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The late-glacial moraine sequences in Mexico: is there evidence for the Younger Dryas event?

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Abstract

Geomorphologic, paleopedologic, tephrostratigraphic, and palynologic investigations together with radiocarbon dates provide ages for several late Quaternary glacier advances on the volcanoes of central Mexico. On the volcanoes La Malinche, Nevado de Toluca, and Iztaccíhuatl, glacier advances have been dated older than 12,000 yr B.P. and between about 10,000 and 8500 yr B.P. The glacial chronostratigraphies from different volcanoes do not indicate a Younger Dryas glacial advance. During the late Quaternary phases with glacier advances can be correlated to changes in Laurentide ice sheet meltwater discharge into the Gulf of Mexico on the one hand and into the North Atlantic Ocean on the other hand. The central Mexican glacial history shows a regional pattern that is different from that of the Rocky Mountains or the South American Andes.

1. Introduction

To test the global relevance of the classical late Weichselian climatic fluctuations of Western and Central Europe many scientists tried to establish chronostratigraphies of climatic variations for other parts of the world. Recent investigations, however, from many different parts of the world, lend support to the supposition that the classical late Weichselian European chronostratigraphy in many aspects is a regional stratigraphy and thus cannot uncritically transferred to other areas of the world.

Of especial interest in global paleoclimate research are the tropics and subtropics and their response to climate change. Here I will present the results of investigations carried out during the last 25 years in the central Mexican highland.

Studies on Mexican glacial sequence were published by White (1962, 1986), White and Valastro (1984) and White et al. (1990), and based on comprehensive research on the volcanoes La Malinche, Pico de Orizaba, Iztaccíhuatl, Popocatépetl and Nevado de Toluca by Heine (1975, 1984a, b, 1988a, 1989) (Fig. 1). Several late Quaternary moraine sequences can be recognized for each volcano within the area. The slopes of the volcanoes are dissected by erosion gullies (barrancas) which show the stratigraphic position of the moraines and tills and their relation to periglacial deposits, paleosols, debris flows, fluvial gravels, fluvial sands, loess-like so-called "toba" sediments, lava flows, ignimbrite deposits, and tephra. Different tephra layers as well as specific paleosols are useful stratigraphic markers in the late Quaternary deposits. To determine the stratigraphic sequence of tephra, both field characteristics and laboratory analyses were carried out. Radiocarbon dating of tephra layers was restricted to woody materials imbedded in the volcanic deposits. In addition wood fragments contained in gravel layers, peats, and calcrete deposits were

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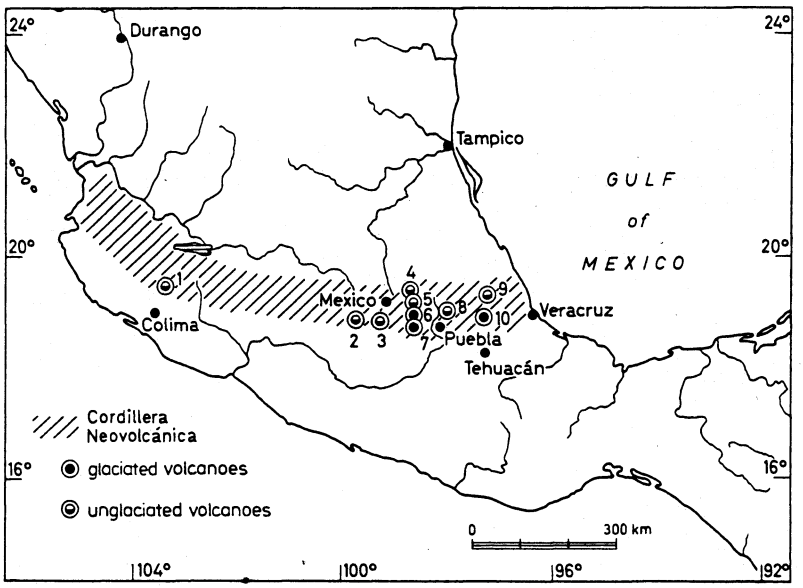

Fig. 1. Location of the volcanoes mentioned in text. *1* = Nevado de Colima (4180 m); *2* = Nevado de Toluca (4558 m); *3* = Ajusco (3952 m); *4* = Tláloc (4160 m); *5* = Telapón (4200 m); *6* = Iztaccíhuatl (5286 m); *7* = Popocatépetl (5452 m); *8* = La Malinche (4461 m); *9* = Cofre de Perote (4282 m); *10* = Pico de Orizaba (5700 m).

dated by radiocarbon. All radiocarbon dates are given as conventional ^{14}C ages. In some cases also archaeologic data were used for age correlation of late Quaternary deposits. Relative age-dating methods were used to demonstrate age difference in the till sequence. Such relative dating methods include topographic position, morphologic shape of the moraines, rock weathering parameters, thickness of eolian "toba" sediments, soil properties, and vegetation cover. Pollen analyses in sediment cores from small volcanic craters, maars, and lakes covering the last 35,000 years were used for paleoclimatic inferences (Straka and Ohngemach, 1989).

