The estimated upper volume of the Ayoloco glacier is 10.04 x 10^6 m^3; this figure will have to be revised when more, perpendicular GPR transects are performed.

INTRODUCTION

The study of glaciers is crucial to understand climate variations and have a strong applicability in hazard assessment. During the last decades glaciers worldwide have experienced strong retreat. Several reasons have been argued to justify ice retreat high-latitudes (Oerlemans, 1994). However, not much has been done at tropical or equatorial latitudes. In this context, Mexican glaciers are unique since they are the only ice bodies at 19° N latitude and thus, the glaciological information they may provide have a large importance to understand the climate variations at tropical latitudes.

On the other hand, the inventory of ice bodies is needed to evaluate the amount of water contained as ice on the mountains. This is very important at ice clad volcanoes since the interaction among ice and pyroclastic material during eruptions may produce a series of debris-yielded flows so called lahars, potentially dangerous. The destruction of the town of Armero, Colombia in 1985 recalled strong attention from glaciologists and volcanologists regarding the hazard glaciers pose during eruptions. It is necessary to know the areal extent of glaciers and its depth distribution, in order to carry out volumetric estimates.

In Mexico three mountains (volcanoes) host ice bodies at their summits: Citlaltépetl, Popocatépetl, and Iztaccíhuatl (Figure 1). Lorenzo (1964) described all the Mexican glaciers and estimated for the first time the area of each ice body. More recently, Delgado (1997) and Huggel and

Delgado (1999) documented the extent of the glaciated areas of Popocatépetl volcano as well as a strong retreat at Popocatépetl volcano's glaciers due to climatic effects, as well as volcanic activity influence. Those glaciers are considered currently extinct and evaluations of other Mexican glaciers become of major importance. Nevertheless, none of the previous studies reported good estimates of the volumes of ice owing to the difficulty to measure its thickness. This work is a preliminary estimate of the ice volume of one of the glaciers of Iztaccíhuatl volcano (Ayoloco), by profiling a cross-section using a ground penetrating radar (GPR).

