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Pliocene to Holocene volcanic geology at the junction of Las Cruces, Chichinautzin and Ajusco ranges, southwest of Mexico City

Hugo Delgado Granados and Ana Lillian Martin del Pozzo
Instituto de Geofísica, UNAM, México.

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RESUMEN

Este trabajo está enfocado al estudio de la estratigrafía de una pequeña área volcánica al sur de la ciudad de México, aportando información volcanológica y tratando de respetar la formalidad estratigráfica. Entre el Plioceno Tardío y el Holoceno ocurrieron tres diferentes períodos de volcanismo en la región donde se unen las sierras de Las Cruces, el Ajusco y Chichinautzin. El período más antiguo, denominado Período Eruptivo Las Cruces, está representado por la actividad del volcán poligenético Los Picachos consistente de flujos piroclásticos dacíticos, lahares y lavas de la Formación Las Cruces (constituído de dos miembros: Brecha Piroclástica Cantimplora y Lava Dacítica Apilulco), formada principalmente durante el Plioceno Tardío~Pleistoceno Temprano. Durante el Período Eruptivo Ajusco (Pleistoceno Medio), el volcán Ajusco se formó por el emplazamiento de varios domos de lava andesítica. La última etapa eruptiva en la región fue el Período Eruptivo Chichinautzin (volcanismo monogenético desarrollado durante el Pleistoceno Tardío y el Holoceno), de naturaleza estromboliana. Los conos de escoria y de lava que fueron formados en este período, constituyen a las diferentes unidades del Grupo Chichinautzin. Los volcanes Los Picachos, Ajusco, Panza y conos asociados están alineados sobre un sistema de fractura N 65° W (activo desde el Plioceno Tardío). Varias fallas normales son paralelas a este alineamiento. Glaciares correspondientes a las glaciaciones Santo Tomás y Albergue dejaron "cuernos", valles en forma de "U", circos y morrenas en los volcanes Los Picachos y Ajusco. El volcanismo del período Eruptivo Chichinautzin fue contemporáneo con un período interglacial durante el Pleistoceno Tardío (entre las glaciaciones Santo Tomás y Albergue).

PALABRAS CLAVE: Geología volcánica, estratigrafía, Las Cruces, Chichinautzin, Ajusco.

ABSTRACT

The geology of Mexico City's southern volcanic area is discussed on the basis of volcanological, stratigraphic and glacial criteria. Three different eruptive periods occurred from Late Pliocene to Holocene in the juncture between Las Cruces, Ajusco and Chichinautzin ranges. The oldest (Las Cruces) Eruptive Period is represented by the activity of Los Picachos polygenetic volcano with dacitic pyroclastic flows, lahars and lavas of Las Cruces Formation (Cantimplora Pyroclastic Breccia Member and Apilulco Dacitic Lava Member), formed mostly during Late Pliocene~Early Pleistocene. During the Ajusco Eruptive Period (Middle Pleistocene), Ajusco volcano was formed by extrusion of several andesitic lava domes. The last stage is the Chichinautzin Eruptive Period of monogenetic volcanism, characterized by Strombolian-type activity during the Late Pleistocene-Holocene. Scoria and lava cones formed in this period constitute the different units of Chichinautzin Group. The Picachos, Ajusco and Panza volcanoes and related advent cones are aligned on a N 65° W fracture system (active at least since Late Pliocene). Dip slip faults are parallel to this alignment. Glaciers of the Santo Tomás and Albergue Glaciations left horns, U shaped valleys, cirques and moraines in Los Picachos and Ajusco volcanoes. The volcanism of the Chichinautzin Eruptive Period was contemporaneous during Late Pleistocene with an interglacial period (between Santo Tomás and Albergue Glaciations).

KEY WORDS: Volcanic geology, stratigraphy, Las Cruces, Chichinautzin, Ajusco.

INTRODUCTION

The study area is located 27 km south of Mexico City (Figure 1), where the southern Sierra de Las Cruces, western Sierra del Ajusco and northern Sierra Chichinautzin ranges join. Several volcanic episodes and glacial events influenced the geological development of the region and strongly shaped the landscape.

Formal stratigraphy of the area south of Mexico City was first given by Fries (1960) and Schlaepfer (1968). Bloomfield (1975) and Martin del Pozzo (1982) carried out petrographic, geochemical and stratigraphic studies in the monogenetic volcanic field south and west of Mexico City. Reports of glacial geomorphology in neighboring areas have also been published (White, 1978; White and Valastro, 1984; Heine, 1984; Delgado, 1986). Several studies have been carried out in adjacent areas, but few discussed the spatial and stratigraphic relationship between the volcanic and glacial events in this area close to Mexico City.

On the other hand, most currently published data on volcanic products include names of rocks and deposits with genetic or lithologic implications (i.e. ash-flow deposits, ash-flow tuffs). In this paper, we formally name the mapped units according to the International Stratigraphic Guide (Hedberg, 1976).

STRATIGRAPHY

The rocks in this region comprise the following stratigraphic units (Figure 2): Las Cruces Formation, Ajus-