2. Late glacial moraines and tills (15,000–8500 yr B.P.)

2.1. La Malinche volcano

A sequence of late Quaternary lateral and terminal moraines is exhibited in Barranca Colorado on the western slopes of the La Malinche volcano (Fig. 2). The moraines of group M III are dated between 12,000 to 8500 yr B.P. based on tephra correlation. The underlying rB pumice marker horizon and the M II debris layer (Fig. 3) give the maximum age of 12,060±165 yr B.P. (Hv 4244) and the overlying tephra layers a minimum age of 8240±300 yr B.P. (W-1909). After the deposition of the rB pumice at about 12,000 yr B.P., "toba" sediments document a phase of eolian influence. This phase ended with the development of a soil (Typic Hapludand); this phase of soil forming is wide-spread and recognized all over central Mexico. These fossil soils (fBo2, see Heine, 1975) developed between 12,000 and 10,000 yr B.P. Based on extensive field observations and sedimentation rate calculations of the "toba" deposits as well as of an estimation of the time needed for the fBo2 soil development (Heine, 1975), the glacial advance of the group M III moraines was estimated to have occurred after circa 10,000 yr B.P.

The moraines of group M III can be attributed to three individual advances. The moraine M III 1 is separated from the moraine M III 2 by a thin layer of pumice and "toba" material and a weakly developed A_h soil horizon. The moraines of group

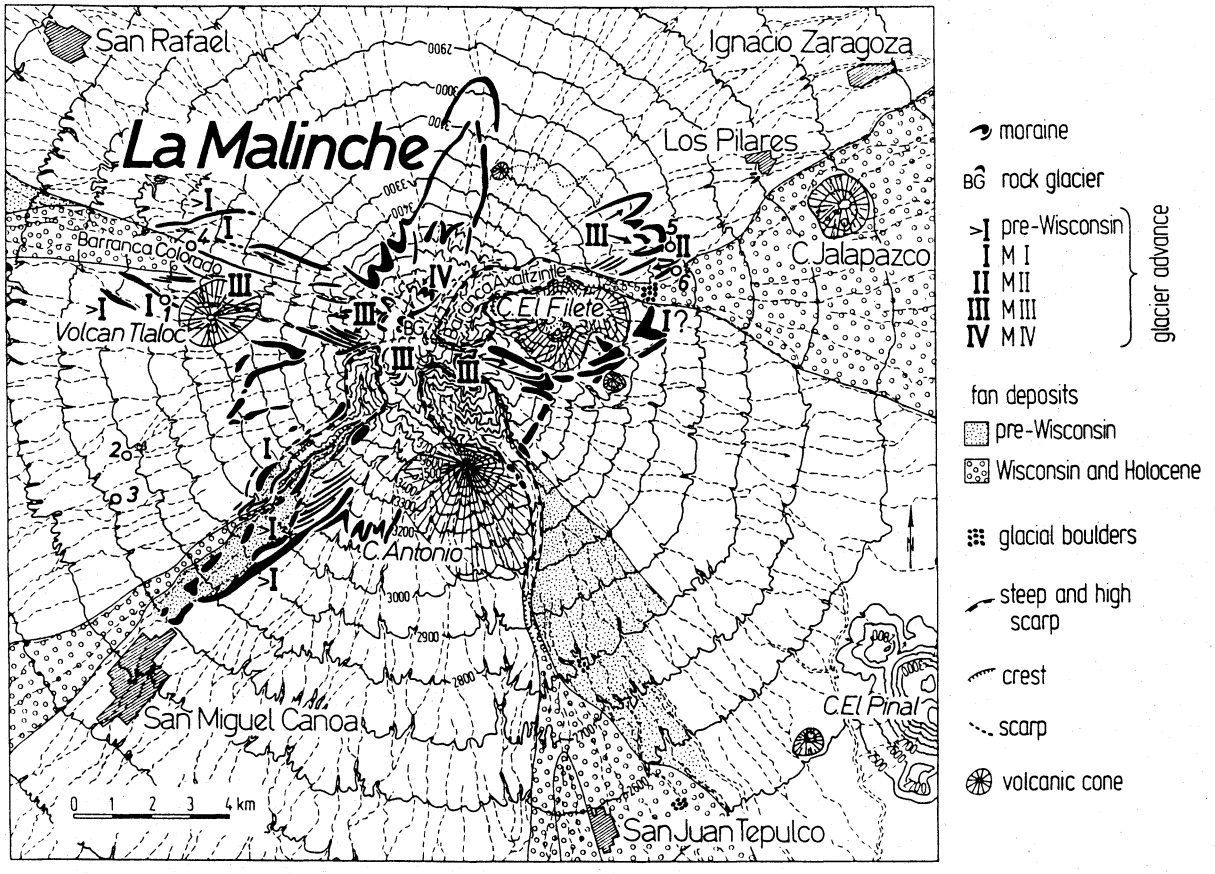

Fig. 2. La Malinche volcano. Glacial geomorphology. The sections of Fig. 3 are indicated by circles (*1–6*).