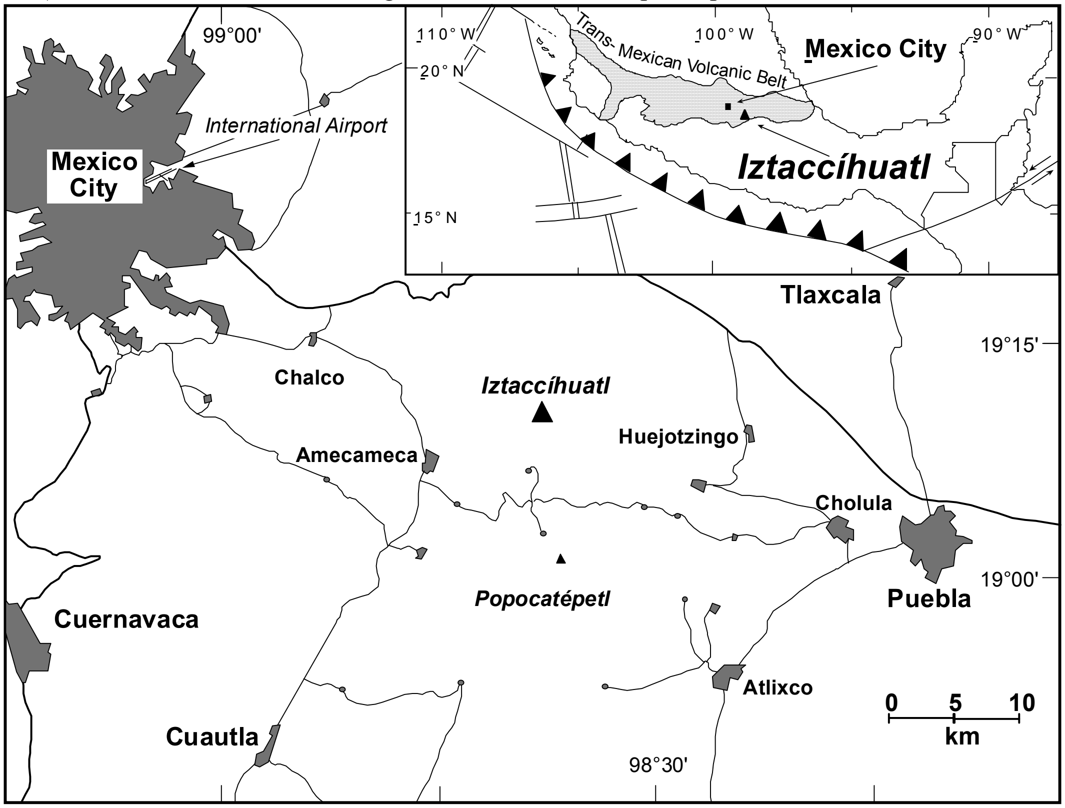

Fig. 1. Location of Iztaccíhuatl volcano in Central Mexico.

GEOLOGICAL DESCRIPTION

Iztaccíhuatl (White Woman in ancient Nahuatl language) is a large Pleistocene stratovolcano located 50 km east of Mexico City (Figure 1). It is in fact a volcanic complex developed since 1.7 Ma BP (Nixon, 1987). A series of lava flows and pyroclastic material of dacitic and andesitic composition built up the volcano. The last eruptive activity occurred at 5000 yr BP (Siebe and others, 1985). Superposition of the volcanic material and development of the different volcanoes that made up the complex resulted in a very particular morphology consisting of a lying human female shape, and therefore the names of geographical sites are referred as parts of a female body.

The present study was made at *La Panza* (the abdomen) of the volcano, at an altitude of 5000 masl. The measured profile was made at the top of the Ayoloco glacier where few longitudinal and shallow, commonly less than 2 meters deep, crevasses are found. However, narrow crevasses, 1-2 m in width, develop in the study area sometimes reaching several meters in depth. Some crevasses can be appreciated in the aerial photograph of Figure 3b.

Glaciers of the region are strongly affected during the dry season by sublimation producing a strikingly irregular surface. Thus, thickness measurements should be done at the end of the accumulation season or at the beginning of the ablation season. Measurements were performed in March, which is the dry part of the year in this region of Mexico.