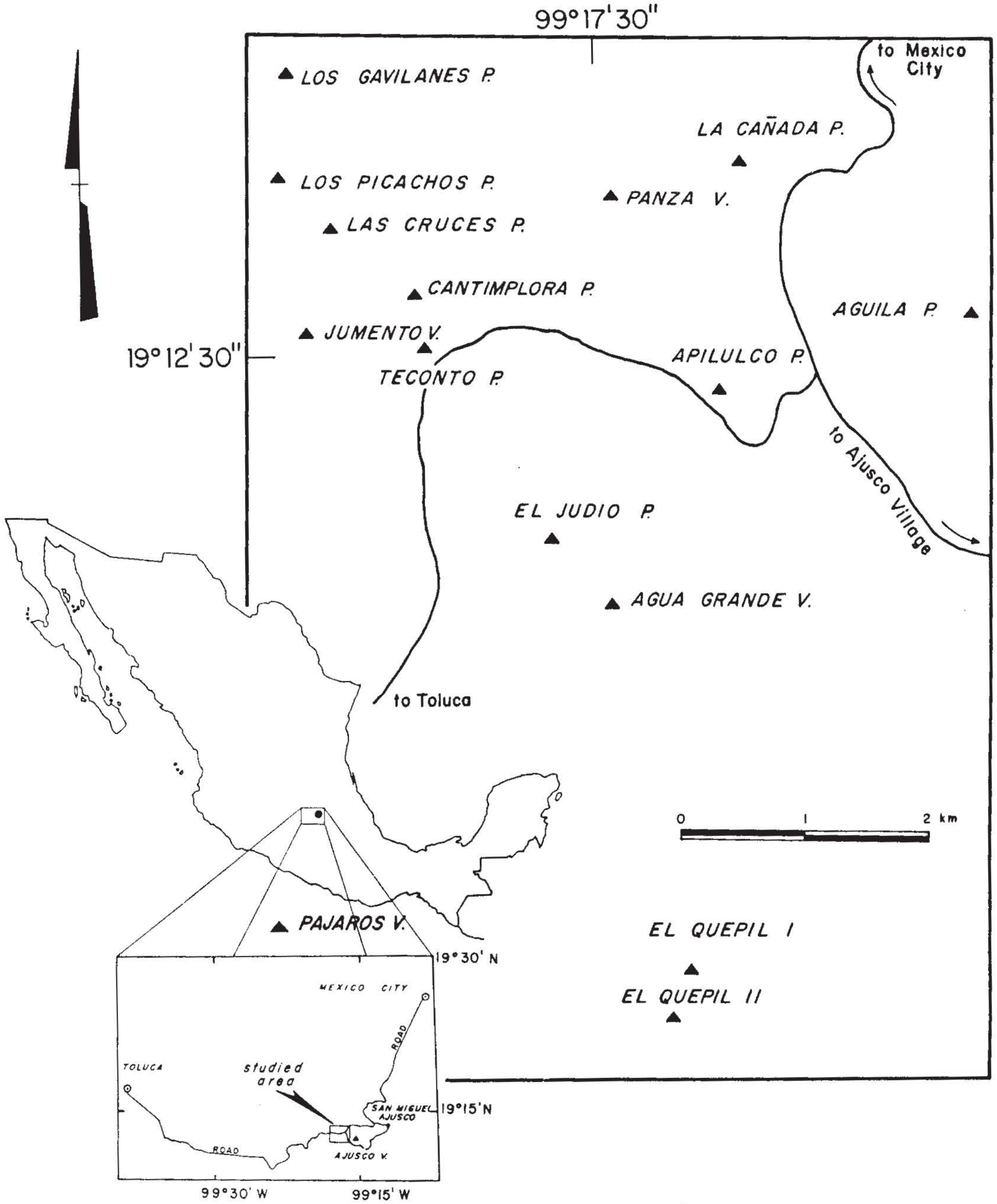

Fig. 1. Location map. Access roads and relevant topographic names are shown.

co Formation, Chichinautzin Group and Quaternary colluvial and alluvial deposits (Figure 3).

Las Cruces Formation. Defined by Schlaepfer (1968) and described by Sánchez-Rubio (1978) as a series of porphyritic dacites. In the present study, Las Cruces Formation is divided into two members: a) the Cantimplora Pyroclastic Breccia Member (Tcl) and b) the Apilulco Dacitic Lava Member (Tcc).

The Cantimplora Pyroclastic Breccia Member is made up of block and ash flow and lahar deposits. The block and ash-flow is a welded pyroclastic breccia including lapilli fragments and blocks (<1 m) mainly of dacitic composition. The lapilli fragments show crystals of plagioclase, pyroxene, hornblende and quartz. Subangular to subrounded blocks are embedded in a fine sandy gray matrix with abundant lithic fragments, which constitute around 30 % of the volume. The laharic deposits are unconsolidated, they occur in recent stream cuts filling old stream channels, and are composed of angular to subangular blocks averaging 20~30 cm but which can be up to 1 m in diameter. Most of the clasts are light-gray porphyritic dacites embedded in a matrix of lithic fragments of the same composition mixed with clay. The contact surfaces below the ancient channels do not show residual soils. This may be due to the erosive effect of the lahars during their emplacement. Outcrops of

