

An Ice Thickness Study Utilizing Ground Penetrating Radar on the Lower Jamapa Glacier of Citlaltépetl (El Pico de Orizaba), Mexico. S. B. Brown¹, B. P. Weissling² and M. J. Lewis³, ^{1,2,3}Department of Earth and Environmental Science, University of Texas at San Antonio, 6900 N. Loop 1604 W., San Antonio, Texas, 78249, ¹stephen.brown@utsa, ²bweissli@lonestar.utsa.edu, ³mjlewis@satx.rr.com.

Introduction: Citlaltépetl (Pico de Orizaba) is a dormant stratovolcano located at the eastern end of the trans-Mexican Volcanic Belt at approximately 19 degrees of latitude (Figure 1). It is one of the largest stratovolcanos in the world and at 5,630 meters above sea level, the highest mountain in Mexico and the third highest in North America. Situated on the summit cone and north face of the volcano is a permanent ice cap known as the Jamapa Glacier.



Figure 1. Citlaltépetl and the Jamapa Glacier viewed from the northwest.

Recent and historical studies of Citlaltépetl have been based primarily on volcanic risk assessment (Zimbelman, et. al., 2004), in particular stability assessments of the summit cone. Relatively little work has been directed toward the glacial environment of the mountain, possibly due in part to its high altitude, steep slopes, and general inaccessibility. In addition to this glacier's potential to contribute to a better understanding of climate change, the Jamapa glacier and its environmental, cryologic and geologic setting could also serve as a valuable terrestrial analog to studies of Martian geology, hydrology, and subsurface ice.

Methodology: A Geophysical Survey System, Inc. (GSSI) SIR-3000 GPR utilizing a 400 MHz antenna was used to survey three sampling transects on the lower Jamapa Glacier. Twenty-six samples were collected as static points over a run of approximately 1 kilometer. GPR sampling time at each point was approximately 10 seconds. All transect positions were calculated using a Trimble GeoExplorer III Global Positioning System (GPS) receiver collecting autonomous data in a WGS 1984 datum (Figure 2.).

Transect A began at latitude 19.040213431, longitude -97.268328676 at an altitude of 5026 meters

MSL. Transect A ended at latitude 19.039190296, longitude -97.272958227 at an altitude of 5132 meters MSL. The total length of Transect A was approximately 562 meters. Fifteen GPR samples were taken along this transect (Figure 2.).

Transect B, an ascending transect, began at latitude 19.039190296, longitude -97.272958227 at an altitude of 5132 meters MSL. Transect B ended at latitude 19.037365658, longitude -97.272963897 at an altitude of 5206 meters MSL. Five GPR samples were taken along this transect including the end and start points of transects A and C. The total length of Transect B was approximately 184 meters (Figure 2.).

Transect C began at latitude 19.037365658, longitude -97.272963897 at an altitude of 5206 meters MSL. Transect C ended at latitude 19.037136685, longitude -97.269668900 at an altitude of 5219 meters MSL. Eight GPR samples were taken along this transect. The total length of Transect C was approximately 352 meters (Figure 2.). Rapidly deteriorating weather conditions dramatically reduced the number of GPR positions sampled during this study.

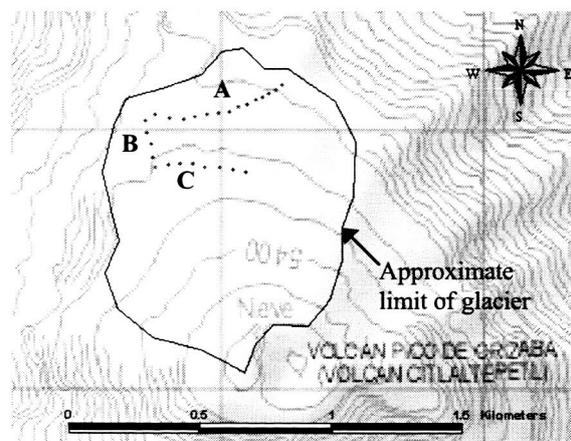


Figure 2. Location of sampling point along transects A, B, And C with approximate limit of the Jamapa Glacier.

