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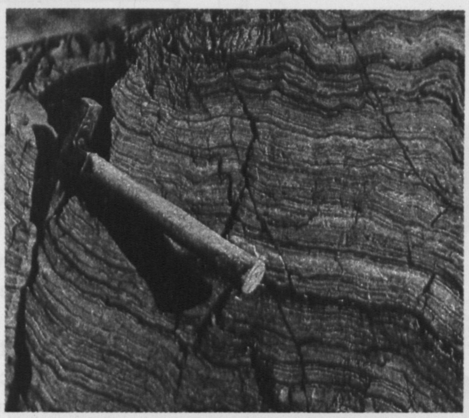
Inhalt

Titelbild



Gebänderte Eisensteine (Itabirite) sind ein Hinweis auf weitgehend O_2-freie subaerische Verwitterungs- und Transportvorgänge, aber oxidierende Bedingungen in marinen Teilbereichen bei der Fällung des Eisens. M. Schidlowski und H. Wiggering (S. 212) ziehen unter anderem daraus Rückschlüsse auf die Entwicklung des atmosphärischen Sauerstoffs im Präkambrium (Foto: H. L. James).

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Klaus Heine

Late Quaternary Glacial Chronology of the Mexican Volcanoes

Jungquartäre Glazialchronologie mexikanischer Vulkane

Zusammenfassung

Die Gliederung der jungquartären Gletschervorstöße in der Cordillera Neovolcánica (Zentralmexiko) basiert auf tephrochronologischen Korrelierungen, Radiokarbondatierungen, fossilen Bodensequenzen, Pollenanalysen sowie geomorphologischen und sedimentologischen Kriterien. Die Untersuchungen wurden an den Vulkanen Nevado de Toluca, Ajusco, Iztaccíhuatl, La Malinche und Pico de Orizaba ausgeführt.

Während des Jungquartärs lassen sich an den höchsten Vulkanen fünf Gletschervorstöße nachweisen. Die M I-Vergletscherung datiert auf etwa 36 000 bis 32 000 a BP, der M II-Vorstoß erfolgte um 12 000 a BP, und die M III-Vergletscherung, der zwei Vorstöße und eine Rückzugsphase angehören, begann vor ungefähr 10 000 a BP und endete um 8500 a BP. Während des Holozäns rückten die Gletscher um 3000 bis 2000 a BP und zwischen 1590 und 1850 A. D. (Kleine Eiszeit) vor. Seit etwa 1850 A. D. schmelzen die Gletscher zurück.

Die Glazialgeschichte Zentralmexikos bestätigt die Hypothese, daß das jungquartäre Klima in den Randtropen zwischen etwa 18 000 und 10 000 a BP relativ trocken war und daß feuchtere Phasen auf das Ende des Sauerstoff-Isotopen-Stadiums 3 sowie für das frühe Holozän beschränkt waren. Eine kurze, jedoch markante Niederschlagszunahme

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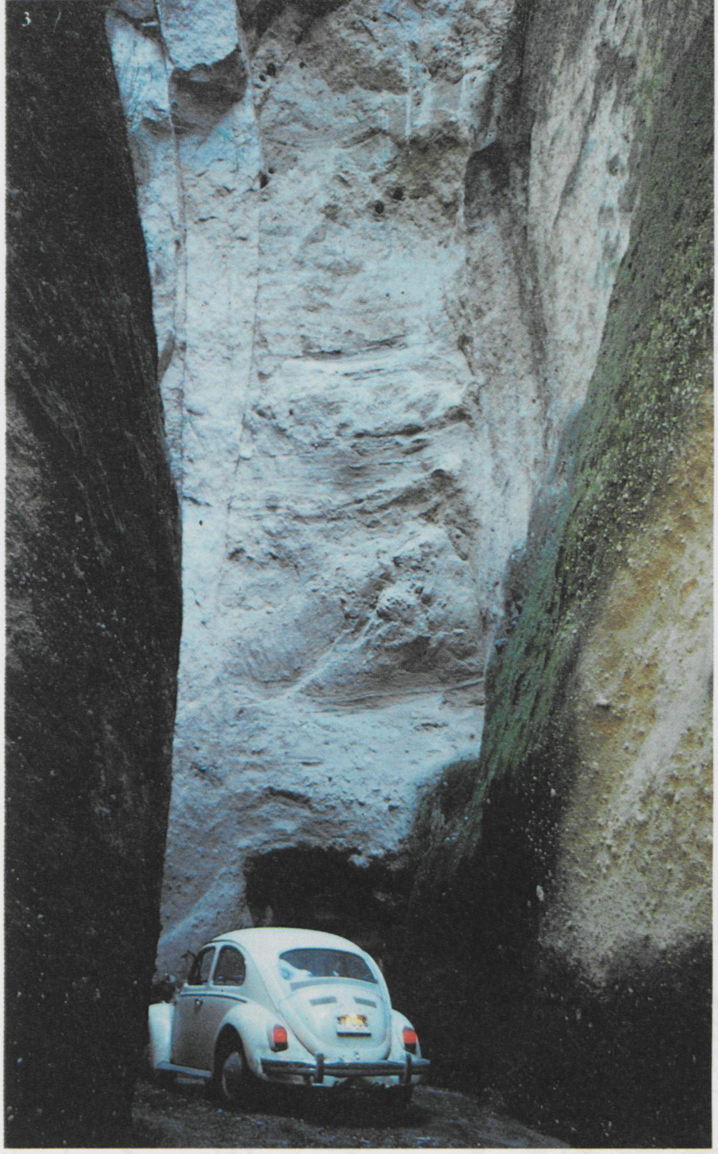
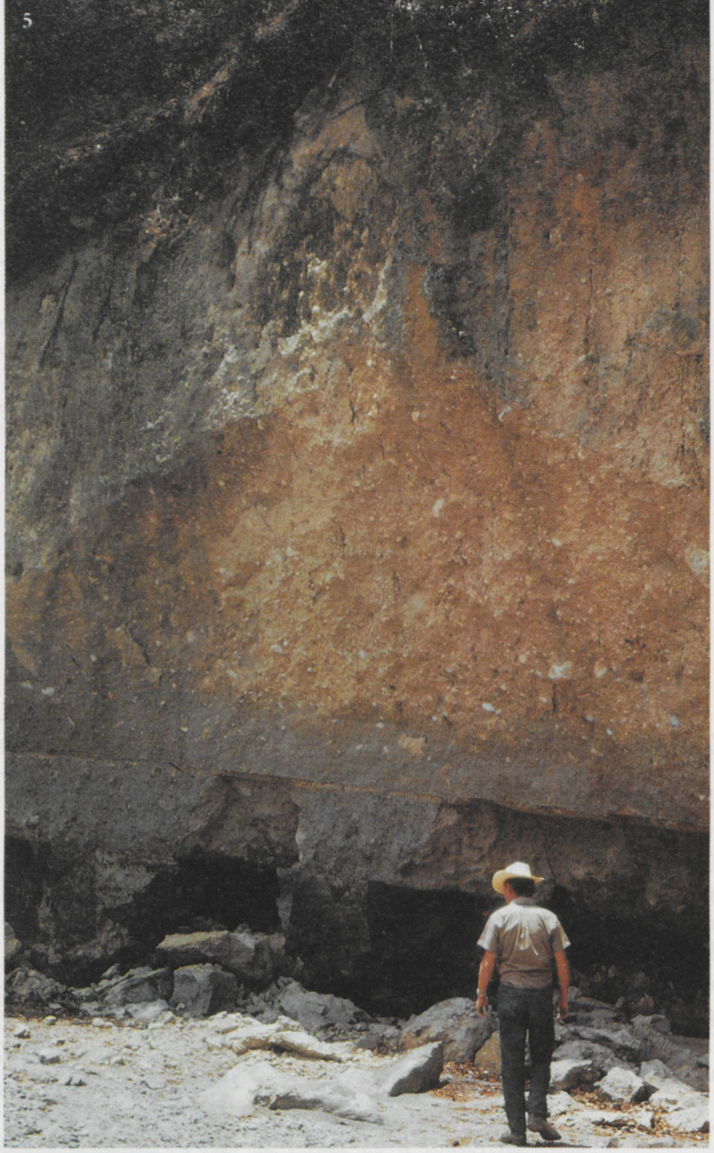
Fig. 1. Map of the Cordillera Neovolcánica, Mexico. Circles indicate the location of the volcanoes.