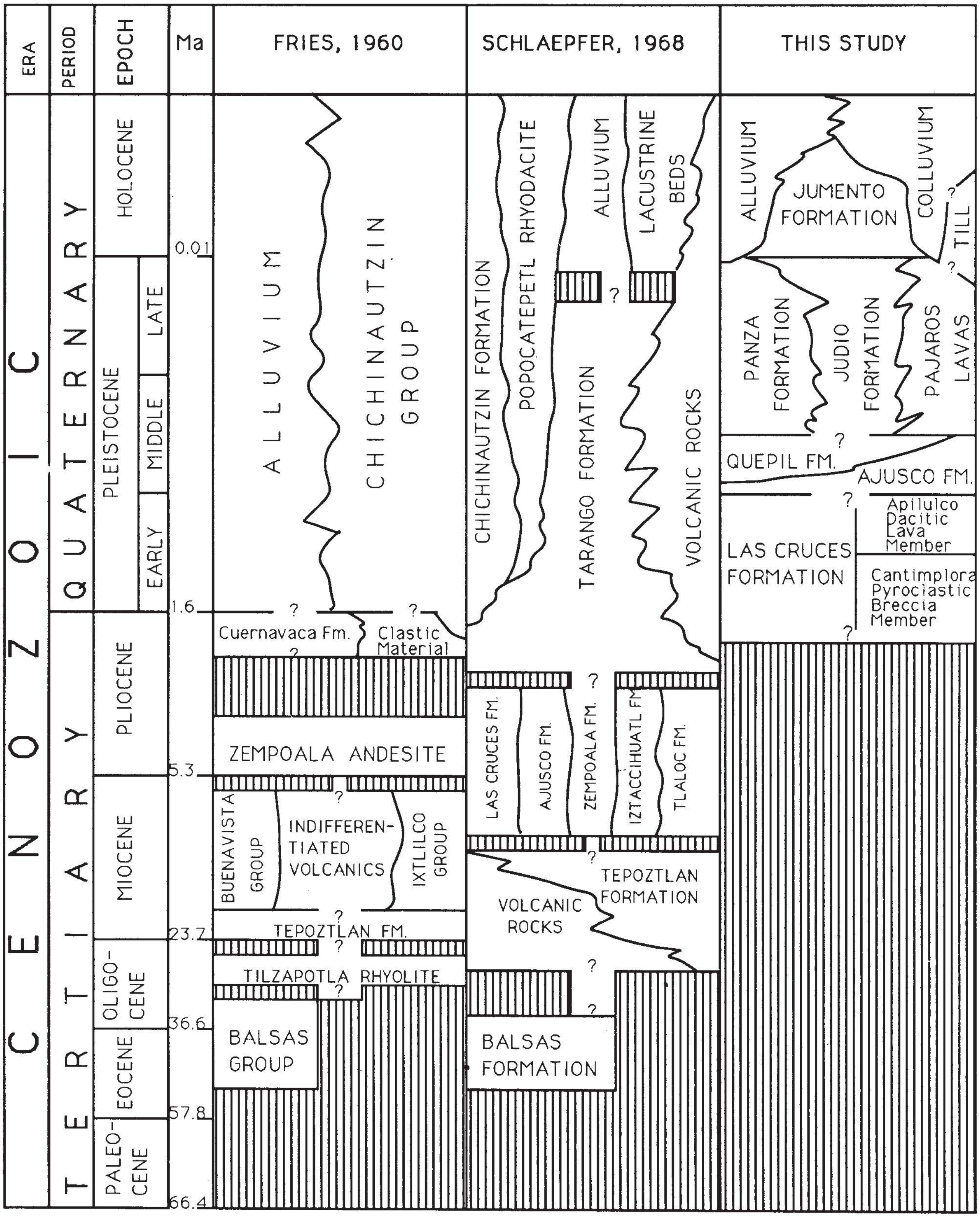

Fig. 2. Correlation chart. Stratigraphic units of the studied and adjacent areas.

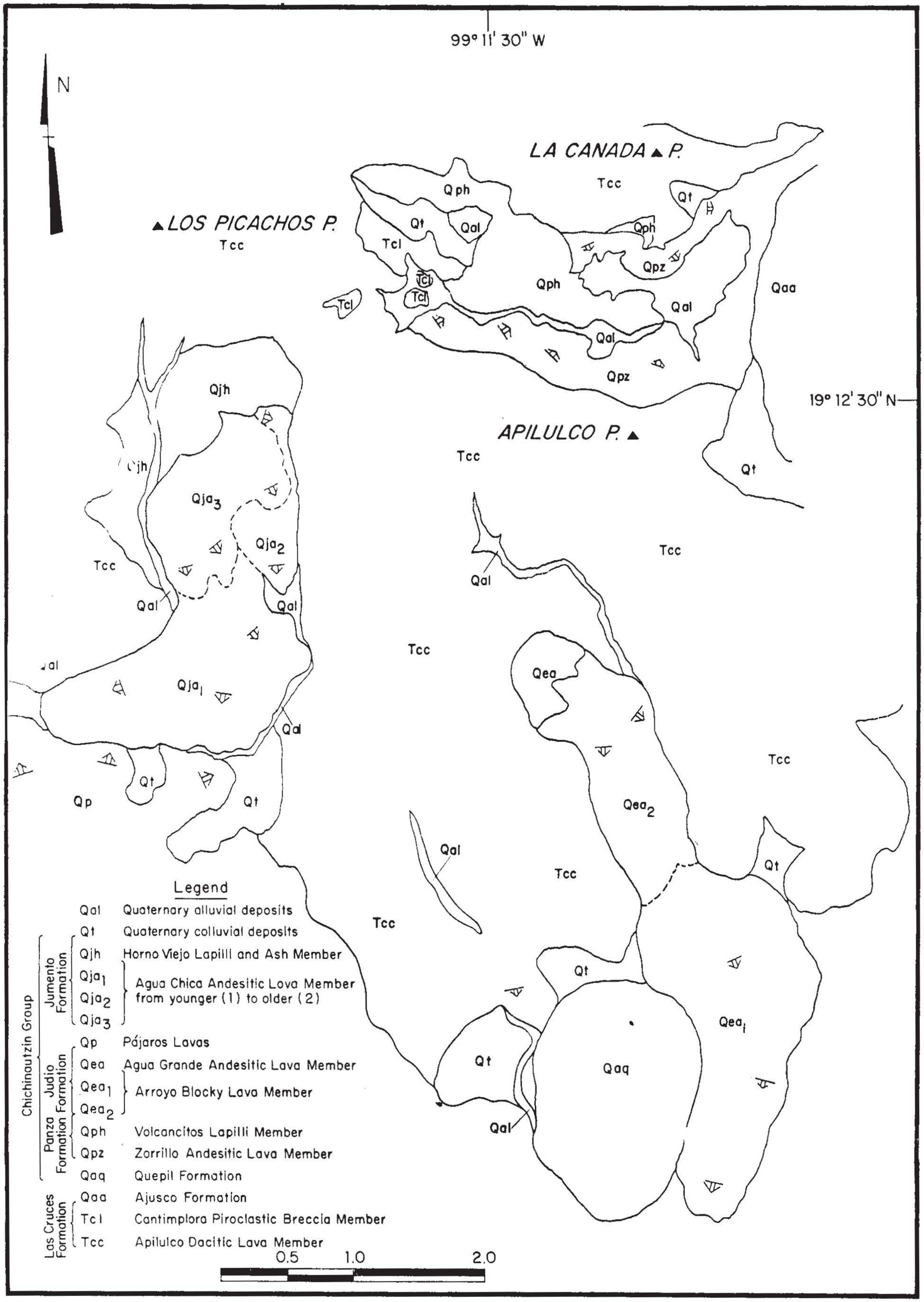

Fig. 3. Geologic map. Explanation of keys is in text.

these deposits are not widespread but in some places they crop out in scarps of more than 80 m. The total thickness of Tcl is more than 150 m. Exposures of this unit may be seen in the Cantimplora valley, covered by dacitic lava flows and laharic deposits of the overlying member.