M III 2 are divided into two different till layers, again with a weakly developed A_h horizon on top of the older till. According to investigations on age-dependent formation of andosols at different altitudes and on different material (Miehlich, 1991) the soil forming period of the fossil soils interbedded in the group III moraines could only have taken a short time (some tens of years), whereas the formation of the fossil soil underneath the moraine M III 1 must have lasted a minimum of 500 years.

On the eastern slopes of La Malinche volcano, the terminal moraines of group M III are found often at about 2930–3000 m a.s.l. An erosional cut in the tills of the moraine M III 2 show the glacial sediments and their correlation to fossil soils and different tephra horizons (Fig. 3). The moraine material is unweathered and overlain by toba. A weakly developed brown-earth soil of half a meter thickness was formed after the retreat of the glaciers and before the eruption of the volcanic tephra. Estimating the weathering thickness of the toba/debris sediments overlying the moraine and ^{14}C ages of the tephra layers the retreat of the glaciers occurred not earlier than approximately 1000 years before the fall of the volcanic breccia, pumice, and ashes. Therefore, we assume that the M III glacier advances happened during the early Holocene between roughly 10,000 and 8500 yr B.P. For further details see Heine (1975, 1988a) and Heine and Ohngemach (1976).

2.2. Nevado de Toluca volcano

The geomorphologic map of the summit area of the Nevado de Toluca volcano (Fig. 4) shows

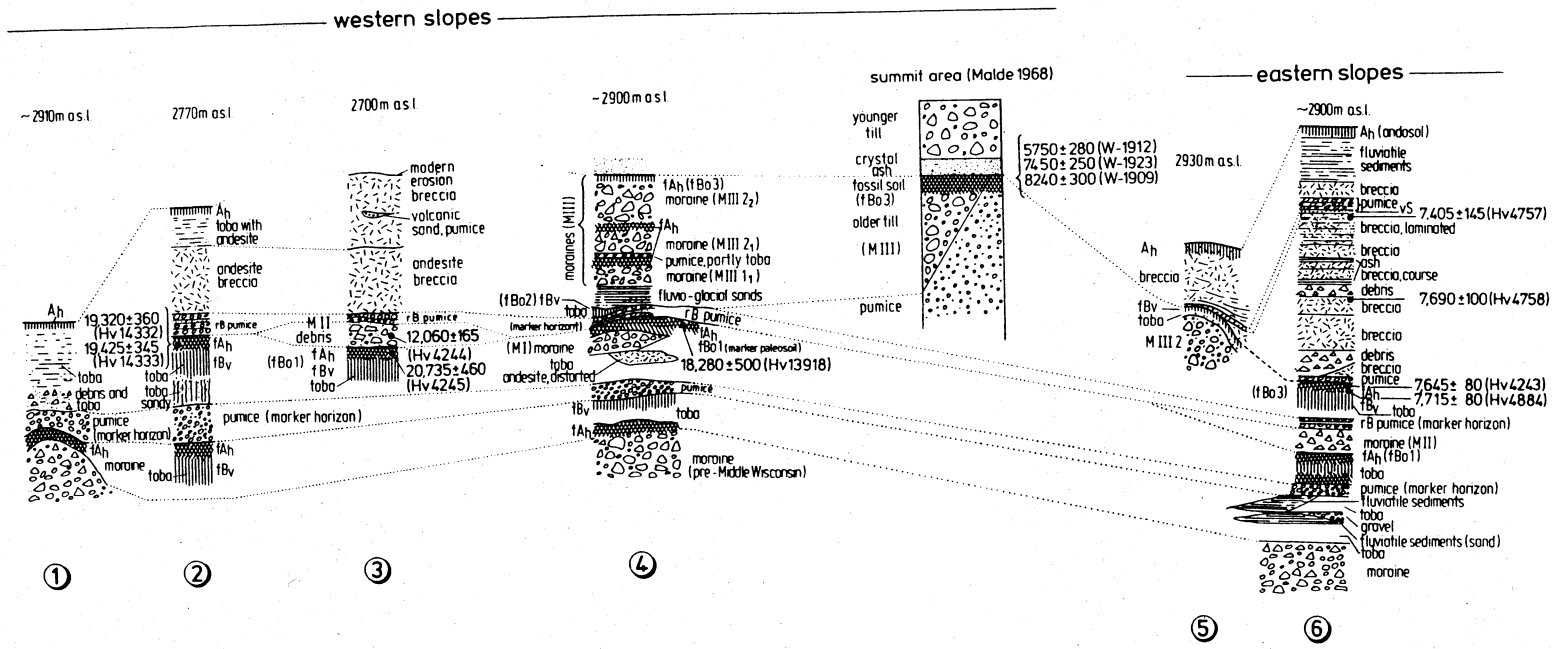

Fig. 3. La Malinche volcano. Late Quaternary sediments and tephrostratigraphic correlations.