Fig. 2. View from the basin of Puebla-Tlaxcala to the Sierra Nevada with de Popocatépetl on the left and the Iztaccíhuatl on the right.





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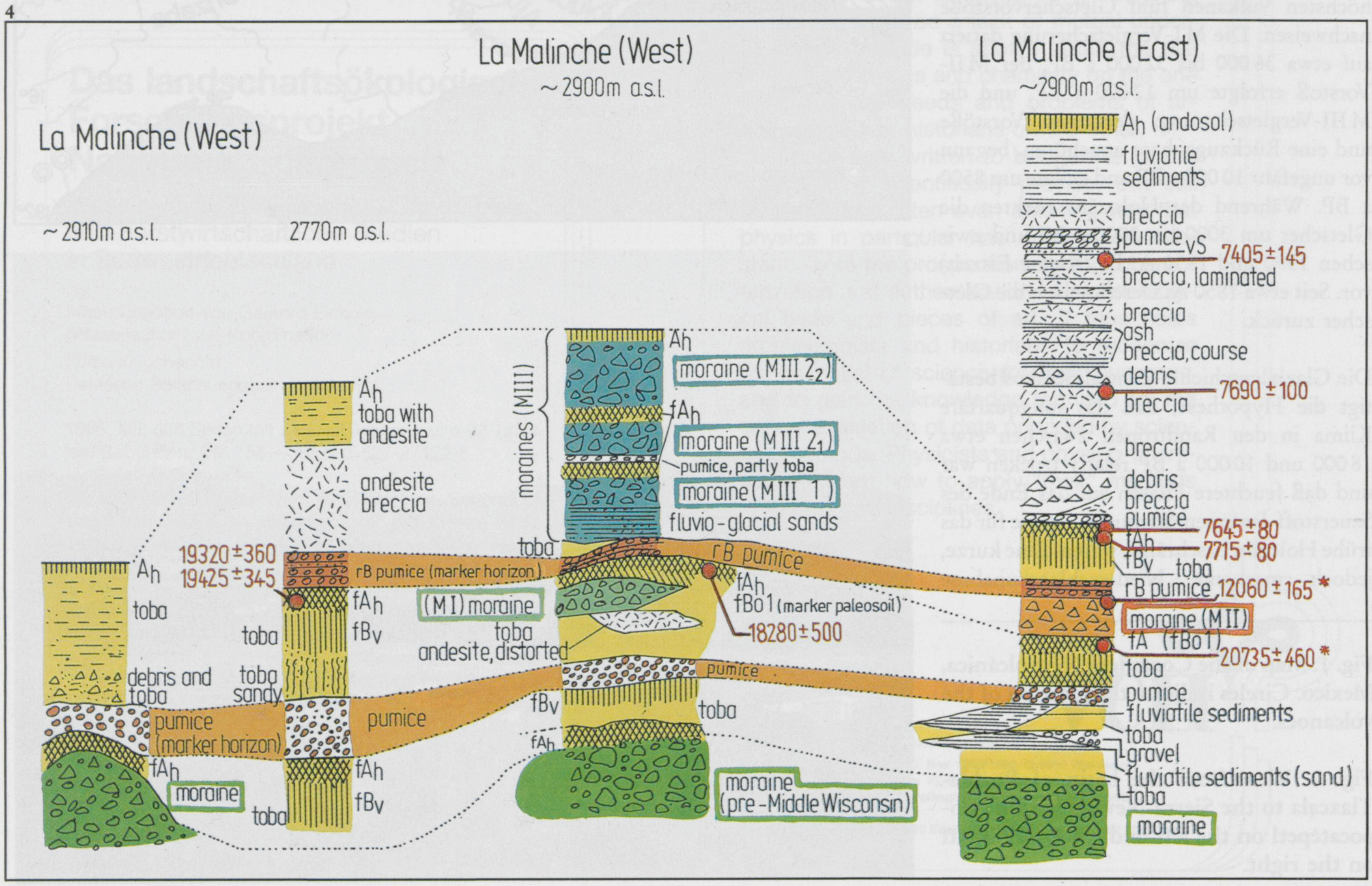

La Malinche (West)
~2910m a.s.l.
2770m a.s.l.
La Malinche (West)
~2900m a.s.l.
La Malinche (East)
~2900m a.s.l.
Ah
toba
debris and toba
pumice (marker horizon)
fAh
moraine
toba
19320±360
19425±345
Ah
toba with andesite
andesite breccia
rB pumice (marker horizon)
fAh
fBv
toba
toba sandy
pumice
fAh
fBv
toba
(MI) moraine
moraines (MIII)
Ah
moraine (MIII 2₂)
fAh
moraine (MIII 2₁)
pumice, partly toba
moraine (MIII 1)
fluvio-glacial sands
toba
rB pumice
fAh
fBo1 (marker paleosoil)
18280±500
toba
andesite, distorted
pumice
fBv
toba
fAh
moraine (pre-Middle Wisconsin)
Ah (andosol)
fluviatile sediments
breccia
pumice
vS
7405±145
breccia, laminated
breccia
ash
breccia, course
debris
7690±100
breccia
breccia
debris
breccia
pumice
fAh
7645±80
fBv
7715±80
toba
rB pumice
12060±165 *
moraine (MII)
fA (fBo1)
20735±460 *
toba
pumice
fluviatile sediments
toba
gravel
fluviatile sediments (sand)
toba
moraine

wird durch den M II-Vorstoß um 12 000 a BP dokumentiert, der aber nur in der Nähe des Golfes von Mexiko nachweisbar ist. Im Holozän gab es keine bedeutenden Temperatur- und Niederschlagsschwankungen. Es muß hervorgehoben werden, daß das Stadial der Jüngeren Dryaszeit nicht durch Gletscherschwankungen repräsentiert wird.

1 Introduction

With respect to the classical Late Weichselian climatic fluctuations of Western and Central Europe many scientists tried to establish similar chronostratigraphies of climatic variations for other parts of the world. Recent investigations give more and more evidence that the classical West European chronostratigraphy of the Late Weichselian is in many details a regional stratigraphy and cannot be transferred to other areas of the world.