The Apilulco Dacitic Lava Member is widely distributed and crops out in most of the area. It is mainly composed of several dacitic lava flows (point 3, Figure 4) made up of zoned plagioclase (oligoclase-andesine), hornblende and hypersthene crystals in a microcrystalline matrix of plagioclase apatite and opaque minerals (small crystals of intergranular titanomagnetite, hematite, magnetite and illmenite). There are also lavas with phenocrysts of orthopyroxene and augite embedded in a microlithic plagioclase matrix (point 4, Figure 4). There are some laharic units interbedded with the lavas. Total thickness of this member is more than 400 m.

Delgado (1986) suggested a Pliocene~Early Pleistocene age for this formation, based on the denudation of the unit. In addition, Mora and others (1987) reported K-Ar ages between 1.79 ± 0.1 Ma and 2.87 ± 0.15 Ma (Late Pliocene~Early Pleistocene) for the Las Cruces Formation in adjacent areas. Las Cruces Formation underlies the Ajusco Formation north of El Quepil volcano and is covered by the pyroclasts and lavas of the Chichinautzin Group in most of the area.

Ajusco Formation. This was defined by Schlaepfer (1968) as a Late Miocene to Late Pliocene andesitic unit, exposed northwest of the village of Ajusco. The Ajusco Formation is composed of reddish brown porphyritic andesite (point 6, Figure 4) with zoned plagioclase phenocrysts and subhedral crystals of oxyhornblende and augite included in a glassy matrix with andesine and hematite. Lavas of this formation are exposed in the northeastern part of the area. Most of the volume of these rocks is outside the mapped area, where thickness is more than 900 m. Martin del Pozzo and others (1984), recognized reverse polarities of the rocks of Ajusco Formation, indicating a minimum age of 0.73 Ma (age of the Brunhes normal polarity epoch; Harland and others, 1982). Mora and others (1987) obtained a date of 0.394 ± 0.155 Ma for a basalt on the southern flank of Ajusco volcano. Yet this basalt probably pertains to younger vulcanism rather than the Ajusco volcano. Hence, the Ajusco Formation should be dated older than 0.73 Ma (Middle Pleistocene).

Chichinautzin Group. Fries (1960) used the name of Chichinautzin Group for the Quaternary volcanic rocks south of Mexico City. Although Fries used the term "group", he did not publish a subdivision. Here the Chichinautzin Group is described comprising four Pleistocene units and one Holocene unit. The Pleistocene units are: Quepil Formation, Panza Formation, El Judío Formation and Pájaros Lavas. The Holocene unit is the Jumento Formation. According to the dates of Bloomfield (1975) and the geomorphological parameters of Martin del Pozzo (1982) the age of Quepil volcano is about 38 Ka, being the oldest formation of the Chichinautzin Group. The other Pleistocene units are about 22 Ka in age. The age of the Holocene volcano is estimated near 8.4 Ka.

Quepil Formation. This unit (Qaq) is made up of andesitic lavas (point 7, Figure 4) constituted by subhedral plagioclase phenocrysts (An, 150 μ), phenocrysts of oxyhornblende (150~300 μ) and biotite (3 mm), titanomagnetite, radiated crystals of augite and rounded quartz xenocrysts embedded in a microlithic groundmass of plagioclase and glass. These rocks constitute the Quepil volcano, which in fact is composed by two superimposed cones. The thickness of this formation is at least 500 meters. This unit covers the Las Cruces Formation.

Panza Formation. This is made up of two members. The Volcancitos Lapilli Member (Qph) and the Zorrillo Andesitic Lava Member (Qpz). Qph is represented by the eroded pyroclastic remnants of the Panza volcano and associated advent cones. These products constitute the cone and are widespread within the valley of Rancho Zorrillo. The volcano is made up of basaltic scoria (blocks and bombs) and lapilli fragments of a black color interbedded with yellow lapilli fragments. In the black lapilli fragments, crystals of augite and olivine occur (point 8, Figure 4). Other smaller eroded cinder cones of black and red scoria and bombs in the valley have about the same composition as the Panza volcano and were erupted along the same fracture. The thickness of this member is about 85 meters. The Zorrillo Andesitic Lava Member consists of a fissure lava flow erupted along fractures parallel to the Panza volcanic system. The lava flows occur along the valley flanks of Rancho Zorrillo and extend down-valley for 2 km. These lava flows are younger than the products of the explosive events that built the cones (Panza and smaller associated cones), based on the fact that cinders of Panza volcano do not cover the lavas. The Zorrillo Andesitic Lava Member is 50 meters thick and covers the rocks of Las Cruces Formation and part of the flanks of Ajusco volcano.

Judío Formation. This comprises two members: (a) The Agua Grande Andesitic Lava Member (Qea) and (b) The Arroyo Blocky Lava Member (Qea_1 and Qea_2). The Agua Grande Andesitic Lava Member is made up of blocky lavas (andesites with plagioclase phenocrysts of 0.5 cm) which built the lava cone of Agua Grande. It is a smaller cone than Panza volcano and its products are less widespread. Thickness of the Agua Grande unit is about 70 meters with an outcrop area of approximately 1 km^2 in the valley of Agua Grande stream. The Arroyo Blocky Lava Members (Qea_1 and Qea_2) are lavas which flowed from two vents. These lavas are augite and hypersthene andesites with plagioclase phenocrysts. Arroyo volcano grew at the foothill of a spur and its lavas flowed downstream over a steep slope (more than 3.5 km), passed alongside Quepil volcano (Qea_1) and slowed down when they reached the flat plain of Rancho Jaras Verdes. A second lava flow unit