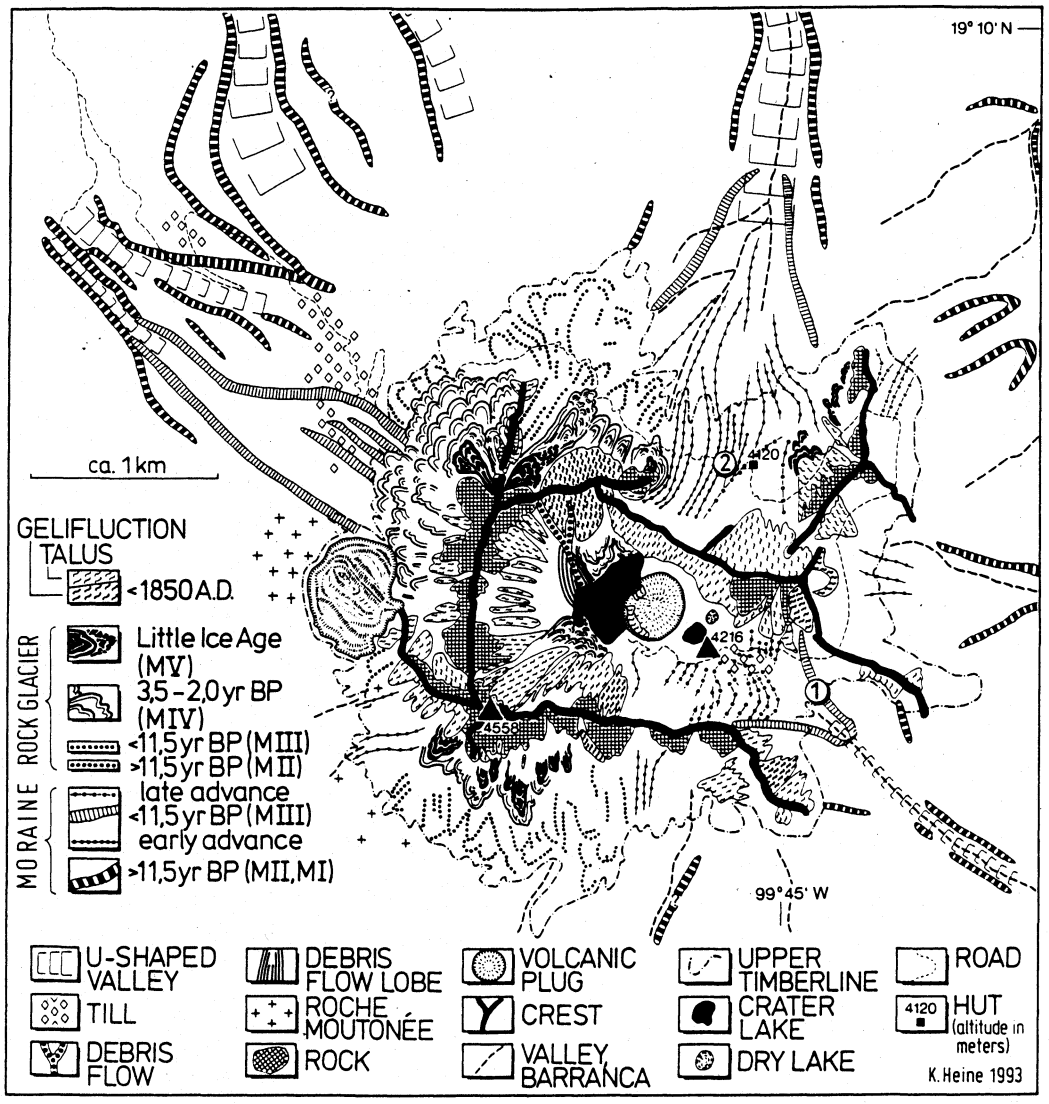

Fig. 4. Nevado de Toluca volcano. Glacial and periglacial geomorphology. The sections of Fig. 5 are indicated by circles (*1* and *2*).

several moraine systems. The moraines of group M III are developed on the northwestern, northern and southeastern slopes. Apart from the northwestern slopes where Holocene rock glaciers override the recessional moraines of group M III, many small recessional moraine walls are found between the M III terminal moraines and the summit areas of the volcano.