Therefore it is necessary to focus our attention on many different parts of the world, especially on the tropics and subtropics in order to establish a great number of seperate chronostratigraphies. Here I will present the results of investigations carried out during the last three decades in the central Mexican highland (Puebla/Tlaxcala area) by several scientists who were involved in the German-Mexican Mexico Project of the German Science Foundation (Figures 1 and 2).

Fig. 3. Barranca (erosion gully) at the eastern flanks of the Iztaccíhuatl.

Fig. 4. Some sections from the La Malinche volcano showing the rB-marker horizon and different glacial deposits. The ^{14}C dates marked with stars refer to the western flank of the volcano.

Fig. 5. The barranca Xotanacatla on the western flank of La Malinche volcano. The dark horizon at the base of the section is the fossil soil ‚fBo1', the ‚rB' pumice marker horizon is indicated by the thin line in the lower part of the andesite breccia.

Fig. 6. Pollen diagram of the Pleistocene/Holocene boundary at the La Malinche volcano. The glaciations M III and M IV are clearly documented by the pollen assemblages. According to Ohngemach and Straka (1983).

2 Chronology

Independent of the standard Mexican glacial sequence published by Sidney White [1, 2], a chronostratigraphy based on comprehensive research on La Malinche volcano, Pico de Orizaba, Iztaccíhuatl, Popocatépetl, and Nevado de Toluca Volcano was developed [3].

Different Late Quaternary stratigraphic successions for each volcano are recognizable within this area. The slopes of the volcanoes are dissected by barrancas (erosion gullies), radiating from the upper parts of the forest belt and descending towards the basins (Figure 3). Thus the stratigraphic successions can easily be traced from one barranca to an-

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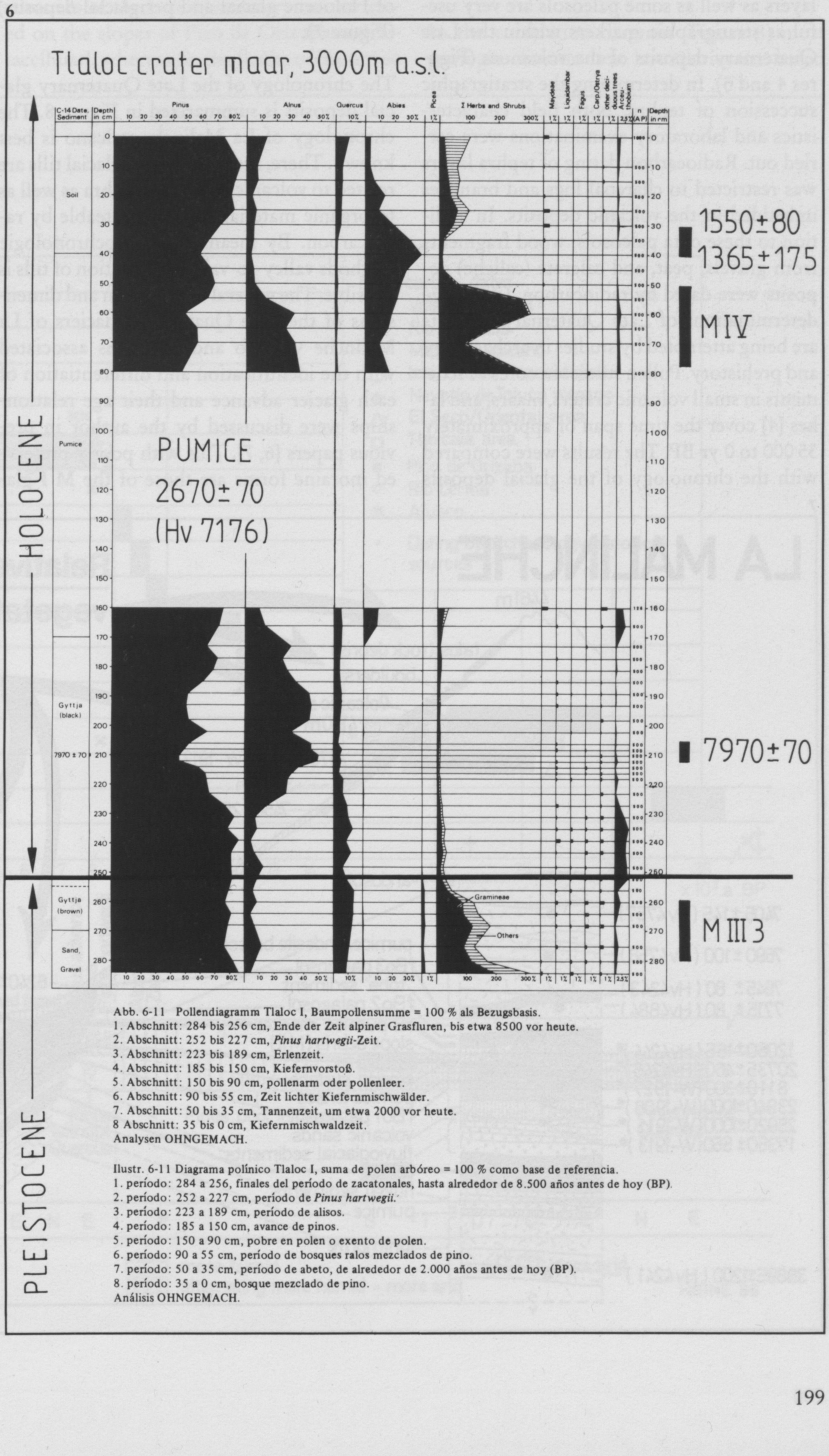

other by different layers of glacial and periglacial deposits, paleosols, debris, fluvial gravels and sands, and loess-like so-called „toba“ sediments which are interbedded with lava flows, ignimbrite deposits and tephra (the term tephra pertains to all pyroclastic fragments, such as fine and coarse ash, lapilli, volcanic bombs, and blocks). Different tephra layers as well as some paleosols are very useful as stratigraphic markers within the Late Quaternary deposits of the volcanoes (Figures 4 and 5). In determining the stratigraphic succession of tephra, both field characteristics and laboratory examinations were carried out. Radiocarbon dating of tephra layers was restricted to charcoal logs and branches imbedded in the volcanic deposits. In addition to these data paleosols, wood fragments from gravels, peat, and calcrete (caliche) deposits were dated by radiocarbon. Other age determinations of Late Quaternary deposits are being attempted by studies in archaeology and prehistory. Pollen studies in cores of sediments in small volcanic craters, maars, and lakes [4] cover the time span of approximately 35 000 to 0 yr BP. The results were compared with the chronology of the glacial deposits (Figure 6). Furthermore, relative age-dating methods were used to demonstrate age differences 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 [5], and vegetation cover (including lichen data of Holocene glacial and periglacial deposits) (Figure 7).

The chronology of the Late Quaternary glacial deposits is summarized in Figure 8. The chronology of La Malinche volcano is best known. There, most of the late glacial tills are related to volcanic rocks and tephra as well as to organic materials that are dateable by radiocarbon. By means of tephrochronologic methods valley-to-valley correlation of tills is possible. The general distribution and dimensions of the Late Quaternary glaciers of La Malinche volcano and problems associated with the identification and differentiation of each glacier advance and their age relationships were discussed by the author in previous papers [6, 7]. Tills with poorly preserved moraine forms are those of the M I-glacier advance between 36 000 and > 32 000 yr BP as well as tills deposited during the M II-glaciation about 12 000 yr BP. Lateral and end moraines deposited during the M III-glaciation between 10 000 and 8500 yr BP show well preserved morainal forms, so do the Holocene neoglacial deposits which are divisible into two advances (M IV: 3000–2000 yr BP; M V: Little Ice Age). An outline of the local stratigraphy of the glacial deposits on the eastern slopes of La Malinche volcano (Figure 7), mainly based on paleosols (fBo1, fBo3) and tephra layers (marker horizon rB), provides sufficient information on how different Late Quaternary stratigraphic successions were elaborated.