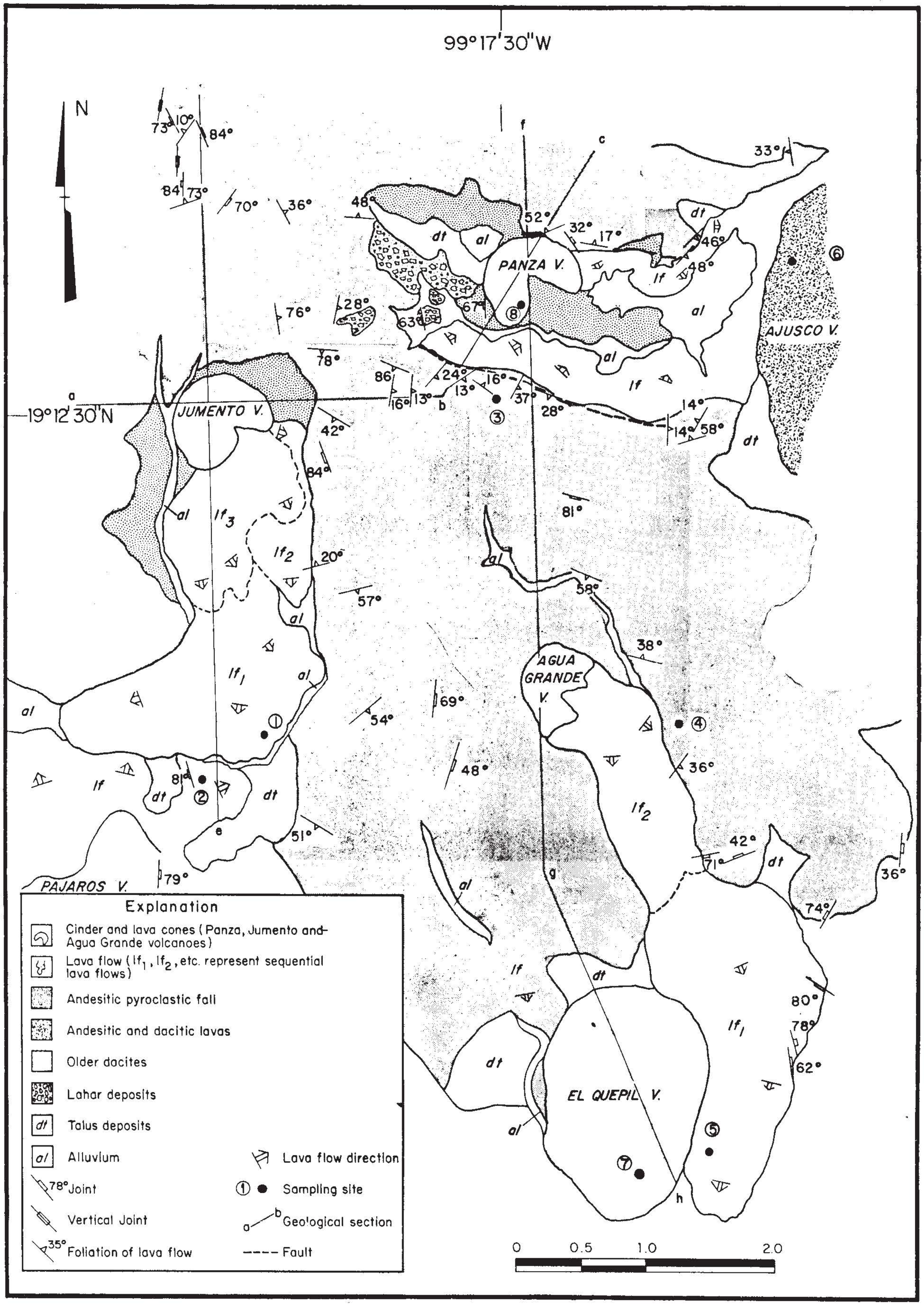

Fig. 4. Lithologic map. Shows distribution of the rocks according to lithologic criteria.

(Qea_2), flowed on a steeper surface over the first lavas for 1.5 km. The thicknesses of both lavas are about 80 meters each and their volume is .207 km^3. The first lavas of this unit cover part of the Quepil cone and both lavas cover the Las Cruces Formation lavas.

Pájaros Lavas. This unit (Qp) occurs in the southwestern part of the area and corresponds to emissions of Pájaros volcano. These blocky lavas are gray andesites with porphyritic texture (point 2, Figure 4) and contain subhedral phenocrysts of bytownite (50~100 μ), subhedral microcrysts of augite (30 μ), subhedral crystals of hypersthene (60~100 μ) in a cryptocrystalline groundmass. In this area 40 meters of lava flows are exposed. These rocks are partially covered by the Jumento Formation lavas.

Jumento Formation. This unit comprises the Horno Viejo Lapilli and Ash Member (Qjh) and the Agua Chica Andesitic Lava Member (Qja_1, Qja_2 and Qja_3). The Horno Viejo Lapilli and Ash Member comprises the pyroclasts of Horno Viejo volcano and includes intercalations of black coarse lapilli fragments and brown fine lapilli fragments (surrounding the cone) and scoriaceous blocks (Jumento cone). The thickness of the unit is estimated as 130 m. The Agua Chica Andesitic Lava Members (Qja_1, Qja_2 and Qja3) comprise the andesitic lava flows of Jumento volcano (point 1, Figure 4). Lavas consist of plagioclase phenocrysts and microliths ($An_{70\sim80}$, 10~200 μ) subhedral phenocrysts of olivine ($Fo_{80\sim90}$, 200 μ), subhedral microcrystals of augite (40 μ) embedded in a glassy matrix. Some quartz xenocrysts are present. The lavas of this member are made of three different flows with well marked levees, which flowed distances of 3.5 km (Qaj_1), 1.5 km (Qaj_2) and 1 km (Qja_3). Average thickness of these lava flows is 50 m with a total volume of .15 km^3. These flows partially cover the Pájaros Lavas.

Other Deposits. Alluvial (Qal) and Colluvial (Qt) deposits consist mainly of volcanic clasts derived from the loose materials of the Chichinautzin Group and Las Cruces Formation. These deposits cover the Chichinautzin volcanics. In Monte Alegre valley, dark brown deposits of subangular~subrounded volcanic clasts (pebbles and blocks) of the Apilulco Dacitic Lava Member are in a silty clay matrix, covered by 1~2 m of ash. These poorly sorted deposits with a wide range of sizes, were found in elongated hills flanking the valley topographically below erosive cirques (Figure 5). They were identified as glacial deposits forming moraines.

STRUCTURES

Volcanic and tectonic structures are described in the following section. The data on the size of the different volcanic structures is listed in Table 1, where height, basal diameter and crater rim diameter of each volcano are shown. The distribution of primary foliation data measured on the Apilulco Dacitic Lava Member and at Los Picachos, Los Gavilanes and Las Palmas peaks lead to the identification of a major volcanic structure with an eroded crater rim. The foliation data was plotted on a stereographic net (Figure 6); the points concentrate in the central part of the diagram. The clustering of the data suggests that the lavas flowed away from the summit (former crater), showing the existence of an eruptive center (Los Picachos volcano). Dispersion of the data is due to irregular lava flow following the preexisting topography. The lavas of all the Quaternary volcanoes still show fresh primary structures such as pressure ridges, and the pyroclastic deposits show slight to well marked bedding in horizontal position in the flat planes, inclined on the slopes.