Tephrostratigraphic investigations document, that the moraines of group M III are underlain by a characteristic yellow-brown pumice/lapilli layer that can be traced all over the Nevado de Toluca volcano (Fig. 5). This layer is the result of a violent Plinian-type eruption (Cantagrel et al., 1981; Bloomfield and Valastro, 1974) that took place at about 11,600 yr B.P. (Bloomfield and Valastro, 1974). The layer is called the Upper Toluca Pumice. Charcoal from thin layers between the Upper Toluca Pumice and the underlying soil, fluvial sands, weathered Tertiary andesite, and valley-fill lahar deposits was dated to 11,850±220 yr B.P. (Tx-1601), 11,470±90 yr B.P. (Tx 1602),

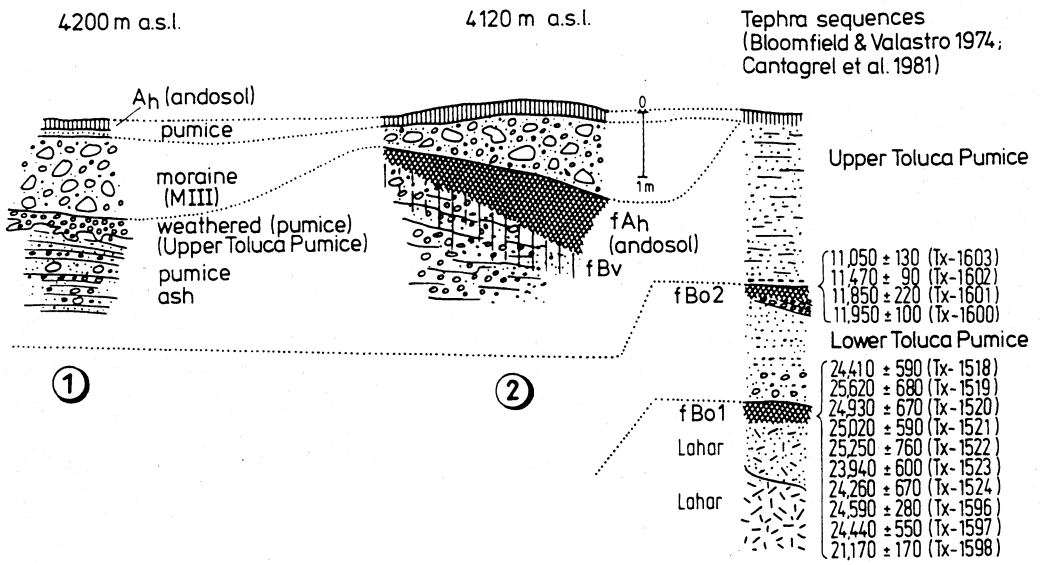

Fig. 5. Nevado de Toluca volcano. Late Quaternary glacial sediments and tephrostratigraphic correlation with the sections of Bloomfield and Valastro (1974).

11,050 ± 130 yr B.P. (Tx 1603), and 11,950 ± 100 yr B.P. (Tx 1600) (Bloomfield and Valastro, 1974).

The upper Toluca Pumice was overridden by a glacier advance. At many sites glacial deposits rest on the Upper Toluca Pumice layers (Fig. 5). It is striking that the Upper Toluca Pumice deposits are deeply weathered. Even in altitudes above 4000 m thick andosols developed on the pumice beds documenting a long period of undisturbed soil formation after the eruption of the tephra ca. 11,600 yr B.P. Fully developed andosols are found in such altitudes only after several thousand years of weathering (Miehlich, 1991). Therefore, the glacier advance forming the moraines of group M III must have happened at the earliest after 10,000 yr B.P.

2.3. *Iztaccíhuatl*

Late Quaternary glacial sequences were investigated by White (1962), Heine (1975, 1988a), and Vázquez Selem (1989, 1991). Unfortunately, no exact dating of the late glacial moraines was possible. To obtain more ^{14}C dates for the late glacial moraines, I cored the sediments between the moraine walls of group M II and M III in the Apatlaco valley on the southern slopes of Iztaccíhuatl (Fig. 6). The sedimentary sequence is shown in Fig. 7.

Again, different tephra layers can be used as marker horizons (Heine, 1975; Miehlich, 1974; Robin, 1984; Boudal and Robin, 1989). The area of the Apatlaco valley was glaciated after the deposition of the so-called P 3 pumice layer (Miehlich, 1974; Heine, 1975). The pumice P 3 is attributed to an eruption of Popocatépetl volcano about 14,000–15,000 yr B.P. (a discussion of the P 3 pumice and its age is given by Vázquez Selem, 1989). Lozano-García et al. (1993) estimate an age of ca. 16,500 yr B.P. for this pumice. The moraines of group M II (Fig. 6) indicate a glacier advance after 15,000/14,000 yr B.P. in the Apatlaco valley. Several recessional moraines show that the glacier retreated while forming terminal moraines near the coring site. The advance of the glacier forming the group M III moraine near the coring site documents that the ratio between glacier tongue and accumulation area was different from that of the glaciers of group M II; the M III glacier is characterized by a longer glacier tongue in the Apatlaco valley. This observation clearly documents that the M III glacier advance deposited the long lateral moraine that dammed up the outlet of the small cirque valley. The sediment