Deposits of the other volcanoes of the Mexican volcanic belt, stemming from the major glaciations of the Late Quaternary are

Fig. 7. Scheme of the stratigraphy of the Late Quaternary deposits on the eastern slopes of La Malinche volcano. The ^{14}C dates marked with stars refer to the western flank of the volcano.

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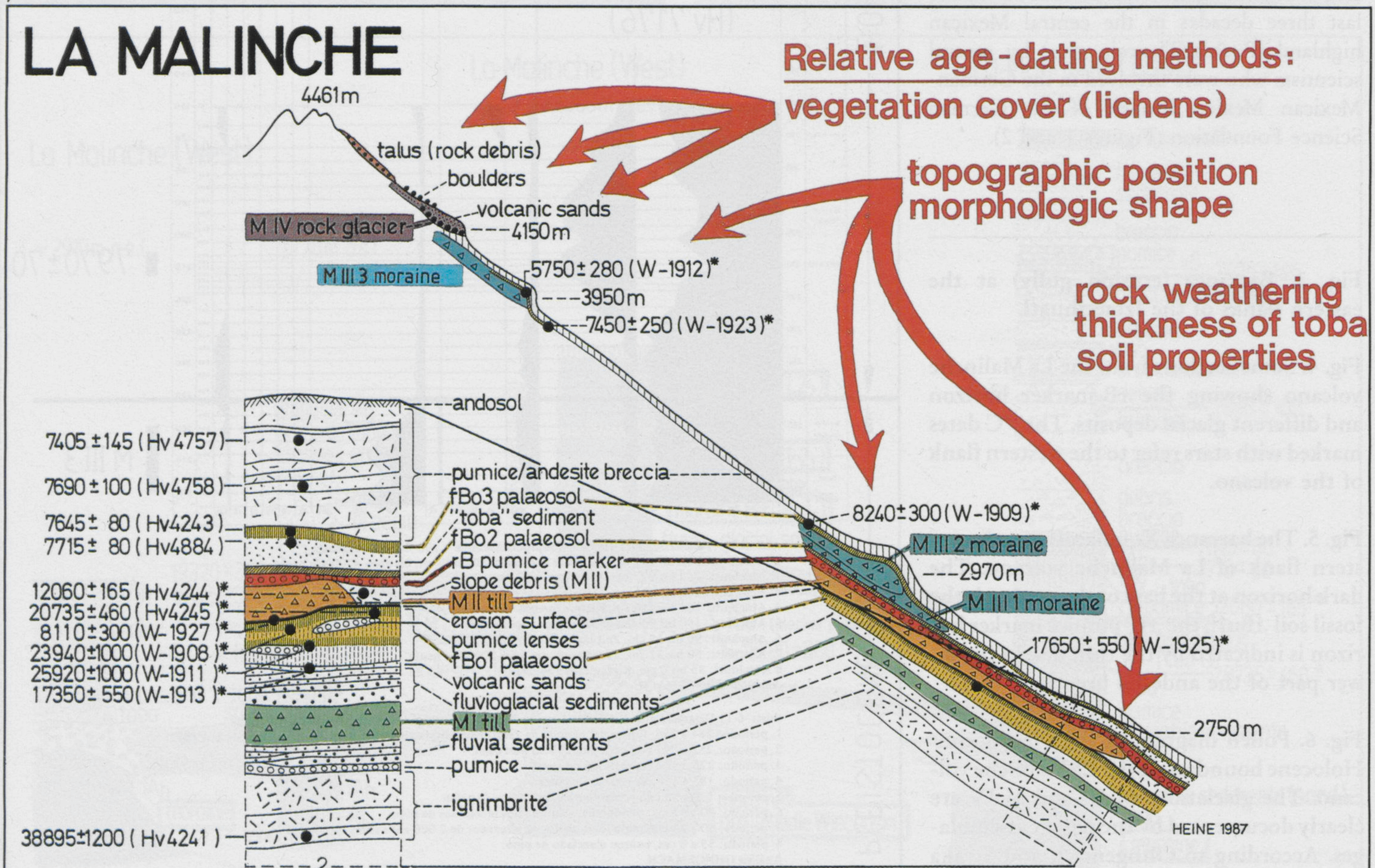

known. Figures 9 to 11 give evidence of the locations of the glacial and periglacial deposits on Pico de Orizaba (Figure 9), the southern part of Iztaccíhuatl (Figure 10), and the Nevado de Toluca volcano (Figure 11). The glacial deposits of these volcanoes are comparable to the Late Quaternary stratigraphic succession of La Malinche volcano. Apart from the M II-glaciation [8] that did not exist on the Nevado de Toluca volcano, five glacier advances of the Late Quaternary can be traced on the slopes of Pico de Orizaba and Iztaccíhuatl, whereas on the flanks of the not so high volcanoes of Nevado de Toluca and La Malinche the Holocene glacial deposits of the M IV and M V phase do not occur. Instead of glacial deposits periglacial forms and deposits developed here (rock glaciers, ice-cored moraines, rock debris) [9].

3 Results

In the correlation diagram (Figure 8) most geologic-climatic unit boundaries are based