Volcanic and tectonic structures are closely related in this area. Los Picachos volcano was built on a N 65° W trending set of fractures. The three Panza volcanoes are aligned on the same fracture system of Los Picachos volcano (N 65° W), a weakness zone on which Ajusco volcano was also formed. Joints measured on rocks of Las Cruces Formation (Figure 7) indicate a relative maximum at N 65° W, coinciding with the alignment of Los Picachos volcano, Ajusco volcano and Panza volcanoes. The fissure lavas of Rancho Zorrillo valley also were extruded along those fractures. In sections b-c and f-g (Figure 8), dip slip faults are seen forming a graben structure parallel to the aligned volcanoes. This alignment can be followed at least for 10 km indicating the direction of local maximum compressive stress (Nakamura, 1977). Agua Grande volcano was extruded along a N 14° W fracture. Jumento volcano is associated with a fracture N 5° W. The rose diagram (Figure 7) show concentrations between N 5° E and N 25° W. Those directions coincide with the directions of the fractures on which Agua Grande and Jumento volcanoes were formed (Figures 4 and 8). The horseshoe shape of the Panza, Agua Grande and Jumento volcanoes, is due to the collapse due to lava movement of one of the flanks, which in most cases is the southeastern flank (see Figure 5). This pattern is related to the direction of the maximum horizontal compressive stress mentioned above.

ERUPTIVE HISTORY

Volcanism in this area has been active at least from 2.87 ± 0.15 Ma until 8840 ± 70 years B. P. During the first activity period, Los Picachos volcano erupted dacitic lava flows, pyroclastic flows and lahars (Las Cruces Formation). A second eruptive period is related to Ajusco volcano activity. Volcanism at Ajusco volcano has a minimum age of 0.73 Ma. Dates ranging from 38590 ± 3210 years B. P. to 2400 years B. P. are reported for volcanic rocks of the Chichinautzin Group (Libby, 1951; Bloomfield, 1975), suggesting that volcanic activity spanned since Late Pleistocene until the Holocene; but due to its normal polarity it could be up to 0.73 Ma (Urrutia *et al.*, 1991). The deposits of Panza, Agua Grande and Jumento volcanoes suggest that activity was Strombolian in this particular area.

Contemporary with part of the volcanism of the Chichinautzin Eruptive Period, there were three glaciations and two neoglacial events at Ajusco volcano (White and

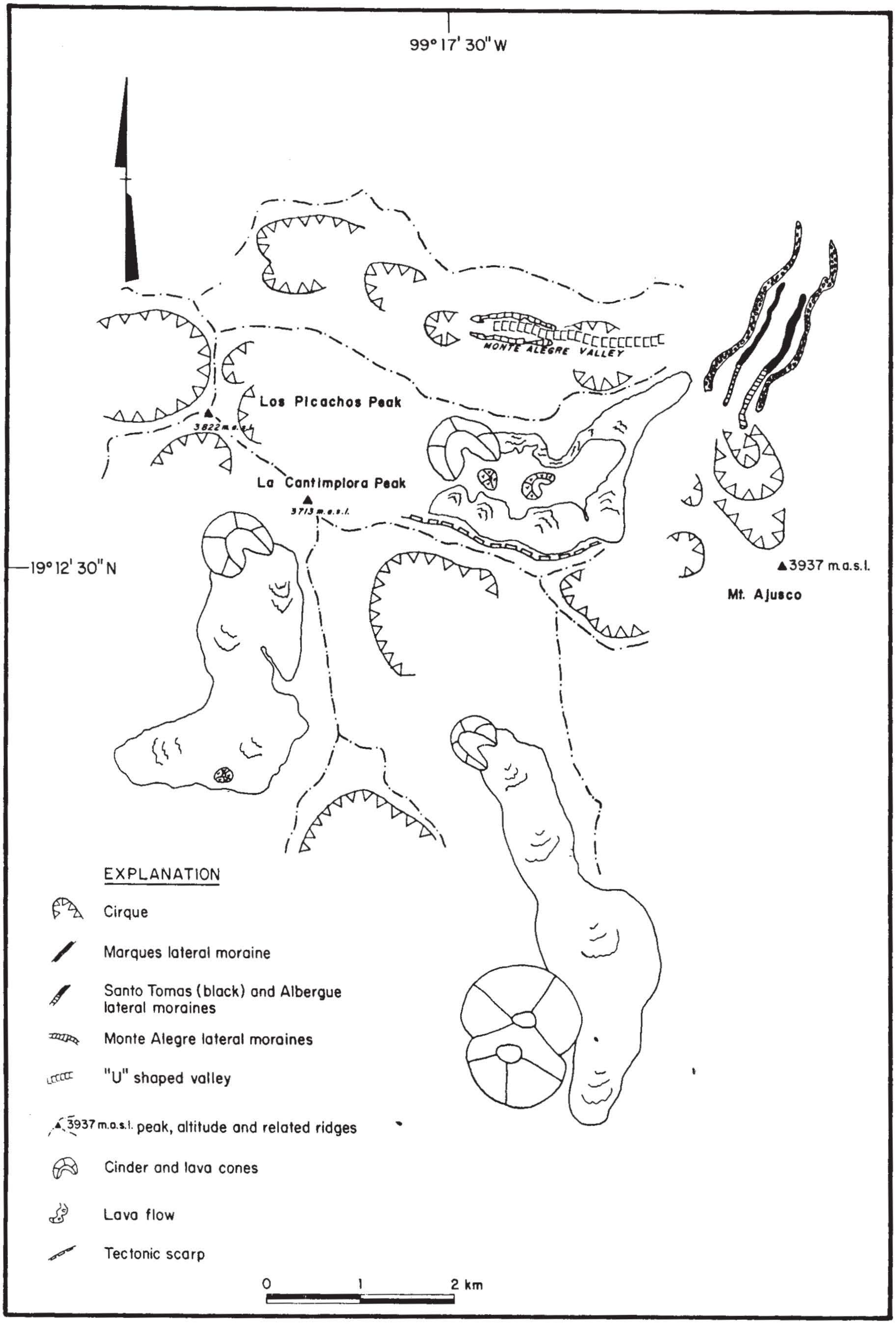

Fig. 5. Geomorphologic map. Glacial features of Ajusco volcano according to White and Valastro, 1984.