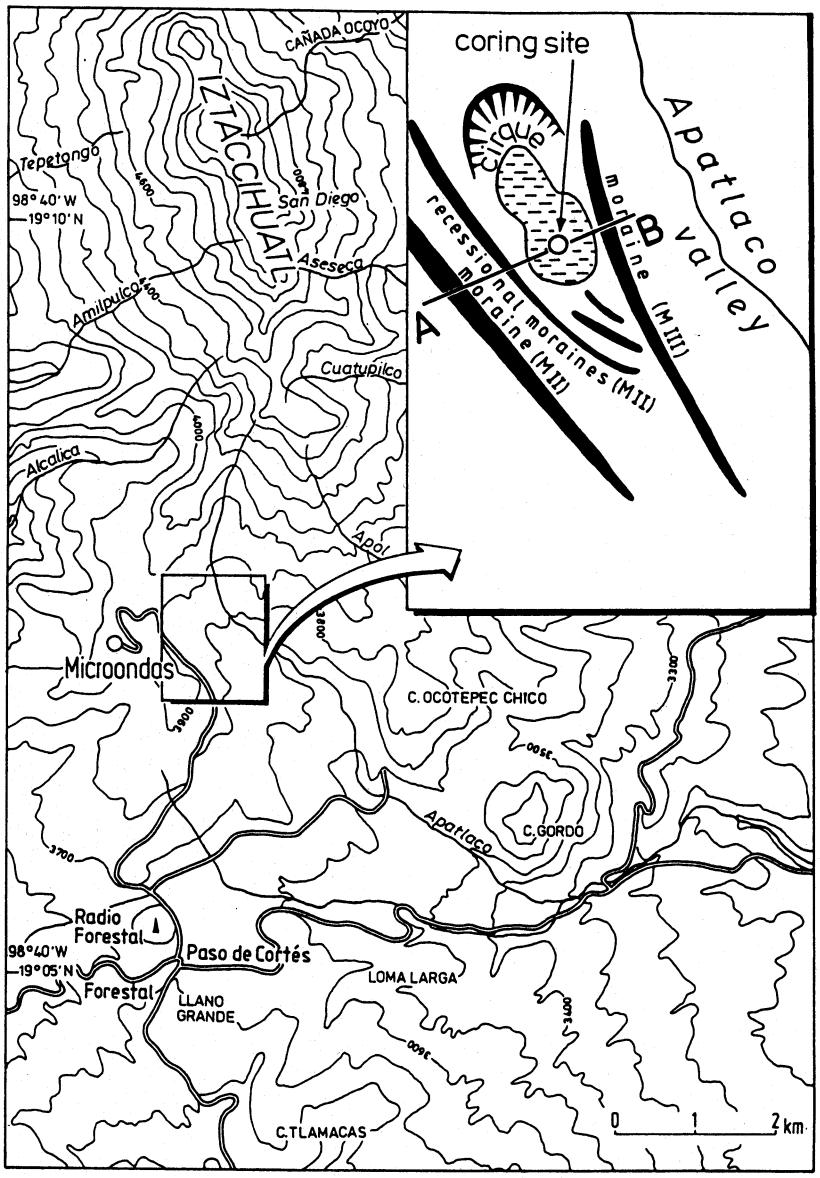

Fig. 6. Iztaccíhuatl–Paso de Cortés area with Apatlaco valley coring site.

sequence behind the moraine wall M III was formed after the M III glacier advance.

The oldest sediments of the core (Fig. 7) yield a ^{14}C age of 10,190±215 yr B.P. (Hv 13919). This date and correlation with different tephras of the adjacent area suggest an age of the M III glacier advance prior to ca. 10,000 yr B.P. Absence of organic material underlying the dated sample, suggests that the M III moraine was deposited not much before ca. 10,000 yr B.P.

3. Results

Dated sections containing glacial deposits from three different volcanoes of the central Mexican