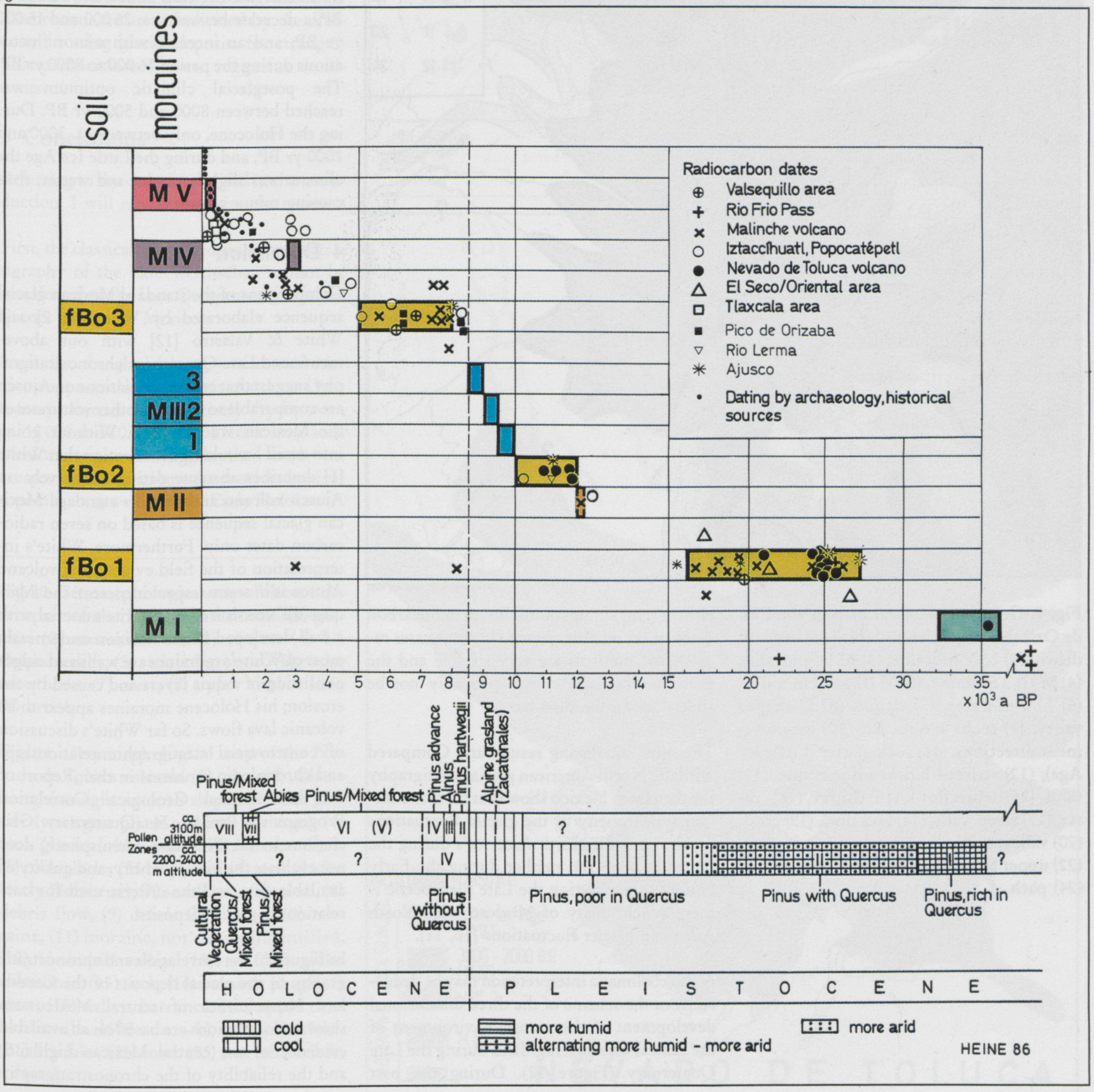

Fig. 8. Correlation diagram. Geologic-climatic unit boundaries are based on radiocarbon ages, tephrochronologic correlations, soil development, pollen analyses, sedimentologic criteria, and topographic position. Pollen zones according to Ohngemach and Straka (1983).

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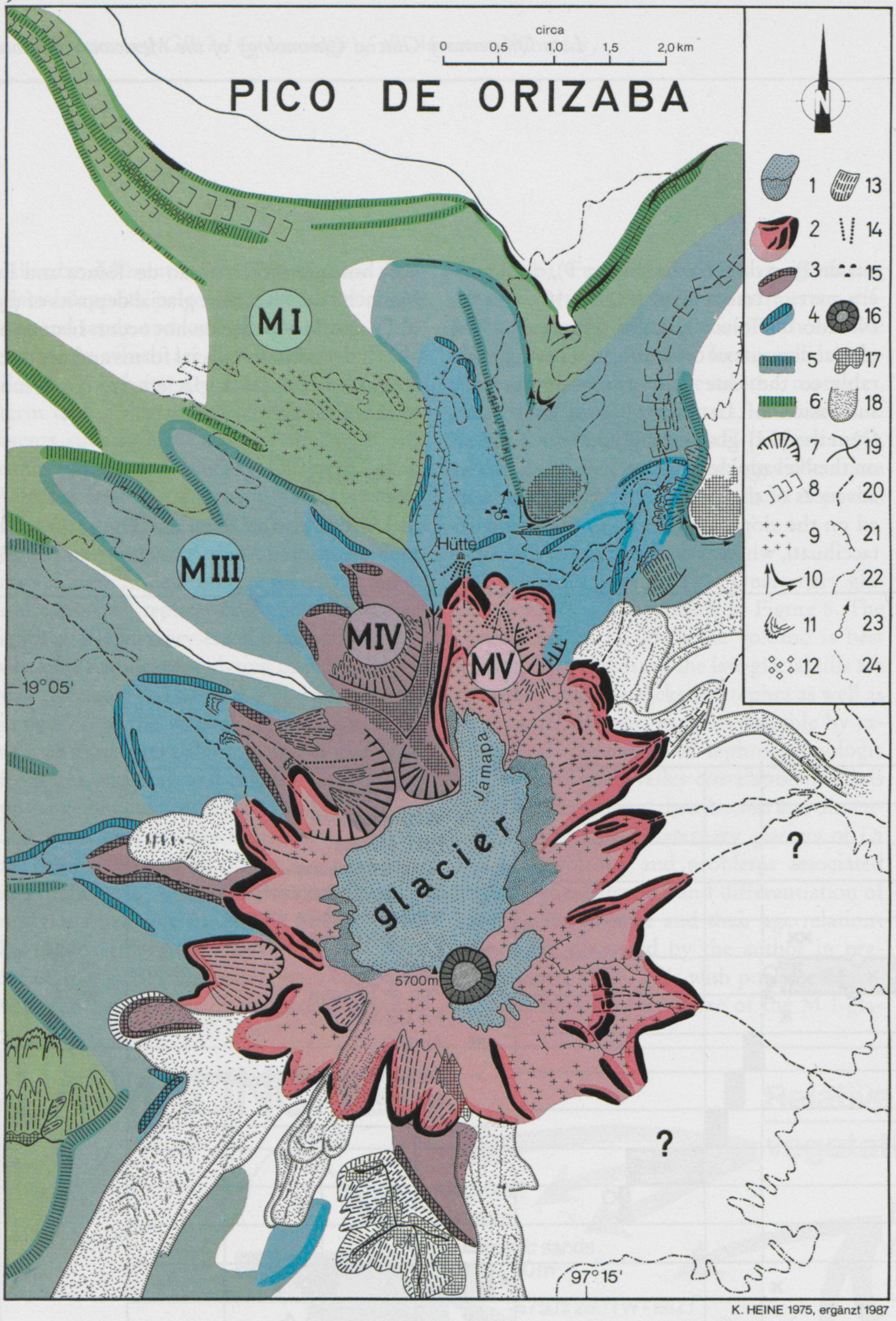

Fig. 9. Geomorphological map of the Pico de Orizaba. (1) glacier and fossil ice beneath debris, (2) M V moraine, (3) M IV moraine, (4) M III 3 moraine, (5) M III 1 + 2 moraine, (6) M I moraine, (7) cirque, (8) U-shaped valley, (9) roche moutonée, (10) ice movement directions, (11) rock glacier (Little Ice Age), (12) striated blocks on moraine, (13) talus, (14) debris flows, (15) thufur, (16) crater, (17) steep walls, (18) lava flow, (19) crest, (20) valley, barranca, (21) edge versus valley, (22) upper timber line, (23) well with brook, (24) path.

either on maximum or minimum radiocarbon dates or on relative criteria. In most cases radiometric controls are very reliable and the presented boundaries will probably not be shifted along the time bar.

The most interesting results are: Compared with the North American glacial stratigraphy the data from Mexico show that there is a certain synchroneity of the glacier fluctuations of Mexico with North America's during the Little Ice Age. But neither during the Early Holocene nor during the Late Pleistocene is there synchroneity of Mexican with North American glacier fluctuations [10, 11].