Table 1.

Volcano Name	Type of Volcano	Height (m)	Basal Diameter (m)	Crater Rim Diameter (m)
Los Picachos	composite	•500	>16000	
Quepil I	lava cone	280	1000-1250	250
Quepil II	lava cone	300	1000-1250	280
Panza I	scoria cone	140	750	340
Panza II	cinder cone	30	500	(?)
Panza III	cinder cone	35	300	(?)
Agua Grande	lava cone	50	560	250
Jumento	cinder cone	150	750	300

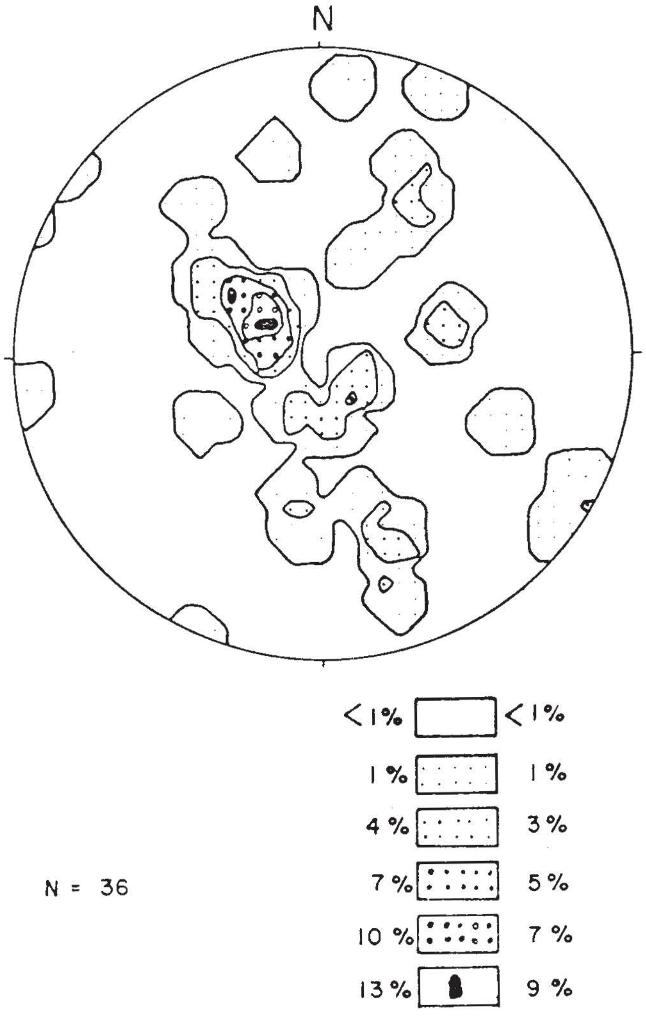

Fig. 6. Schmidt plot of the foliation data measured in lavas of Apilulco Dacitic Lava Member.

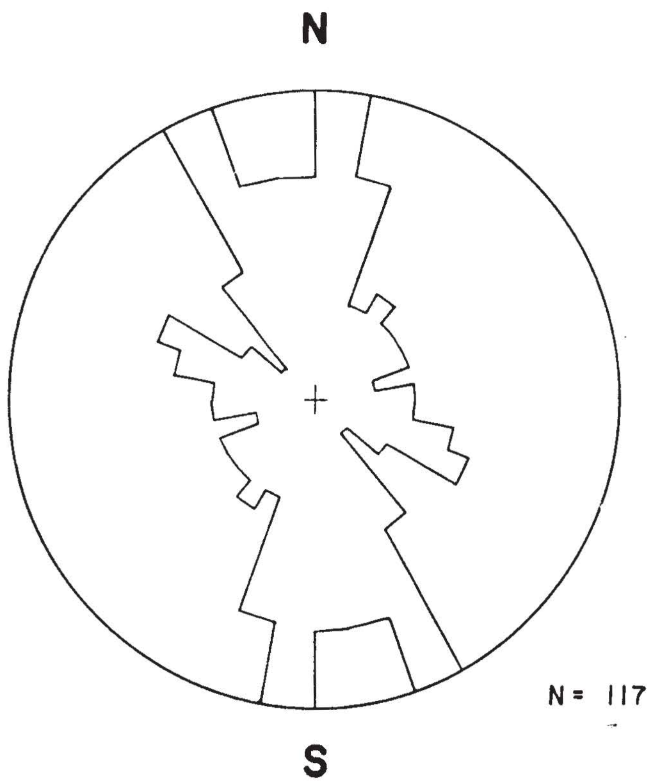

Fig. 7. Rose diagram of fracture strikes, measured in lavas of Apilulco Dacitic Lava Member.

Valastro, 1984; White *et al.*, 1991): Marqués, Santo Tomás and Albergue glaciations (27000, 25000 and 15000~8000 years B. P.) and neoglacial events during the last 2000 years B. P. Evidence of glaciation has been reported by Delgado (1986) for the Monte Alegre valley, where morphology reveals the presence of moraines and cirques (Figure 5). The Marqués Glaciation affected Los Picachos volcano, which eroded the high altitude cirques (3700 m) around the summit. The moraines of the Monte Alegre valley can be correlated in altitude with the moraines described by White (1978) at 3420 m~3500 m at Ajusco volcano (and also the corresponding cirques). These moraines were built during the Santo Tomás Glaciation. The estimated ages of Panza and Agua Grande volcanoes (22 Ka) suggest that volcanic activity was contemporaneous with an interglacial period (between Santo Tomás and Albergue glaciations). Dry and cold weather conditions during the Pleistocene in central Mexico have been reported from the sediments of the neighboring Texcoco and Chalco lakes (Bradbury, 1971; Watts and Bradbury, 1984). By this time, glaciers of Los Picachos volcano (those related with Santo Tomás glaciation) may have vanished in part, due to the eruptions of Panza volcano. The Albergue Glaciation's moraines or neoglaciational deposits are not exposed. Nevertheless, glacial cirques at 3500 m and 3420 m are present (Figure 5). These cirques are correlatable with the Albergue Glaciation's cirques reported by White (1978) and White *et al.* (1990) at Ajusco volcano on topographical basis. The associated glaciers may have been affected by the emissions of the Jumento volcano (8.4 Ka).