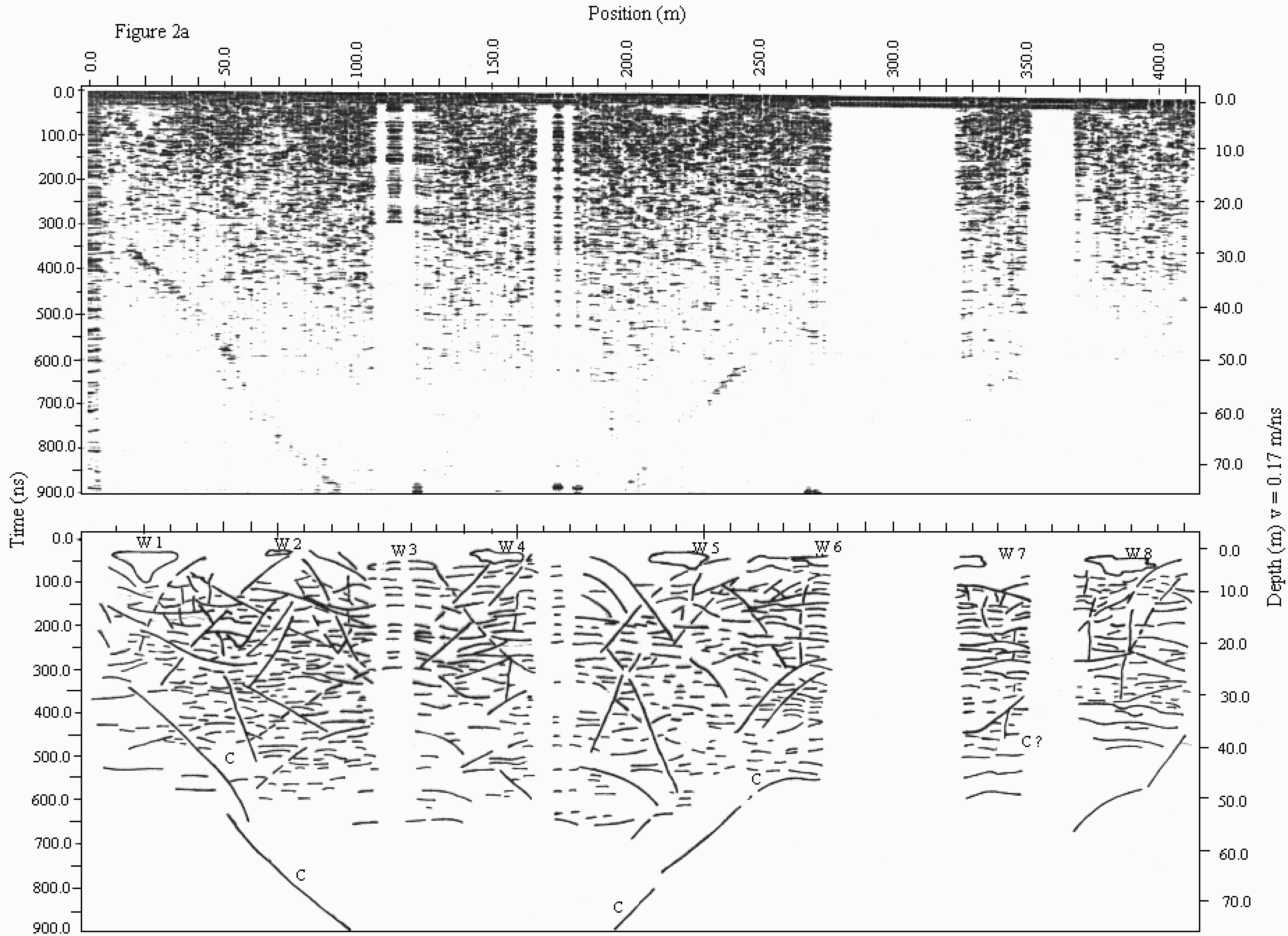

Figure 2a
Position (m)
Time (ns)
Depth (m) v = 0.17 m/ns
W 1
W 2
W 3
W 4
W 5
W 6
W 7
W 8
C
C ?

Figure 2b

Glacier monitoring in Mexico

Since the mountains hosting glaciers in Mexico are all volcanoes, it is crucial to understand the interactions of ice bodies with the volcanoes previous to eruptive phases. Current work is addressed to update the inventories of glaciated areas at the Mexican volcanoes. This inventory should include a volumetric estimate in order to better assess hazards associated with the sudden melt of ice during eruptions.

GLACIER PROFILING WITH GPR

Profiling of glaciers has been one of the most successful applications of the GPR. This is due to the signal contrast among low-density material such as ice (less than 1 g/cm^3) as compared with volcanic rocks (commonly 2.5-3 1 g/cm^3) for instance. For this reason, GPR profiling was chosen for the task of determination of glacier thickness by using an Ekko IV radar system.

Profile description

A radar profile of 415 m in length with orientation of 190° in azimuth was carried out using 100 Mhz antennas in the reflection mode, with a separation of 2.5 m and a step size of 2.5 m; signal-recording time was from 0 to 900 ns. No crevasses were intersected along the profile line.

A common mid-point (CMP) survey was performed containing 12 stations, at a separation of 0.5 m, to determine the wave velocity propagation in the glacier's ice. Results yield a value of 0.17 m/ns, which is close to the reported value for ice of 0.16 m/ns (e.g., Arcone et al., 1998). The antennas were in close contact with the ice cover. Figure 2a shows the radargram obtained along the profile. Saturation correction, first break point correction, and first break shift were applied. The average trace has been subtracted from all the record in order to enhance dipping layers. A constant gain of 5.0 was applied. Data have been suppressed at various intervals, since the radar response contained spurious signals at those locations.

INTERPRETATION

Figures 2a and 2b show the GPR profile and its interpretation. The profile can be described in general as a layered medium with thin surface layering (0.3-0.5 m), and thicker layering (1.5-2.0 m) underneath, which is perturbed by faulting at various inclinations. The response can be roughly divided in three sections: from the surface to 10 m, from 10 to 50 m, and below 50 m. The former shows eight, near-surface areas (W_1-W_8), no deeper than 5 m, where the signal amplitude is small. These are thought to be shallow water pockets; some were observed at the surface, in the vicinity of the profile line. Small thickness layering is observed in this section.