A palaeoclimatic interpretation may be deduced from the scheme of the three-dimensional development of the natural environment of the central Mexican highland during the Late Quaternary (Figure 12). During the past 36 000 years three major periods with climatically induced high erosion intensities and glacier advances can be distinguished: (1) 36 000 to > 32 000 yr BP, (2) around 12 000 yr BP, and (3) 10 000 to 8500 yr BP. These periods coincide with climatic changes from relative aridity to greater humidity. The scheme shows that there is no synchroneous development of the trend of temperature on the one hand with the trend of humidity on the other hand. The temperature curve is characterized by an increase between 36 000 and 32 000 yr BP, a decrease between ca. 26 000 and 16 000 yr BP, and an increase with minor fluctuations during the period 16 000 to 8000 yr BP. The postglacial climatic optimum was reached between 8000 and 5000 yr BP. During the Holocene, only between ca. 3000 and 2000 yr BP, and during the Little Ice Age the climate was slightly cooler and wetter, thus causing minor advances.

4 Discussion

Comparisons of the standard Mexican glacial sequence elaborated by White [1, 2] and White & Valastro [12] with our abovementioned Late Quaternary chronostratigraphy suggest that certain glaciations on Ajusco are comparable to those on other volcanoes of the Mexican volcanic belt. Without going into detail I would like to mention that White [1] describes absolute dating exclusively on Ajusco volcano and that his standard Mexican glacial sequence is based on seven radiocarbon dates only. Furthermore, White's interpretation of the field evidence of volcano Ajusco is in some respect incorrect: the ‚Marques till' consists of ignimbrite material with a well developed fritted horizon underneath; most of White's moraines are walls and ridges consisting of debris layers and caused by the erosion; his Holocene moraines appear to be volcanic lava flows. So far White's discussion of controversial stratigraphic relationships and chronologic problems in the „Report of the International Geological Correlation Programm", Project 24 (Quaternary Glaciations in the Northern Hemisphere) does not evaluate the kind, quantity, and quality of available data and the criteria used for correlation of glacial deposits.

In Figure 13 the correlation and chronostratigraphy of the glacial deposits of the Cordillera Neovolcánica of central Mexico are shown. Correlations are based on all available evidence of the central Mexican highland, and the reliability of the chronostratigraphy is very high. In Mexico maximum Late Quaternary glaciations occurred approximately 33 000–35 000 yr BP, around 12 000 yr BP and 8500–10 000 yr BP. Thus maximum Late Wisconsin glaciations in Mexico may have occurred at the end of oxygen isotope stage 3 and at the beginning of the Holocene. There is no synchroneity of glacial events regarding the Mexican glaciers and the North American Cordilleran and Laurentide or even the Fennoscandian ice sheets. Glacial advances and recessions are time-transgressive, and their diachronous nature is indicated by the difficulty in using glacial deposits for stratigraphic correleations between regions or continents.

5 Conclusions

Referring to the questions raised in the introduction, I will now summarize the results.

First, the classical West European chronostratigraphy of the Late Weichselian cannot be transferred to the Late Quaternary glacial sequence of central Mexico.

Secondly, the glacial history of central Mexico supports the hypothesis that Late Quaternary climates were relatively dry between ca. 18 000 and 10 000 yr BP. Data from glacial Mexican sequences suggest that major increases in precipitation were restricted to isotope stage 3 as well as to the Early Holocene.

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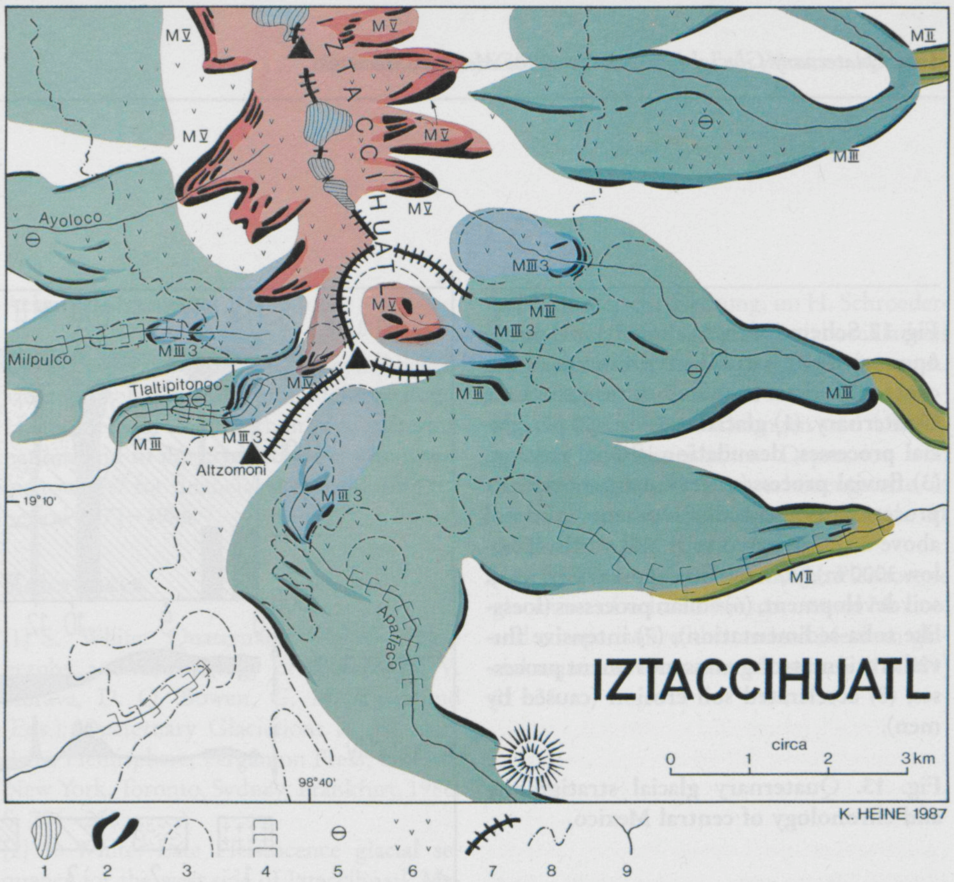

Fig. 10. Geomorphological map of the southern part of the Iztaccíhuatl massif. (1) glacier, (2) moraine wall, (3) cirque, (4) U-shaped valley, (5) striated ground, (6) roche moutonée, (7) crest, (8) upper timber line, (9) brook.