CONCLUSIONS

Volcanic activity in the area has been continuous from the Pliocene. Three periods of volcanic activity can be identified: Las Cruces Eruptive Period (during this time, the Los Picachos composite volcano was active and erupt-

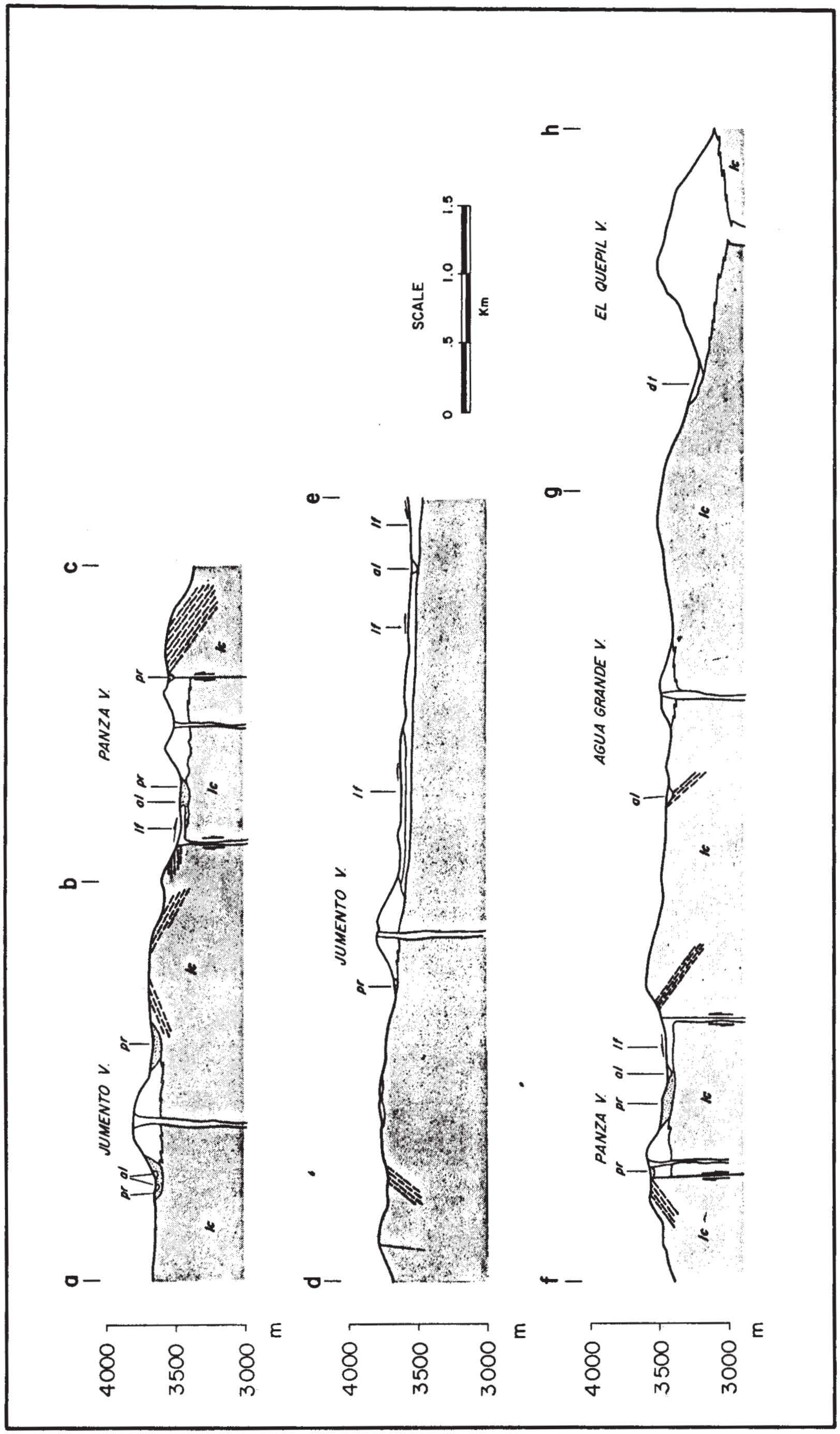

Fig. 8. Geologic sections. Horizontal and vertical scales are equivalent. Nomenclature is the same as Fig. 4.

ed a considerable volume of igneous material constituting Las Cruces Formation), Ajusco Eruptive Period and Chichinautzin Eruptive Period.The rocks which make up the Las Cruces Formation suggest the activity of a composite volcano during the Late Pliocene~Early Pleistocene (2.87~1.79 Ma) with eruption of block-and ash-flows of dacitic composition, laharic activity (Cantimplora Pyroclastic Breccia Member) and emission of dacitic lava flows (Apilulco Dacitic Lava Member). The Ajusco Formation was formed by andesitic lavas rocks during the Middle Pleistocene (more than 0.73 Ma). The Chichinautzin Group deposits are mainly andesitic though the latest rocks (Jumento Formation) are more basic in composition. The volcanic activity of the Chichinautzin Volcanic Period in this area spanned from Late Pleistocene to Holocene.

Tectonic activity has been closely related to volcanism since Late Pliocene. The N 65° W alignment of Los Picachos, Ajusco and Panza volcanoes is related to normal faulting, which also represents a local maximum compressive stress direction. Glacial processes extensively shaped the landscape of this area during the Late Pleistocene. Glaciers eroded Los Picachos and Ajusco volcanoes developing horns, U shaped valleys, cirques and depositing moraines. Part of the volcanism of the Chichinautzin Eruptive Period was contemporaneous with interglacial periods.

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Hugo Delgado Granados and Ana Lilian Martin del Pozzo
Instituto de Geofísica, UNAM.,
Del. Coyoacán, 04510, México, D.F.
México.