The second section, from 10 to 50 m, shows thicker layers which dip gently towards the south. The layers are well developed at 10-15 m depth at the northern tip of the line, and are also observed at depths of 20-30 m. A series of fractures and faults are observed dipping mainly to the north at angles close to 45°. They start near the surface, cut the layers, and die out at depths of 30 to 50 m. Some are listric faults. This region behaves as brittle ice and the deepest crevasses have roots into here. At the southern tip of the profile, beneath the bottom of the glacier, a series of layered structures are also observed, these are probably layers of volcanic material.

The third section is thought to be related to the presence of ductile ice since fractures are absent here. A transitional region from the brittle to the ductile ice is inferred under locations 60 to 230 m, at 50 m depth. Projection of the glacier-bedrock interface, marked as C, suggests a depth of approximately 85 m at location 150 m. The geometry resembles the shape of a small volcanic crater, that has been filled by ice and an ice-rock mixture. As mentioned above, Iztaccíhuatl volcano has many volcanic craters at the summit.

Since the survey line was bounded by rock outcrops at both ends, the crater's length must be close to the size of the line (i.e., ~500 m). This geometry allows for a preliminary estimate of the volume of the ice body of the Ayoloco glacier.

Figure 3a shows the snow clad volcano Iztaccihuatl with a line representing the GPR transect and the approximate extent of the Ayoloco glacier; this is an ASTER satellite image (e.g., Smailbegovic et al., 2000) dated September 6, 2000, band 01 corresponding to the visible, and with a spatial resolution of 15 m. The extent of the Ayoloco glacier was estimated from the topographic map of INEGI (1982); the central N-S dimension is close to the surveyed line and the lateral geometry is assumed from the local topography. Using this information we obtain a glaciated area of 25.1 ha or 251,000 m^2. To calculate the volume, and based on the GPR depth information, we consider upper and lower average depths of 40 and 20 m, respectively. The resulting limits for the volume are 10.04 x 10^6 and 5.02 x 10^6 m^3. The measured ice density is 0.9 g/cm^3, yielding thus equivalent water contents of 9.04 x 10^9 and 4.52 x 10^9 liters of water trapped in the glacier. These preliminary figures should be revised once additional GPR transects across the glacier are available.