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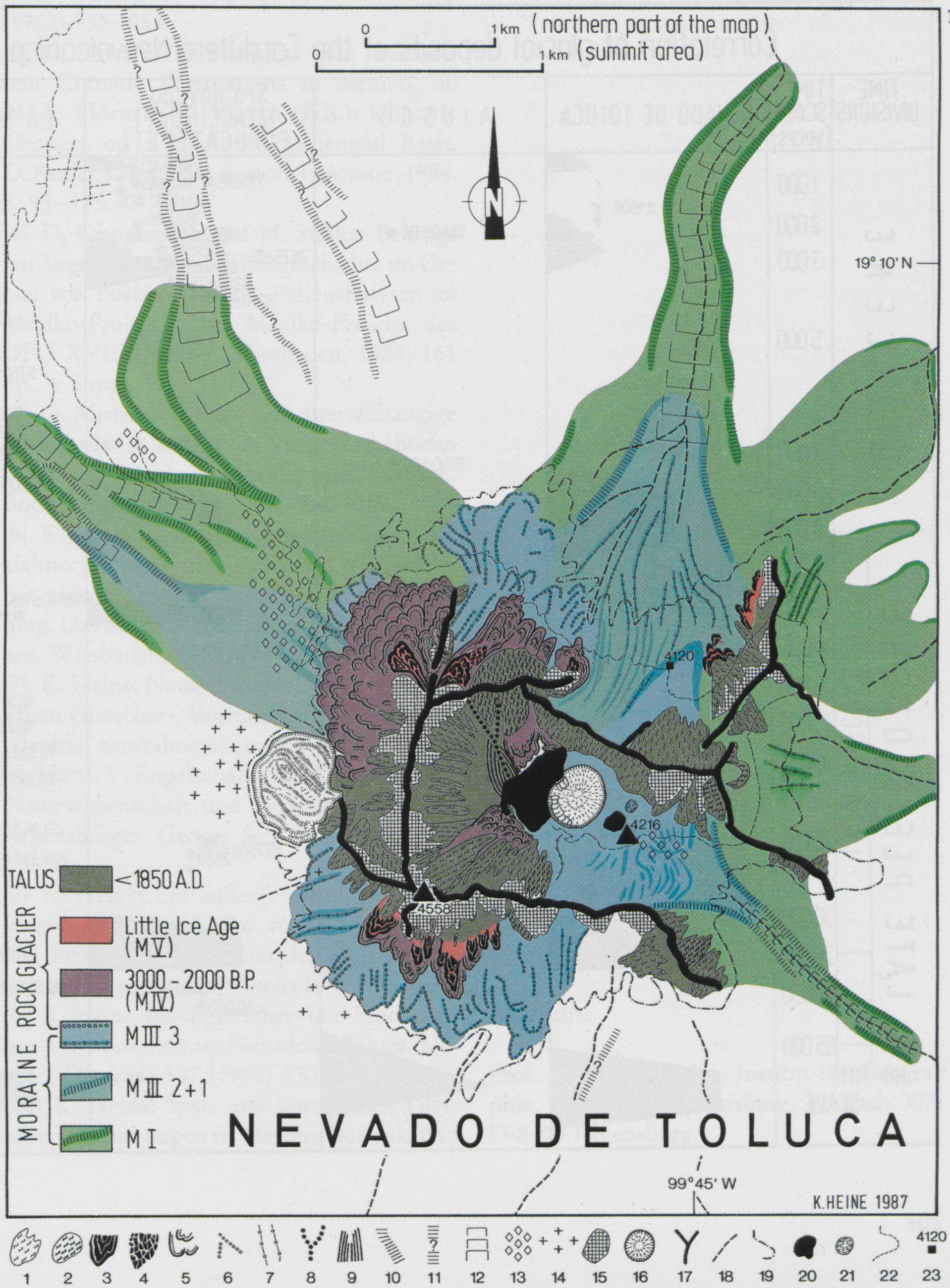

Fig. 11. Geomorphological map of the Nevado de Toluca volcano. (1) talus, (2) ‚Glatthang' (straight smooth slope), (3) rock glacier (youngest phase of Little Ice Age), (4) rock glacier (older phase of Little Ice Age), (5) rock glacier (M IV phase), (6) rock glacier (early Holocene), (7) small moraine wall, (8) debris flow, (9) debris flow lobe, (10) moraine, (11) moraine, not clearly indentified, (12) U-shaped valley, (13) till, (14) roche moutonée, (15) rock, (16) volcanic plug, (17) crest, (18) valley, barranca, (19) upper timber line (ca. 4000 m a. s. l.), (20) crater lake, (21) dry lake, (22) road, (23) hut (altitude in meters).

Fig. 12. Scheme of three-dimensional development of the natural environment of the central Mexican highland during the Late Quaternary. (1) glacial erosion, (2) periglacial processes, denudation, fluvial erosion, (3) fluvial processes, weak mass movement processes, (4) soil development (andosol above 3000 m, barro soils and vertisols below 3000 m), (5) weak fluvial processes, weak soil development, (6) eolian processes (loess-like toba-sedimentation), (7) intensive fluvial erosion, strong mass movement processes, (8) accelerated soil erosion (caused by men).

Fig. 13. Quaternary glacial stratigraphy and chronology of central Mexico.

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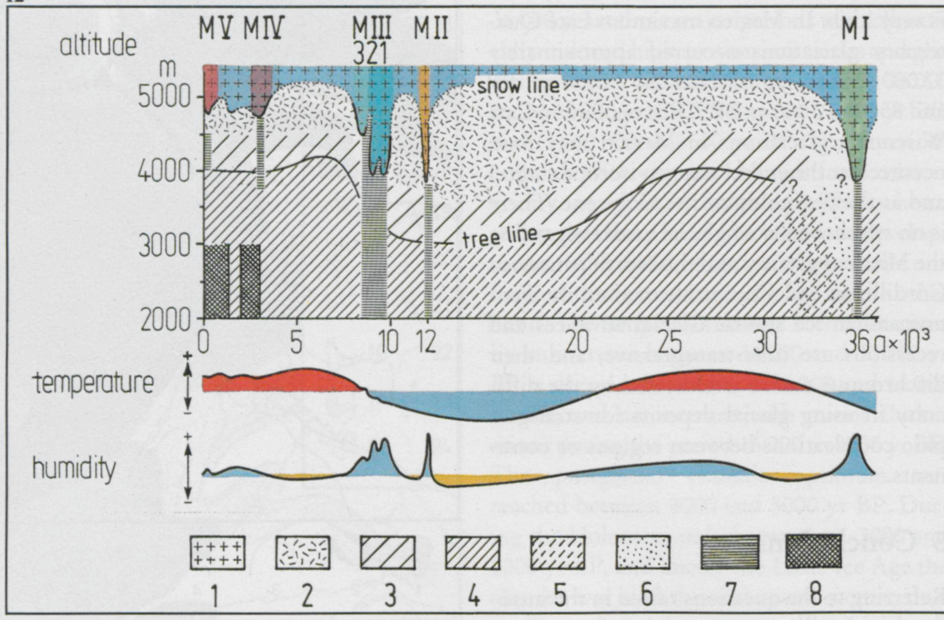