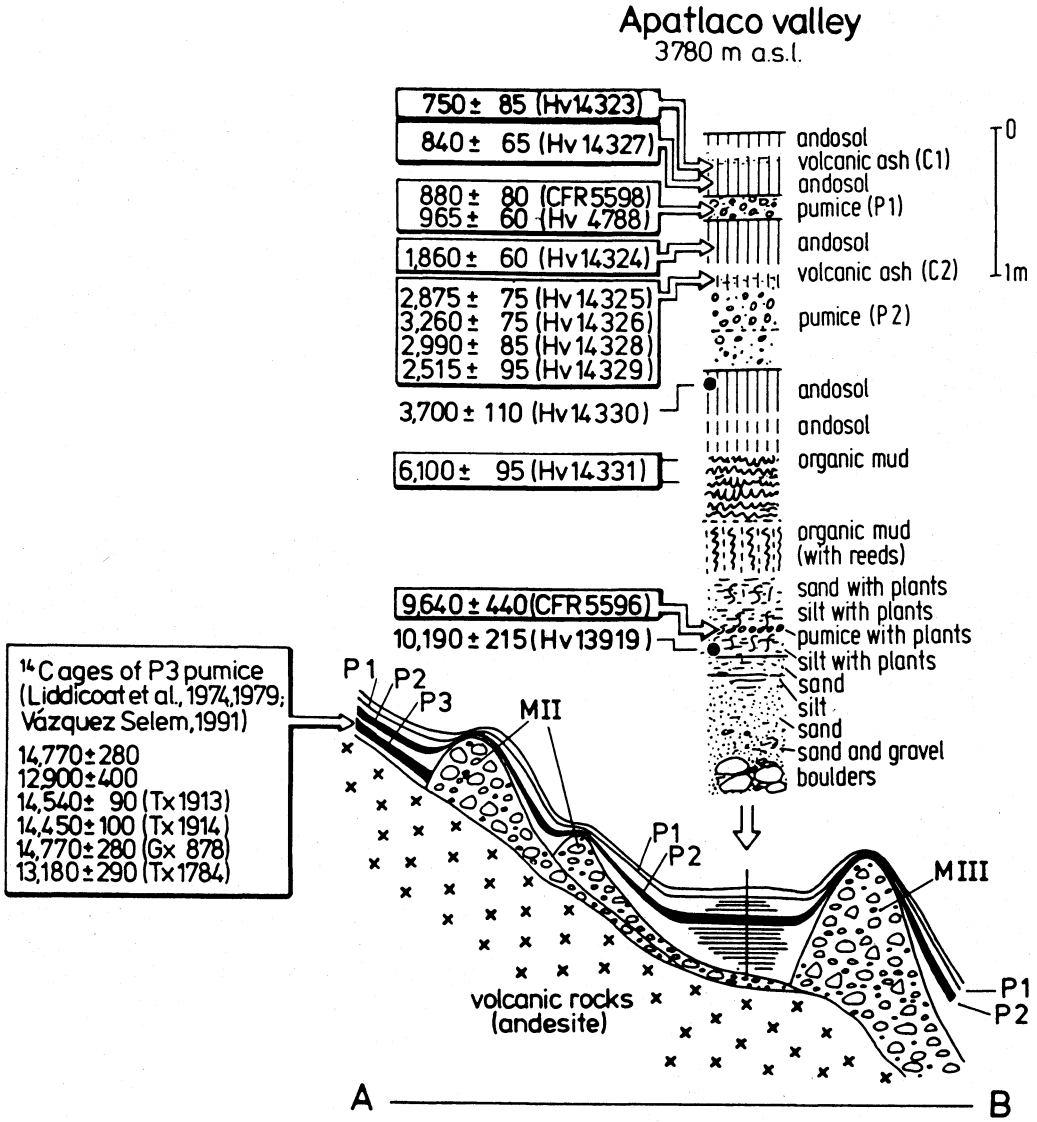

Fig. 7. Apatlaco valley, Iztaccíhuatl. Situation of the late Pleistocene moraines and tephra layers. ^{14}C ages in boxes refer to sections in the vicinity. The stratigraphic correlation is based on the tephra layers P1 and P2 (see Heine, 1988b; Boudal and Robin, 1989).

highland give evidence for late Quaternary glacier advances that occurred between ca. 10,500 and 8500 yr B.P. (conventional radiocarbon years). Although there are no ^{14}C dates for the very onset of the so-called M III glaciation, tephrostratigraphic correlations as well as soil development suggest that there was no glacial advance during the period 12,000–10,000 (10,500) yr B.P. Thus, during the Younger Dryas period no expansion of glaciers occurred in central Mexico. Evidence for this was presented in earlier publications (e.g. Heine, 1975, 1988a).

Why do the central Mexican glaciers not readvance during the Younger Dryas period? We suggest that the Mexican glaciers reflect the climatic conditions of the Gulf of Mexico. In recent years, the late Quaternary history of the Gulf of Mexico was studied in detail. Many authors show that in