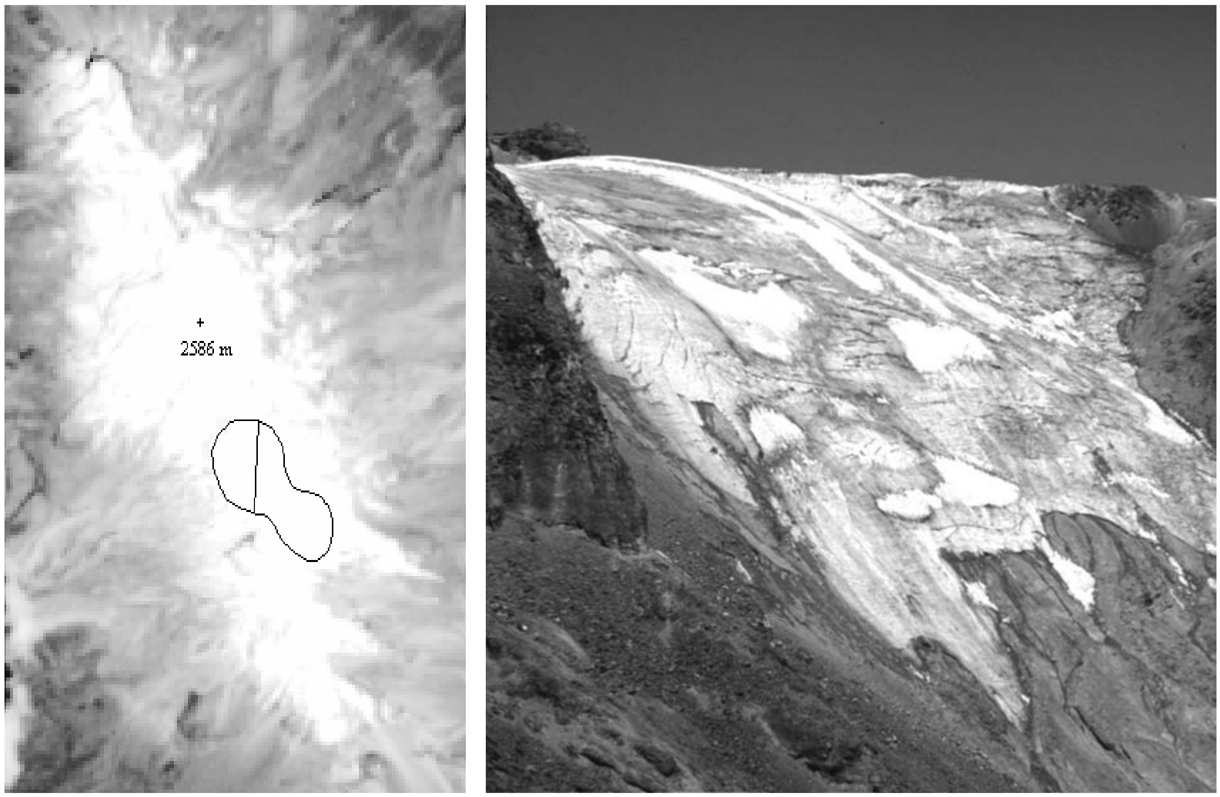

Fig. 3. a) ASTER image of Iztaccihuatl snow clad area showing the GPR line (N-S) and a polygon representing the approximate extent of the Ayoloco glacier. b) View of the glacier from a helicopter. The view is towards the southeast.

REFERENCES

Arcone, S.A., D.E. Lawson, A.J. Delaney, J.C. Strasser, and J.D. Strasser, 1998.Ground-penetrating radar reflection profiling of groundwater and bedrock in an area of discontinuous permafrost. *Geophysics*, **63**, 1573-1584.

Delgado, H., 1997 (1996), The glaciers of Popocatépetl volcano (Mexico): Changes and causes, *Quaternay International*, **43/44**, 53-60.

Huggel, C. and H. Delgado, 2000. Glacier monitoring at Popocatépetl volcano, Mexico: glacier shrinkage and possible causes. *In*: Hegg, C., Vonder Muehll, D. (Eds.): Beitraege zur Geomorphologie, Proceedings der Fachtagung der Schweizerischen Geomorphologischen Gesellschaft vom 8-10 Juli 1999 in Bramois (Kt. Wallis), Birmensdorf, Eidgenoessische Forschungsanstalt WSL, 97-106.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1982, Mapa Topográfico del Iztaccíhuatl, scale 1:20,000.

Lorenzo, J. L., 1964, *Los Glaciares de México*. Monografías del Instituto de Geofísica, **I**, 123 pp. Universidad Nacional Autónoma de México

Nixon, A. G., 1989, The geology of Iztaccíhuatl volcano and adjacent areas of the Sierra Nevada and Valley of Mexico, *Geol. Soc. Am., Special Paper 219*, 58 p.

Oerlemans, J., 1994. Quantifying Global Warming from the Retreat of Glaciers. Science, Vol. 264, 8 April, 243-245.

Siebe, C., M. Abrams, and J. L. Macías, 1995, Derrumbes gigantes, depósitos de avalancha de escombros y edad del actual cono del volcán Popocatépetl, *In*: Volcán Popocatépetl, Estudios Realizados Durante la Crisis de 1994-1995, pp. 195-220. Centro Nacional de Prevención de Desastres y Universidad Nacional Autónoma de México.

Smailbegovic, A., J.V. Taranik, R.G. Vaughan, and F.A. Kruse, 2000. Geological utilty of ASTER, MASTER, TIMS and SEABASS multiband thermal data. Proc. Fourteenth Int. Conf. Applied Geologic Remote Sensing, 141-149. ERIM, Michigan.