Results: The 400 MHz antenna provided a source frequency suitable for ice profiling and was appropriately sized for portability at high altitude. Interpreted GPR results, as ice thickness in meters, based on a dielectric constant of 3.5 are presented in Table 1.

Transect A yielded generally excellent data (Figure 3) with strong ice base/bedrock radar returns up to 21 meters in depth. Transect B and the beginning of transect C (Figure 2) were problematic in that the expected ice base returns were obscured either by a low-frequency "ringing" noise or by strong internal reflections.

GPR Point	Transect	Ice Thickness (m)
1	A	< 0.5
2	A	2.04
3	A	5.02
4	A	(a)
5	A	10.09
6	A	9.30
7	A	13.28
8	A	14.95
9	A	15.65
10	A	15.61
11	A	20.92
12, 13	A	(b)
14	A	13.58
15 - 21	B, C	(b)
22	C	15.36
23	C	17.44
24	C	14.25
25	C	12.87
26	C	15.51

Table 1. Ice thickness in meters at each sampling point along Transects A, B and C. Note: (a) record length was insufficient to reach base of ice, (b) low frequency and "ringing" noise confounded data interpretation.

Discussion: As substantiated in numerous research studies since the mid-century, ground penetrating radar is a superior tool for sub-surface studies in glacial environments. High altitude glacial environments are often difficult to assess due to a number of logistic challenges including unpredictable weather, remote locations, and climbing contingencies. The results of this study indicated surveys performed under these extreme conditions can be used to profile glacial ice and to determine ice thickness. What the authors initially construed as noise in samples along transect B might in fact be legitimate radar returns from a different glacial stratigraphy not seen in transect A and the latter part of transect C, perhaps caused by ash layers from the last recorded eruption in the 17th century. It has long been assumed that the glacier and ice cap of Citlaltépetl was destroyed in the 17th century eruption -

however, it is possible that a portion of the glacier survived and was encapsulated by ash.

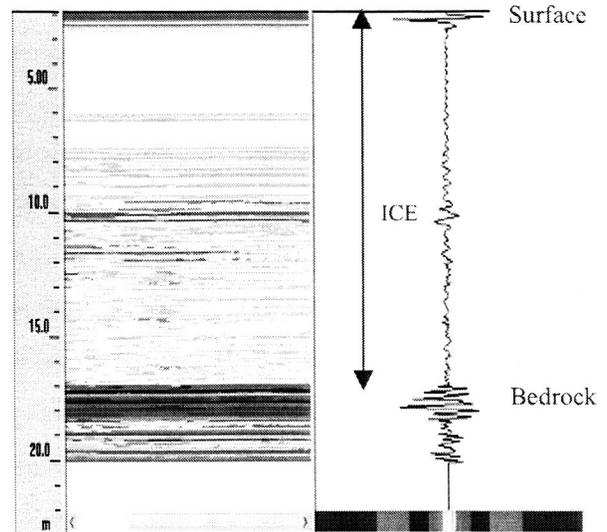


Figure 3. Figure (at right) represents one oscilloscope trace from a collection of scans (at left) recorded at sample point 8. At this location, ice thickness was determined to be 14.95 meters based on an ice dielectric constant of 3.5.

Future Research: A more extensive GPR survey of Citlaltépetl is planned for the Spring of 2005. The 2005 expedition will include surveys of the upper Jamapa Glacier and will utilize more traditional continuous surveying techniques rather than the static point system utilized in this study. If logistically feasible, a lower frequency antenna will be used for greater penetration. Of particular interest is whether the glacier is underlain by solid bedrock or by ash deposits and, if the latter, do those deposits conceal a relict ice mass. The logistical and technical experience gained in this and future surveys could well be useful in other high altitude and remote location glacial studies.

References:

Zimbelman, D. R., Watters, R.J., Firth, I. R., Breit, G. N., Carrasco-Nunez, G. 2004. Stratovolcano stability assessment methods and results from Citlaltépetl, Mexico. *Bulletin of Volcanology* 66: 66-79.

Acknowledgements: The authors wish to thank the following organizations and individuals for their contributions to this project: Exploration Instruments, American Alpine Club, Trimble Navigation, Arturo Ortiz, Tobin Martin, Subsecretaria de Protección Civil, Estado de Veracruz, Augustine Morales, and Manuel Pallares.