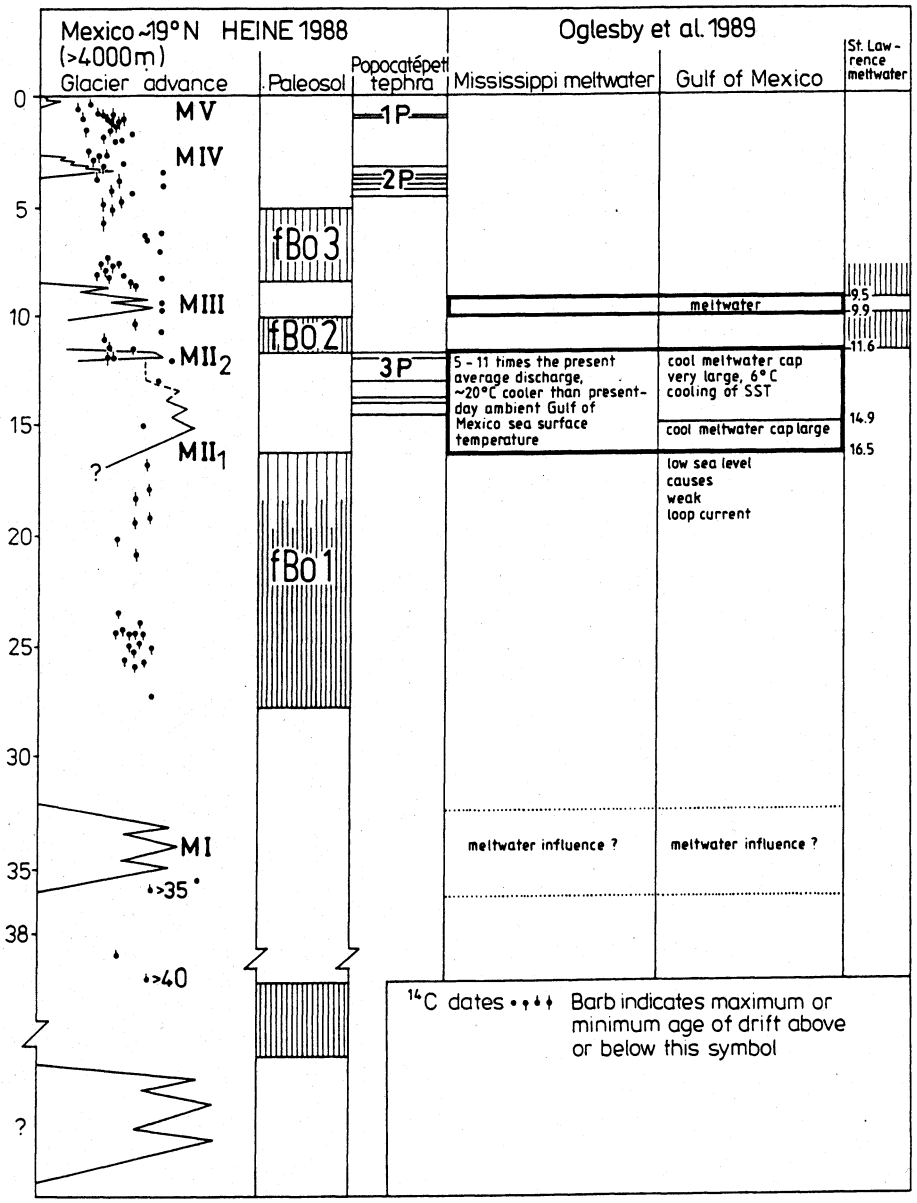

Fig. 8. Late Quaternary glacier advances, paleosols, Popocatépetl tephras, Mississippi meltwater discharge, and Gulf of Mexico sea surface temperature conditions.

the circum-North Atlantic region the timing of late Quaternary deglaciation is linked to the discharge of glacial meltwater and precipitation runoff to the Gulf of Mexico and to the North Atlantic Ocean from Lake Agassiz and eastern North America drainage basins between 14,000 and 8000 yr. B.P. (Broecker et al., 1988, 1989; Kennett and Shackleton, 1975; Leventer et al., 1982; Oglesby et al., 1989; Overpeck et al., 1989; Teller, 1990a, 1990b) (Fig. 8). There is no doubt that the meltwater cap leads to cooling of the Gulf of Mexico which in turn leads to about 6°C lower temperatures in central Mexico. This cooling is documented by the late Quaternary vegetation

history of the Mexican highland (Straka and Ohngemach, 1989). On La Malinche volcano during the M III glaciation the upper tree line was lowered by about 1000 m which corresponds to a temperature depression of about 6°C. This cooling was far more substantial than during the last glacial maximum (ca. 18,000 yr B.P.). It is evident that the late Quaternary glacier advances are related to meltwater discharge events into the Gulf of Mexico (Fig. 8). Therefore, episodes of maximum glaciation during the late Wisconsin occurred in two steps at times when meltwater was discharged into the Gulf of Mexico. In contrast during times of meltwater discharge into the North Atlantic, i.e. between 11,600 and 9900 yr B.P. the Mexican glaciers receded. This behaviour contrasts the glacier behaviour in the circum-North Atlantic region. Thus the late Quaternary Mexican glacial history shows a regional pattern that is not suitable for uncritical correlations with the Rocky Mountains or the South American Andes.

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