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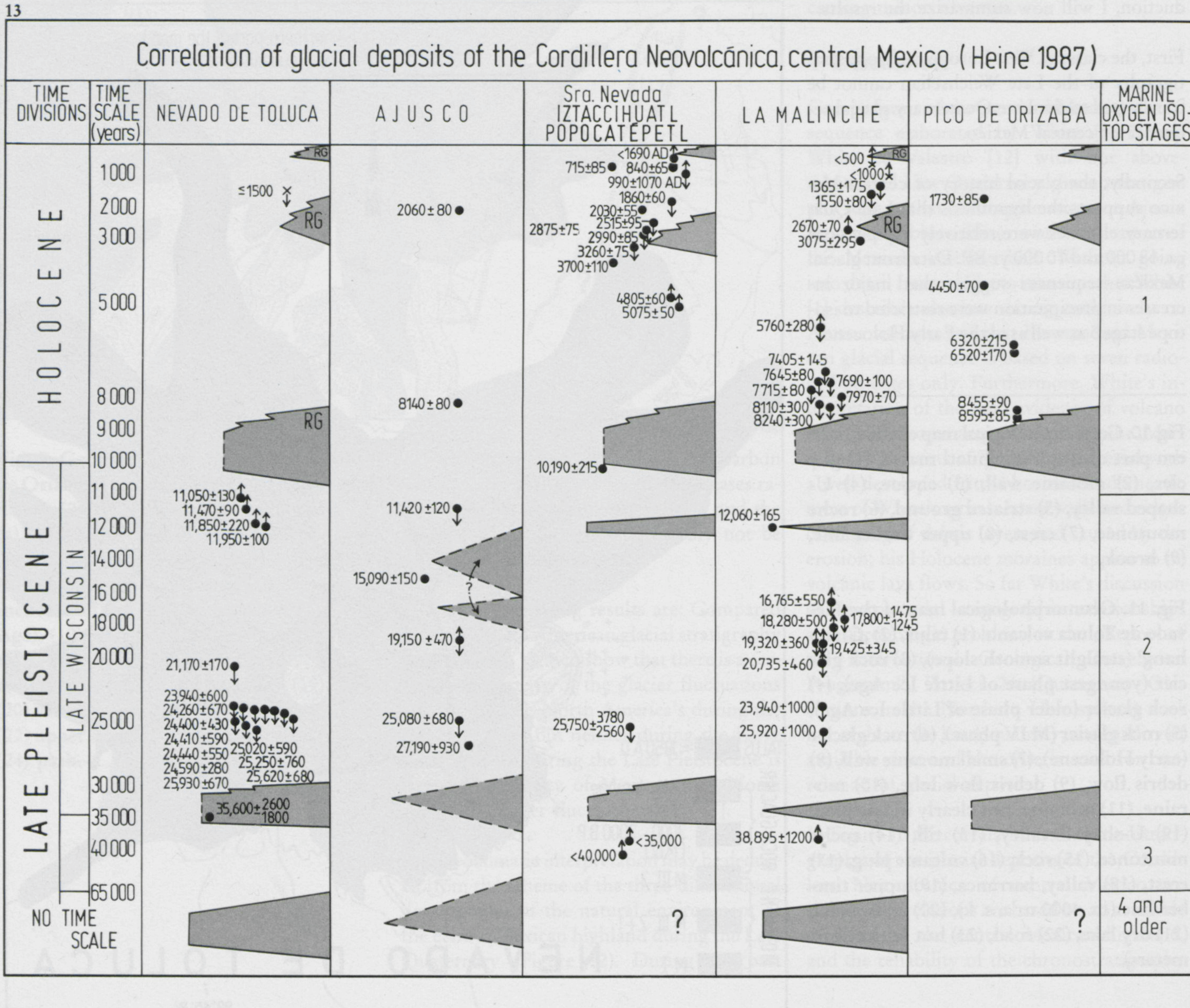
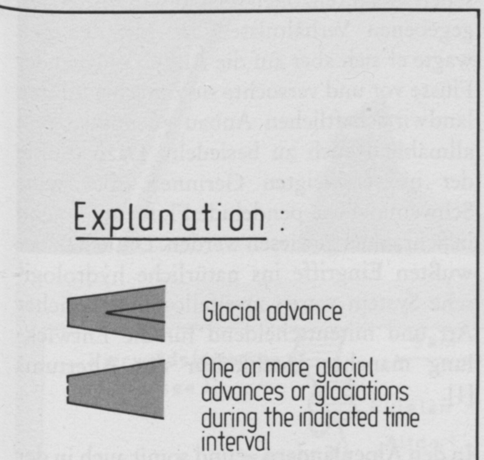


Thirdly, a short but great increase in precipitation at about 12000 yr BP is documented only by glacial advances on volcanoes near the Gulf of Mexico.

Fourthly, the classical Late Weichselian climatic fluctuation of the Younger Dryas period did not occur. The Mexican low-latitude stratigraphy presents a Late Quaternary transition from a full glacial dry and cold/cool climate to postglacial conditions without significant cold temperature anomalies.

Last not least, the application of tephrochronology supplies us with a detailed chronostratigraphy of the Late Quaternary events in Mexico, a chronostratigraphy in which stratigraphic and chronologic relationships are much more clarified than in many other tropical and subtropical parts of the world.



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References

[1] S. White: Quaternary Glacial Stratigraphy and Chronology of Mexico, in: V. Šibrava, D. Q. Bowen, G. M. Richmond (Eds.): Quaternary Glaciations in the Northern Hemisphere, Pergamon Press, Oxford, New York, Toronto, Sydney, Frankfurt, 1986. S. 201–205.

[2] S. White: Late Pleistocence glacial sequence for the west side of Iztaccíhuatl, Mexico; Geological Society of America **73** (1962) 935–958.

[3] K. Heine: The Classical Late Weichselian Climatic Fluctuations in Mexico, in: N.-A. Mörner, W. Karlén (Eds.): Climatic Changes on a Yearly to Millennial Basis, D. Reidel, Dordrecht, Boston, Lancaster, 1984. S. 95–115.

[4] D. Ohngemach and H. Straka: Beiträge zur Vegetations- und Klimageschichte im Gebiet von Puebla-Tlaxcala. Pollenanalysen im Mexiko-Projekt. Das Mexiko-Projekt der DFG XVIII. Steiner, Wiesbaden, 1983. 161 pp. + Suppl.

[5] G. Miehlich: Klima- und altersabhängige Bodenentwicklungen von Vulkanascheböden der Sierra Nevada de México; Mitt. Deutsch. Bodenkundl. Ges. **18** (1974) 360–369.

[6] K. Heine: Studien zur jungquartären Glazialmorphologie mexikanischer Vulkane – mit einem Ausblick auf die Klimaentwicklung. Das Mexiko-Projekt der DFG VII. Steiner, Wiesbaden, 1975, 178 pp.

[7] K. Heine: Neue absolute Daten zur holozänen Gletscher-, Vegetations- und Klimageschichte zentralmexikanischer Vulkane, in: M. Hartl, V. Engelschalk (Eds.): Geographie, Naturwissenschaft und Geisteswissenschaft, Regensburger Geogr. Schr. **19/20**, (1985). 79–92.

[8] K. Heine: Ein außergewöhnlicher Gletschervorstoß in Mexiko vor 12000 Jahren. Ein Beitrag zum Problem der spätglazialen Klimaschwankungen; Catena **10** (1983) 1–25.

[9] K. Heine: Blockgletscher- und Blockzungen-Generationen am Nevado de Toluca, Mexiko; Die Erde **107** (1976) 330–352.

[10] K. Heine: Spät- und postglaziale Gletscherschwankungen in Mexiko: Befunde und paläoklimatische Deutung, in: H. Schroeder-Lanz (Ed.): Late- and postglacial oscillations of glaciers: Glacial and periglacial forms, A. A. Balkema, Rotterdam, 1983. S. 291–304.

[11] K. Heine: Beobachtungen und Überlegungen zur eiszeitlichen Depression von Schneegrenze und Strukturbodengrenze in den Tropen und Subtropen; Erdkunde **31** (1977) 161–178.

[12] S. White and S. Valastro Jr: Pleistocene glaciation of volcano Ajusco, central Mexico, and comparison with standard Mexican glacial sequence; Quaternary Research **21** (1984) 21–35.

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